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Effect of Fly Ash and Silica Fume on Mechanical Properties of High-Performance FRCC

Zhang Pan[1], Xiaohui Zeng [2] and Zhongwei Hu [2]

[1] School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China
[2] School of Civil Engineering Central South University, Changsha 410075, China

Abstract. Based on the development and application of high-performance FRCC (Fiber Reinforced Cementitious Composite), the effect of different content of fly ash and silica fume on the compressive strength, flexural strength and toughness of high-performance FRCC is studied. The results show that the addition of fly ash and silica fume significantly affects the mechanical properties of high-performance FRCC. The specific optimization content with 50% ash and 15% silica fume can make the flexural strength of high-performance FRCC up to 19.5MPa, the compressive strength to75.2MPa, and the ratio of bending strength to compressive strength to about 0.26. Compared with ordinary fiber reinforced cementitious composite, its flexural strength and compressive strength are increased by 35% and 40% respectively and the ratio of bending strength to compressive strength is increased by about 6%. It can be seen that the optimization mixture can significantly enhance the compressive strength, flexural strength and toughness of high-performance FRCC and may provide reference for practical use.

1. Introduction

With the expansion of the application field of concrete structure and the increase of scale, the structure engineering gradually develops towards the direction of higher, larger span and heavier load. Therefore, structural materials are required to have higher strength and higher toughness. In order to meet the needs of development, it is vital to improve the structural concrete materials, which aims to improve their service performance [1]. According to the study, at present at home and abroad, perhaps the most dramatic special concrete is a fiber cement matrix composite material ECC (Engineering Cementitious Composities). Facture mechanics and micro mechanics are utilized to design and optimize this material, which will enhance its tensile strength and ductility [2]. This kind of material can make its flexural strength reach to 10MPa and compressive strength reach to 40MPa through adding fiber such as PVA and PE with comparatively large content [3].

Although this kind of material has enhanced the mechanical properties of cement-based materials, the strength of this kind of material will appear to be inadequate in some structures that require particularly highly for materials [4]. In order to further improve the service performance of fiber-reinforced cement-based materials, the mechanical properties of fiber-reinforced cement-based materials were studied under the condition of appropriate fiber content and the fly ash and silica fume with different amounts. So that the mix proportion was optimized to obtain high-strength fiber-reinforced cement-based materials [5]. This is not only conducive to the control of costs, but also conducive to the engineering and technical personnel to apply the admixture technology on this basis [6], or other methods to adjust the composition of the material, and the production of high strength fiber cement base material with superior performance.

2. Test Materials and Test Scheme

2.1. Test Materials

(1) Cement

The Portland cement (P.O.42.5 R) used in this test is produced by Lafarge Ryanon Cement Co., Ltd.

(2) Fly ash

This experiment adopts grade I fly ash produced by Sichuan Jintang Woneng Fine fly Ash material Co., Ltd. The main performance parameters of the fly ash are listed in Table 1.

Table 1. Main performance parameters of fly ash

Parameter	Technical requirement	Result of inspection	Single decision
Fineness (45μm) (%)	≤12.0	11.2	qualified
Water demand ratio%	≤95	93	qualified
Ignition loss%	≤5.0	2.9	qualified
Water content (%)	≤1.0	0.3	qualified
SO_3 content (%)	≤3.0	1.6	qualified
Free CaO content(%)	≤1.0	0	qualified

Table 1 shows that the fly ash meets the requirements of Class I fly ash in < fly ash in cement and concrete > (GB/T1596-2005).

(3) Silica fume

The silica fume used in this experiment is produced by Chengdu Huiye silica fume material Co., Ltd. The main performance parameters of the silica fume are shown in Table 2.

Table 2. Main performance parameters of silica fume

Parameter	SiO_2 content/%	Mean grain size/um	Specific surface area/ (mm^2/ kg)	Ignition loss/%
silica fume	90.25	0.12	20 000	3.72

Table 2 shows that the performance parameters of the silica fume meet the requirements of < silica fume for mortar and concrete > (GB / T 27690 / 2011).

(4) PVA fiber

The PVA fiber used in this experiment was produced by Sinopec Sichuan Vinylon Plant. The performance parameters are shown in Table 3.

Table 3. Main performance parameters of PVA fiber

Fiber type	Diameter (um)	Length(mm)	Density ($g/cm^{3)}$	Modulus of elasticity(GPA)	Intensity(MPA·S)
China Petroleum	31	12	1.3	≥48.4	1500

(5) Other materials

The water-binder ratio in experimental basic mix ratio prepare to be 0.25 that is belong to low water-binder ratio[7]. Therefore, we need to add water reducer. In this experiment, the high efficiency poly carboxylic acid water reducer produced by Chengdu Shun American International Trade Co., Ltd, the content is added according to the flow performance of fiber cement-based materials. The test water is tap water and the aggregate is 70 ~ 140 mesh quartz sand.

2.2. Mix Proportion Design

In order to enhance the service performance of the high-strength fiber cement-based material in the practical engineering, a suitable matching ratio is explored to improve the mechanical properties of the material. According to the current study, the volume content of PVA fiber is generally 2%, and the basic water-binder ratio is 0.5% .From this point, By comparing and analyzing the compressive strength, folding strength and folding pressure ratio of different raw materials, the optimal mix proportion was obtained. The test coordination score is 11 groups, and the specific test condition is set as: F0. 1, F0. 2, F0. 3, F0. 4, F0. 5, F0. 6, F0. 7, F0. 5 -SF0. 05, F0. 5 - SF0. 1, F0. 5 -SF0.15, F0.5-SF0. 2(‘F’ represents fly ash, ‘SF’ represents silica fume), we respectively explore the influence of fly ash and silica fume on the mechanical properties of high strength fiber cement based materials. The mix proportioning ratio programs for each group are shown in Table 4.

Table 4. High strength fiber cement - based material mix proportion scheme

Serial number	cement	Fly ash	Silica fume	water	sand	PVA fiber volume
F0.1	0.9	0.1	0	0.25	0.36	2%
F0.2	0.8	0.2	0	0.25	0.36	2%
F0.3	0.7	0.3	0	0.25	0.36	2%
F0.4	0.6	0.4	0	0.25	0.36	2%
F0.5	0.5	0.5	0	0.25	0.36	2%
F0.6 F0.5	0.4	0.6	0	0.25	0.36	2%
F0.7	0.3	0.7	0	0.25	0.36	2%
F0.5-SF0.05	0.45	0.5	0.05	0.25	0.36	2%
F0.5-SF0.1	0.4	0.5	0.1	0.25	0.36	2%
F0.5-SF0.15	0.35	0.5	0.15	0.25	0.36	2%
F0.5-SF0.2	0.3	0.5	0.2	0.25	0.36	2%

2.3. Production of Samples

According to the design of material mix proportion scheme, the rubberized sand specimen was made(40 mm×40mm×160 mm). The production process is as follows:①Weigh the dry ingredients, water, and fiber according to the mix ratio;②Pour all the dry ingredients into the blender and mix up for 1 min;③Adding water and water reducer(According to the condition of fiber reinforced concrete, add water reducing agent as appropriate),mix up for 2 min;④While stirring, slowly add the dispersed PVA fiber, stirring for about 10 minutes, until close observation of the fiber does not unite, evenly dispersed;⑤Casting test blocks and vibrate them into shape. Three test blocks were made in each working condition, and the mold was removed after the test blocks were formed for 1d and put into the standard curing room for curing for 28d.

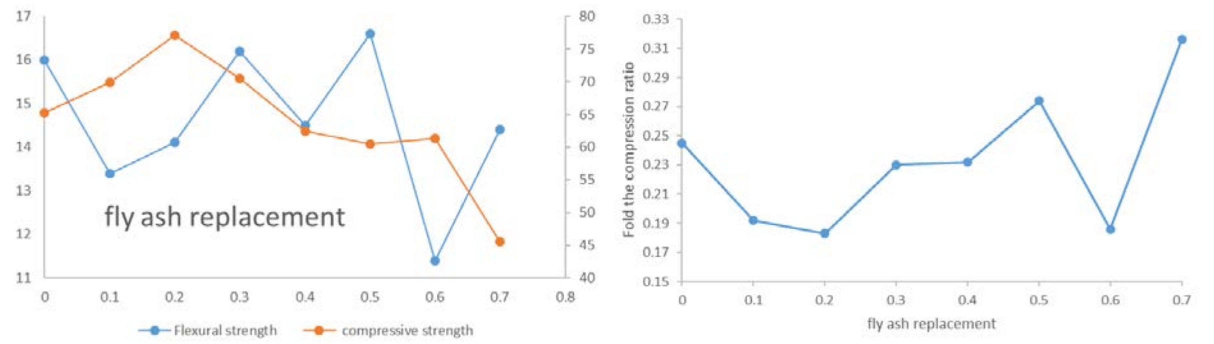
2.4. The Test Method

According to the Test method of cement mortar strength (ISO method) [8], we test the flexural strength and compressive strength of the test block separately. The flexural strength was tested by using WDW series microcomputer controlled universal material testing machine and cement flexural fixture, and the loading rate was set as 0.3mm/min. The compressive strength is tested by using the specimen broken after the flexural test, using the WDW series microcomputer controlled universal material testing machine and cement compression jig, and the loading rate is set as 1 mm/min. Two flat surfaces of the mortar block were used as loading planes for both flexural and compressive strength tests.

3. Mix Proportion Design Result and Analysis

The influence of fly ash and silica fume on the compressive strength, flexural strength and flexural pressure ratio of the material was analyzed after the specimen was cured to 28 d in each working condition. The test results are shown in table 6 and table 7.The flexural strength(①~③) in the table is respectively the measured data of 3 test blocks, The compressive strength(① and②)of each specimen are respectively the measured data of 2 pieces of broken specimens after the flexural strength test of a complete specimen. The representative value of compressive strength(or flexural strength) is the average value of test values of multiple groups.

In order to more intuitively compare the influence of fly ash content changes on mechanical properties of cement-based materials under various working conditions, the relationship curves of strength, folding pressure ratio and fly ash content are drawn, as shown in Figure 1.

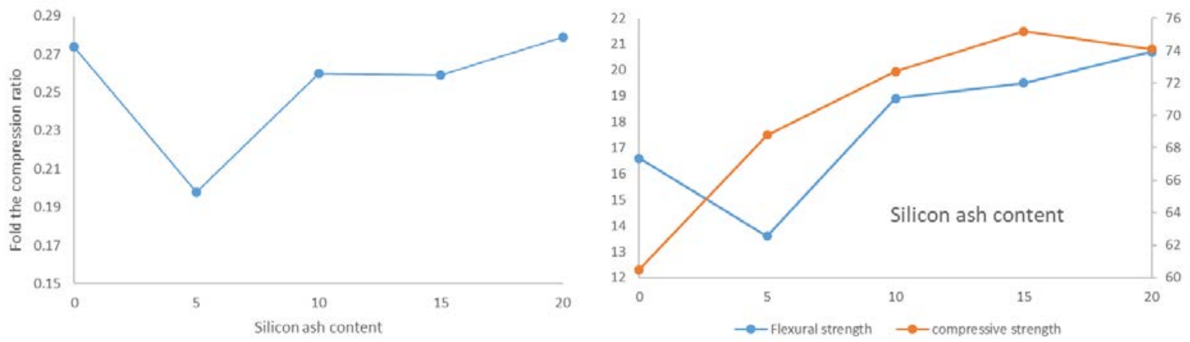


a **b**

Figure 1. Curve of strength, folding pressure ratio and fly ash content

It can be seen from Figure 1(a) that the change of fly ash content will significantly change the flexural strength and compressive strength of high-strength fiber-cement based materials. With the increase of fly ash content, the representative value of compressive strength increases firstly and then decreases. When the content of fly ash is 20%, it reaches the maximum value of 77.1MPa. When the content of fly ash exceeds 30%, the compressive strength will be lower than the compressive strength of the reference sample. The flexural strength reaches its peak when the fly ash content is 50%, and the increase from 40% to 50% and the decrease from 50% to 60% are the maximum values, indicating that 50% fly ash content is the optimal content for the flexural strength. In addition, it can be seen from figure 1 (b) that the bending pressure ratio is relatively large at 50% fly ash content, indicating that the material corresponding to 50% fly ash content has excellent toughness. Therefore, the mixture ratio of fly ash content of 50% is adopted below to explore the influence of silica fume content on the mechanical properties of high-strength fiber-cement based materials.

Similarly, in order to more intuitively compare the influence of silica fume content changes on the mechanical properties of fibrous cement-based materials under various working conditions, The relationship curves of strength, folding pressure ratio and silica fume content are drawn, as shown in Figure 2.



a **b**

Figure 2. Curve of strength, folding ratio and silica fume content

The following conclusions can be drawn from figure 2.

(1)It can be seen from Figure 2 (a) that with the increase of silica fume content, the flexural strength

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first decreases and then increases. When the content of silica fume increases from 5% to 20%, the flexural strength increases too, and the increase is significant. The amplitude increases from 12.06MPa when the silica fume content is 5% to 20.7MPa when the silica fume content is 20%71.6 6%, and the flexural strength of more than 10% silica fume content is greater than the flexural strength of zero silica fume content. The compressive strength presents a hump shape with the increase of silica fume content. When the content of silica fume is 15%, the compressive strength reaches a peak value of 75.2MPa. The compressive strength increases by 12.7% with the proportion of silica fume not added.

(2)It can be seen from Figure 2(b) that with the increase of silica fume content, the folding pressure ratio also presents a trend of gradual increase, from 0.183 when silica fume is not added to 0.279 when silica fume is added to 0.2, with an increase of 52.4 percent. The folding pressure ratio is an important index to evaluate the toughness of material. The increase of the folding pressure ratio indicates that the addition of silica fume obviously enhances the ductility and tensile strength of fiber cement based materials.

Based on the analysis of compressive strength and folding ratio, the silica fume with reasonable content can not only enhance the strength of high strength fiber cement base material, but also improve its toughness. It is essential admixture improves the service performance of high - strength fiber cement - based materials.

4. Conclusions

More than 20% fly ash content will reduce the compressive strength of high-strength fiber-cement based materials, but when the content is 50%, the flexural strength and the folding pressure ratio are significantly stronger than when no other content is added or added.

Adding silica fume to the high strength fiber cement base material can obviously improve its strength, and when the silica fume content is 15%, the compressive strength is the maximum. When the silica fume content increases from 5% to 20%, the flexural strength keeps increasing, from 12.06MPa when the silica fume content is 5% to 20.7MPa when the silica fume content is 20%, the increase rate reaches 71.6%, and also reaches 19.5MPa when the silica fume content is 15%. Therefore, considering from both the strength and economy, 15% silica fume can be added into the high strength fiber cement based material.

The folding pressure ratio is positively correlated with the silica fume content. When the silica fume content is 20%, the folding pressure ratio reaches 0.279, which is an increase of 52.4 percent compared with that without silica fume, indicating that proper addition of silica fume can significantly enhance the toughness of fibrous cement-based materials.

In practical engineering application, considering economic cost and practicability, it is recommended when the water-binder ratio is 0.25 and the PVA fiber content is 2%,The blending schemes are: 35% cement, 50% fly ash, 15% silica fume, 25% water, 36% sand and 2% PVA fiber, which are used to enhance the compressive strength, flexural strength and toughness of high-strength fiber cement-based materials.

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