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# Experimental Study on Durability and Mechanical Properties of Basalt Fiber Reinforced Concrete under Sodium Sulfate Erosion

Zhenshan Wang*, Kai Zhao, Zhe Li, Hui Ma

School of civil engineering and architecture, Xi'an University of Technology, Xi'an 710055, China
wangdayuwang@126.com

In this paper, the durability and mechanical properties of basalt fiber reinforced concrete under sodium sulfate erosion were studied. The concrete with 0%, 0.05%, 0.1%, 0.2% and 0.3% basalt fiber were respectively soaked in 5.0% sodium sulfate solution and clean water for 90 days, and the observations and records were used to analyse the changes in the water absorption rate of the test pieces and conduct compression tests. The main conclusions are as follows: The basalt fiber has little effect on the bearing capacity of concrete, but can improve the deformation capacity of concrete to certain extent. Under the erosion of sodium sulfate, basalt fiber can effectively lower the porosity growth rate, while excessive fiber adversely affects the durability, with the fiber content of about 0.1% leading to the best result. In view of the difficulty in basalt fiber dispersion, this paper put forward "Powder Particle Basalt Fiber Dispersion Method". Therefore, this research will provide some theoretical foundation for engineering application of basalt fiber.

## 1. Introduction

Destruction of concrete structures by sulphate is a common problem of durability (Gao et al., 2013; Bassuoni and Nehdi, 2009). Basalt fiber can improve the mechanical properties, corrosion resistance and chemical stability of concrete. Many domestic and foreign scholars have studied the mechanical properties and durability of basalt fiber reinforced concrete. The study by Jin et al. (2015) has shown that basalt fiber can significantly enhance the anti-freeze-thaw ability of the concrete under erosion conditions. Lu et al., (2017) found that the compression strength of early aged concrete in corrosive solution tends to decrease with the increase of basalt fiber content. Gao et al., (2010) carried out the durability test of concrete under sulfate action, and analyzed the erosion mechanism. Gao et al., (2013) studied the failure process of the concrete exposed to sulphate erosion under bending load and dry-wet cycles. Bassuoni and Nehdi (2009) studied the sulfate erosion resistance of self-consolidating concrete under mixed cycle and bending loads. Dong et al., found that basalt fiber can improve the compression strength and bending strength of concrete. He and Tian (2013) studied the anti-permeability and anti-frost performance of high-performance hydraulic basalt fiber reinforced concrete. Liu et al., (2015) studied the effect of the fly ash and slag powder on the concrete performance changes under the coupling of sulfate and wet and dry cycles. Jiang and Niu (2015) studied concrete microscopic changes under the sulfate erosion. At present, there are few studies on the durability of basalt fiber reinforced concrete, especially in the sodium sulfate corrosion environment. Therefore, in this paper, the sodium sulfate solution corrosion test was used to study the durability and mechanical properties of concrete with different basalt fiber contents, which is of sound practical significance.

## 2. Experiment Design

The experiment designed the concrete with five different contents of basalt fiber, with the ratio shown in Table 1. Each dosage was applied in 3 test pieces, and the size was all 100mm. As for the basalt fiber dispersion, during the mixing of basalt fiber and concrete, the poor fiber dispersion would have a direct impact on all performances of the concrete. In line with the experimental study, basalt fibers and fine particles (such as fine sand), after rubbing, are easier to break up, leading to the "powder particle basalt fiber dispersion method" proposed. This method requires breaking up the materials as powder with the moisture rate of about 0.5%. The concrete test pieces, after 28-day maintenance in the standard maintenance room, were put into the sodium sulfate solution with the concentration of 5.0% and clean water respectively. Every 30 days, the concrete test pieces were taken out to observe the corrosion and measure the changes in the water absorption. After 90 days, the compression strength was tested to analyze the changing rule of water absorption and strength over time.

(a) Pre-dispersion state (b) Post-dispersion state

*Figure 1: Effect of powder particle basalt fiber dispersion method*

*Table 1: Concrete mix ratio*

| No | Cement / (kg • m$^{-3}$) | Fine aggregates / (kg • m$^{-3}$) | Coarse aggregates / (kg•m$^{-3}$) | Water / (kg•m$^{-3}$) | Fiber / (kg•m$^{-3}$) | Water-reducing agents / (kg • m$^{-3}$) |
|---|---|---|---|---|---|---|
| C1 | 524 | 532 | 1129 | 215 | 0 | 5.24 |
| C2 | 524 | 532 | 1129 | 215 | 1.325 | 5.24 |
| C3 | 524 | 532 | 1129 | 215 | 2.650 | 5.24 |
| C4 | 524 | 532 | 1129 | 215 | 5.300 | 5.24 |
| C5 | 524 | 532 | 1129 | 215 | 7.950 | 5.24 |

## 3. Experiment Process General

The erosion process was roughly as follows:

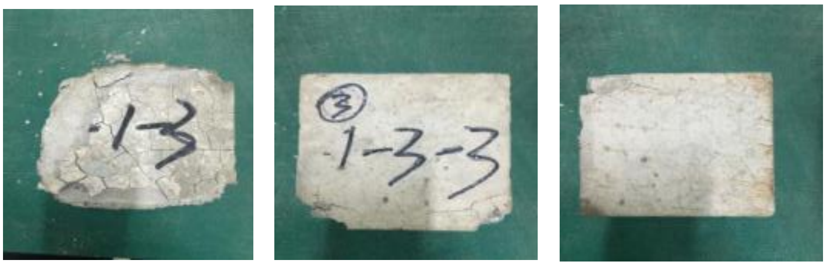
After 30 days, the concrete test piece without basalt fiber showed macroscopic fine cracks on the surface, while the surface of the concrete test pieces with 0.1% and 0.3% basalt fiber showed no obvious changes. After 60 days, the cracks on the surface of the concrete test piece without basalt fiber widened, with concrete shedding on the corner, and the aggregates inside the test piece was clearly visible. However, the test piece incorporating 0.1% and 0.3% basalt fibers showed no significant changes from the initial test piece. After 90 days, the concrete test piece without basalt fiber was severely damaged, with cracks densely covering the surface and a lot of shedding concrete. The test piece with 0.1% fiber content saw cracks on the corner with the shedding of concrete. The test piece with 0.3% fiber content displayed a penetrating crack, with slight concrete shedding on the corner. Based on the experiment on the erosion of basalt fiber reinforced concrete in sodium sulfate solution, basalt fiber can dramatically prevent the erosion-enabled crack expansion, and the concrete with basalt fiber added show obviously improved ability of resistance to sodium sulfate erosion.


*(a)Fiber content 0%* *(b) Fiber content 0.1%* *(c) Fiber content 0.3%*

*Figure 2: Concrete surface erosion after 30 days*


*(a) Fiber content 0%* *(b) Fiber content 0.1%* *(c) Fiber content 0.3%*

*Figure 3: Concrete surface erosion after 60 days*




*(a) Fiber content 0%* *(b) Fiber content 0.1%* *(c) Fiber content 0.3%*

*Figure 4: Concrete surface erosion after 90 days*

## 4. Changes in Water Absorption Rates

Water absorption rates, to a certain extent, can reflect the evolving law of internal pores of concrete. Specific measurements were as follows: the water absorption of concrete test pieces every 30 days was measured. First, the mass of saturated concrete test piece was identified; the test piece was placed in a drying oven for the drying process (measure the mass every 4 hours until no changes in the mass to complete drying). Then the water absorption rate was calculated in accordance with the following formula:

$$w = \frac{m_s - m_d}{m_d} \tag{1}$$

In the formula, $m_s$ refers to the mass of the saturated test piece, and $m_d$ means the mass of the dried test piece.

The average value was regarded as the water absorption rate. It can be seen from Table 2 that after the test piece was soaked 30 days, the porosity became smaller, and the porosity increased from the 60$^{th}$ day. After comparison, it can be told that porosity of C1 increased by 20% after being soaked 90 days, and that of C2, C3, C4, and C5 increased by 25.5%, 17.3%, 29.4%, and 37.5% respectively. Therefore, 0.1% basalt fiber content can best restrain the porosity of basalt fiber reinforced concrete in the sodium sulfate solution.

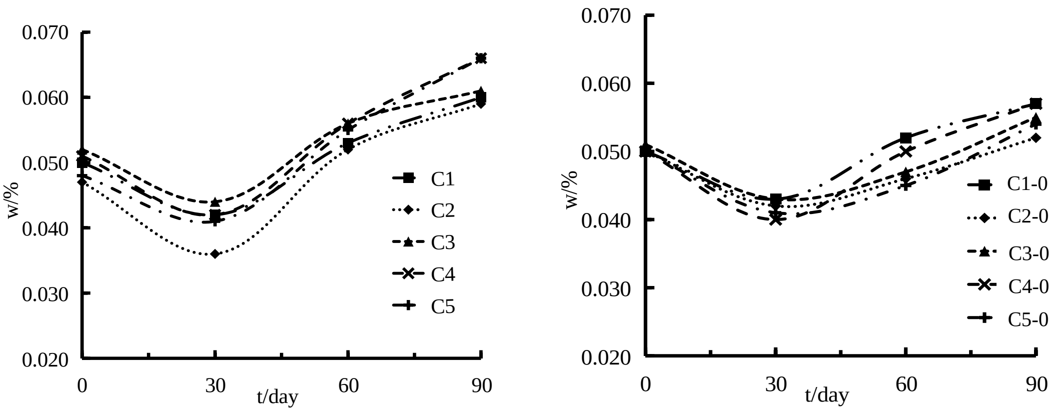
*Table 2: Changes in water absorption rate of concrete test pieces under sodium sulfate erosion*

| No | Initial pore | | | Erosion 30 days | | | Erosion 60 days | | | Erosion 90 days | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| C1 | 0.050 | 0.048 | 0.052 | 0.043 | 0.040 | 0.043 | 0.052 | 0.053 | 0.055 | 0.062 | 0.058 | 0.060 |
| C2 | 0.046 | 0.051 | 0.045 | 0.034 | 0.037 | 0.038 | 0.049 | 0.055 | 0.053 | 0.059 | 0.061 | 0.057 |
| C3 | 0.049 | 0.055 | 0.053 | 0.043 | 0.048 | 0.042 | 0.054 | 0.055 | 0.059 | 0.061 | 0.058 | 0.063 |
| C4 | 0.050 | 0.049 | 0.053 | 0.044 | 0.040 | 0.043 | 0.053 | 0.056 | 0.058 | 0.067 | 0.066 | 0.066 |
| C5 | 0.049 | 0.049 | 0.047 | 0.041 | 0.042 | 0.040 | 0.056 | 0.058 | 0.050 | 0.065 | 0.060 | 0.072 |

In order to clearly understand the effect of sodium sulfate erosion on the water absorption rate of concrete test pieces, the water absorption rate of the test pieces soaked in clean water was also tested, with the mixing ratio the same as that of sodium sulfate erosion test. From Table 3, the test piece soaked in clean water had lower water absorption rate with the rate changing within 20%. From the water absorption curve shown in Figure 5, the water absorption changes are basically the same, all showing the trend of decreasing first and then increasing. However, the water absorption rate under the sulphate condition was higher, in that in the early stage of corrosion, the sulphate corrosion products were filled in the internal voids of the concrete to compact the concrete structure; while with the increase of the corrosion period, a large amount of expansion-oriented corrosion products filled the pores and interface zones, causing the concrete expansion and increasing internal porosity.

*Table 3: Changes in water absorption rate of concrete test pieces under clear water*

| No | Initial pore | | | Erosion 30 days | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| C1-0 | 0.046 | 0.055 | 0.050 | 0.041 | 0.050 | 0.039 |
| C2-0 | 0.049 | 0.053 | 0.048 | 0.04 | 0.045 | 0.042 |
| C3-0 | 0.057 | 0.045 | 0.05 | 0.047 | 0.039 | 0.043 |
| C4-0 | 0.055 | 0.048 | 0.046 | 0.044 | 0.039 | 0.038 |
| C5-0 | 0.049 | 0.048 | 0.052 | 0.038 | 0.040 | 0.044 |
| No | Erosion 60 days | | | Erosion 90 days | | |
| | 1 | 2 | 3 | 1 | 2 | 3 |
| C1-0 | 0.048 | 0.058 | 0.049 | 0.055 | 0.062 | 0.055 |
| C2-0 | 0.042 | 0.049 | 0.048 | 0.051 | 0.049 | 0.055 |
| C3-0 | 0.049 | 0.045 | 0.046 | 0.055 | 0.057 | 0.052 |
| C4-0 | 0.062 | 0.047 | 0.042 | 0.064 | 0.049 | 0.059 |
| C5-0 | 0.042 | 0.044 | 0.049 | 0.059 | 0.049 | 0.055 |




*(a) Changes in water absorption rate under sodium sulfate condition*

*(b) Changes in water absorption rate under clean water condition*

*Figure 5: The rule of water absorption rate changes of basalt fiber reinforced concrete*

## 5. Compressive Strength Analysis

The compressive strength of concrete suffering erosion over 90 days was tested, with the damage shown in Figure 6 and the load-displacement curve shown in Figure 7 (taking the median curve for analysis).

The specimens soaked in water had higher and stable compressive strength (no erosion); in contrast, 0.1% led to the best strength and 0.3% to a lower strength. For the compression performance after erosion, the strength of the test piece with 0.1% dosage was the highest, 23.43%, 22.89%, and 28.15% higher than the strength of the concrete test piece with 0%, 0.2%, and 0.3% dosage respectively. It can be basically concluded that the higher fiber content of the basalt does not necessarily enable higher compressive strength, and no matter concerning the durability or the basic mechanical properties, about 0.1% of the basalt fiber content is the most reasonable.


(a)Test piece without basalt fibers

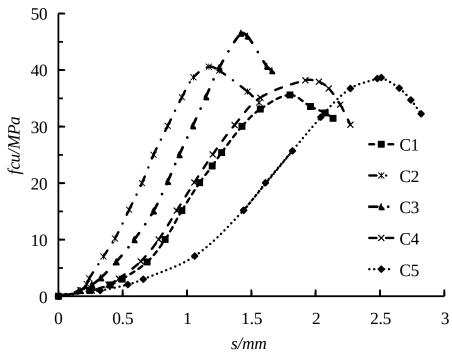

*(b) Test piece with 0.05% basalt fiber*

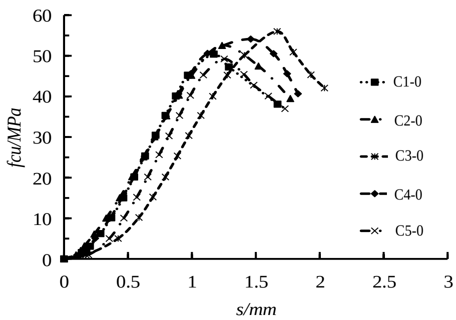

*(c) Test piece with 0.1% basalt fiber*


*(d) Test piece with 0.2% basalt fiber*

*(e) Test piece with 0.3% basalt fiber*

*Figure 6: Compression test of basalt fiber reinforced concrete after erosion*




*(a) Changes under sodium sulfate erosion* *(b) Changes under clean water condition*

*Figure 7: Load-displacement comparison of basalt fiber reinforced concretes*

## 6. Conclusion

In line with the erosion experiments on concrete test pieces with different content of basalt fiber in 5.0% sodium sulfate solution, it is found that:

1) Basalt fiber can significantly improve the internal pores and crack propagation in concrete, and an appropriate amount can reduce the internal pores of concrete and enhance the erosion resistance of concrete. The addition of 0.1% basalt fiber brings the most obvious enhancement of the concrete erosion resistance to sodium sulfate, while excess basalt fiber content can hardly improve, or even decrease, the concrete erosion resistance to sodium sulfate.

2) Based on the compressive tests on basalt fiber reinforced concrete, with an addition of 0.1% basalt fiber, the compressive strength of concrete blocks increases by 24.5%, which is also about 30.7% higher than the concrete with 0.3% basalt fiber.

3) The 0.1% basalt fiber content for the concrete is the most economical and reasonable.

4) The “Powder Particle Basalt Fiber Dispersion Method” proposed in this paper is simple to easy to operate, which can easily solve the problem of difficult dispersion of basalt fiber.

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