Experimental Study on the Influence of Vibration Mixing Technology on Engineering Characteristics of Steel Fiber Reinforced Concrete

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Abstract. In order to improve the problems of uneven dispersion, easy agglomeration and insufficient mechanical properties of steel fiber reinforced concrete, vibration mixing and conventional mixing were used to prepare two kinds of test samples. The effects of vibration mixing and conventional mixing on the compressive strength, splitting tensile strength and flexural strength of steel fiber reinforced concrete were compared and analyzed. The results show that, compared with the conventional mixing, vibration mixing compression test can better maintain the integrity of the specimen, only a small number of cracks and small gap, no integral extension cracks appear. Compared with conventional mixing, the average compressive strength of steel fiber concrete for 3d, 7d and 28d under vibration mixing increased by 12.9\%, and the splitting strength increased by 12.3\%, and the flexural strength increased by 16.8\%, and the mechanical properties were strengthened. It provides a reference for the effective application of vibration mixing steel fiber concrete in engineering structure.

Keywords: Vibration mixing, steel fiber reinforced concrete, mechanical properties, coefficient of variation.

1. Introduction
Concrete is the most widely used engineering material in modern engineering construction because of its easy shaping, high strength and good durability. With the increasing requirements for concrete strength and durability in modern engineering construction, ordinary concrete cannot meet the requirements. Adding steel fiber into ordinary concrete can improve the tensile strength and toughness of concrete, inhibit and delay the formation of cracks, and improve its engineering application performance. Therefore, it is widely used in the engineering field, and is also widely concerned by researchers and engineering users [1-4]. Changhong added steel fiber with different volume ratios into concrete to study the influence of steel fiber content on the mechanical properties of concrete. The results show that the maximum compressive strength of concrete increased by 13\% ~ 30\% [5]. Zhang Yujie studied the influence of steel fiber content on the compressive strength and splitting tensile strength of steel fiber concrete cubes. The results show that when the volume content of steel fiber was 1.5\%, the compressive strength of 28d increased by 23.8\%, and the splitting tensile strength increases by 78.7\%, and the mechanical properties are obviously improved [6]. Zhang Yannian et al. analyzed the influence of steel fiber ratio, concrete matrix strength and steel fiber type on the
tension-compression ratio of concrete. It was concluded that the tension-compression ratio of concrete was increased by steel fiber, which increased gradually with the increase of steel fiber volume ratio, and the maximum increase reached 27.4% [7]. Liu et al. studied the effects of steel fiber and silica fume on the mechanical properties and fracture properties of ultra-high performance geopolymer concrete (UHPGC), using four volume fractions of steel fiber (0%, 1%, 2% and 3%). The results showed that with the increase of steel fiber content, the processing performance of UHPGC decreased, but the mechanical and fracture performance improved continuously [8]. Jin et al. conducted experimental research on the static and dynamic mechanical properties of steel fiber ultra-high-strength concrete. The introduction of steel fiber improved the splitting tensile strength and bending strength of steel fiber. With the increase of strain rate and steel fiber content, the dynamic compressive strength of concrete increases, but its strain rate effect is slightly lower than that of ordinary concrete. However, the steel fiber concrete also has some obvious disadvantages, such as the easy agglomeration and uneven dispersion of steel fiber in the mixing process, resulting in insufficient bond strength between steel fiber and concrete and affecting its mechanical properties [9].

In this paper, steel fiber concrete is prepared by vibration mixing equipment. The compressive strength, flexural strength and flexural strength of SFRC under vibration mixing were studied in order to solve the problem of uneven dispersion of SFRC under conventional mixing, improve the mechanical properties of SFRC, and provide engineering reference for the application of vibration mixing in steel fiber concrete.

2. Experiment Method

2.1. Test Material
The cement in the test is P· O 52.5 ordinary Portland cement, whose index conforms to the national standard of "General Portland Cement" (GB175-2007). The grade of fly ash is the first grade. The ore powder used in the test is grade S95 slag powder and grade S90 silica fume. The steel fiber used in the test is Shanghai Zhenqiang steel wire cutting steel fiber, and its specific performance is shown in table 1. Ordinary river sand (medium sand) was selected with apparent density of 2658Kg/m3 and fineness modulus of 2.68. On the basis of referring to the mix design theory of active powder concrete at home and abroad, the test results of compressive strength and splitting strength at the age of 28 days were finally obtained through field test. The final mix design of steel fiber concrete is shown in table 2.

| Table 1. Steel fiber performance indexes. |
|------------------------------------------|
| Steel fiber types | Length (mm) | Diameter (mm) | L/D | Tensile strength(MPa) |
| End hook         | 20          | 0.3           | 65  | 2000                  |

| Table 2. Mixture ratio of reactive powder concrete (kg/m³). |
|------------------------------------------------------------|
| Steel fiber | Cement | Coal ash | Ore powder | Silica fume | Sand | Water | Water-reducing agents |
|-------------|--------|----------|------------|-------------|------|-------|-----------------------|
| 78          | 750    | 42.5     | 85         | 112         | 1290 | 169   | 28.72                 |

2.2. Test Equipment
In the test, samples of steel fiber concrete were mixing using vibration mixer (DT60, Xuchang Detong). Vibration mixing can make the cement particles in the mixture vibrate by applying mechanical vibration at the same time of ordinary mixing, which will destroy the cement agglomerated unit and make the cement particles quickly and evenly distributed. In addition, vibration can purify the aggregate surface and increase the interfacial bonding force between cement and aggregate. Turning off vibration is conventional static mixing and turning on vibration is vibration mixing.
2.3. Test Method

The test samples of concrete were formed by vibration forming method. The prepared SFRC mixture was put into the standard test die and vibrated to form on the shaking table. The formed specimens were put into the standard curing room (temperature of 20℃, humidity of 98%) for standard curing, and finally the test results were tested. In this paper, SYE200AYA test press was used to test the mechanical properties of steel fiber concrete (compressive strength, splitting strength and bending strength).

3. Results and Discussion

3.1. Failure Modes of Compressive Test Specimens

The steel fiber concrete mixed by ordinary mixing and vibration mixing was prepared into cubic (100mm*100mm*100mm) test samples, as shown in figure 1. The sample was tested on a pressure testing machine, and the failure pattern of the sample was observed and the stress data was recorded. Compared with the sample under vibration mixing, the crack time of steel fiber reinforced concrete specimen under ordinary mixing is earlier in the process of compression failure under the same loading condition. In the later period, the cracks increase and develop gradually, and there is less peeling on the surface of the specimen. After loading, the specimen showed obvious plastic failure and large penetrating crack. The failure process of steel fiber reinforced concrete (SFRC) shaken by vibration is similar to that of ordinary stirred specimens. The difference is that in the case of compression failure, the amount of spalling on the surface of the specimen is less, the number of cracks is small and the width is narrow, and there is no large penetration crack. Vibration mixing can better maintain the integrity of test pieces than ordinary mixing.

3.2. Mechanical Property

The compressive strength, splitting strength and bending strength of the test pieces were compared and analyzed by using vibration mixing and ordinary mixing. Table 3 shows the comparison of compressive strength under the two mixing processes, table 4 shows the splitting strength under the two mixing processes, and table 5 shows the comparison of the flexural strength under the two mixing processes. It can be seen from table 3 that, compared with ordinary mixing, the 3d, 7d and 28d compressive strengths of the vibration mixing steel fiber concrete specimens are increased by 11.8%, 12.7%, and 14.1%, and the coefficient of variation is reduced by 47.9%, 54.6%, and 45.7%, respectively. Table 4 shows that compared with ordinary mixing, the 3d, 7d and 28d splitting strengths of the vibration mixing steel fiber concrete specimens were increased by 5.3%, 12.4%, and 17.6%, respectively, and the coefficient of variation was reduced by 40.2%, 42.7%, and 44.3%, respectively. It can be seen from table 5 that, compared with ordinary mixing, the 3d, 7d and 28d compressive
strengths of the vibration mixing steel fiber concrete specimens were increased by 6.7%, 20.9%, and 21.2%, respectively, and the coefficient of variation were decreased by 30.9%, 36.2%, and 30.3%, respectively. By comparing the three strength relations of the two mixing processes, the mechanical properties of steel fiber concrete can be strengthened and the coefficient of variation can be greatly reduced by using vibration mixing.

### Table 3. Comparison of compressive strength between the two mixing processes.

| Cement content /% | 3d     | Ordinary | Vibration | 7 d     | Ordinary | Vibration | 28 d     | Ordinary | Vibration |
|-------------------|--------|----------|-----------|--------|----------|-----------|--------|----------|-----------|
| Stirring method   | Average compressive strength/MPa | 65.4 | 73.1 | 72.4 | 81.6 | 88.4 | 100.8 |
|                   | Variable coefficient(%) | 0.071 | 0.037 | 0.075 | 0.034 | 0.070 | 0.038 |

### Table 4. Comparison of splitting strength between the two mixing processes.

| Cement content /% | 3d | Ordinary | Vibration | 7 d | Ordinary | Vibration | 28 d | Ordinary | Vibration |
|-------------------|----|----------|-----------|-----|----------|-----------|------|----------|-----------|
| Stirring method   | Average splitting strength/MPa | 9.8 | 10.3 | 10.5 | 11.8 | 13.1 | 15.4 |
|                   | Variable coefficient(%) | 0.082 | 0.049 | 0.082 | 0.047 | 0.088 | 0.049 |

### Table 5. Comparison of flexural strength between the two mixing processes.

| Cement content /% | 3d     | Ordinary | Vibration | 7 d     | Ordinary | Vibration | 28 d     | Ordinary | Vibration |
|-------------------|--------|----------|-----------|--------|----------|-----------|--------|----------|-----------|
| Stirring method   | Average flexural strength/MPa | 25.4 | 27.1 | 27.8 | 33.6 | 33.5 | 40.6 |
|                   | Variable coefficient(%) | 0.068 | 0.047 | 0.069 | 0.044 | 0.066 | 0.046 |

In order to analyze the influence of ordinary mixing and vibration mixing on the mechanical properties of steel fiber concrete more intuitively, the strength values under the 3d, 7d and 28d curing cycles are averaged to estimate the mechanical properties of the two processes under the full life cycle. As shown in figure 2. Compared with ordinary mixing, the compressive strength under vibratory mixing was increased by 12.9%, and the coefficient of variation was reduced by 49.4%; the splitting strength was increased by 12.3%, and the coefficient of variation was reduced by 42.4%; the flexural strength was increased by 16.8%, and the coefficient of variation was reduced 32.5%. The results showed that the vibration mixing made the micro-particles in steel fiber reinforced concrete disperse evenly and bind more closely. On the whole, the mechanical properties of steel fiber reinforced concrete are obviously improved by vibration mixing.
Figure 2. Rate of change of average strength and variable coefficient under two mixing processes.

4. Conclusion
In this paper, the comparative test method is used to study the mechanical properties of steel fiber concrete under vibration mixing and conventional mixing. The main conclusions are as follows:

(1) The failure process of steel fiber reinforced concrete specimens under vibration mixing shows that vibration mixing can better maintain the integrity of specimens than ordinary mixing. Only a few cracks and small gaps can be seen and no overall extension cracks appear.

(2) Compared with ordinary mixing, the compressive strength under vibration mixing increased by 12.9%, and the splitting strength increased by 12.3%, and the flexural strength increased by 16.8%. The coefficient of variation decreased by 49.4%, 42.4% and 32.5%, respectively. Vibration mixing can significantly improve the mechanical properties of steel fiber reinforced concrete.

Acknowledgments
This work is supported by Science and Technology Entrepreneurship Leading Project of Zhongyuan, Science and Technology Innovation Leading Project of Zhongyuan (194200510029) and Fundamental Research Funds for the Central Universities of China (No. 310825163408).

References
[1] Xu J Y, Li W M, Huang X M and Li P 2010 Dynamic constitutive model of basalt fiber reinforced geopolymeric concrete Engineering Mechanics 04 111-116.
[2] An X X, Ning Z Y and Meng M Q 2018 Study on tensile and compressive strength model of steel fiber recycled concrete Sichuan Building Science 04 97-101.
[3] Liu C, Cui W W, Deng J Z and Pei C C 2016 Influences of Hydrid Steel Fiber with Different Mixing Rates on Performances of Recycled Concrete China Concrete and Cement Products 12 53-56.
[4] Zhao Z H, Liu X B, Hou X Y and Ma Y H 2011 Application of basalt fiber in concrete Low Temperature Architecture Technology 07 5-7.
[5] Chang H, Shen P and Gu F G 2020 Analysis of the influence law of steel fiber on concrete thermal conductivity and pressure strength Concrete 4 67-69.
[6] Zhang Y J, Chen B C and Wang Y 2020 Analysis on the mechanical properties of steel fiber
reinforced concrete. Concrete 4 74-77.

[7] Zhang Y N, Liu X Y, Dong H and Zheng Y 2018 Experimental study on tensile and flexural behavior of steel fiber reinforced concrete with low content Journal of Liaoning Technical University (Natural Science) 1 66-69.

[8] Liu Y W, Shi C J, Zhang Z H, Li N and Shi D 2020 Cement and Concrete Composites 112 1-13.

[9] Jin L, Zhang R B, Tian Y D, Dou G Q and Du X L 2018 Experimental investigation on static and dynamic mechanical properties of steel fiber reinforced ultra-high-strength concretes. Construction and Building Materials 178 102-111.