**Review on Research and Application of BF**

# Abstract

Basalt fiber (BF), as an environmentally friendly material, is widely used in civil engineering due to its low energy consumption, non-polluting nature, and excellent physical-chemical properties. This paper systematically reviews the research progress of BF in enhancing the mechanical properties, frost resistance, and crack resistance of concrete. In terms of mechanical performance, an appropriate BF dosage (0.1%–0.2%) significantly improves compressive strength, tensile strength, and flexural strength while reducing internal porosity. However, excessive fiber content leads to agglomeration and increased porosity. Studies indicate that 12mm-long BF exhibits optimal comprehensive reinforcement effects. For frost resistance, BF suppresses microcrack propagation induced by freeze-thaw cycles (FTCs), thereby delaying strength degradation and durability loss. Synergistic effects with nanomaterials (e.g., nano-SiO₂) further enhance performance; for instance, specimens with 2% BF and nano-SiO₂ showed 10%–18% lower residual strength loss after 180 FTCs. Regarding crack resistance, BF bridges cracks and promotes self-healing, achieving crack reduction coefficients of 8.2%–78.0% at 0.1%–1.5% dosage. Hybrid use with silica fume or cellulose ether optimizes both workability and mechanical properties. Despite its potential, challenges such as fiber dispersion, optimal dosage thresholds, and multi-factor synergy mechanisms require further exploration.

Keywords: Basalt fibers Mechanical Properties Crack Resistance Frost Resistance

# 1. Introduction

BF is a type of fiber produced by continuous spinning technology after basalt is melted at a temperature range of 1450°C to 1500°C [1][2]. Its manufacturing process does not require additives [3], and its carbon emission is only 30% to 50% of that of glass fiber. Basalt is a basic volcanic rock formed by volcanic eruptions and is extremely abundant in nature. The reserves of basalt ore account for more than 8% of the composition of the Earth's crust. Therefore, compared with other types of fibers, BF has economic advantages. The main chemical components of basalt include silicon dioxide (SiO₂), aluminum oxide (Al₂O₃), calcium oxide (CaO), magnesium oxide (MgO), ferric oxide (Fe₂O₃), and ferrous oxide (FeO). Among them, silicon dioxide accounts for approximately 45% to 50% of its main components. These chemical components do not contain any corrosive components like steel fibers, and they will not impose any additional load on the structure [4]. BF will not release toxic substances in air and water media. After degradation, it will become the parent material of the soil [5]. Even if it is incinerated or cremated, the final residue is un-melted basalt, which can be reused [6]. Due to its special manufacturing process and stable composition, BF is hailed as the "green and pollution-free material of the 21st century" [7]. Since the Soviet Union first achieved industrial production in the 1950s, the preparation process of BF has been gradually optimized, and it has been applied in various fields. In recent years, with the growth of the demand for composite materials, the applied research on BF has significantly increased.

# 2.Enhancement of Mechanical Properties by BF

Environmental protection can be achieved by adding industrial waste to concrete and reducing the use of cement. Pi, Z et al [8]. studied the influence of iron ore tailings (IOT) replacing river sand on the physical and mechanical properties and crack resistance of cement mortar. A series of experiments were carried out by adding different contents of BF and polyacrylonitrile fiber (PANF). With the increase in the contents of BF and PANF, the consistency of the mortar decreased significantly. An appropriate fiber content can enable the fibers to be evenly distributed in the mortar, playing a role in filling the voids, reducing the porosity. At the same time, the fibers can enhance the crack resistance of the specimens. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) tests show that an excessively high fiber content will lead to fiber agglomeration, and the internal voids of the specimens will increase. However, an appropriate fiber content can promote the hydration reaction. Zong Liang et al[9]. processed waste tires into rubber particles and incorporated them into concrete, and studied the influence law of BFs with different lengths on the mechanical properties of rubber concrete. BFs with three different lengths were incorporated into rubber concrete, and mechanical property tests were carried out. The results show that when the BF content is 0.1%, the compressive strength is the highest, and the splitting tensile strength increases with the increase in the BF content. Among the three BFs with different lengths, the one with a length of 12mm has the highest compressive strength, splitting tensile strength and flexural strength, and the fiber with a length of 18mm is superior to that with a length of 6mm.

Gao Cui [10] carried out compression tests on prefabricated cracked BF concrete under different confining pressures, and analyzed the influence laws of the prefabricated crack angle, BF content and confining pressure on the peak stress and elastic modulus of the specimens. The results show that when the confining pressure and fiber content are fixed, both the peak stress and the ultimate strain bearing capacity µ of the specimens first decrease and then increase with the increase in the crack angle. The peak stress of the specimens is linearly positively correlated with the confining pressure. The increase in the fiber content makes the peak stress and elastic modulus of the specimens first increase and then decrease. When the fiber content is 0.2%, its performance is better.

By mixing BF with other materials, the purpose of further improving the mechanical properties can be achieved. Jing Shen et al[11]. studied the crack resistance and toughening of superabsorbent resin (SAP) internal curing concrete by BF. Through mechanical strength tests and fracture performance tests, the enhancement effect of BF on the mechanical properties and fracture performance of internal curing concrete was studied, and its shrinkage deformation ability and fracture performance were verified through shrinkage deformation tests and fracture tests. The results show that the water release holes left by SAP have an adverse effect on the mechanical properties of concrete, but the lap joint and toughening effects of BF can not only make up for this defect, but also the mechanical properties and fracture performance of the composite internal curing concrete have been greatly improved compared with those of ordinary concrete. Ji Longping[12].studied the slump and mechanical properties of BF lightweight aggregate concrete (BF-LAC) with different fly ash (FA) contents and different curing ages as variables. The test results show that BF (BF) can reduce the fluidity and plasticity of lightweight aggregate concrete (LAC), but the addition of FA will increase the fluidity of LAC; the addition of FA effectively enhances the later mechanical strength of BF-LAC, but due to the relatively low reaction rate of the active components of FA, it has a negative effect on the early tensile and flexural strengths of LAC.

# 3.Enhancement of Frost Resistance by BF

The frost resistance and thawing resistance of concrete can be improved by mixing BF with admixtures. Guler, S et al[13]. studied the influence of freeze-thaw cycles (FTC) on the durability and structural integrity of concrete by incorporating nanomaterials and fibers into the concrete mixture. The test results show that after adding BA and NS to the mortar, compared with the control group, the strength and durability of the specimens after FTC have been significantly improved. At the same time, the void-filling ability and pozzolanic effect of NS have also significantly improved the performance of the specimens. After 180 FTCs, the residual compressive strength (RCS) and residual flexural strength (RFS) of the control group K0 decreased by 34.17% and 34.56% respectively. In contrast, for the K10 specimen containing 2% NS and BA fibers, the reduction rates of RCS and RFS were lower, being 23.69% and 16.99% respectively. Lu Qichao et al[14]. conducted rapid freeze-thaw cycle tests on high-performance concrete reinforced by polypropylene fiber (PF), BF, and basalt-polypropylene fiber, and studied the influence of PF and BF with different volume fractions on the mechanical properties of high-performance concrete (HPC) before and after the freeze-thaw cycle. The test results show that PF and BF improve the corrosion resistance of HPC and effectively alleviate the loss of dynamic elastic modulus. Incorporating PF into HPC reduces the compressive strength before freeze-thawing, but effectively delays the decrease rate of the compressive strength of the specimens during freeze-thaw cycles. Under the same fiber content, when BF and PF are separately added to the specimens, BF has a better enhancement effect on the mechanical properties before and after freeze-thawing than PF.

Zhang Y Z et al [15]. studied the flexural bearing capacity of BF-reinforced concrete beams in a freeze-thaw environment. By comparing the static flexural tests of ordinary concrete beams and BF-reinforced concrete beams under different numbers of freeze-thaw cycles, the improvement effect of BF on concrete under freeze-thaw cycles was explored. The results show that incorporating BF into the beam enhances the cracking load and ultimate load. With the increase in the number of freeze-thaw cycles, the ultimate load and cracking load of all specimen beams decrease, but the degradation rate of the specimen beams with BF is lower than that of ordinary concrete beams. After 100 freeze-thaw cycles, the ordinary concrete beam changes from the designed under-reinforced failure to over-reinforced failure, while the BF-reinforced concrete beam still shows under-reinforced failure, indicating that the incorporation of BF not only increases the limit reinforcement ratio of the specimen beam but also reduces the damage caused by freeze-thawing.

Yan J F[16]. studied the influence laws of freeze-thaw cycles and confining pressure on the microscopic pore structure and permeability of fiber-reinforced concrete. The nuclear magnetic resonance detection device (NMR) was used to measure the pore size distribution and porosity of four types of fiber-reinforced concrete under different numbers of freeze-thaw cycles. The TWM-3000 triaxial press was used to carry out variable confining pressure permeability tests on the specimens after freeze-thawing, and the influence laws of fiber types, freeze-thaw cycles, and confining pressure on the permeability of concrete materials were analyzed. The results show that the incorporation of fibers can enhance the frost resistance of concrete materials and slow down the degree of freeze-thaw damage of the specimens. The freeze-thaw cycle action causes damage to the internal structure of the concrete material, and its microscopic manifestation is the expansion of cracks and the increase in the number of pores, and the porosity increases accordingly. The permeability of the four types of concrete specimens has a negative logarithmic function correlation with the confining pressure and a positive quadratic function correlation with the number of freeze-thaw cycles. The incorporation of BF has the most significant effect on improving the impermeability of concrete materials. Both the decrease in confining pressure and the increase in freeze-thaw cycles make the permeability of the specimens increase, and the influence degree of confining pressure on the permeability of the specimens is higher than that of freeze-thaw cycles.

Xiao J J [17]. studied the influence of BF on the durability of cement-stabilized macadam and carried out unconfined compressive strength, freeze-thaw, and splitting fatigue tests of cement-stabilized macadam under different BF contents. The results show that when the BF content is lower than 0.9%, with the increase in the fiber content, the mechanical properties and frost resistance of the cement-stabilized macadam are better. When 0.9% BF is incorporated into the cement-stabilized macadam, its compressive strength is increased by 18.8%. Considering the economic benefits and enhancement effect comprehensively, the recommended BF content is 0.6%.

# 4. Enhancement of Crack Resistance by BF

Zhang, G. Z et al[18]. added BF into the microbial repair mortar to explore the micro-crack healing effect of BF on the microbial repair mortar. During the research process, coconut shell charcoal was used as the carrier for adsorbing bacteria, and the addition of BF enhanced the micro-crack healing effect of the microbial mortar. Microscopic experiments revealed the complete process of micro-crack healing by microorganisms. The results show that due to the bridging effect of the fibers, the calcium carbonate formed on the fibers transforms the healing products from two-dimensional to three-dimensional, enhancing the micro-crack healing ability of the mortar.

Wu, G. X et al [19]. studied the improvement effect of BF on the cracks in asphalt pavement. The beam bending test and semi-circular bending tensile test (SCB) were adopted. Taking the flexural tensile strength, maximum flexural tensile strain, flexural stiffness modulus, fracture energy, fracture energy index, and flexibility index of the specimens as the test indexes, the crack resistance of BF asphalt mixture was studied from two aspects: whether the fiber was added or not and the molding method of the mixture. The results show that after adding BF, the crack resistance of the asphalt mixture has been significantly improved.

Studying the improvement effect of fiber content and fiber length on crack resistance is an important aspect of researching BF. Zhou, S. X [20].studied the improvement effect of chopped BF on the crack resistance of concrete. The test shows that the 28-day cubic compressive strength of BF-reinforced concrete is basically equivalent to that of plain concrete. Through the outdoor exposure method for the early-age crack resistance test of concrete, the relevant parameters such as the maximum crack width, average crack width, crack area, and crack reduction coefficient of BF-reinforced concrete and plain concrete in the early age were compared, proving that the chopped BF with a content of 0.1% can significantly improve the early-age crack resistance of plain concrete. Wang, G. C et al [21]. explored the influence of the BF content on the early-age crack resistance of concrete. The early-age crack resistance tests were carried out on the concrete with the chopped BF contents of 0.5%, 1.0%, and 1.5%, taking the width and number of cracks of the specimens as the evaluation indexes. The test results show that after the early-age crack resistance comparison test of the BFs with the volume contents of 0.5%, 1.0%, and 1.5%, the crack reduction coefficients are 8.2%, 59.3%, and 78.0% respectively. With the increase in the fiber content, the early-age crack resistance of the concrete gradually improves. Xu, J et al [22]. used the orthogonal test method to study the influence of BF length, fiber content, cellulose ether, and silica fume on the cracking performance and mechanical properties of the mortar. The experimental results show that silica fume can enhance the mechanical properties, the fiber length has the greatest influence on the cracking performance of the mortar, and cellulose ether is the main factor affecting the water loss rate and fluidity of the mortar. When 0.1% BF with a length of 12mm is added to the mortar, and the silica fume content is 8% and the cellulose ether content is 0.3%, the mortar has better comprehensive performance.

# 5. Conclusion

As an environmentally friendly material, BF has excellent reinforcement effects on concrete and has broad application prospects in the field of concrete.

In terms of mechanical properties, when the BF content is between 0.1% and 0.2%, it can significantly improve the mechanical properties of the results. However, an excessive amount (more than 0.5%) will lead to the agglomeration effect of fibers and increase the porosity. The fibers with a length of 12mm can significantly enhance the mechanical properties of rubber concrete.

Regarding frost resistance, BF can delay the strength loss by inhibiting freeze-thaw damage. When working synergistically with nanomaterials, it can optimize the internal pores of the concrete. After the specimens undergo 180 freeze-thaw cycles, the loss of residual strength is reduced by more than 10%.

In terms of crack resistance, the fibers can effectively improve the crack resistance of concrete through the bridging effect. When the BF content is between 0.1% and 1.5%, the crack reduction coefficient decreases with the increase in the fiber content. At the same time, when mixed with silica fume and cellulose ether, it can play a synergistic role to improve the fluidity and mechanical properties of concrete.

In addition, in lightweight aggregate concrete, BF, combined with fly ash, can balance the fluidity and strength. In prefabricated cracked concrete, it can optimize the crack propagation path through the distribution of fibers. However, the fiber dispersibility, the economic content threshold, and the mechanism of the coupling effect of multiple factors still need to be further explored.

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