Study on Mechanical and Crack Resistance of Expanded Fiber Reinforced Concrete

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Abstract. In order to effectively improve the mechanical properties, deformation properties and crack resistance of concrete, and to control the cracking of concrete, high crack resistance concrete with excellent comprehensive performance is prepared. The basalt fiber and calcium magnesium expansion agent are mixed into the concrete to increase the tensile strength and limit the shrinkage deformation. Starting from the fundamental factors of concrete cracking, control the cracking of concrete and improve its crack resistance. The effects of different basalt fiber (BF) and calcium magnesium expansion agent (EA) and different w/c on the mechanical and crack resistance of concrete were investigated. Three-factor and three-level orthogonal tests were carried out to research the compressive, tensile, flexural, free deformation tests of expanded fiber concrete, at the same time, the best mix ratio was determined. Finally, the SEM test was carried out to analyze the mechanism of crack resistance improvement from the microstructure. The results show that when the fiber content is 1% and the expansion agent is 7%, the concrete has the best crack resistance and the performance improvement effect.

1. Introduction

In recent years, cracks have appeared continuously in concrete structure engineering, which has affected the normal use of the structure and left a safety hazard. In order to prevent or reduce the cracking of concrete, a large number of studies have chosen to add fibers to concrete [1-2]. The fibers usually added to concrete are mainly carbon fiber, polypropylene fiber, steel fiber, glass fiber, basalt fiber, etc. [3]. Among them, basalt fiber is a new type of inorganic material, which has the advantages of environmental protection and it is a high-performance fiber material. Its density is close to the density of concrete, 2.65-3.0 g/cm³, tensile strength is 3000-4800 MPa, and it can maintain high stability in alkaline medium such as cement. It has good compatibility and can be used as a reinforcing material for concrete building structure to effectively improve the tensile strength of concrete, inhibit the free deformation of concrete and reduce the risk of concrete cracking. [4-5].

Min [6] studied the effects of basalt fiber and ceramic sand on concrete shrinkage and cracking. Research results show the tendency of shrinkage and cracking of basalt fiber-reinforced concrete and ceramic sand double-concrete concrete is significantly reduced. Ruijie et al. [7] studied the effect of basalt fiber aspect ratio on the shrinkage of concrete was studied. The research finds that the basalt fiber effectively reduces the shrinkage of concrete, and different volumetric requirements have different requirements on aspect ratio. Cheng Xin et al. [8] studied the effect of basalt fiber aspect ratio, volume and other factors on shrinkage cracking of foam concrete. Research shows that when the volume is 0.3% and the length is 10mm, the shrinkage cracking of concrete can be significantly reduced. Xinjian Sun et al. [9] simulated the effects of the content and size of basalt fiber on the
various properties of concrete. The study shows that the concrete with 6 mm basalt fiber can achieve maximum strength when the content is 2%. Li et al. [10] researched the effect of steel fiber and expansion agent on the bonding properties of steel bars in concrete. Studies have shown that two materials can greatly improve the bond strength and bond stiffness.

It is of great limitation to improve the crack resistance of concrete by single fiber blending, and its mechanism and effect are also controversial. The addition of a swelling agent will form ettringite crystals during hydration and expand, thereby improving the crack resistance of concrete. Therefore, basalt fiber and calcium-magnesium bulking agent are added to the concrete at the same time, and the effects of fiber, expansion agent volume and w/c on the mechanical properties and crack resistance of concrete are studied.

2. Experiment

2.1. Experimental Materials
Ordinary Portland cement P·O 42.5 (produced by a cement company in Nanjing, Jiangsu Province); Grade I fly ash (produced by a company in Nanjing, Jiangsu Province); basalt gravel (filled 5-30mm); natural river sand (fineness modulus) 2.56); 12 mm chopped basalt fiber (produced by a company in Shanghai, its mechanical properties are shown in table 1); calcium magnesium expansion agent (produced by a company in Shandong, its chemical composition is listed in the table 2); polycarboxylic acid type superplasticizer (Jiangsu Nanjing Co., Ltd. produces, reducing water into 30-40%).

| Material | Diameter (μm) | Length (mm) | Density (kg/m³) | Elastic Modulus (GPa) | Tensile Strength (MPa) | Elongation at break (%) | Maximum temperature (°C) | Softening Point |
|----------|---------------|-------------|-----------------|-----------------------|-----------------------|-------------------------|--------------------------|----------------|
| BF       | 16            | 12          | 2650            | 100                   | 4150                  | 3.2                     | 650                      | 960            |

Table 2. Chemical composition of expansion agent (%).

| Material | CaO   | MgO   | SiO₂  | Fe₂O₃ | Al₂O₃ | L.O.I  | ∑     |
|----------|-------|-------|-------|--------|--------|--------|-------|
| EA       | 40.06 | 49.09 | 6.34  | 1.24   | 0.91   | 1.35   | 99.98 |

2.2. Experimental Methods
In this experiment, the C40 reference concrete mix ratio was selected. The orthogonal test of three factors of w/c (A), expansion agent (B) and basalt fiber (C) is listed in table 3.

Table 3. Factor level table of orthogonal test.

| Level | A  | B  | C   |
|-------|----|----|-----|
| 1     | 0.4 | 5% | 0.8%|
| 2     | 0.42 | 7% | 1%  |
| 3     | 0.45 | 9% | 1.2%|

Concrete compression, tensile strength, flexural strength test and free deformation test are all carried out in accordance with SL352-2006 “Hydraulic Concrete Test Procedures”. The free deformation test uses 55mm × 55mm × 280 mm prismatic specimens. The SEM test used JSM-6510 high-resolution scanning electron microscope to observe the microstructure.
3. Results and Discussion

3.1. Analysis of Compressive Strength Test Results

After the test piece has been subjected to standard curing, the test results of the compressive strength of each component are clearly shown in figure 1a. The test results were fitted, and the results of compressive strength test were analyzed by the range analysis to investigate the effects of different factors such as the mixing amount and w/c on the compressive strength of concrete. The results are shown in figures 1b-1d.

![Compressive Strength Test Results](image)

(a) Test results of concrete compressive strength of each group

(b) Effect of w/c on compressive strength

(c) Effect of EA on compressive strength

(d) Effect of BF on compressive strength

**Figure 1.** Concrete compressive strength test results and analysis.

It can be seen from figures 1b-1d that the compressive strength of concrete gradually decreases with increasing w/c. With the increase of the volume of the expansion agent, the compressive strength of the concrete increases first and then decreases, and the strength is maximum when the dosage is 7%. This is because the bulking agent generates a large amount of ettringite crystals when hydrating and hardening, so that the internal structure is more compact. If the amount of expansion agent is too large, it will cause a lot of pores in the skeleton structure of the crystal to increase the porosity of the concrete and adversely affect the compressive strength of the concrete. With the increase of basalt fiber content, the compressive strength of concrete first showed an upward trend, and then began to decrease after reaching the maximum value. When the fiber volume is 1.0%, the strength is maximum. This is because the basalt fiber absorbs a part of the deformation of the concrete, and the fiber plays a certain connection role inside the concrete, which reduces the shrinkage deformation and improves the strength; more than 1% is reduced because when the amount of the fiber is excessive, it is difficult to disperse a large amount of the fiber, resulting in agglomeration of the fiber. The phenomenon of the group leads to a decrease in the joint effect of the concrete and a decrease in the compressive strength of the concrete. At the same time, the specific surface area of the fiber is large, especially for basalt fiber as an inorganic material, which requires a large amount of cement slurry to be wrapped. If the amount of fiber is too large, it will cause the limited cement slurry to not completely wrap it. There
will be no cement stone connection between the fiber and the internal aggregate, and the direct contact between the two inorganic materials of basalt fiber and aggregate will occur in local areas of the concrete, resulting in relative slippage and voids between them during the stress, greatly reducing the strength of the concrete. According to the range analysis, we can see that the volumetric content of basalt fiber has the greatest impact on the compressive strength, followed by the w/c and finally the expansion agent.

3.2. Analysis of Tensile Strength Test Results

The results of concrete tensile strength of each group are shown in figure 2a. The results of the tensile strength test fitting and the range analysis are analyzed. The results are shown in figures 2b-2d.

According to figures 2b-2d, it can be concluded that the tensile strength of concrete decreases with the increase of w/c; with the increase of volume of expansion agent, it increases first and then decreases, and reaches the maximum at 7%; With the increase of basalt fiber content, the tensile strength of concrete first increases slowly and then decreases significantly, and the maximum strength is obtained at 1%. The change law of tensile strength is similar to compressive strength and the reason is the same as that described in the compressive strength analysis. According to the range analysis, the basalt fiber content has the greatest influence on the tensile strength, followed by the w/c, and the expansion agent has the least effect.

Figure 2. Concrete tensile strength test results and analysis.

3.3. Analysis of the Results of the Flexural Strength Test

The test results of concrete flexural strength of each group are presented in figure 3a. The results of the fitting and range analysis are shown in figures 3b-3d.

It can be concluded from figures 3b-3d that as the w/c increases, the flexural strength tends to decrease slowly. With the increase of the amount of expansion agent, the flexural strength increases first and then decreases slightly. When the dosage is 7%, the flexural strength is the largest; with the increase of basalt fiber content, the flexural strength increases first and then decreases significantly,
which is the largest at 1%. The change law of tensile strength is similar to compressive strength and tensile strength, the reason is the same as that described in the compressive strength analysis. According to the range analysis, the volumetric content of basalt fiber has the greatest influence on the flexural strength, followed by the w/c, and finally the expansion agent.

3.4. Analysis of Deformation Test Results
Under the standard curing conditions, the free deformation test results and range analysis of different groups of concrete at different ages are presented in figure 4.

It can be seen from figure 4 that the use of basalt fiber and expansion agent technology can effectively improve the self-shrinkage. Among them, the expansion agent has the greatest impact on the free deformation. The effect of w/c on free deformation is second. When the w/c increases, the free water in the concrete increases, which compensates for the water loss of the capillary pores inside the concrete and reduces the drying shrinkage of the concrete. At the same time, the increase of moisture can make the cementitious material inside the concrete more hydrated, and the internal structure is more substantial. Finally, the fibers and fibers have a certain limiting effect on the expansion and deformation of the concrete itself.

3.5. SEM Microstructure Analysis
The concrete CZ0 and CZ2 were selected for microscopic analysis. Figures 5 and 6 are SEM electron micrographs of the two groups of concrete. From figure 5 we can see that the concrete inside mainly contains hydrated products such as cloud-like CSH gels, calcium hydrated aluminate crystals, layered calcium hydroxide, and spherical granular fly ash. The pores in the ordinary concrete are relatively large and the structure is relatively loose. In addition to the general hydration products, the CZ2 group of concrete in figure 6 also produces ettringite crystals (AFt) and fibrous brucite, which improves the bond strength between the fiber and the cement matrix, and fills the micro-cracks and holes inside the concrete interior. The production of crystals also causes the concrete to expand and make the structure...
more compact, which effectively improves the mechanical properties and crack resistance of the concrete. At the same time, we can see the existence of fibers in the picture.

(a) Test results of free deformation of concrete in each group

(b) Deformation test range analysis

Figure 4. Concrete free deformation test results and analysis.

Figure 5. SEM image of ordinary concrete.

Figure 6. SEM image of expanded fiber concrete.

4. Conclusion
In this paper, the mechanical properties, deformation properties and crack resistance of concrete were studied by changing the blending amount of basalt fiber and calcium magnesium expansion agent and the w/c. The test results were analyzed from compressive strength, splitting tensile strength, flexural strength, free deformation and SEM, and the following results were obtained:

(1) The addition of proper amount of basalt fiber and expansion agent can effectively improve the mechanical properties, and the effect of strength improvement is from large to small: splitting tensile strength > flexural strength > compressive strength. At the same time, the fiber and expansion agent double blending technology can also effectively suppress its shrinkage and deformation.
(2) As the w/c increases, the strength decreases. With the increase of the amount of fiber and expansion agent, the mechanical properties of concrete tend to increase first and then decrease. When the basalt fiber content is 1% and the expansion agent content is 7%, the mechanical properties of the expanded fiber concrete are the best. Fiber has the greatest effect on the mechanical properties of concrete, followed by w/c, and the least effect of expansion agents.

(3) From the microscopic, the addition of an appropriate amount of expansion agent can promote the degree of concrete hydration. Its self-expansion efficiency effectively fills the internal pores, effectively improve the compactness and mechanical properties, and reduce the shrinkage deformation.

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