

Experimental Analysis of the Influence of Basalt Fibers on the Frost Resistance of Concrete

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Abstract

Concrete buildings used in cold regions are prone to freeze-thaw damage, leading to internal cracking and surface peeling of the concrete. Therefore, improving the freeze-thaw resistance of concrete is of great significance for the safety of hydraulic engineering. This paper explores the effect of basalt fibers on improving the frost resistance index of concrete through a series of experiments, and analyzes the influencing mechanism. The results show that adding an appropriate amount of basalt fibers can significantly improve the frost resistance of concrete and reduce the freeze-thaw damage phenomenon indicated by concrete specimens. Adding 0.1% basalt fiber can maintain the relative dynamic modulus of concrete specimens at 98% after 150 freeze-thaw cycles, while adding 0.3% basalt fiber can control the quality loss rate of concrete specimens after 150 freeze-thaw cycles at 0.87%. Taking into account both the frost resistance effect and economic factors, it is recommended that the basalt fiber content in frost resistant concrete be 0.1%. The research results can provide reference and guidance for the optimization design of the mix proportion of hydraulic concrete in cold regions.

Keywords

Basalt Fiber, Concrete, Frost Resistance, Dynamic Modulus of Elasticity

1. Introduction

Since the 14th Five Year Plan period, China has accelerated the construction of major water conservancy infrastructure, providing guarantees for sustainable agricultural development (Dilbas & Çakir, 2020). As a typical engineering carrier of water conservancy infrastructure, hydraulic structures have the characteristics

of diverse types and wide distribution, and need to adapt to different geographical environments and hydrological and meteorological characteristics, which puts forward high requirements for the various mechanical performance indicators of concrete structures. Adding high-performance fiber materials to conventional concrete can improve to some extent the mechanical properties and durability of concrete structures, thus adapting to different working environments (Ludovico et al., 2012).

Wang conducted a test study on the fracture performance of fly ash concrete with different fiber contents and found that adding basalt fibers can improve the toughness of the polymer (Wang et al., 2022). Huang found that adding fibers to high-strength lightweight aggregate concrete can slow down the development of small cracks inside the test block, and has the effect of preventing crack propagation (Huang et al., 2020a). Wang found through experiments that the addition of basalt fibers improved the brittleness of high-strength lightweight aggregate concrete, and obtained the optimal fiber volume ratio for short cut basalt fiber high-strength lightweight aggregate concrete (Wang et al., 2017). Chen used CT scanning to analyze the influence of fiber distribution and matrix primary pore characteristics on the compressive strength of concrete at the microscopic level (Chen et al., 2021). They found that fibers can inhibit pore connectivity, change the ratio of porosity to pore size distribution, and improve the overall performance of concrete. Muhammad found that fibers have a greater impact on the compressive performance, crack resistance, durability, ductility, and crack control ability of large particle coarse aggregate concrete than small particle coarse aggregate concrete (Muhammad, 2019).

In summary, there have been many studies on the conventional mechanical properties testing of basalt fiber reinforced concrete, such as compressive strength and crack resistance (Huang et al., 2020a; Chen et al., 2022; Wang et al., 2019). However, there is still limited research on the frost resistance performance indicators of concrete in special environments in hydraulic engineering. Therefore, this experiment investigates the frost resistance performance indicators of C30 concrete with basalt fiber added, aiming to analyze the influence of basalt fiber content on the frost resistance of concrete and optimize the mix design of frost resistant concrete.

2. Materials and Methods

2.1. Materials

This experiment uses ordinary Portland cement with a strength grade of P O 42.5 R level. The basalt fiber bundle has a length of 12 mm, a width of 1.5 mm, a thickness of 0.1 mm, a density of 2700 kg/m³, an elastic modulus of 150 GPa, a tensile strength of 3000 MPa, and a fracture elongation of 3.2%, as shown in Figure 1.

The design concrete strength grade is C30. The experimental water cement ratio is set to 0.51 and the sand ratio is set to 0.52. The water reducer adopts a polycarboxylate



Figure 1. Basalt fiber bundle samples.

based high-performance water reducer (retarder type). The required raw materials and mix proportions for testing the amount of concrete per cubic meter are shown in the table below. This experiment was divided into four groups based on different fiber contents. The volume fraction of basalt fiber (V_{BF}) was 0, 0.1%, 0.2%, and 0.3%, respectively. The concrete mix proportion is shown in **Table 1** below.

Table 1. Basic mix proportions of basalt fiber reinforced concrete.

Group number	V_{BF} (%)	Water (kg/m ³)	Cement (kg/m ³)	Sand (kg/m ³)	Stone (kg/m ³)	Water reducing agent (kg/m ³)	Slump (mm)
1	0	184	360	967	893	3	40
2	0.1%	184	360	967	893	3	49
3	0.2%	184	360	967	893	3	36
4	0.3%	184	360	967	893	3	8

Due to the lack of specific standards, the preparation and curing of basalt fiber reinforced concrete specimens shall be carried out in accordance with the provisions of relevant standards.

1) Weigh cement, water, sand, crushed stone, water reducer, and basalt fiber according to the calculated mix design.

2) Add the weighed stones, sand, and cement in sequence to the concrete mixer, and dry mix for 30 seconds. During the mixing process, evenly distribute the basalt fibers into the mixing drum; After mixing evenly, add accurately weighed water and water reducing agent to the concrete mixing bucket, and start the mixer again for 90 seconds.

3) After cleaning the mold, apply the release agent evenly on its surface, pour the mixed concrete into the mold, fix the mold on the vibration table and vibrate for 30 seconds. Then, scrape off the excess part of the trial mold with a trowel and continue to vibrate until the concrete volume stabilizes.

4) Use a spatula to level the surface of the specimen in one direction, as shown in **Figure 2**. Mark the test piece with a marker pen, then place it in a standard constant temperature and humidity curing room for curing. After curing the test piece for 24 hours, demold it, and then cure it in the curing room until the specified age.

Figure 2 below shows the test samples of basalt fiber reinforced concrete prepared in this study.

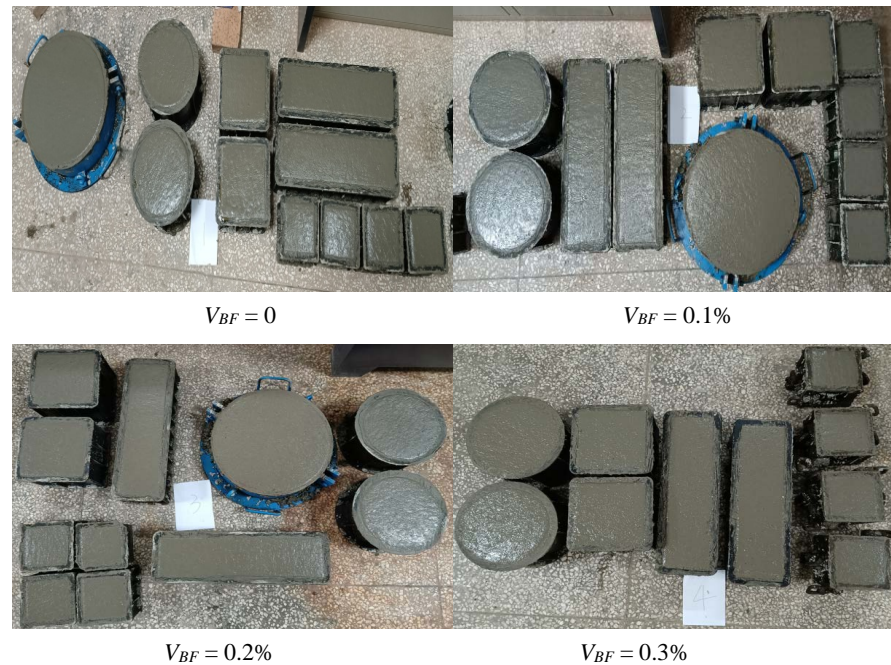


Figure 2. Basalt fiber reinforced concrete specimens.

2.2. Methods

This experiment determines the frost resistance level of concrete through a rapid freeze-thaw cycle process, with a specimen size of 100 mm × 100 mm × 400 mm. Control indicators for freeze-thaw test of specimens: 1) Relative dynamic modulus of elasticity ≤ 60%; 2) Quality loss rate ≥ 5%. The relative dynamic elastic modulus of a single specimen is calculated using the following formula:

$$P_n = \frac{f_n^2}{f_0^2} \times 100\% \quad (1)$$

where P_n is relative dynamic elastic modulus of the specimen after n freeze-thaw cycles; f_0 is the natural vibration frequency of the specimen before freeze-thaw cycles, Hz; f_n is the natural vibration frequency of the specimen after n freeze-thaw cycles, Hz. The mass loss rate of a single specimen is calculated according to the following formula:

$$W_n = \frac{G_0 - G_n}{G_0} \times 100\% \quad (2)$$

where W_n is the loss rate of specimen quality after n freeze-thaw cycles; G_0 is the

quality of specimens before freeze-thaw cycles, g ; G_n is the mass of specimens after n freeze-thaw cycles, g ; If one of the following three situations occurs, the freeze-thaw test of the corresponding specimen can be stopped: 1) The number of freeze-thaw cycles corresponding to the frost resistance level; 2) Relative dynamic modulus of elasticity $\leq 60\%$; 3) Quality loss rate $\geq 5\%$. The frost resistance test consists of 2 specimens in each group with a mix ratio and an age of 28 days. **Figure 3** below shows the frost resistance testing machine used in this experiment.



Figure 3. The freeze-thaw testing machine used in the experiment.

3. Results and Discussion

This experiment adopts the rapid freezing method and uses the TDRF-III concrete rapid freeze-thaw testing machine. The freezing temperature is $(-18 \pm 2)^\circ\text{C}$. When the curing age of the specimen reaches 28 days, the specimen should be promptly removed and soaked in water to saturate it. The number of freeze-thaw cycles is 25, 50, 75, 100, 125, and 150.

1) The influence of basalt fiber content on the appearance of concrete

Analyzing the specimen in **Figure 4**, it can be seen that when basalt fibers are not added, there is a significant peeling phenomenon on the surface of the plain concrete after 150 freeze-thaw cycles. All edges and corners have started to powder and peel off, and large cracks have appeared between the side aggregates and the surface cement slurry. After adding a certain amount of basalt fibers, the peeling phenomenon on the surface of the concrete is lighter than that without fibers, and the surface is more complete. There is slight powdering and peeling at the edges and corners, and no obvious cracks appear. The aggregate and slurry do not show obvious looseness, and the overall integrity of the test block is still good. The addition of basalt fibers into concrete can significantly improve its frost resistance.

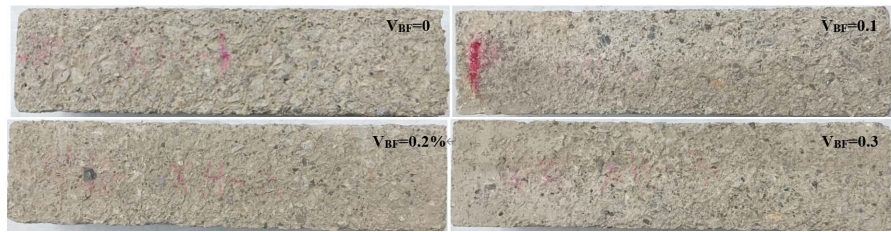


Figure 4. Test piece after 150 freeze-thaw cycles.

2) The influence of basalt fiber content on the relative dynamic modulus of concrete

Calculate the relative dynamic elastic modulus of each specimen using the formula for calculating the relative dynamic elastic modulus of the frost resistance test, and take the average value. The relative dynamic modulus data of concrete specimens with different basalt fiber contents after 25, 50, 75, 100, 125, and 150 freeze-thaw cycles are shown in **Figure 5**.

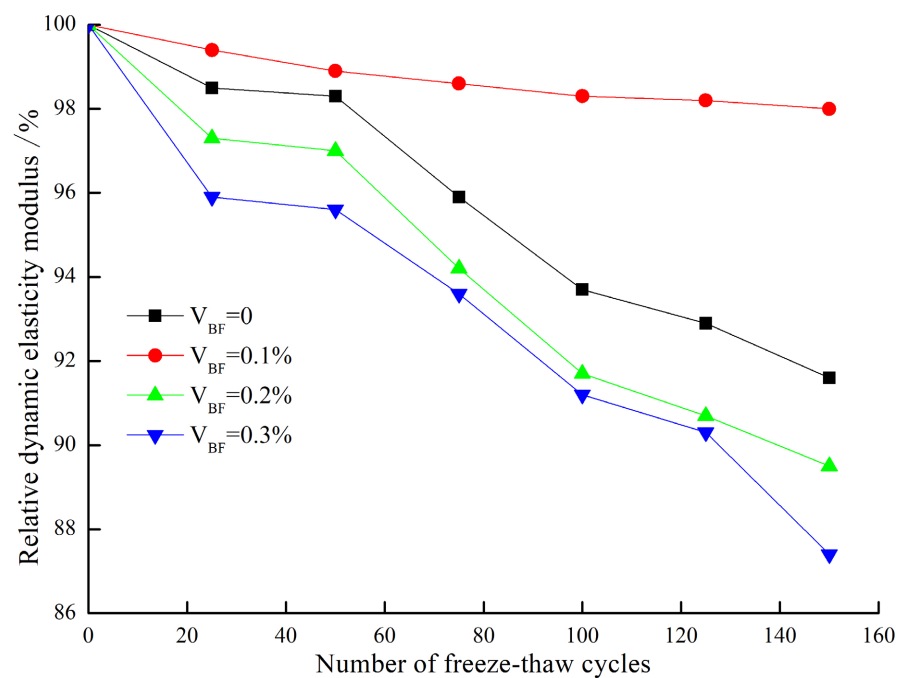


Figure 5. Relative dynamic modulus of specimens after freeze-thaw cycles.

The relative dynamic modulus of concrete with four different volumes of basalt shows a decreasing trend with the increase of freeze-thaw cycles. When the freeze-thaw cycles are 25 and 50 times, there is not much difference in the relative dynamic modulus of concrete between different basalt fiber contents, and the relative dynamic modulus loss rate is low, all within 5%. As the number of freeze-thaw cycles increases, the relative dynamic modulus loss rate of the specimen gradually increases. Among them, when the content of basalt fiber is 0.1%, the relative dynamic modulus does not change much with the increase of freeze-thaw cycles. The relative dynamic modulus of the specimens corresponding to each

freeze-thaw cycle is greater than that of the control group. For example, after 150 freeze-thaw cycles, the relative dynamic modulus still has 98%, while the control group without basalt fiber only has 91.6%, an increase of 7%. However, when the content of basalt fiber increased to 0.2% and 0.3%, the relative dynamic modulus of the specimens corresponding to each freeze-thaw cycle was smaller than that of the control group. The decrease was most significant at a content of 0.3%. After 150 freeze-thaw cycles, the relative dynamic modulus of the concrete with both types of basalt fiber content was 89.5% and 87.4%, respectively, which were reduced by 2% and 5% compared to the control group without basalt fiber content. Indicating that adding 0.1% basalt fiber to concrete can significantly improve its freeze-thaw cycle resistance.

The reason leading to this experimental result is that when the content of basalt fiber is 0.1%, the bridging effect of basalt fiber can well control the development of microcracks in concrete, maintain the microstructural integrity of concrete, minimize the microscopic and macroscopic cracks formed after freeze-thaw cycles, and reduce the decline of relative dynamic modulus value. However, when the basalt fiber content is large, the fiber is easy to agglomerate and the dispersion is not good, resulting in the bond between the fiber and the concrete is not tight, the gas content increases, the microstructure becomes loose, and the internal defects are easy to occur, so its relative dynamic elastic modulus value decreases greatly.

3) The influence of basalt fiber content on the loss rate of concrete quality

Figure 6 indicates the average loss rate of concrete quality during testing. The mass loss rate of concrete with four different volumes of basalt increases with the increase of freeze-thaw cycles. The quality loss rate remained relatively stable during the initial 25 freeze-thaw cycles, but showed an accelerating upward trend in the later stages. The quality loss rate of plain concrete is the highest, with a quality loss rate of 0.99% when subjected to 75 freeze-thaw cycles and 2.62% when subjected to 150 freeze-thaw cycles.

In basalt fiber reinforced concrete, when the content of basalt fiber is 0.30%, the quality loss rate after 75 freeze-thaw cycles is only 0.22%, and after 150 freeze-thaw cycles, the quality loss rate is only 0.87%, which is the smallest. When the other two dosages were 0.1% and 0.2%, after 150 freeze-thaw cycles, their mass loss rates were 1.3% and 1.98%, respectively, and their frost resistance was better than the control group ($V_{BF} = 0$).

The reason leading to this experimental result is that the basalt fibers will be randomly distributed in the concrete after being evenly stirred, and the fibers will be staggered and overlapped, and the concrete will be more tightly bonded. And because the concrete shedding caused by freeze-thaw damage is only the shedding of the surface material, the higher the fiber content, the more obvious the adhesion of the fiber to the concrete material, so the mass loss of concrete is smaller.

In summary, the freeze-thaw cycle resistance of basalt fiber reinforced concrete is significantly better than that of ordinary plain concrete. After the basalt fiber is

mixed evenly, it will show a random and disordered distribution in the concrete, and the fibers overlap and interweave with each other, so that the bonding of the concrete is more tight, and the bridging effect of the fiber improves the fatigue resistance of the concrete, so the addition of basalt fiber can enhance the ability of the concrete to resist freezing and thawing. Taking into account the results of the relative dynamic modulus and mass loss rate tests of basalt fiber reinforced concrete, as well as economic considerations, the optimal volume fraction of basalt fiber in frost resistant concrete is 0.1%.

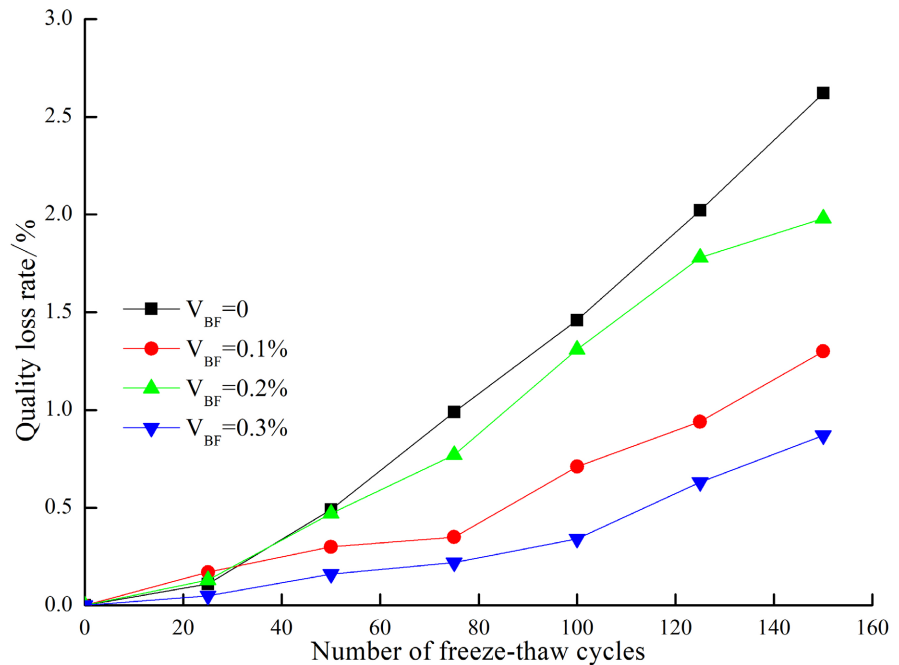


Figure 6. Quality loss rate of specimens after freeze-thaw cycles.

4. Conclusion

The article conducts freeze-thaw performance tests on concrete specimens with different basalt fiber contents (length 12 mm) through indoor experiments, while also testing the influence of basalt fiber content on the comprehensive performance of concrete. The experiment finds that the freeze-thaw cycle resistance of basalt fiber reinforced concrete is significantly better than that of ordinary plain concrete. Specifically, basalt fiber can control the crack propagation of concrete specimens after freeze-thaw, significantly improve the relative dynamic modulus, and reduce the quality loss caused by freeze-thaw cycles. The reason is that after the basalt fibers are mixed evenly, they will show a random and disordered distribution in the concrete, and the fibers overlap and interweave with each other, so that the bonding of the concrete is tighter, and the bridging effect of the basalt fibers improves the fatigue resistance of the concrete. Based on the test results of the relative dynamic modulus and mass loss rate of basalt fiber reinforced concrete, and considering the economy, the recommended optimal volume fraction of basalt

fiber in frost resistant concrete is 0.1%.

Data Availability

Data will be made available on request.

Acknowledgments

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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