Experimental Study of Basic Mechanical Properties of Short Basalt Fiber Bundle Reinforced Concrete

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Abstract. In this paper, the mechanical properties of basalt short fiber bundle reinforced concrete (sbfrbrc) are designed, and the effects of basalt fiber bundle content and diameter on its compression, splitting and bending properties are studied. The results show that basalt fiber bundle has good dispersion in concrete. The splitting tensile strength and flexural strength of high-strength concrete are significantly improved, but the compressive strength is not significantly improved. The compressive strength of concrete increases first and then decreases. When the fiber bundle content is 0.2%, the compressive strength increases by 6.11%. The splitting tensile strength and bending strength increase with the increase of fiber bundle content. When the fiber bundle content was 0.6%, they increased by 19.54% and 20.32% respectively compared with the reference group. Compared with basalt fiber bundle with diameter of 0.5mm and 0.8mm respectively, basalt fiber bundle with diameter of 0.2mm has better effect on improving the compressive, splitting, tensile and flexural properties of concrete

Keywords. basalt fiber bundle; compressive strength; splitting tensile strength; flexural strength

1.Introduction
Basalt fiber (BF) has the advantages of high elastic modulus, high tensile strength, excellent physical and mechanical properties, green environmental protection and low cost. In recent years, its application in concrete has attracted the attention of many scholars. Scholars at home and abroad have done a lot of research on the mechanical properties of basalt fiber concrete. Kabay et al,[1] Branston et al,[2] Zeynep et al,[3] Mahzabin et al,[4] Sruthi et al,[5] Kizilkaran et al[6] found that the flexural strength of concrete can be improved obviously by using the appropriate amount of basalt fiber. However, some studies have shown that a small amount of chopped basalt fiber can not significantly increase the compressive strength [7-9], and increasing the amount will result in a decrease in the compressive strength of concrete [5,10]. Besides, Branston et al,[2] Jiang et al[11] found that the addition of short cut basalt fiber will reduce the fluidity of concrete mixture, and the phenomenon of fiber agglomeration is serious with the increase of content. The agglomeration phenomenon may lead to the increase of holes in the mixture, thus increasing the weak interface inside the concrete and decreasing the strength of the concrete. At the same time, the water absorption of basalt fiber itself reduces the flowing water in the mixture, resulting in a large decrease in the fluidity of concrete, and the incorporation of fiber reduces the water that can be used for cement hydration, which affects the production and development of concrete matrix strength[12].
To reduce the problem of easy agglomeration and uneven dispersion of basalt fibers, the author of this paper proposes to use basalt fiber bundle[13] instead of chopped basalt fiber to prepare a new type of short basalt fiber bundle concrete (SBFBRC). Because the basalt fiber bundle can better match the coarse aggregate in concrete, the basalt fiber bundle and the concrete matrix form a good cooperative work, to achieve a better effect of strengthening and toughening, improve the toughness of concrete, and enhance the basic mechanical properties of concrete, such as compression, splitting and folding resistance. However, there is no systematic study on the influence of basalt fiber bundle content and fiber bundle diameter on the mechanical properties of concrete.

This test compares the mechanical properties of plain concrete and short basalt fiber bundle concrete(SBFBRC), explores the influence of basalt fiber bundle with different dosages and length-to-diameter ratios on the mechanical properties of concrete and compares the test results of the cube compression test, split tensile test, and flexural test , the short basalt fiber bundle concrete (SBFBRC) with good working performance.

2. Experimental study

2.1 Materials and test design
For the establishment of the model, this article first imports the fiber coordinates output from MATLAB into ANSYS through APDL files and then generates the fiber geometry. After assigning material properties to the fibers, dividing the mesh, the CDB file is output. In the ABAQUS software, the CDB file is directly imported, the fiber material properties are modified, and the concrete model is built. Among them, the elastoplastic damage constitutive model is selected for concrete, the elastic constitutive model is selected for fiber, and then the steps of defining analysis steps, defining constraints, defining loads, and extracting post-processing results are performed.

2.2 Establishment of the three-dimensional numerical model of the basalt fiber bundle
The cement adopts 42.5 ordinary Portland cement. The fine aggregate is river sand, and the fineness modulus is 2.85. The gravel consists of 5~10 mm，10~20 mm and the ratio is 4:6. Powder polycarboxylic acid is a high performance water reducer. The basalt fiber bundles used in this paper are made of basalt fiber monofilament strands impregnated with glue and then cut short. As shown in figure 1, the fiber bundle length is 30 mm, and the diameter is 0.2 mm ,0.5 mm, 0.8 mm respectively, the basalt fiber monofilament parameters are shown in table 1.

![Image](image_url)

(a)0.2mm diameter  (b)0.5mm diameter
Figure 1. Basalt fiber bundles of different diameters

Table 1. Basalt fiber physical index

| Material     | Monofilament diameter/μm | Length/m m | Density/kg. m³ | Tensile strength/M Pa | Elastic Modulus/G Pa | Ultimate elongation/ % |
|--------------|--------------------------|------------|----------------|-----------------------|----------------------|------------------------|
| Basalt fiber | 13                       | 30         | 2.65           | >3000                 | 85                   | 3.2                    |

High strength concrete with C60 strength grade is taken as the benchmark material for this test, and its cooperation is shown in Table 2.

Table 2. Benchmark mix ratio (kg/m³)

| Water | Cement | Sand | Stone | Water reducer |
|-------|--------|------|-------|---------------|
| 155   | 450    | 700  | 1095  | 2.0           |

Cube compression and splitting tensile tests are in accordance with the requirements of "Standard for Test Methods of Mechanical Properties of Ordinary Concrete" GB/T50081-2002, using standard specimens. The size of the specimens used in the flexural test is 100 mm×100 mm×400 mm.

The experiment researches the influence of basalt fiber bundle content and aspect ratio on the mechanical properties of concrete. There are 3 test pieces in each group, and the test groups are shown in Table 3.
| Test group | Fiber bundle length (mm) | Fiber bundle diameter (mm) | Fiber bundle content (%) |
|------------|-------------------------|----------------------------|--------------------------|
| L-0        | 0                       | 0                          | 0                        |
| L-1        | 30                      | 0.5                        | 0.2                      |
| L-2        | 30                      | 0.5                        | 0.4                      |
| L-3        | 30                      | 0.5                        | 0.6                      |
| L-4        | 30                      | 0.2                        | 0.4                      |
| L-5        | 30                      | 0.8                        | 0.4                      |

2.3 Forming and curing of specimens

When the test piece is made, it is stirred by a forced mixer and shaken on a vibrating table. Feeding order: first according to stone, sand order, dry mixing 30 s, add cement and water mixing 30 s, while stirring the fiber evenly into the mixing pot, then mixing 1.5 min, so that the concrete mixing evenly. Strictly control the mixing time of the fiber bundle to prevent damage to the surface of the fiber bundle due to excessive mixing time. After 24 h, remove the mold and put it into the standard maintenance room for maintenance.

2.4 Test methods

According to the requirements of GB/T 50080 in "Test Methods for Performance of Ordinary Concrete Mixtures", this paper uses the slump method to test the fluidity of basalt fiber concrete (BFRC). According to the "Standard for Test Methods of Mechanical Properties of Ordinary Concrete" GB/T 50081-2002, the cube compression, splitting tensile and flexural tests are carried out. Among them, the flexural test adopts displacement loading, and adopts Donghua DHDAS dynamic signal acquisition and analysis system to collect data. As shown in Figures 2 and 3.

![Figure 2. Split-pull test device](image)
3. Test results and analysis

The compressive, splitting and flexural strength of concrete and its growth rate are shown in Table 4.

| Test group         | 28d cube compressive strength (MPa) | Compressive strength growth rate (%) | 28d splitting strength (MPa) | Cleavage Strength Growth Rate (%) | 28d flexural strength (MPa) |
|--------------------|-------------------------------------|-------------------------------------|-----------------------------|----------------------------------|-----------------------------|
| Benchmark group    | 65.5                                | 0.00                                | 5.17                        | 0.00                             | 5.61                        |
| 30mm-0.5mm-0.2%    | 69.5                                | 6.11                                | 5.56                        | 7.54                             | 5.85                        |
| 30mm-0.5mm-0.4%    | 66.2                                | 1.07                                | 5.74                        | 11.03                            | 6.09                        |
| 30mm-0.5mm-0.6%    | 64.9                                | -0.91                               | 6.18                        | 19.54                            | 6.75                        |
| 30mm-0.2mm-0.4%    | 67.5                                | 3.05                                | 6.28                        | 21.47                            | 6.29                        |
| 30mm-0.8mm-0.4%    | 63.1                                | -3.66                               | 5.28                        | 2.13                             | 5.41                        |

3.1 Experimental Study on Working Performance of SBFRC

The basalt fiber bundle after twisting and soaking has good dispersion in concrete, and the basalt fiber bundle has little effect on the fluidity of concrete, so it is convenient to cast.
As shown in figure 4, with the increase of fiber content in the concrete mixture, the fiber bundle has little effect on the fluidity of concrete, and the slump value decreases only slightly. When the content of fiber bundle was 0.2%, 0.4%, 0.6%, the slump was 2.6%, 4.7%, 8.3% lower than that of the reference group, and the mixture was in good condition.

It can be seen from figure 5 that the addition of fiber bundle fiber leads to the decrease of the slump of concrete, and the effect of small diameter fiber bundle on slump is more significant. As the diameter of fiber bundle was 0.2 mm, 0.5 mm, 0.8 mm, the slump value of concrete decreased by 10.9%, 4.7%, 3.6% respectively. At the same volume content, the small diameter fiber bundle has a larger specific surface area, more cement slurry is needed to wrap, the flowing water in the concrete mixture decreases, and the friction between the aggregates increases, which leads to the decrease of the fluidity of the concrete mixture.
3.2 Experimental study on compressive strength of SBFBRC

It can be seen from figure 6 that when the fiber bundle content in the mixture increases gradually, the cube compressive strength of concrete increases first and then decreases. When the volume ratio of basalt fiber bundle is 0.2, the compressive strength of fiber bundle concrete increases by 6.11%. When the fiber bundle content is 0.6%, the compressive strength of concrete is slightly lower than that of the reference group. It is concluded that for a certain mix ratio and fiber parameters, there will be a critical volume content[14], when the fiber content is lower than the critical volume content, the compressive strength increases gradually. With the increase of fiber bundle volume ratio, the compactness of concrete matrix is destroyed, the internal void increases, the defect is more obvious, and the compressive strength is reduced. However, with the increase of fiber content, the ability of concrete to resist deformation is enhanced, and the integrity can be maintained under the action of load, and the whole surface will not fall off. As shown in figure 9, after adding 0.2% basalt fiber bundle, the specimen can maintain good integrity after
compression test. In contrast, the control group of plain concrete showed obvious failure after the compression test (Fig. 8). The addition of fiber bundle obviously improves the plastic deformation performance of concrete and the crack resistance of concrete.

![Figure 8. Compression failure form of plain concrete](image)

![Figure 9. Compression failure form of 0.2% content fiber bundle concrete](image)

As can be seen from figure 7, with the increase of diameter, the compression strength increases first and then decreases. When the diameter is 0.2 mm, the strength reaches the peak value, which is 3.05% higher than that of the reference group. When the diameter is 0.8 mm, the strength is slightly lower than plain concrete. In summary, basalt fiber bundle has a certain effect on improving the compression strength of concrete, but with the increase of fiber content in the mixture, the strength is slightly lower than that of the reference group.

3.3 Experimental study on tensile strength of SBFBRC

The concrete splitting strength test is shown in Fig. 10,11. Under the action of load, the fine crack appears near the cushion strip. The fine crack expands rapidly through the whole specimen, and the specimen is
split and destroyed, while the fiber bundle concrete develops zigzag along the side of the specimen under the action of load. The width of the crack is small and the integrity of the specimen is good.

Figure 10. Splitting failure mode of plain concrete

Figure 11. Splitting and breaking morphology of 0.2% fiber bundle concrete
Figure 12. Relationship between splitting strength and fiber bundle volume content

Figure 13. Relationship between splitting strength and fiber bundle diameter

It can be seen from figure 12 that the split tensile strength of concrete can be improved by adding basalt fiber bundle in the concrete mixture, and with the increase of fiber bundle content, the split tensile strength of concrete increases gradually. When the fiber bundle content of basalt is 0.6%, the splitting tensile strength is 19.54% higher than that of reference concrete. It can be seen from figure 13 that the splitting tensile strength of concrete increases first and then decreases with the increase of the diameter of basalt fiber bundle, but the splitting tensile strength is higher than that of reference concrete. When the fiber bundle diameter is 0.2 mm, the split tensile strength of the concrete is increased by 21.47% compared with the benchmark group. Compared with 0.5 mm and 0.8 mm diameter, the 0.2 mm diameter fiber bundle has a better effect on improving the split tensile strength.

Fig.14 is a 30 mm-0.5mm-0.6% section with a large number of fiber bundles distributed on the section, and most of the fiber bundles are fracture failure, which indicates that basalt fiber bundles have strong adhesion to the concrete matrix. As the load increases, the fiber bears part of the stress for the concrete
until the fiber bundle breaks or pulls out. Therefore, the incorporation of basalt fiber bundles can significantly enhance the splitting tensile strength of concrete.

![Image of 30mm-0.5mm-0.6% cross-sectional view](image)

**Figure 14.** 30mm-0.5mm-0.6% cross-sectional view

### 3.4 Experimental Study on flexural strength of SBFBRC

Compared with plain concrete, after adding basalt fiber bundle, cracks appear under the specimen a little later and the cracks develop stably for a longer time. Observing its section, it is found that the section cracks are more tortuous. See Figure 15, 16.

![Image of bending failure mode of the reference group test piece](image)

**Figure 15.** Bending failure mode of the reference group test piece

![Image of bending failure mode of 30mm-0.5mm-0.6% specimen](image)

**Figure 16.** Bending failure mode of 30mm-0.5mm-0.6% specimen
Figure 17. Relationship between flexural strength and fiber bundle content

![Figure 17](image1.png)

Figure 18. Relationship between flexural strength and fiber bundle diameter

![Figure 18](image2.png)

It can be seen from figure 17 that with the increase of fiber bundle content, the flexural strength of concrete increases gradually. Compared with the reference group, when the fiber bundle content is 0.6, the flexural strength is 20.32% higher than that of the reference group. The addition of basalt fiber bundle delays the damage of concrete and increases the toughness of concrete. When the content of fiber bundle increases, the fluidity of concrete decreases a little, but the fiber bundle is more distributed on the section of the specimen, and the energy is absorbed in the form of pull-out or fracture of the fiber bundle of the specimen section to enhance the flexural strength of concrete.

It can be seen from figure 18 that with the increase of basalt fiber bundle diameter, the flexural strength of concrete increases first and then decreases. When the fiber bundle diameter is 0.2 mm and 0.5 mm, the flexural strength is 12.12% and 8.56% higher than that of the reference group. At 0.8 mm diameter, the flexural strength was 3.57% lower than that of the reference group.
4. Conclusions
Based on the experiment, the performance of basalt fiber bundle concrete, cube compression, splitting tensile and flexural resistance were studied. The main findings are as follows:

1. The addition of basalt fiber bundle reduces the fluidity of the mixture to some extent. With the increase of the content, the fluidity of the mixture decreases gradually. The fiber bundle diameter has a significant effect on the fluidity of the mixture, and the decrease of the diameter leads to the decrease of the fluidity.

2. With the increase of basalt fiber bundle content, the compression strength increases first and then decreases, and when the fiber bundle content is 0.2%, the maximum increase is 6.1%. Compared with 0.5 mm diameter and 0.8 mm, diameter 0.2 mm, the compression strength of fiber bundle is better than that of reference group.

3. Basalt fiber bundles can significantly improve the split tensile strength and flexural strength of concrete. Influence of dosage: With the increase of fiber bundle volume, the splitting tensile strength and flexural strength of concrete gradually increase. When the fiber bundle dosage is 0.6%, the splitting tensile strength and flexural strength Compared with the benchmark group, the intensity increased by 19.54% and 20.32%. Influence of diameter: Compared with 0.5 mm and 0.8 mm diameter, fiber bundle with a diameter of 0.2 mm have a better effect on enhancing the splitting tensile strength and flexural strength of concrete.

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