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Study on flexural strength of composite steel fiber reinforced concrete based on orthogonal test

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Abstract

Based on orthogonal test, the flexural strength of composite steel fiber reinforce concrete(CSFRC) is analyzed by range and variance, and the sensitivity of flexural strength factors and the optimal combination of factors are obtained. The results show that the order of influencing factors on flexural strength is volume content of steel fiber, steel fiber mixing combination and steel fiber composite layer height; the optimal combination was 1.5% of steel fiber volume, 4cm of composite layer height, 3/4 S-type steel fiber and 1/4 L-type steel fiber; The flexural strength of S-type steel fiber group is always higher than which group of L-type steel fiber

Keywords

Teel fiber; flexural strength; orthogonal test;concrete.

1. Introduction

Concrete is the most widely used building material in the world. However, the significant shortcomings of concrete materials are low tensile strength, poor crack resistance, poor toughness, adding steel fiber to concrete can improve the brittle behavior of concrete, so as to improve its ability to absorb energy[1-3]. At present, in engineering application, cement-based materials are mainly compounded to improve their properties and improve their defects, that is, one or several fibers are added to the matrix material as reinforcement phase to strengthen some properties[4-6]. However, fiber reinforced concrete(FRC) has some problems, such as high cost and low material utilization rate[7]. The CSFRC selected in this paper, as shown in Figure 1, is formed only by arranging steel fiber reinforced concrete(SFRC) under the plain concrete(PC) during pouring, which can reduce the cost and improve the material utilization while continuing the advantages of SFRC. In order to further explore the influence of different factors on compressive strength, this paper selected the content of steel fiber, the height of composite layer and the mixing combination as variables to conduct orthogonal experimental design and explore the significance of the influence of each factor.

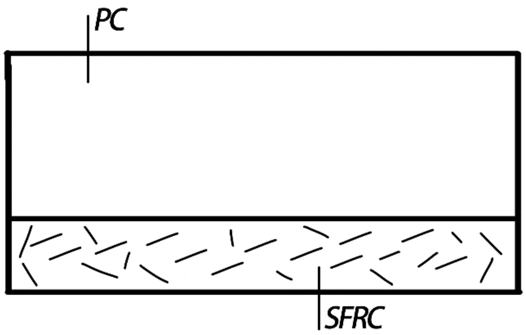

Fig. 1. Composite steel fiber reinforce concrete

2. Experimental campaign

2.1. Material

P.O 42.5 ordinary portland cement shall be selected as the cement. The well graded crushed stone coarse aggregate with particle size of 5mm ~ 15mm is selected for the test. Admixture of polycarboxylic acid efficient water reducing agent produced by a chemical plant in Shandong, mixing water for tap water. Two kinds of steel fibers with different length diameter ratio, milling type and copper coated microfilament, are selected in the test, as shown in Fig. 2. Figure 2a shows milling type, and figure 2b shows copper coated microfilament steel fiber. The performance parameters of steel fiber are shown in Table 1.

a) Milling type steel fiber

b) Copper plated microfilament steel fiber

Fig. 2. Different types of steel fibers

Table 1 Steel fiber performance parameters

Type	length/ mm	diameter /mm	aspect ratio	Elastic modulus /GPa	tensile strength /MPa
L-type	38	0.6	63	210	≥700
S-type	13	0.22	60	240	≥2850

[Note]L-type: Milling type steel fiber; S-type: Copper plated microfilament steel fiber.

2.2. Test design

Sixteen groups of prismatic specimen with size of 150mm * 150mm * 550mm were designed by orthogonal test, and each group had three specimens. The average strength was taken as the flexural strength of concrete. Feeding process: first cement, coarse aggregate, fine aggregate into the blender dry mixing 1 minutes; Then add steel fiber and mix again for 1 minute. Finally, add the water reducer and water to the blender in turn. The steel fiber content, composite layer height and mixing combination were selected as influencing factors, denoted as A,B and C respectively. Orthogonal test was conducted at 4 levels for each factor, as shown in Table 2.

Table 2 Orthogonal experimental design

Level	A-V_f/%	B-h/cm	C-M_c
1	0.6	1	S
2	0.9	2	L
3	1.2	3	1/4S+3/4L
4	1.5	4	3/4S+1/4L

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[Note] V_f-Volume fraction, h-Composite height, M_c-Mixied combination, S-Short steel fiber, L-long steel fiber.

3. Experimental results and analysis

3.1. Result

Table 3 Orthogonal test results of flexural strength

Number	A- V_f /%	B-h/cm	C- M_c	*f*/Mpa
CSFRC-1	0.6	1	S	4.12
CSFRC-2	0.6	2	L	3.96
CSFRC-3	0.6	3	1/4 S+3/4 L	5.20
CSFRC-4	0.6	4	3/4 S+1/4 L	5.43
CSFRC-5	0.9	1	L	4.37
CSFRC-6	0.9	2	S	4.55
CSFRC-7	0.9	3	3/4 S+1/4 L	5.36
CSFRC-8	0.9	4	1/4 S+3/4 L	5.52
CSFRC-9	1.2	1	1/4 S+3/4 L	5.28
CSFRC-10	1.2	2	3/4 S+1/4 L	5.46
CSFRC-11	1.2	3	S	6.11
CSFRC-12	1.2	4	L	5.88
CSFRC-13	1.5	1	3/4 S+1/4 L	5.51
CSFRC-14	1.5	2	1/4 S+3/4 L	5.73
CSFRC-15	1.5	3	L	5.61
CSFRC-16	1.5	4	S	6.18

[Note] *f*-flexural stress.

The experimental results are shown in Table 3. The results show that the minimum value of flexural strength is 3.96 MPa and the maximum value is 6.18 MPa, which is about 56.06% higher than the minimum value. Under the same steel fiber content, the flexural strength basically shows an upward trend with the increase of composite layer height. However, for the group of single S-type and L-type steel fiber, it can be obviously found that the change trend is different. For example, the content of CSFRC-11 and CSFRC-12 is the same as 1.2%, the height of the composite layer is increased from 3cm to 4cm, and the final flexural strength is reduced from 6.11mpa to 5.88MPA, with a decrease of about 3.76%. Moreover, it can be found from the data in the table that when S-type fiber is mixed alone, the flexural strength of this group is always higher than that of L-type steel fiber with the same content. This may be because S-type steel fiber can be more widely distributed in the tensile area of concrete, improve the concrete defects in the tensile area, inhibit the generation of microcracks, and delay the occurrence time of the main cracks of the specimen[8-10]. In addition, when the crack spacing is small, S-type steel fiber can better transfer and bear the stress due to its quantitative advantage, prevent the crack from developing into through joint rapidly, and then improve the flexural strength[11, 12].

a) failure mode b) section characteristic

Fig. 3. Failure mode and section characteristics of flexural strength test

Fig. 3 shows the flexural failure and section characteristics of CSFRC. Before failure, a fine main crack from the bottom will be generated somewhere between the loading points, and then the crack will develop irregularly upward with time, and finally form a through crack. However, the specimen does not break directly after failure, and maintains good integrity and small crack width (Fig. 3a). By observing the section (Fig. 3b), it can be clearly found that the steel fiber on the section still has effective bonding with the matrix. Due to the high tensile strength of steel fiber, the failure of the specimen is generally caused by the fact that the concrete matrix can not bear the tensile stress, which leads to the pulling out of the fiber, not the fracture of the fiber. Most of these residual steel fibers form a certain angle with the section. Compared with the steel fibers perpendicular to the crack, these steel fibers obviously bond more firmly with the matrix and still have high bond strength after failure[13, 14]. In addition, it can be observed that a piece of concrete fragment in the section, although the surrounding concrete has peeled off, is still connected with the main body through the bridge of steel fiber.

3.2. Range analysis

Table 4 Range analysis

factors	K1	K2	K3	K4	k1	k2	k3	k4	R
V_f	18.71	19.80	22.73	23.03	4.68	4.95	5.68	5.76	1.08
h	19.28	19.70	22.28	23.01	4.82	4.93	5.57	5.75	0.93
M_c	20.96	19.82	21.73	21.76	5.24	4.96	5.43	5.44	0.48

Range analysis results are shown in Table 4. According to the range analysis, for the flexural strength, the influence degree of different factors is A > B > C, that is, the volume content of steel fiber > the height of steel fiber composite layer > the mixing combination of steel fiber. The range of factor A - volume content of steel fiber is 1.08, which has the greatest impact on the results. The second factor is the height of b-steel fiber composite layer, and the range is 0.93. It is worth noting that the R value of factor A is slightly higher than that of factor B, with a difference of only 0.15 and an increase of about 16.1%. This shows that changing one of the two factors A and B in this test will significantly change the test results. The flexural strength will be significantly affected not only by the content of steel fiber, but also by the increase or decrease of the height of the composite layer. The influence of factor C - mixing combination is the smallest, and the range is 0.48, which is only 51.6% of factor B. The best combination of flexural strength is a4b4c4: that is, the volume content of steel fiber is 1.5%, the height of composite layer is 4cm, 3/4 S-type steel fiber is mixed with 1/4 L-type steel fiber. In order to better display the data, the following will analyze each factor separately.

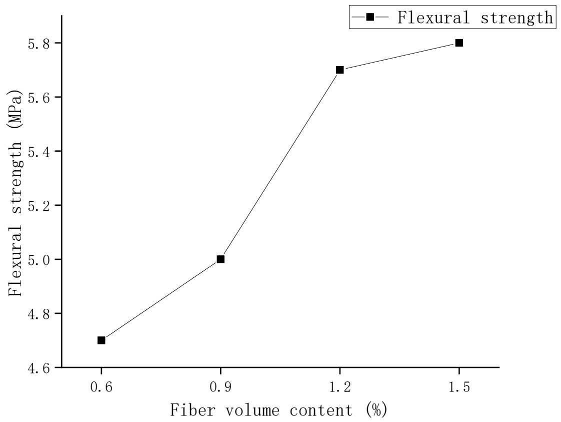

Fig. 4. Effect of steel fiber volume fraction on flexural strength

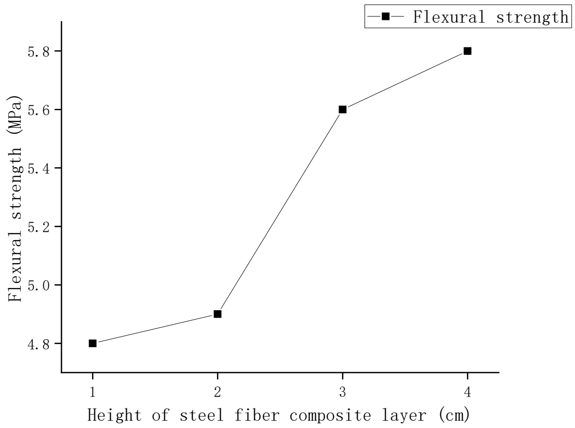

Fig. 5. Effect of composite layer height on flexural strength

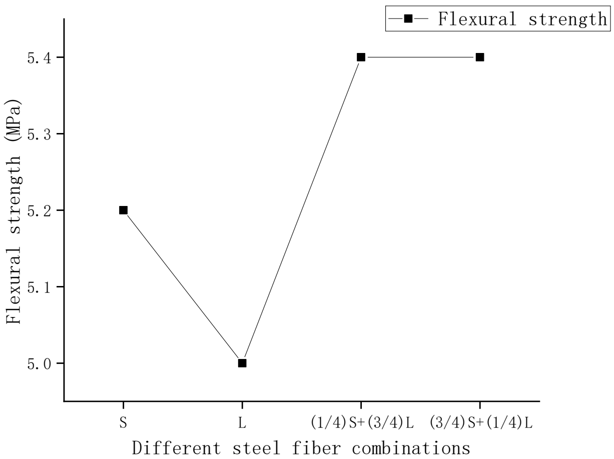

Fig. 6. Effect of different steel fiber combinations on flexural strength

(1) Effect of steel fiber content on flexural strength

As shown in Fig. 4, with the increase of steel fiber content from 0.6% to 1.5%, the change of flexural strength of the specimen is showing an upward trend. The minimum flexural strength is 4.7mpa when the content value is 0.6%. When the steel fiber content reaches 0.9%, 1.2% and 1.5%, the flexural strength is increased by 6.4%, 21.3% and 23.4% respectively compared with 0.6% content. It can be found from the observation curve that the slope of 0.9% ~ 1.2% steel fiber content is greater than that of 0.6% ~ 0.9% and 1.2% ~ 1.5%, which indicates that the flexural strength obtained by increasing the steel fiber content in this range is higher than that obtained in other content ranges with the same increment. The reason may be that under the low steel fiber content (0.6% ~ 0.9%), the number of steel fibers is small and can not be fully and evenly distributed in the test piece, resulting in low steel fiber content in local areas and becoming the weak part of the test piece[15].

(2) Effect of height of steel fiber composite layer on flexural strength

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It can be seen from Fig. 5 that when the height of the composite layer is increased from 1cm to 4cm, the flexural strength of the specimen is effectively improved. When the height of the composite layer is 4cm, the flexural strength reaches 5.8mpa. Compared with the specimen with the height of 1cm, the flexural strength increases by 1MPa and about 20.8%. When the height of the composite layer is 2cm, the flexural strength of the specimen is 4.9mpa, which is only 0.1MPa higher than that of the specimen with a layer thickness of 1cm. When the layer thickness increases from 2cm to 3cm, the flexural strength increases by 0.7MPa, which is 6 times higher than the former. This shows that in terms of flexural strength, there is a threshold for the height of the composite layer. When the composite layer is lower than this threshold, its strengthening effect is not significant. Only when the layer thickness is greater than the threshold, the flexural strength of the specimen can be effectively improved.

(3) Effect of steel fiber mixture on flexural strength

As shown in Fig. 6, different steel fiber combinations have different effects on the flexural strength of concrete. When L-type steel fiber is mixed alone, the flexural strength is the lowest, only 5MPa, while the flexural strength of S-type steel fiber group can reach 5.2mpa, which is 0.2MPa higher than the former, with an increase of 4%. The flexural strength of the two mixing combinations was higher than that of the single mixing group, 0.4MPa higher than that of group L, with an increase of 8%. It can be seen that the mixing combination has a certain impact on the flexural strength of concrete, but it is not obvious, and the range fluctuation is less than 10%.

3.3. Analysis of variance

Table 5 Analysis of variance

Source	Sum of Square	df	Mean Square	F	P
A-V_f/%	3.44	3	1.15	45.60	0.0002
B-h/cm	2.58	3	0.86	34.11	0.0004
C-M_c	0.62	3	0.21	8.23	0.0151
Error	0.15	6	0.03		
Total	6.79	15	0.45		

The results of Analysis of variance are shown in Table 5. The factors affecting the flexural strength of CSFRC are A>B>C, which is the same as the range analysis result of flexural strength. It is noted that the P values of factors A and B are less than 0.01, indicating that factors A and B have a significant impact on the flexural strength of concrete, which can explain the change trend of flexural strength under factors A and B in range analysis: since factors A and B can significantly affect the flexural strength of concrete, when the respective levels of the two factors change from low to high, The corresponding flexural strength also increases. Although the p value of factor C is greater than 0.01, it is less than 0.05, indicating that although the influence of factor C on flexural strength is less than that of a and B, it will also have a significant impact on the test results when its level is changed.

4. Conclusion

The range and variance analysis were used to conduct the flexural test on CSFRC, and three factors were selected for orthogonal test to study the significance of the influence of each factor. The main conclusions are as follows:

1. The sensitivity order of influencing factors of CSFRC's flexural strength is is as follows: steel fiber content > composite layer height > mixing combination.

2. The optimal combination of flexural strength is 1.5% steel fiber volume content, 4cm composite layer height, the mixture of 3/4 S-type steel fiber and 1/4 L-type steel fiber.

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3. No matter how the volume content of steel fiber changes, the flexural strength of concrete with S-type steel fiber is always higher than that with L-type steel fiber. This shows that for the flexural strength, the strength improvement of single S-type steel fiber is significantly better than that of single L-type steel fiber.

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