Effect of Steel Fiber on Fluidity and Compressive Strength of Ultra-high Performance Concrete

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Abstract. The influence of steel fiber content on concrete fluidity and compressive strength was studied through the slump, expansion and compressive strength tests of ultra-high performance concrete specimens with different steel fiber content. The results show that the fluidity of concrete decreases obviously with the increase of steel fiber content, but this situation can be improved by adjusting the amount of water-reducing agent. With the increase of steel fiber content, concrete compressive strength increases obviously, but the higher the steel fiber content is, the better. When it exceeds a certain value, concrete compressive strength begins to decline.

1. Introduction

In the early 1990s, RICHARD et al. [1] successfully developed a new type of concrete material, namely reactive powder concrete (RPC). As a typical representative of ultra-high performance concrete, reactive powder concrete has the advantages of ultra-high strength, high toughness and high durability, which can effectively improve the service life of engineering structures and is widely used in projects such as highway Bridges, railway tracks and cable trough covers [2-6]. In recent years, many researchers have studied the preparation method, mix ratio design and mechanical properties of RPC [7-12]. Zhang Ronghua et al. [7] studied the influence of aggregate, mineral admixture, fiber and other constituent materials as well as the preparation method on RPC performance, and found that steel fiber improved RPC performance more obviously than other fibers. Hao Xianhui et al. [8] studied the influences of water-binder ratio, silica fume, slag powder, water-reducing agent content and steel fiber volume content on the strength and fluidity of reactive powder concrete, and found that, within a certain range, with the increase of steel fiber content, the fluidity of RPC mixture decreased, and the compressive strength gradually increased with the increase of steel fiber content. Zhao Yanru et al. [9] conducted an experimental study on the mechanical properties of steel fiber reinforced cement matrix composites, and found that the incorporation of steel fiber did not significantly increase the compressive strength of cement matrix, but significantly increased the flexural strength and flexural toughness, and both of them increased with the increase of the volume ratio of steel fiber. KouJiaLiang [10], such as the mechanical properties of RPC under the condition of normal temperature curing were studied, found that the water cement ratio, steel fiber content and water reducing agent content is the most significant influence on the mechanical properties of reactive powder concrete, water/cement ratio and the effect of water reducing agent content on the RPC fluidity big, with the increase of steel fiber content, the RPC flexural strength and compressive strength have certain growth. Li xin magnitude [11] based on the orthogonal experiment of reactive powder concrete strength and liquidity
are studied, found that the water cement ratio and steel fiber content on the performance of RPC influence is bigger, the water-binder ratio on RPC strength and liquidity, control components content of RPC degree of the compressive strength of the shadow of size: Water-binder ratio > Steel fiber blending > Fly ash blending quantity > Sand-rubber ratio > Water reducing agent blending quantity > Silica fume blending quantity; The degree of influence on fluidity is: water-binder ratio > Steel fiber blending quantity > Water reducing agent blending Amount > Sand rubber ratio > Fly ash content > Silica fume content.

To sum up, the influence of steel fiber on the fluidity and mechanical properties of RPC is a hot research issue. The influence of steel fiber content on concrete fluidity and compressive strength was studied by slump, expansion and compressive strength tests of reactive powder concrete with different steel fiber content.

2. Test Overview

2.1. The Raw Material
The cementing material is composed of cement and silica fume. Ordinary Portland cement PO 42.5 is used for cement, while silica fume is used Aiken 92. The silica content is 94.1% and the firing loss is 2.43%. The aggregate is composed of natural sand and quartz sand. The natural sand is medium sand with a fineness modulus of 2.6, while the quartz sand is fine grain sand. The fiber is copper plated steel fiber, diameter \( D = 0.2 \text{mm} \), length \( L = 13 \text{mm} \), aspect ratio 65, tensile strength 2850MPa; The mixing water is drinking tap water. The water-reducing agent adopts polycarboxylic acid water-reducing agent, the water-reducing rate is >30%.

![Fig.1](a) Quartz sand (b) Silica fume (b) steel fiber

*Fig. 1. Special raw material*

2.2. Mixture Ratio
According to the mix design regulations in JGJ 55 Ordinary Concrete Mix Design Regulations, JG/T 472 Steel Fiber concrete and GB/T 31387 Reactive powder Concrete, the mix design is carried out in combination with the purpose of the test, expressed in terms of mass ratio, as shown in Table 1.

| No. | water to glue ratio | cement | Silica fume | water | sand | Steel fiber | Water reducing agent |
|-----|---------------------|--------|-------------|-------|------|-------------|----------------------|
| 1   | 0.18                | 1.00   | 0.26        | 0.23  | 1.26 | 0.06        | 0.03                 |
| 2   | 0.18                | 1.00   | 0.26        | 0.23  | 1.26 | 0.09        | 0.03                 |
| 3   | 0.18                | 1.00   | 0.26        | 0.23  | 1.26 | 0.12        | 0.03                 |
| 4   | 0.18                | 1.00   | 0.26        | 0.23  | 1.26 | 0.15        | 0.03                 |
2.3. Preparation and Curing of Specimens
The mixing process of concrete mixture is as follows:
(1) First stir the dry powder (cement, silica fume and quartz sand) for 2min;
(2) Then add 2/3 of the water and water reducer solution, stir until the mixture is agglomerated;
(3) Add the remaining water and superplasticizer solution and stir for 3min;
(4) Add the fibers evenly, and stir continuously for 3min after all the fibers are added;
(5) The total stirring time should be no less than 5min and no more than 15min.
Pour the freshly mixed concrete into the test mold (100mm×100mm×100mm) and vibrate it on the shaking table. Wrap the sample with plastic wrap, place it on site for 24 hours and then remove the mold. After the mold is removed, the specimen is put into a steam incubator and cured at a constant temperature (70°C±5°C) for 48 hours. The specimen is reduced to room temperature at a rate not greater than 15°C/h.

2.4. Test Methods
In combination with GB/T 50080, GB/T 50081, GB/T 50081, GB/T 31387, Reactive powder concrete, JG/T 472, Steel Fiber Concrete, and other specifications, the concrete fluidity and compressive strength test was conducted. DCS-300 pressure tester was used in the compressive strength test. The compressive strength test was carried out in accordance with the specifications. The arithmetic average value of the compressive strength of three specimens was taken as the compressive strength value of each concrete specimen corresponding to each mix ratio.

3. Analysis of Test Results

3.1. Influence of Steel Fiber Content on Concrete Fluidity
According to the 4 mixing ratios listed in Table 1, 4 groups of 3 specimens were prepared for concrete fluidity test, as shown in Figure 2.

![Figure 2. Concrete slump and expansion test](image)

The slump and elongation test results of each sample are shown in Table 2. It can be seen from the table that, with the increase of steel fiber content, concrete slump and expansion degree decrease obviously, indicating that the change of steel fiber content has a significant influence on concrete fluidity while other materials remain unchanged.
Table 2. Concrete slump and expansion

| Set No. | Steel fiber content | Slump (mm) | Extensibiliti (mm) |
|---------|---------------------|------------|-------------------|
| 1       | 0.06                | 278        | 533               |
| 2       | 0.09                | 255        | 502               |
| 3       | 0.12                | 227        | 450               |
| 4       | 0.15                | 205        | 396               |

Table 3 lists concrete slump and expansion degree after adjusting the amount of water-reducing agent on the basis of the original mix ratio. It can be seen from the table that after adjusting the content of water-reducing agent, the situation of concrete fluidity reduction caused by the increase of steel fiber content has been improved.

Table 3. Concrete slump and expansion after adjustment of water reducing agent content

| Set No. | Water reducing agent dosage | Slump (mm) | Extensibiliti (mm) |
|---------|-----------------------------|------------|-------------------|
| 1       | 0.03                        | 278        | 533               |
| 2       | 0.035                       | 280        | 547               |
| 3       | 0.04                        | 267        | 538               |
| 4       | 0.05                        | 274        | 530               |

3.2. Influence of Steel Fiber Content on Concrete Compressive Strength

FIG. 3 shows the typical failure patterns of concrete specimens during cube compressive strength tests. It can be seen from the figure that, different from the ordinary concrete specimen, the surface of the active powder concrete specimen has cracked, but there is no obvious peeling phenomenon when it reaches its compressive strength due to the presence of steel fiber.

(a) Ordinary concrete  
(b) RPC

Figure 3. Compressive resistance of the cube

Table 4 lists the compressive strength test results of concrete cubes. It can be seen from the table that with the increase of steel fiber content, the compressive strength of concrete cube increases significantly. However, the more steel fiber content is not the better. As listed in the table, when the steel fiber content increases from 12% to 15% of the cement quality, the compressive strength of concrete decreases from 159MPa to 139MPa.

Table 4. Compressive strength of concrete cube

| Set No. | Steel fiber content | Compressive strength (MPa) |
|---------|---------------------|-----------------------------|
| 1       | 0.06                | 130                         |
| 2       | 0.09                | 145                         |
| 3       | 0.12                | 159                         |
| 4       | 0.15                | 139                         |
4. Conclusion
In this paper, the influence of steel fiber content on the fluidity and compressive strength of ultra-high performance concrete is studied through experiments, and the main conclusions are as follows:

   (1) With the increase of steel fiber content, concrete slump and expansion degree decrease obviously, and steel fiber content has a significant influence on concrete fluidity.

   (2) With the increase of steel fiber content, the compressive strength of concrete increases significantly. However, the higher the steel fiber content is, the better it is. When it exceeds a certain value, the compressive strength of concrete begins to decline.

5. References
[1] RICHARD P, CHEYREZY M H. Reactive powder concretes with high ductility and 200-800 MPa compressive strength [J]. ACI Journal, 1994, 144(S1):507-508.
[2] Yang jian, Wang jinsheng, Peng xin. Application research and prospect of RPC in ballastless track [J]. Journal of railway science and engineering, 2015, 12(01):53-58.
[3] Sun jianxin. Preparation and engineering application of RPC130 reactive powder concrete [J]. Railway construction, 2017, 57(09):148-150.
[4] Shao xudong, Qiu minghong, Yan banfu, et al. Research and application progress of ultra-high-performance concrete in bridge engineering at home and abroad [J]. Materials bulletin, 2017, 31(23):33-43.
[5] Chen baochun, Ji tao, Huang qingwei, et al. Research review of ultra-high performance concrete [J]. Journal of building science and engineering, 2014, 31(03):1-24.
[6] Zhang yunsheng, Zhang wenhua, Chen zhenyu. A comprehensive review of ultra-high performance concrete: design, preparation, microstructure, mechanics and durability, engineering application [J]. Materials bulletin, 2017, 31(23):1-16.
[7] Zhang R H, Xu X, LUO H H, et al. Review on the composition materials and preparation methods of reactive powder concrete [J]. Concrete & Cement Products, 2019 (10):14-18.
[8] Hao Xianhui, LI Hai-yan, LI Hua, et al. Experiment and Calculation of reactive powder concrete (RPC) mix Ratio Optimization [J]. Concrete, 2018(03):156-160.
[9] Zhao Y R, Yu P T, et al. Experimental study on mechanical properties of Steel Fiber reinforced cement matrix Composites [J]. Concrete, 2019(11):123-126+131.
[10] Koujialiang, Chen junhao, Zhang haobo. Orthogonal experimental study on mechanical properties of reactive powder concrete under normal temperature curing [J]. Architectural structure, 2019, 49(06):92-97.
[11] Li xinxing, Yang caiqian, Zhou quan, et al. Study on strength and fluidity of reactivepowder concrete based on orthogonal test [J]. Chinese journal of silicate, 2019, 38(04):1201-1210.