Study on antifreeze Properties and pore structure of Basalt Fiber Reinforced Concrete

LIU Jun1,2, ZHAO Shuo1, LIU Runqing2

1 School of Material Science and Engineering, Shenyang Jianzhu University, Shenyang 110168, China;
2 School of Material Science and Engineering, Shenyang Ligong University, Shenyang 110159, China;
liujun2699@126.com

Abstract: We designed basalt fiber concrete with a volume content of 0.05%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3%, 0.35%. Through the mass loss rate and dynamic modulus loss rate after different freezing-thawing cycles, the antifreeze performance of concrete was tested. As the internal capillary pores of concrete are the main channel for corrosive medium and other harmful substances to invade the internal concrete, the durability of concrete is closely related to the internal pore structure. The microstructure and pore structure of basalt fiber concrete were tested by SEM and Mercury Injection Apparatus, so as to analyze the microstructure of the interface between fiber and cement and discuss the strengthening mechanism of basalt fiber concrete. The results indicate that the basalt fiber can improve the freeze-thaw cycle of concrete With the increase of the content of basalt fiber, the gel has greater adhesion and binding force to basalt fiber, and the hydration products attached to the surface of basalt fiber gradually decrease. When the content of basalt fiber is 0.3%, the frost resistance of concrete is the best. The addition of basalt fiber optimizes the hole structure and reduces the internal defects of concrete, thus improving the durability.

1. Introduction
Adding fiber can enhance the durability of concrete, and the use of concrete in bridge engineering, super high-rise buildings, ocean engineering and other century-old projects is increasing year by year. However, ordinary concrete has some shortcomings, such as poor toughness, low tensile strength and easy cracking, which make it easy for harmful substances to invade into concrete through cracks, leading to the serious decline of concrete durability and limiting the application of concrete in complex environments. Through experimental research, it is found that with the addition of fiber, the compactness of concrete can be improved, the hole structure inside concrete can be improved, and the connection between holes can be reduced to enhance the frost resistance.[1-4]

Basalt fiber has the advantages of economic and environmental protection, high strength, low temperature resistance, corrosion resistance and so on. Therefore, it is widely concerned by scholars. At present, most of the research is about the mechanical and corrosion resistance of basalt fibers of different lengths and shapes to concrete[5]. However, there are few studies on the effect of basalt fiber on the improvement of concrete's frost resistance and its internal hole structure with different fiber content in a single length. Therefore, this paper selects seven groups of basalt fiber concrete with the same length and different fiber content were selected to study and analyze the influence of fiber
content on concrete's anti-freeze performance and internal hole structure, aiming at the influence of fiber on concrete's strengthening mechanism and internal pore structure. [6]

**2. Materials and test methods**

**2.1 Raw materials and mix proportion**

The raw materials of the specimen were 42.5 ordinary Portland cement, and the coarse aggregate was 5 ~ 25 mm continuous graded gravel. The sand adopts medium sand with good gradation, and the fineness modulus is 2.9. Water is ordinary drinking water; The characteristic parameters of the basalt fibers used in the test are shown in Table 1.

| Length/mm | density/g/cm³ | density modulus/Gpa | tensile strength/MPa | heat conductivity/W/(m.k) | Fracture elongation/% |
|-----------|---------------|---------------------|----------------------|-------------------------|----------------------|
| 10~14     | 2.63~2.65     | 91~110              | 3300~4800            | 0.03~0.04               | 2.4~3.2              |

**2.2 Test method**

**2.2.1 Freeze-thaw cycle test method:** In this experiment, the quick freezing method was adopted and the freezing temperature is (20±2) °C. When the curing age of the specimen reaches 28d, the specimen should be taken out in time and soaked in water. The number of freezing-thawing was 15, 30, 45, 60 and 75 times.

The average relative kinematic modulus of a group of specimens shall be calculated in the following formula.

\[ P = \frac{1}{3} \sum_{i=1}^{3} P_i \]  

In the formula: \( P \) —— After N freezing-thawing cycles, the relative dynamic elastic modulus (%) of a group of concrete specimens was accurate to 0.1.

The average mass loss rate of a group of specimens shall be calculated as follows:

\[ \Delta W_n = \frac{1}{3} \sum_{i=1}^{3} \Delta W_{ni} \times 100 \]  

In the formula: \( \Delta W_n \) —— The average mass loss rate (%) of a group of concrete specimens after N freezing-thawing cycles.

**2.2.2 Scanning electron microscopy and mercury injection test:** Scanning electron microscopy (SEM) was used to observe the microstructure. It can then be observed under scanning electron microscopy (SEM), and images can be stored according to the label, exported for analysis.
3. Experimental results and discussion

3.1 Frost resistance of basalt fiber concrete

As shown in FIGURE 1, after 60 freezing-thawing cycles, the surface of plain concrete has been stripped in large areas, and all edges and corners have begun to pulverize and peel off. The basalt fiber had cracks at the corners of 0.20% of the samples, and a small amount of spallation occurred at the corners of 0.15% of the samples. Other specimens showed no significant changes.

![Figure 1 Test piece after 75 times of freezing and thawing](image)

After testing and calculation, the relative moving modulus data of the specimen after 15 times, 30 times, 45 times, 60 times and 75 times are shown in the figure below:

![Figure 2 Relative dynamic modulus of specimen during freeze-thaw cycle](image)

![Figure 3 Mass loss rate of freeze-thaw cycle](image)

As can be seen from FIGURE 2, with the increase of freezing-thawing times, the relative dynamic modulus loss rate of the specimens increases gradually. After 45 freezing-thawing cycles, the dynamic modulus loss rate of concrete with different basalt fiber content has great difference. When freeze-thaw cycle of plain concrete reaches 75 times, the relative dynamic elastic modulus drops to 56.76%. After 75 freezing-thawing cycles, the relative dynamic modulus was still 88.31% when the basalt fiber content was 0.3%.

With the increase of fiber content, the relative dynamic elastic modulus of concrete decreases. This is because the concrete materials before the frozen-thawing cycle has existed micro-cracks and other damage, these micro-cracks mainly exist in the interface between the coarse aggregate and the cement mortar transition zone. With the accumulation of freezing-thawing cycles, interface microcracks induce cracking, gradually expand, evolve into a large number of cracks, cement slurry loss, resulting in a decrease in the relative dynamic elastic modulus.

At the same time, the addition of fiber can reduce the stress difference between positive and negative temperature and improve the antifreeze and thawing cycling performance of concrete to some extent.
As can be seen from FIGURE 3, the mass loss rate was relatively stable in the early stage and the trend of accelerating upward in the later stage. The mass loss rate of plain concrete was the highest, when freezing-thawing cycle was 75 times, the mass loss rate was 6.93%. In basalt fiber concrete, when the volume content is 0.3%, the mass loss rate of 75 freezing-thawing cycles is 0.1%, and the mass loss rate is the smallest. When mixed with basalt fiber, the first 30 freezing-thawing cycles have almost no mass loss of concrete. When the freezing-thawing cycle reaches 45 times, the mass loss of the test block of basalt fiber concrete is relatively small, but the concrete has begun to crack and flake.

Freezing-thawing resisting cyclic properties of basalt fiber reinforced concrete is better than ordinary concrete, the basalt fibers after mix in three dimensional random distribution in the concrete, fiber crisscross overlap each other, support effect on aggregate, inhibition of concrete have connected before hardening crack formation and connected pores. [13] In addition, the elastic modulus of the substrate at the initial stage of condensation is lower than that of basalt fiber, which improves the plasticity of concrete and reduces the generation of spontaneous cracks in concrete.

3.2 Hole analysis of basalt fiber concrete
The relationship between the measured concrete aperture and the accumulated mercury content is shown in figure 4.

As can be seen from FIGURE 4, adding basalt fiber can significantly reduce the total amount of mercury into concrete, indicating that basalt fiber has an inhibitory effect on the generation of concrete pores.

In order to study the hole structure of concrete more intuitively, the total porosity of concrete was converted from the mercury intake to 3.5.

### Table 3 Total porosity of concrete with different basalt fiber content

| Basalt fiber content% | 0  | 0.05 | 0.1 | 0.15 | 0.2  | 0.25 | 0.3  | 0.35 |
|-----------------------|----|------|-----|------|------|------|------|------|
| Total porosity/%      | 23.99 | 18.68 | 21.09 | 22.03 | 16.51 | 18.51 | 17.45 | 14.02 |

![Figure 4: Mercury intake of basalt fiber concrete](image)

**Figure 4** Mercury intake of basalt fiber concrete

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![Figure 5: Distribution of total porosity](image)

**Figure 5** Distribution of total porosity
As shown in FIGURE 5, after the addition of basalt fiber, the total porosity of concrete decreased significantly. With the increase of fiber content, the total porosity of concrete showed a downward trend. The maximum porosity of plain concrete was 23.99%. When basalt fiber volume content is 0.35%, the minimum porosity of concrete is 14.02%, which is 41.56% lower than that of plain concrete. Fiber reinforced concrete improves the hole structure in concrete to a certain extent, and the general trend is to reduce the formation of less harmful holes, harmful holes and multiple harmful holes in concrete, so that the large hole of internal structure is refined and the distribution of small hole is increased. It can be seen that the effect of basalt fiber on improving pore structure is obvious.

3.3 Microstructure analysis of basalt fiber concrete

Scanning electron microscopy (SEM) was used to observe the microstructure. Then observation was made under scanning electron microscope (SEM), and images were stored according to the label, and exported for analysis.

As you can see from FIGURE 6 that basalt fiber after fully mixing, take the form of monofilament in concrete, the surface covered with a large number of cement hydration products, to strengthen the bond between the fiber and concrete substrate interface capability, reduce the action of external force due to the weak interfacial bond fiber is easy to pull out and fibers lose their function. It indicates that the basalt fiber has a good bonding property with the cement matrix.

When the volume content of basalt fiber is 0.05%, the fiber is coated with a large amount of c-s-h gel due to the low content of basalt fiber. It prevents the basalt fibers from coming into contact with the cement particles, which will lead to the poor adhesion between the fiber and the matrix. However, due to the increase of fiber content, the fiber dispersion in the matrix is more uniform, so the strength and durability are improved with the increase of fiber content in macroscopic performance.

4. Conclusion

Proper amount of basalt fiber can inhibit the expansion of cracks in concrete, reduce the pores in matrix, and improve the antifreeze and thawing circulation of concrete. When the content of basalt fiber is 0.3%, the relative dynamic modulus and quality loss rate of concrete are the lowest, so basalt fiber can improve the freeze-thaw resistance of concrete.

Basalt fibers can reduce the total porosity and average pore size of concrete. The addition of basalt fibers optimizes the pore structure. The total porosity of concrete decreases with the addition of basalt fiber.

With the increase of basalt fibers, the average pore size of concrete decreases gradually. The minimum total porosity of concrete with a fiber volume content of 0.35% was 14.02%. The average pore diameter of plain concrete is 70.6nm. With the increase of basalt fiber, the average pore diameter
of concrete decreases gradually. When the volume of basalt fiber is 0.30%, the average pore diameter reaches the lowest value of 45.9nm.

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References
[1] KIZILKANAT A B, KABAY N, AKYüNCü V, et al. Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study[J]. Construction and Building Materials, 2015, 100 218-24.
[2] ALGIN Z, OZEN M. The properties of chopped basalt fibre reinforced self-compacting concrete[J]. Construction and Building Materials, 2018, 186 678-85.
[3] BRANSTON J, DAS S, KENNO S Y, et al. Mechanical behaviour of basalt fibre reinforced concrete[J]. Construction & Building Materials, 124 878-86.
[4] Yang j. Study on effect of basalt fiber on performance of high performance concrete [D]. Southwest jiaotong university, 2018.
[5] Jiang wei, zhang zhiya, freezing, Yang jin, xu Chen cong, jia sining. Research status and development of basalt fiber concrete [J]. Building materials development guidance, 209,17 (08) : 9-12.
[6] SIM J, PARK C, MOON D Y. Characteristics of basalt fiber as a strengthening material for concrete structures[J]. Composites Part B: Engineering, 2005, 36 (6-7): 504-12.
[7] Ge haojun. Study on mechanical properties and durability of basalt fiber concrete [D]; Dalian university of technology.
[8] Zhang l f, Yin y l, liu J w, et al. Study on mechanical properties of basalt fiber reinforced concrete [J]. Silicate bulletin, (11): 74-7.
[9] Yan Wang, Shaohui Zhang, Ditaor Niu, Li Su, Daming Luo. Strength and chloride ion distribution brought by aggregate of basalt fiber reinforced coral aggregate concrete[J]. Construction and Building Materials, 2020, 234.
[10] Li weimin, xu jinyu. Strengthening and toughening effect of basalt fiber on concrete [J]. Acta silicate sinica, (4): 56-61+6.
[11] Zhu han, liu ang, yu yong. Impact resistance of basalt fiber concrete at low temperature [J]. Chinese journal of materials science and engineering, (4): 600-4.
[12] CHIDIGHIKAOBI P C. Thermal effect on the flexural strength of expanded clay lightweight basalt fiber reinforced concrete[J]. Materials Today: Proceedings, 2019.
[13] Cao yuxin. Experimental study on the influence of steel fiber types on the properties of steel fiber concrete [J]. Journal of lanzhou jiaotong university, 2019, 38(06):1-8.
[14] WANG Y, ZHANG S, NIU D, et al. Strength and chloride ion distribution brought by aggregate of basalt fiber reinforced coral aggregate concrete[J]. Construction and Building Materials, 2020, 234.
[15] Deng wenqin. Analysis of hole structure characteristics and durability of fiber reinforced concrete [D]. Dalian jiaotong university, 2010.
[16] Zhao yanru, guo zilin, fan xiaoqi, shi jinna, wang lei. Stress-strain relationship and pore structure analysis of basalt fiber concrete [J]. Silicate bulletin, 2017, 36(12):4142-4150.