Effect of basalt fiber on chloride ion penetration of Reactive Powder Concrete

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Abstract. In order to investigate the influence of the basalt fiber on the durability of reactive powder concrete (RPC), chloride ion penetration test of nine groups of RPC containing basalt fiber and three groups of RPC without fiber was carried out, carbonization test of one group of basalt fiber RPC was performed. The result showed that, the electrical flux of RPC without basalt fiber varied from $10^4$ to $120$, the chloride ion permeability was very low. The electrical flux of basalt fiber RPC was less than $100$, so the chloride ion permeability can be ignored. When water-to-binder ratio (W/B) was 0.22 and volume fraction of basalt fiber was 0.10\%, the chloride ion permeation resistance of specimens was the best. The basalt fiber RPC had good carbonization resistance, and the carbonation depth was zero in 28 days.

1. Introduction

Concrete materials are widely used in civil engineering construction because of their good economics. In the coastal and salty lake areas, the chloride ion content in the environment is high, and chloride ions can invade into the concrete through penetration, diffusion, and electrochemical migration, causing corrosion of the steel bars, volume expansion, and increase of pores and cracks, affecting the structure. Durability, which is one of the main reasons for the failure of reinforced concrete structures in coastal areas. In addition, ordinary concrete has low tensile strength and it is prone to cracking, which is another important reason for its lack of durability. The addition of short fibers to concrete can effectively improve its crack resistance. Reactive Powder Concrete (RPC) is an ultra-high-performance fiber reinforced cementitious composite. For long-term corrosion-resistant engineering structures in salt lakes, saline soils, and marine engineering, chemical fibers with good corrosion resistance may be a better choice for improving concrete durability. Moreover, instead of metal fibers using of chemical fibers can significantly reduce the cost of concrete materials. Yew carried out experimental research on polypropylene fiber-concrete with different contents. Polypropylene fiber can improve the tensile strength, flexural strength and elastic modulus of concrete,
but it will lead to the drop of a slump. Basalt fiber is a new type of environmentally friendly high-performance fiber with excellent mechanical properties. The tensile strength of basalt fiber is 3000-4800 MPa, which is higher than that of metal fiber such as steel fiber; the elastic modulus is about 80-120 GPa, which is between other chemical fibers such as steel fiber and polypropylene fiber. The addition of basalt fiber can improve the bending strength, toughness and fracture energy of cement-based materials. At present, the research on the properties of basalt fiber concrete is still limited. This paper intends to study the effect of basalt fiber on the chloride ion penetration resistance of RPC and determine the suitable fiber volume fraction.

2. Test design

2.1 Materials and mix proportion.

The basalt fiber reactive powder concrete of this test consists of the following materials: cement, silica fume, quartz sand, basalt fiber, high-efficiency water reducer and water. The cement was made of P.O 42.5 ordinary Portland cement. The silica content in the silica fume was 82.2%. The quartz sand had a particle size range of 0-1.25 mm. The basalt fiber (BF) was a short-cut basalt fiber with a fiber, which 12 mm length and 13 μm diameter and 80-110GPa elastic modulus. The high-efficiency water reducing agent was a new non-naphthalene-based, high-performance water reducer AN3000 with the water reduction rate of 29%. This experiment mainly studied the effect of W/B and basalt fiber volume fraction on the durability of RPC. Considering three different W/B and three basalt fiber volume fraction. At the same time, to compare the improvement effect of basalt fiber on the durability of RPC, the RPC contrast test piece without any fiber was designed. The test mix ratio is shown in Table 1. In the mixed number, A, B, and C respectively represent the two W/B of 0.20, 0.22, and 0.24, and the latter numbers indicate the percentage of basalt volume fraction. For example, “A0.10” indicates that the water-to-binder ratio of the mixture is 0.2. Basalt fiber volume fraction is 0.10%.

| Number | W/B  | Fiber length | Cement | Silica fume | Coarse sand | Medium sand | Fine sand | Fiber quality (volume fraction) | Water reducer | Water  |
|--------|------|--------------|--------|-------------|-------------|-------------|-----------|-------------------------------|---------------|--------|
| A0     | 0.20 | —            | 762.89 | 228.87      | 743.97      | 374.12      | 170.89    | 0                             | 68.66         | 150.60 |
| A0.05  | 0.2  | 12           | 762.53 | 228.76      | 743.62      | 373.94      | 170.81    | 1.2 (0.05%)                   | 68.63         | 150.51 |
| A0.10  | 0.2  | 12           | 762.16 | 228.65      | 743.26      | 373.76      | 170.72    | 2.4 (0.10%)                   | 68.59         | 150.45 |
| A0.15  | 0.2  | 12           | 761.79 | 228.54      | 742.90      | 373.58      | 170.64    | 3.6 (0.15%)                   | 68.56         | 150.39 |
| B0     | 0.2  | —            | 756.89 | 227.07      | 738.12      | 371.18      | 169.54    | 0                             | 68.12         | 169.08 |
| B0.05  | 0.2  | 12           | 756.52 | 226.96      | 737.76      | 371.00      | 169.46    | 1.2 (0.05%)                   | 68.09         | 169.02 |
| B0.10  | 0.2  | 12           | 756.16 | 226.85      | 737.41      | 370.82      | 169.38    | 2.4 (0.10%)                   | 68.05         | 168.93 |
| B0.15  | 0.2  | 12           | 755.80 | 226.74      | 737.06      | 370.64      | 169.30    | 3.6 (0.15%)                   | 68.02         | 168.84 |
| C0     | 0.24 | —            | 750.98 | 225.29      | 732.36      | 368.28      | 168.22    | 0                             | 67.59         | 187.28 |
| C0.05  | 0.24 | 12           | 750.62 | 225.19      | 732.00      | 368.10      | 168.14    | 1.2 (0.05%)                   | 67.56         | 187.19 |
| C0.10  | 0.24 | 12           | 750.26 | 225.08      | 731.65      | 367.93      | 168.06    | 2.4 (0.10%)                   | 67.53         | 187.10 |
| C0.15  | 0.24 | 12           | 749.89 | 224.97      | 731.29      | 367.75      | 167.98    | 3.6 (0.15%)                   | 67.49         | 187.04 |

2.2 Test methods.

The chloride ion permeation test of the basalt fiber RPC of this test used the electric flux method. The chloride ion penetration test used a cylindrical test piece which had a diameter of 100 mm and a height of 50 mm. The test piece was made by cutting and drilling a core piece of 150 mm × 150 mm × 150 mm to ensure uniformity of the test piece, as shown in Fig. 1.
Fig. 1 Anti-chloride ion permeability test specimen

Before the test, the sides of the cut test piece were sealed with paraffin, and the holes in the coating were filled, and then vacuumed. The vacuum water retention test firstly reduces the absolute pressure in the vessel to 1-5 kPa within five minutes, keeps the pressure for 3 hours, and then adds enough distilled water while keeping the vacuum pump running continuously until the test piece is completely submerged by distilled water. The parts were returned to normal pressure after being immersed for 1h, and the test piece was continuously immersed in a water immersion machine for 18h. The prepared test piece was installed in the test tank and clamped, and then the gap between the test piece and the test tank was sealed with paraffin, and the sealing performance between the test piece and the test tank was examined with distilled water.

In the chloride ion permeation test, a constant voltage of 60V was applied to both ends of the test piece, and a test solution on one side of the test piece was a NaCl solution having a mass concentration of 3.0%, and the other side was a NaOH solution having a molar concentration of 0.3mol/L. The test data is automatically collected by the concrete electric flux intelligent measuring instrument, as shown in Figure 1. The initial current reading $I_0$ was recorded every 30 minutes, and tested for 6h.

3. Results and discussion

Fig. 2 shows the relationship between current and time of different water-binder ratio basalt fiber RPC specimens. It can be seen from the test results in the figure that the current value of basalt fiber RPC increases with time, and the growth rate of current value at the initial stage of the test is higher than that of the later current value. The current value of the active powder concrete is significantly higher than that of the basalt fiber RPC, and the current of RPC grows faster with time, while the current growth rate of the basalt fiber RPC is relatively stable.

![Fig. 2 Current value-time relationship of different W/B basalt fiber RPC](image)

According to the current data, the electric flux value of the basalt fiber RPC specimen can be calculated from the simplified calculation Eq. 1 (as shown in Table 2).
\[ Q = 900(I_0 + 2I_{30} + 2I_{60} + \cdots + 2I_t + \cdots + 2I_{300} + 2I_{330} + 2I_{360}) \]  
(1)

Where \( Q \) is the total electrical flux (C) through the test piece, \( I_0 \) is the initial current amount (A) of the test piece, \( I_t \) is the current (A) at time \( t \) (min).

The test piece for the chloride ion penetration resistance of concrete specified in the Standard for test methods of long-term performance and durability for ordinary concrete is a test piece with a diameter of 95 mm. Since the test piece used in this paper is a cylindrical test piece with a diameter of 100 mm, it is necessary to test piece. The measured data is converted according to Eq. 2 (as shown in Table 2):

\[ Q_s = Q_x \times (95/x)^2 \]  
(2)

Where \( Q_s \) is the electric flux through the 95mm diameter test piece (C), \( Q_x \) is the electric flux (C) of the test piece with a diameter of \( x \) (mm), \( x \) is the actual diameter of the test piece (mm).

| Number | W/B | Fiber volume fraction (%) | Electric flux (C) | Converted electric flux (C) |
|--------|-----|--------------------------|------------------|---------------------------|
| A0     | 0.20| 0                        | 114.687          | 103.505                   |
| A0.05  | 0.20| 0.05                     | 83.61            | 75.458                    |
| A0.10  | 0.20| 0.10                     | 55.089           | 49.718                    |
| A0.15  | 0.20| 0.15                     | 91.746           | 82.801                    |
| B0     | 0.22| 0                        | 118.827          | 107.241                   |
| B0.05  | 0.22| 0.05                     | 75.096           | 67.774                    |
| B0.10  | 0.22| 0.10                     | 41.94            | 37.851                    |
| B0.15  | 0.22| 0.15                     | 88.335           | 79.722                    |
| C0     | 0.24| 0                        | 133.056          | 120.083                   |
| C0.05  | 0.24| 0.05                     | 85.761           | 77.399                    |
| C0.10  | 0.24| 0.10                     | 62.874           | 56.744                    |
| C0.15  | 0.24| 0.15                     | 91.539           | 82.614                    |

It can be seen from the test results that the electric flux of the prime RPC increases with the increase of the water-to-binder ratio, which is because the increase of the water-to-binder ratio leads to the decrease of the RPC compactness, thereby increasing the electric flux. For the basalt fiber RPC of the same volume, when the water-to-binder ratio is 0.22, the electrical flux of the test piece is the lowest. For the RPC with a water-to-binder ratio of 0.2 and 0.22, the electric flux is close to that, and the addition of basalt fiber reduces the workability of RPC, which results in its compactness being affected. High performance concrete also exhibits similar properties. Thus, the basalt fiber RPC having a water-to-binder ratio of 0.2 has a chloride ion permeability lower than that of a basalt fiber RPC having a water-to-binder ratio of 0.22. The water-to-binder ratio of 0.24 fiber RPC has the highest electric flux, which is caused by the decrease in the compactness of RPC.

When the water-to-binder ratio is constant, the electric flux of basalt fiber RPC decreases first and then increases with the increase of fiber volume fraction. When the basalt fiber content changes between 0-0.10%, the anti-chloride ion permeability of basalt fiber RPC gradually increases with the enhance of fiber volume fraction. When the dosage exceeds 0.10%, the anti-chloride ion of basalt fiber RPC the permeability decreases as the fiber volume fraction is increased. The anti-chloride ion permeability of basalt fiber RPC is better than that of RPC. The basalt fiber volume is 0.10%, and the water-to-binder ratio is 0.22. The RPC specimen has the highest chloride ion permeability. The flux value is only 35.3% of the prime RPC.

The chloride ion penetration level of concrete can be evaluated by the electric flux value, and its
evaluation index is shown in Table 3.

| Conductivity / Coulomb | Chloride ion permeability |
|------------------------|---------------------------|
| > 4000                 | high                      |
| 2000-4000              | medium                    |
| 1000-2000              | low                       |
| 100-1000               | very low                  |
| < 100                  | ignore                    |

It can be seen from the test results that the basalt fiber RPC has a certain degree of improvement in chloride ion penetration resistance compared with the RPC, and the permeability of the basalt fiber RPC varies with the different fiber volume fraction. The 6h electric flux measured by the anti-chloride ion permeation test of ordinary concrete is usually between 1000C and 1500C, in contrast, the anti-penetration performance of RPC is much better, and its electric flux value not exceeding 150C indicates that its very low chloride ion permeability, because RPC composition contains a variety of cementitious materials, and does not contain coarse aggregates such as stones, so its compactness and crack resistance has been greatly improved, cracks and The pore phase is much less than that of ordinary concrete, so water and chloride ions are less likely to penetrate into the concrete, which in turn greatly improves the chloride ion penetration resistance of RPC. The electric flux of basalt fiber RPC is less than 100C, which can be regarded as negligible in engineering application, and basalt fiber can improve the chloride ion penetration resistance of RPC, which is due to the disordered phase distribution of basalt fiber in RPC. By bridging the internal cracks, preventing the initial crack development, reducing the number of connected cracks, resisting the infiltration of chloride ions, thus further improving the compactness of RPC, improving the internal structure of RPC, and thus improving its resistance to chloride ion penetration ability. This also shows that basalt fiber plays a certain role in improving the durability of RPC.

4. Summary
In this paper, the anti-chloride ion penetration test of basalt fiber RPC was carried out, and the effects of different water-to-binder ratio and basalt fiber content on the anti-penetration performance of RPC were determined. The results show that the electrical flux of the nine groups of basalt fiber RPC specimens designed in this paper are all lower than 100C, and the chloride ion permeability is negligible. It can be used in the corrosive environment such as saline soil, coastal and deicing salt. When the water-to-binder ratio is 0.22 and the basalt fiber volume fraction is 0.10%, the basalt fiber RPC has the best chloride ion penetration resistance.

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