Experimental study on durability of basalt fiber concrete after elevated temperature

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Abstract

The durability of concrete material after exposure to elevated temperatures is important for the serviceability prediction of concrete structures in a fire disaster scenario. Existing researches show that an appropriate amount of basalt fiber can significantly improve the splitting tensile strength and chloride penetration resistance of concrete. However, the mechanical properties of basalt fiber concrete after elevated temperatures and its durability properties are still not clear. In this paper, the mechanical properties, carbonization law and chloride ion penetration law of ordinary concrete and basalt fiber concrete under high temperatures are studied. The concept of a burnt layer for concrete exposed to elevated temperatures is proposed, and the thickness of this burnt layer for concrete under different temperatures were measured. The results show that the addition of basalt fiber can inhibit the carbonization of concrete at elevated temperatures, diminish the thickness of the burnt layer, and significantly improve the chloride penetration resistance of concrete.

Keywords: high temperature; basalt fiber concrete; burnt layer; carbonization; chloride ion penetration.

1. Introduction

Fire is one of the most common disasters that occurs on concrete structures. While in most cases, concrete structures are still serviceable following one such exposure, it is important to assess the durability of concrete material after exposure to elevated temperatures for the serviceability prediction of concrete structures. Much existing research focuses on the carbonization depth and the chloride ion penetration law of normal concrete material after exposure to elevated temperatures. Gupta et al. [1] prepared concrete by replacing the fine aggregate with waste rubber fiber, and studied changes in water permeability and chloride ion permeability after elevated temperature by considering six temperatures and three heating times. Ozawa et al. [2] used tracers to estimate the chloride diffusion coefficient of concrete after fire and concluded that the apparent chloride diffusion coefficient of concrete increased with an increase in heating temperature, and that thermal damage reduced the penetration resistance and durability of concrete. Nadeem et al. [3] measured the chloride ion permeability and water adsorption of fly ash and metakaolin concrete at four temperatures in the range 200°C ~800°C, and it is proposed that 400°C can be regarded as the critical temperature for performance change of concrete. Wang et al. [4] conducted experimental research on the carbonization resistance of fly ash concrete subjected to tensile stress after exposure to high temperature and showed that under the combined influence of tensile stress, high temperature, and high content of fly ash, the carbonization resistance of concrete significantly decreased. Karahan et al. [5] conducted experimental research on the permeability of mass fly ash and slag concrete after exposure to high temperature, and found that the chloride ion permeability coefficient of concrete increased with the increase in temperature. The permeability of concrete significantly improved after 400°C, with slag concrete performing better than fly ash concrete.

Basalt fiber has excellent overall performance and ability to adapt to the environment, which can greatly improve the durability of concrete. A proper proportion of basalt fiber can effectively constrain non-structural cracks in concrete, hinder early plastic cracks, and prolong the service life of a concrete structure. Dias et al. [6] conducted three-point bending and compression tests on concrete samples prepared with

different proportions of basalt staple fiber. The results showed that basalt fiber has a significant toughening effect on cement. Kabay et al. [7] evaluated the influence of basalt fiber on the physical and mechanical properties of concrete, and found that the application of basalt fiber can improve the bending strength, fracture energy, and wear resistance of the material even at low content. The research of Lipatov et al. [8] showed that the basalt fiber concrete mixed with Zirconia exhibited excellent performance. Branston et al. [9] studied the influence of two types of basalt fiber on the mechanical properties of concrete and found that both types of fiber could enhance the pre-cracking performance of concrete, and minibars fiber could enhance the post-cracking performance of concrete. Li et al. [10] studied the relationship between the fractal dimension of the pore surface of basalt fiber reinforced concrete and pore structure parameters, strength, and shrinkage performance, and found that the addition of basalt fiber improved the pore structure of concrete. Katkhuda et al. [11] showed that the addition of appropriate basalt fiber can greatly improve the splitting tensile and bending strength of recycled aggregate concrete. Ayub et al. [12] analyzed the mechanical properties of basalt fiber reinforced concrete (BFRC) for mixing amounts of basalt fiber of 1%, 2%, and 3%, respectively. The results showed that when the mixing amount of basalt fiber was 2%, the compressive strength of BFRC was significantly improved, but its influence on the elastic modulus was negligible. Jiang et al. [13] researched the influence of the volume fraction and length of the basalt fiber on the mechanical properties of concrete, and found that basalt fiber could significantly improve the tensile strength, bending strength, and toughness index of composite materials. Li et al. [14] conducted an experimental study on the impact of mechanical properties of carbon fiber concrete and basalt fiber concrete, and concluded that, compared with carbon fiber, basalt fiber had a better strengthening and toughening effect on concrete, and that the appropriate mixing amount was 0.1%. In short, these studies prove that basalt fiber has strong corrosion resistance, elevated temperature stability, oxidation resistance, and radiation resistance.

Borhan et al. [15] studied the influence of basalt short-cut fiber on the mechanical and thermal properties of concrete, and found that the addition of basalt fiber could

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significantly reduce the heat transfer in the heating test. In addition, scholars have studied the high-temperature performance, durability and micro-structure of basalt fiber concrete. For example, Sim et al. [16] and High et al. [17] conducted experimental studies on the high-temperature performance of basalt fiber concrete, and found that basalt rock has a nucleation property at high temperature, which implies volume stability of basalt fibers at high temperatures. Liu et al. [18] studied the tensile resistance of basalt fiber concrete at different temperatures and found the initial tensile stress, peak tensile force, tension work, and peak work of the samples showed a downward trend with an increase in temperature. Ramachandran and Scheffler et al. [19, 20] respectively proved that basalt fiber has excellent resistance to alkaline erosion, and the stress reduction of fiber filament in an alkaline cement solution was not significant, indicating that basalt fiber is suitable for use as a reinforcing material in an alkaline concrete matrix. Afroz et al. [21] conducted an in-depth study on the durability of basalt fiber in concrete matrix and found that $\text{Ca}(\text{OH})_2$ formed non-smooth material on the fiber and provided good interlocking between concrete substrates. Jiang et al. [22] argued that basalt fiber concrete has a higher porosity than ordinary concrete, as demonstrated by the Mercury intrusion porosimetry (MIP). Xue et al. [23] studied the osmotic evolution of thermal-damaged BFRC under effective stress, and analyzed its osmotic mechanism through NMR and SEM results. Dong et al. [24] found that the accumulation of basalt fiber in concrete pores and on mortar surfaces not only enhanced the material performance of the concrete but also improved the microstructure property of the interfacial transition zone, thus further improving the ductility of the concrete. However, there are few reports on the mechanism of chloride diffusion and carbonization rate of basalt fiber concrete after exposure to elevated temperatures, and thus this is a topic that requires further study.

In this paper, the mechanical properties, carbonization rule, and chloride ion penetration rule of basalt fiber concrete and ordinary concrete subjected to elevated temperatures of $100^\circ\text{C} \sim 600^\circ\text{C}$ were studied. The effects of different temperatures on concrete carbonization and chloride ion penetration were analyzed, providing a basis for predicting the service life of concrete structures after fire disaster.

2 Experiment process

2.1 Experimental Materials

The experimental specimens were cast with two kinds of concrete, ordinary concrete and basalt fiber reinforced concrete. The sand used for the fine aggregate belongs to medium sand, and the particle size distribution meets the requirements of Sand for construction GB/T14684-2011[25] in Zone 2. Coarse aggregate meets the requirements of 5-20mm continuous particle size distribution in Pebble and crushed stone for construction GB/T 14685-2011[26]. The objective strength of the concrete is C40, the compressive strength of 100mm × 100mm × 100mm cubes after 28 days of standard curing is 44.88 MPa and the standard compressive strength is 42.64 MPa. Strength test was carried out in accordance with GB/T50081-2019 [27], Standard for Test Methods of Concrete Physical and Mechanical Property. The specific mechanical properties of the basalt fiber are shown in Table 1.

The appropriate mixing amount (0.15% in volume ratio) was selected following basalt fiber mix proportion test. The mixing process of basalt fiber into concrete was carried out following CECS13-2009 standard test methods for fiber reinforced concrete [28]. Mix proportions of ordinary concrete and basalt fiber concrete was shown in Table 2.

2.2 Specimen Information

In the heating test, 21 cube specimens of basalt fiber concrete and ordinary concrete in sizes of 100mm × 100mm × 100mm were selected and divided into seven groups corresponding to temperature. In the carbonization test, 21 prism specimens of basalt fiber concrete and ordinary concrete in sizes of 100mm × 100mm × 300mm were selected, divided into three groups, based on carbonization time and seven temperatures. In total, 63 cube samples in sizes of 100mm × 100mm × 100mm and 12 prismatic specimens in sizes of 100mm × 100mm × 300mm were tested in the chloride ion penetration test (see Table 3).

2.3 Heating test

To obtain the material properties under various temperatures, the standard curing for 28 days specimens were subjected to seven temperatures, respectively, 20°C, 100°C, 200°C, 300°C, 400°C, 500°C, and 600°C. The furnace worked at heating rate of 10°C/minute and remained at a steady temperature for three hours once the target temperature was reached. After the heating test was completed, the specimens were naturally cooled to room temperature. The heating furnace is shown in Figure 1.

2.4 Carbonization test

Five carbonization conditions were considered: carbonized for 0 days, 3 days, 7 days, 14 days, and 28 days after being submitted to elevated temperatures. The samples were made in accordance with the standard for test methods of long-term performance and durability of ordinary concrete (GB50082-2009) [29], with size of 100mm × 100mm × 300mm. For each condition, three samples were measured to ensure accuracy; given the two types of concrete (with basalt fiber and without) and the seven temperature conditions, there were a total of 42 samples. A CCB-70B concrete carbonization test box was selected, with control temperature of $20 \pm 3^\circ\text{C}$, relative humidity of $70 \pm 5\%$, and CO_2 concentration of $20 \pm 3\%$, in line with the carbonization test requirements.

After the heating test, a non-pouring surface was selected as the carbonization permeable surface; the other five faces were sealed with paraffin, and the sealed samples were placed in the carbonization box in sequence, at an interval between samples of not less than 50 mm. When the specimens were carbonized for the designated time, the carbonization depth was measured via the phenolphthalein titration method. The specimen was split from 1/3 of the section, and the phenolphthalein solution with a concentration of 1% was sprayed. Concrete that has not been carbonized is still highly alkaline and the sprayed surface is pink, while on the carbonized part, the surface is colorless. The carbonization depth of concrete was measured with a ruler after spraying for about 30s. After the measurement, the split surface of the samples was sealed with paraffin and then put into the carbonization box for the following test period. When the samples were carbonized for 3 days, 7 days, 14 days, and 28 days respectively, they were taken out and the above test operation repeated. Figure 2 is a photo of splitting the concrete specimen.

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5 2 2.5 Chloride ion penetration test

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7 3 2.5.1 Chloride ion penetration test without load

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9 4 Ordinary concrete and basalt fiber concrete specimens in size of a 100mm × 100mm
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11 5 × 100mm were prepared. After the heating test, the samples were immersed in a 5%
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13 6 NaCl solution for 28 days, 56 days, and 84 days respectively, to measure the chloride
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15 7 ion content at different depths of the specimen. The 42 experimental conditions,
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17 8 combined with the three specimens for each condition, implied 126 specimens in total.

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19 9 After being soaked for the predetermined number of days, powder samples at each
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21 10 additional 5 mm depth were taken by drilling holes on the invasion surface of the
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23 11 specimen, to a final the depth of 30 mm. Several holes per surface were created in this
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25 12 way, and the powder samples at the same depth mixed, with particles larger than 0.63
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27 13 mm screened. There are six powder samples for each specimen, corresponding to depths
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29 14 of 2.5 mm, 7.5 mm, 12.5 mm, 17.5 mm, 22.5 mm, and 27.5 mm respectively. The
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31 15 concentration of chloride ion in the solution was measured by measuring the potential
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33 16 difference between the probe electrode and the reference electrode with DY-2501B
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35 17 portable chloride ion content tester.

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37 18 2.5.2 Chloride ion penetration test under load

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39 19 The axial compressive strength f_u of the two types of concrete was tested. After
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41 20 submitted to heating tests, at target temperatures of 20°C, 200°C, 400°C, and 600°C, the
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43 21 specimens were immersed in a 5% NaCl solution and loaded by a self-made loading
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45 22 device at $0.1f_u$, $0.2f_u$, and $0.3f_u$, respectively, as shown by Figure 3. The load level was
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47 23 controlled by sensors, which have been checked regularly during the test to ensure the
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49 24 stable of the load level.

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51 25 After being soaked for 28 days, 56 days, and 84 days respectively, the chloride ion
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53 26 content at different depths of the specimens was measured. The same sampling method
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55 27 as in Section 2.5.1 was used.

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57 28 **3. Results and discussions**

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59 29 3.1 Carbonization test results

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30 3.1.1 High temperature burnt layer

For the same carbonization condition, the carbonization speed of concrete after fire disaster was faster than that in a natural state. This is because of the number of hydrocolloids in concrete that decomposed under high temperatures. The unstable decomposition products of the hydrate colloid react with the high concentration of acid smoke, resulting in neutralization of the concrete. This situation has similar characteristics to carbonization, and the carbonized concrete depth under high temperature is defined as burnt layer. To study the carbonization regularity of concrete after fire disaster, the depth of burnt layer caused by various high temperatures should be measured in prior, as the initial carbonization depth. The depth of high temperature burnt layer δ_T of concrete increases with the rise of temperature, the measured results for different temperatures are shown in Table 4 and the color development is shown in Figure 4.

When the heating temperature is lower than 300°C, the depth of the high temperature burnt layer increases slowly both in ordinary concrete and basalt fiber concrete. When above 400°C, the hydration product calcium hydroxide and other alkaline substances gradually begin to decompose, and the outside of the concrete is heated for a long time and decomposes thoroughly. At the same time, the high temperature causes the concrete surface to produce subtle cracks, free water and the bound water are heated out, gas can diffuse into the concrete interior along with the cracks and pore channels, and further undergo a chemical neutralization reaction with alkaline substances. After phenolphthalein titration, an obvious color interface appears. At 600°C, the depth of the high temperature burnt layer of ordinary concrete has exceeds 10 mm.

The basalt fiber in the concrete matrix disordered distribution can effectively restrain the expansion of cracks in the concrete under high temperature, reducing the number of through cracks and preventing harmful gases such as CO₂ from neutralization reaction inside the concrete. The addition of suitable basalt fiber can increase the wet packing density of concrete. Some current studies [30-31] have shown that it has a positive effect on improving the durability of concrete. Thus, basalt fiber reinforced

concrete under high temperatures has significantly greater carbonization resistance than ordinary concrete.

3.1.2 Results of the rapid carbonization test

After 28 days of carbonization in the rapid carbonization box, the samples were taken out for splitting and sprayed with a 1% phenolphthalein solution. The color development of the samples is shown in Figure 5 and Figure 6.

Considering the influence of the depth of the high temperature burnt layer, the measured carbonization depth after rapid carbonization minus the depth of the burnt layer at the corresponding temperature is regarded as the effective carbonization depth of concrete. The effective carbonization depth for 28 days of rapid carbonization are listed in Table 5. Figure 5 shows that the higher the temperature, the lighter the chromatic ability of the phenolphthalein solution, with a gradual reduction in chromatic affecting depth. The chromatic affecting depth of basalt fiber concrete is greater than that of ordinary concrete. This means that the residual alkalinity is stronger and the carbonization depth is smaller. After rapid carbonization of 3 days and 7 days, the ordinary concrete samples heated to 600 °C appeared in a state of complete carbonization. After 14 days of rapid carbonization, the ordinary concrete samples subjected to 500°C and 600°C appeared in a state of complete carbonization, while the basalt fiber concrete only 600°C in this state. After 28 days of rapid carbonization, ordinary concrete samples subjected to 400°C, 500°C and 600°C appeared in a state of complete carbonization, while basalt fiber concrete still only 600°C.

From Table 5, it can be seen that the effective carbonization depth still exhibits a trend of gradual increase with temperature, while the measured carbonization depth value from 500°C has reached a limit, and both ordinary concrete and basalt fiber concrete are fully carbonized. Comparing the effective carbonization depths of basalt fiber concrete and ordinary concrete over the range 100°C to 400°C, that for the basalt fiber was lower than that for ordinary concrete by margins of 24.02%, 29.48%, 24.52%, and 23.66%, respectively. This shows that basalt fibers have an obvious inhibitory effect on the carbonization reaction of concrete.

3.2 Results of chloride ion penetration test

3.2.1 Without load

In coincide with the positive effect of basalt fiber on mechanical properties of concrete, basalt fiber concrete also shows a better permeability resistance to chloride ion than the normal concrete. Figure 6 shows the test results for chloride ion content (the unit of chloride ion content is the mass percentage) at different depths of basalt fiber concrete 28 days after elevated temperatures.

It can be seen that after 28 days of soaking, the chloride ion content at 2.5 mm is the highest and that at 27.5 mm is the lowest, showing a trend of rapid decrease from the outside to the inside. After the concrete samples were subjected to high temperatures of 100°C, 200°C, 300°C, 400°C, 500°C, and 600°C, the chloride ion content at 2.5 mm increased by 2.36%, 27.19%, 50.96%, 105.14%, 151.61%, and 183.94%, respectively, compared with that at normal temperature. The chloride ion content at other depths also increased significantly due to high temperatures. This leads to the conclusion that the chloride penetration resistance of concrete decreases after submitted to elevated temperatures, especially when the temperature reached 400°C or above.

The results for 56 and 84 days of erosion were basically in consistent with observed trends for 28 days of erosion, but the longer the erosion time, the higher the chloride ion content at the same depth.

3.2.2 Under load condition

The relationship between the chloride ion content and different compressive stress levels after 28 days of erosion of basalt fiber concrete at normal temperature is shown in Figure 7.

The chloride ion concentration of each layer from the outside to the inside also showed a rapidly decreasing trend. As compressive stress increased from zero to $0.3f_u$, the concentration of chloride ion in the same layer decreased continuously. For example, at depth 2.5 mm, compared with without load condition, the chloride ion content decreased by 3.85 %, 13.7 % and 16.9 % at the $0.1f_u$, $0.2f_u$, and $0.3f_u$ load levels,

respectively. In general, the greater the stress, the greater the decrease of chloride ion content, implying that stresses of $0.3f_u$ and below inhibits the invasion of chloride ions.

However, for basalt fiber concrete, chloride ion concentration changes under different stress effects after exposure to high temperatures and normal temperature are quite different. The change in chloride ion content in concrete with a stress level after 28 days of chloride ion immersion at 200°C , 400°C , and 600°C can be clearly seen in Figures. 8, 9, and 10. Illustration for each figure are shown below:

- (1) Figure 8 shows that, after heating basalt fiber concrete to 200°C , the chloride ion content follows almost the same changing rule as for the normal temperature, from the outside to the inside layers, the chloride ion concentration presents a fast diminishing trend. However, chloride ion content after 200°C is much higher than at normal temperature, as at higher temperatures, the chloride ions are more likely to enter the concrete matrix and the permeability resistance of concrete decreases;
- (2) Figure 9 shows that compared with normal temperature and 200°C , the content of chloride ion at 400°C is greatly increased. After 400°C , calcium hydroxide and gel in concrete begin to decompose. High temperature cracks also provide more channels for the diffusion of chloride ion, and the permeability resistance of concrete is significantly reduced. From the outside to the inside layers, the chloride ion content first decreases before increasing again with increasing stress. Chloride ion content is lowest at $0.1f_u$ stress; $0.2f_u$ stress, it has recovered to be almost the same as under no stress condition; and at $0.3f_u$ stress, it has increased again to be higher than that of the no stress state. This indicates that when compressive stress is greater than a certain level, the concentration of chloride ion in the concrete surface layer suddenly increases. This value is known as the chloride ion penetration compressive stress threshold of concrete [32]. The existing study shows that the chloride ion penetration compressive stress threshold of concrete at normal temperature is about $0.5f_u$. However, after a high temperature of 400°C , the chloride ion penetration compressive stress threshold has been reduced to 0.1 to $0.2f_u$. This result has a significant implication for concrete structures after a fire disaster;

(3) By analyzing the results that experienced 600°C and under different stress levels (Figure 10), it shows the chloride ion content of basalt fiber concrete as a whole is significantly higher compared with that of lower temperatures. After 600°C, a large amount of calcium hydroxide and gel in concrete has decomposed, density decreases, and high-temperature cracks continue to expand and penetrate, providing more channels for the diffusion of chloride ion. The chloride ion penetration compressive stress threshold for basalt fiber concrete disappears after experiencing a high temperature of 600°C, and no matter the load, this has a negative impact on the chloride ion diffusion resistance of concrete.

After 56 days and 84 days of erosion, the change of chloride ion content at different depths of the basalt fiber concrete is roughly in consistent with that at 28 days of erosion. The higher the temperature, the higher the chloride ion content. At normal temperature and 200°C, stress of $0.3f_u$ and below can inhibit the entry of chloride ions into concrete. At 400°C, the compressive stress threshold affecting the entry of chlorine salts into concrete is about $0.1f_u$. In line with the serious deterioration of concrete material performance at 600°C, the compressive stress always reduces the chloride ion permeability resistance of the concrete.

To clarify the difference in chloride ion resistance between basalt fiber concrete and ordinary concrete after high temperatures, the chloride ion content at a depth of 12.5 mm after 28 days of erosion was selected for comparison, as shown by Figure 11.

It was found that the addition of basalt fiber reduces the chloride ion content of concrete at the same depth by 19.65%, 7.51%, 13.08%, 21.07%, 21.71%, 22.27%, and 26.95%, respectively. The rehydration of ordinary concrete is significant at 100°C and 200°C, resulting in improvement in mechanical properties and a tendency toward compactness of the internal structure, while the density of basalt fiber concrete itself is relatively high, so the rate of decrease of chloride ion content in basalt fiber reinforced concrete is small at these two temperatures. However, as the temperature continues to rise, starting from 300°C, the advantages of basalt fiber concrete with small cracks and

porosity defects become obvious, the chloride ion content at the same depth decreases significantly, and the chloride ion permeability resistance improves continuously.

4 Conclusions

Based on the rapid carbonization test and chloride ion penetration test for basalt fiber concrete and ordinary concrete, the durability of basalt fiber concrete under elevated temperatures was studied. The main conclusions are as follows:

- 1) The carbonization resistance of concrete is significantly weakened after high temperatures, and the neutralization degree of concrete increases with the rise in heating temperature;
- 2) The burnt layer thickness of basalt fiber concrete after exposure to various high temperatures is lower than that of ordinary concrete. The matrix sequence distribution of basalt fibers in concrete effectively restrains the expansion of inner cracks in concrete under high temperatures, reduces the number of through cracks, and hinders the neutralization reaction. Therefore, the carbonization resistance of basalt fiber concrete under high temperatures is significantly better than that of ordinary concrete;
- 3) The chloride ion penetration resistance of basalt fiber concrete is better than that of ordinary concrete after elevated temperatures both with and without loading. With increases temperature, starting from 300°C, the advantages of basalt fiber concrete with small cracks and pore defects became evident, the chloride iron content at the same depth decreased significantly, and the chloride ion penetration resistance continuously improved; and
- 4) For the loaded state, there was a chloride ion penetration compressive stress threshold of concrete under elevated temperatures. At 400°C, the addition of basalt fiber could improve the chloride iron penetration compressive stress threshold of concrete. At 600°C, the concrete material performance deteriorated seriously, the chloride ion penetration compressive stress threshold decreased to zero, and the application of compressive stress will always reduce the chloride ion penetration resistance of concrete after exposed to elevated temperatures.

Acknowledgements

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LIST OF FIGURES

FIG. 1 Heating furnace: (a) Heating furnace body; (b) Control cabinet

FIG. 2 Splitting concrete specimen

FIG. 3 Loading device

FIG. 4 Color development of the high temperature burnt layer: (a) Ordinary concrete; (b) Basalt fiber concrete

FIG. 5 Color development after 28 days of rapid carbonization: (a) Ordinary concrete; (b) Basalt fiber concrete

FIG. 6 Distribution of chloride ion content in concrete after 28 days of erosion after high temperature

FIG. 7 Chloride ion content in specimens under load after 28 days of erosion at normal temperature

FIG. 8 Change of chloride ion content of concrete under load after 28 days of erosion after 200°C

FIG. 9 Change of chloride content of concrete under load after 28 days of erosion after 400°C

FIG. 10 Change of chloride content of concrete under load after 28 days of erosion after 600°C

FIG. 11 Change of chloride ion content at 12.5 mm in two kinds of concrete

Table 1. Performance parameters of basalt fiber

Material	Monofilament diameter (μm)	Length (mm)	Tensile strength (MPa)	Elastic modulus (GPa)	Ultimate elongation (%)	Density (kg/m^3)
Basalt fiber	22	18	4500	102	3.1	2650

Table 2 Mix proportion of Concrete

Material	Cement	Water	Sand	Gravel	Basalt fiber	Water reducing agent
Consumption (kg/m^3)	400	175	703.1	1054.6	3.975	0.8

Table 3. Details of specimen information

Temperature	Ordinary concrete / Basalt fiber concrete		
	Heating test	Carbonization	Chloride ion penetration test

Running head: DURABILITY OF BASALT FIBER CONCRETE ON ELEVATED TEMPERATURE

	100×100	100×100	100×100×100mm			100×100×300mm		
	×100mm	×300mm	28d	56d	72d	0.1 f_u	0.2 f_u	0.3 f_u
20°C	3	3	3	3	3	1	1	1
100°C	3	3	3	3	3			
200°C	3	3	3	3	3	1	1	1
300°C	3	3	3	3	3			
400°C	3	3	3	3	3	1	1	1
500°C	3	3	3	3	3			
600°C	3	3	3	3	3	1	1	1

Table 4. High temperature burnt layer of concrete δ_T

δ_T (mm)	Temperature / °C					
	100	200	300	400	500	600
Ordinary concrete	0.98	2.88	3.06	4.58	6.32	11.01
Basalt fiber concrete	0.71	1.69	2.87	4.19	5.31	8.57

Table 5. Measured and effective carbonization depth of concrete after 28 days of rapid carbonization

Carbonation depth /mm	Types of concrete	Temperature /°C					
		100	200	300	400	500	600
Measured value	Ordinary concrete	18.88	29.68	39.36	49.38	50	50
	Basalt fiber concrete	14.31	20.59	30.27	38.39	50	50
Effective values	Ordinary concrete	17.9	26.8	36.3	44.8	50	50
	Basalt fiber concrete	13.6	18.9	27.4	34.2	45.6	50

(a)

(b)

Fig. 1 Heating furnace: (a) Heating furnace body; (b) Control cabinet

228x127mm (192 x 192 DPI)

FIG. 2 Splitting concrete specimen
129x98mm (192 x 192 DPI)

FIG. 3 Loading device

147x109mm (192 x 192 DPI)

FIG. 4 Color development of the high temperature burnt layer: (a) Ordinary concrete; (b) Basalt fiber concrete

124x166mm (192 x 192 DPI)

FIG. 5 Color development after 28 days of rapid carbonization: (a) Ordinary concrete; (b) Basalt fiber concrete

109x151mm (192 x 192 DPI)

FIG. 6 Distribution of chloride ion content in concrete after 28 days of erosion after high temperature
246x147mm (96 x 96 DPI)

FIG. 7 Chloride ion content in specimens under load after 28 days of erosion at normal temperature
217x133mm (96 x 96 DPI)

FIG. 8 Change of chloride ion content of concrete under load after 28 days of erosion after 200°C

222x124mm (96 x 96 DPI)

FIG. 9 Change of chloride content of concrete under load after 28 days of erosion after 400°C
226x129mm (96 x 96 DPI)

FIG. 10 Change of chloride content of concrete under load after 28 days of erosion after 600°C

233x132mm (96 x 96 DPI)

FIG. 11 Change of chloride ion content at 12.5 mm in two kinds of concrete
245x130mm (96 x 96 DPI)