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Impermeability Test on Carbon Fibre Reinforced Concrete

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This paper uses the orthogonal test method to analyze various factors affecting the impermeability of concrete. By preparing carbon fibre reinforced concrete specimens and performing hydraulic pressure test on the specimens, this paper studies how various factors affect the impermeability of concrete. The test results show that the effects of carbon fibre and silica fume on the impermeability of concrete are significant. When C40 concrete was mixed with 0.5% carbon fibre, 0.019% methylcellulose, and 0.18% silica fume, the permeated height decreased from 5.7cm to 2.7cm, a decrease of 52.6%. On the other hand, carbon fibre length has no significant effect on the impermeability of concrete.

1. Introduction

When concrete is used in dams, tunnels and other structures in large-scale hydropower and thermal power projects, it should be highly impermeable. Once the impermeability of concrete is insufficient or compromised, the functions of these structures will be severely degraded, resulting in serious pollution and leaks.

Scholars at home and abroad attempted to increase the strength properties of concrete by adding fibre materials to it. Wang et.al. (2017), Sofia Real et.al. (2017), Long et al. (2016), and Elisa et.al. (2016) studied the effects of different amounts of carbon fibre on the compressive and flexural strengths of foam concrete, and the results showed that carbon fibre with a content of 0.6% had the most significant enhancement effect on the compressive and flexural strengths of foam concrete. Wang et al. (2014), Zhao et.al. (2015), and Alghamri et.al. (2016) studied the effects of carbon fibre on various mechanical properties of concrete, and the results showed that appropriate carbon fibre content had no obvious enhancement effect on the compressive strength of concrete, but that it did on the flexural strength. Du et al. (2014), Sang et al. (2016), Pan et al. (2014) studied the corrosion resistance of the concrete matrix after it was mixed with carbon fibre, and the test results showed that carbon fibre could improve the erosion resistance of concrete.

At present, few research has been conducted on the effects of fibre and silica fume on the impermeability of concrete at home and abroad. This paper attempts to optimize the content of carbon fibre and silica fume the by the orthogonal test method, and focuses on the improvement effect of carbon fibre on the impermeability of concrete, which provides reliable experimental data and theoretical support for the improvement of concrete impermeability.

2 Testing materials and methods

2.1 Test purpose

The author tested the impermeability of carbon fibre reinforced concrete by the hydraulic pressure method (Zhang, 2009; Bing and Juan, 2008; Sujith et al., 2017; Mo et al., 2017) to explore the various factors affecting concrete impermeability and their effect patterns.

2.2 Testing materials

P•O 32.5 cement; river sand with a fineness modulus of 2.6 and a maximum particle size of 1mm; common gravel, with a maximum size of 16 mm; chopped PAN-based carbon fibre with a length of 6, 10, and 15mm, respectively (Table 1), powdered methylcellulose dispersant, 920U silica fume, and CNF-2 high-efficiency water reducing agent, all produced by Shanghai Xinka Carbon Co., Ltd.

Table 1: Performance indices of carbon fibre

Technical indices	Tensile strength	Tensile modulus	Elongation (%)	Density	Line resistance	Corrosion resistance	Permeability
Data	2928MPa	205GPa	2.1	1.76 g·cm-3	2.1×10-3 Ω·cm	Excellent	Good

2.3 Mix proportion

With C40 concrete as an example, this test was intended to explore the effect of carbon fibre on concrete impermeability. The basic mix proportion, the length and content of carbon fibre and the and mix proportion of silica fume and methylcellulose are shown in Table 2.

Table 2: Mix proportion of carbon fibre reinforced concrete

Specimen No.	Cement model	mix proportion							
		Cement	Fine aggregate	Coarse aggregate	Water	Water reducing agent	Carbon fibre	Silica fume	Methylcellulose
0~16	32.5	1	1.85	3.43	0.54	0.01	0~0.5	0~0.12	0~0.19

2.4 Design of the orthogonal test scheme

The concrete impermeability test was designed using the orthogonal test method (Li, 2014). The orthogonal test is a test plan design method based on the probability theory, mathematical statistics and practical experience. It uses a standardized orthogonal table to arrange tests in a flexible and convenient way. The test point layout is balanced, the number of tests is reduced, and more importantly, the main factors will not be missed, and the results are more visual and easier to analyze. Each level of tests are repeated for the same number of times to eliminate the interferences by some experimental errors. As this method is orthogonal and can help researchers easily find out the main effects of various factors, it has been widely applied in research.

This test studied the effects of carbon fibre content and length, methylcellulose, and silica fume on the impermeability of concrete. The selected orthogonal test table was L16 (45). The interactions among various factors were not taken into account.

2.5 Testing methods

2.5.1 Preparation of carbon fibre reinforced concrete

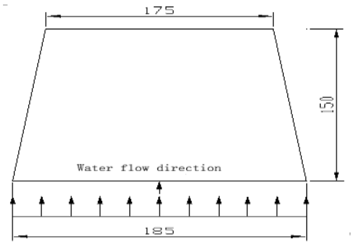
First heat the water to 40°C, add methylcellulose and stir it to make it fully dissolved, and then add carbon fibre and stir it to make it evenly dispersed. After that, add the coarse aggregate and water reducing agent, and finally add the mixture of sand and cement. Stir the mixture 2min and then the homogeneously dispersed carbon fibre reinforced concrete is obtained.

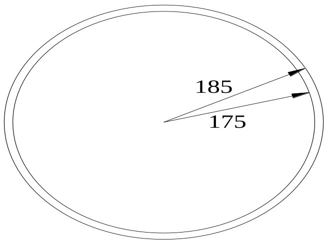
2.5.2 Casting of specimens

According to SD105-82 Test Procedure for Hydraulic Concrete, the relative impermeability test was performed by the one-time pressurization method. The impermeability test used truncated cone shaped specimens with an upper diameter of 175 mm and a lower diameter of 185 mm, and a height of 150mm, as shown in Figure 1.

2.5.3 Loading method

After curing for 28 days, take out the specimen one day before the test. Let its surface air-dried and then coat the side face of the specimen with melted paraffin wax. Immediately after that, place the specimen on a screw press and press it into a preheated specimen casing. After it is cooled for some time, relieve the pressure, and place the specimen together with its casing on the permeability tester. Boost the hydraulic pressure permeability tester to 0.8MPa for once and keep the pressure constant for 24h. The pressurization process should not take more than 5min. The time when the pressure is stabilized should be regarded as the recording start time (accurate to min). If no water seepage appears on the end face of the specimen during the pressure holding process, place the specimen on the press and split the specimen into two halves along the longitudinal section. Test the average permeated height to determine the impermeability of concrete.





Elevation of the specimen (mm) Plan view size of the specimen (mm)

Figure 1: Diagram of the concrete specimen for impermeability test

3 Testing results and analysis

3.1 Testing results

While the hydraulic pressure was kept constant, tests were arranged using the orthogonal test method. Impermeability tests were performed on 17 groups of specimens, with 3 truncated cone shaped specimens in each group. The test results are shown in Table 3.

Table 3: Permeated height of carbon fibre reinforced concrete

Test No.	Carbon fibre content (%)	Carbon fibre length(mm)	Methylcellulose (%)	Silica fume (%)	Permeated height (cm)
0	0	0	0	0	5.7
1	0.2	5	0.01	0.06	5.1
2	0.2	10	0.013	0.08	4.8
3	0.2	12	0.016	0.1	4.2
4	0.2	15	0.019	0.12	4
5	0.3	5	0.013	0.1	4.1
6	0.3	10	0.01	0.12	3.9
7	0.3	12	0.019	0.06	4
8	0.3	15	0.016	0.08	4
9	0.4	5	0.016	0.12	3.4
10	0.4	10	0.019	0.1	3.6
11	0.4	12	0.01	0.08	3.7
12	0.4	15	0.013	0.06	3.8
13	0.5	5	0.019	0.08	3.2
14	0.5	10	0.016	0.06	3.4
15	0.5	12	0.013	0.12	3
16	0.5	15	0.01	0.1	3.1

3.2 Results analysis

The author analyzed the test results of various factors affecting the impermeability of concrete using the range R. This index can reflect the fluctuation range of a set of data. The larger the range and the degree of dispersion are, the great effects the changes of the influencing factor will have on the test index, showing it is the main influencing factor. Therefore, based on the permeated height test results, the author performed range analysis on the carbon fibre content and length, methylcellulose, and silica fume. The results are shown in Table 4.

3.2.1 Effect of carbon fibre content on the permeability coefficient of concrete

From the test results, it can be seen that the impermeability of concrete in each group of specimens increased as the carbon fibre content increased. When the carbon fibre content was 0.4%, the impermeability was good. When the carbon fibre content was increased to 0.5%, the ranges of the permeated heights of concrete were very close, and the impermeability increased more slowly.

3.2.2 Effect of carbon fibre length on the impermeability of concrete

It can be seen from the ranges in the table that, when the carbon fibre length was 5, 10, 12 and 15mm, the impermeability of concrete was basically the same, so the effect of carbon fibre length on the impermeability of concrete can be ignored.

3.2.3 Effect of methylcellulose on the permeability coefficient of concrete

From the test results, it can be seen that when the methylcellulose content was 0.019%, the impermeability of concrete was the best. This was because as the carbon fibre content increased, its dispersion uniformity was worsened. Therefore, increasing the methylcellulose content can uniformly disperse the carbon fibre.

3.2.4 Effects of silica fume on the permeability coefficient of concrete

According to the test results, as the silica fume content increased, the impermeability of concrete increased accordingly, so silica fume has a great effect on the impermeability of concrete.
Through the analysis of the test results, it is found that, the effect of carbon fibre length on concrete impermeability can be ignored, and that the contents of carbon fibre and silica fume have great effects on the impermeability, so tests should be re-arranged to further verify these two factors.

Table 4: Range analysis of permeated heights

K1	18.10	15.80	15.80	16.30
K2	16.00	15.70	15.70	15.70
K3	14.50	14.9	15.00	15.00
K4	12.70	14.90	14.80	14.30
k1	4.53	3.95	3.95	4.08
k2	4.00	3.93	3.93	3.93
k3	3.63	3.73	3.75	3.75
k4	3.18	3.73	3.70	3.58
Range R	1.35	0.17	0.25	0.50
Order of factors	Carbon fibre content>silica fume>methylcellulose>carbon fibre length			
Optimal level	Carbon fibre content 0.5%	Carbon fibre length 12 mm	Methylcellulose content 0.019	Silica fume content 0.12

Table 5: Improved test scheme and data analysis table for the mix proportion of carbon fibre reinforced concrete

Test No.	Carbon fibre content (%)	Methylcellulose (%)	Silica fume (%)	Permeated height (cm)
1	0.5	0.019	0.12	3
2	0.5	0.022	0.15	2.8
3	0.5	0.025	0.18	2.8
4	0.6	0.019	0.15	3.1
5	0.6	0.022	0.18	3
6	0.6	0.025	0.12	3.2
7	0.7	0.019	0.18	3.5
8	0.7	0.022	0.12	3.7
9	0.7	0.025	0.15	3.6
K1	8.60	9.60	9.90	
K2	9.30	9.50	9.50	
K3	10.80	9.60	9.30	
k1	2.87	3.20	3.30	
k2	3.10	3.17	3.17	
k3	3.60	3.20	3.10	
Range R	0.73	0.03	0.20	
Order of factors	Carbon fibre content>silica fume>methylcellulose			
Optimal level	Carbon fibre content 0.5%	Methylcellulose content 0.019%	Silica fume content 0.18%	

3.3 Test improvements

In order to further obtain more accurate conclusions, based on the above test results, three factors and three levels were selected. The carbon fibre content was set at 0.5%, 0.6% and 0.7%, the methylcellulose content was set at 0.019%, 0.022% and 0.025%, and the silica fume content was set at 0.12%, 0.15%, and 0.18%. The tests were re-arranged using the orthogonal table L9 (34). The test results are shown in Table 5.
From the results of the range analysis in Table 5, it can be seen that carbon fibre content has a great effect on

the impermeability of concrete. When the carbon fibre content was 0.5%, the impermeability was the best. With the further increase of the content, the impermeability of concrete decreased, probably because with the content of carbon fibre increasing, the distribution of carbon fibre became uneven, resulting in poor impermeability. This also shows that with the increase of carbon fibre content, the dispersibility of methylcellulose on carbon fibre was weakened. At the same time, it can be seen that when the silica fume content reached 0.15%, its effect on the impermeability of concrete did not change much. According to the results of the orthogonal test, the best contents of carbon fibre, methylcellulose, and silica fume were 0.5%, 0.019%, and 0.18%, respectively. The test was repeated using this mix proportion, and the permeated height of the concrete measured was 2.7cm. Compared with that of the standard concrete, the permeated height was reduced by 3cm, a fall of 52.6%.

3.4 Effects of carbon fibre length on the permeability coefficient of concrete

According to the test results, in every group of test specimens, the concrete specimens with a carbon fibre length of 10mm have both smaller permeated heights and permeability coefficients than those with a carbon fibre length of 6mm and 15mm.
The relationship between the content of carbon fibre and the permeability coefficient of concrete is shown in Figure 2:

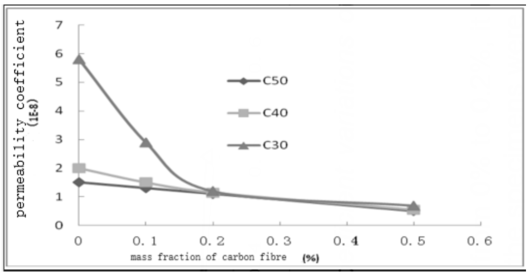


Figure 2: Diagram of the permeability coefficient variations of concrete specimens with different contents of carbon fibre

According to Figure 2:
When the content of carbon fibre ranged from 0% to 0.2%, it had a significant effect on the impermeability of concrete. The permeability coefficients of the specimens were reduced from 5.8×10-8, 2×10-8 and 1.5×10-8 to 1.2×10-8, 1.15×10-8 and 1.1×10-8, a reduction of 79.3%, 42.5% and 26.7%, respectively.
When the content of carbon fibre ranged from 0.2% to 0.5%, it had a small effect on the impermeability of concrete. The permeability coefficients of the specimens were reduced to around 0.7×10-8, 0.65×10-8 and 0.5×10-8, a reduction of 88%, 67.5% and 66.7%, respectively. The reduction speed slowed down.
Therefore, when the content of carbon fibre reached 0.2%, the impermeability of type A specimens was significantly affected, but when the content exceeded 0.2%, the effect was reduced.

3.5 Effects of hydraulic pressure on the concrete impermeability

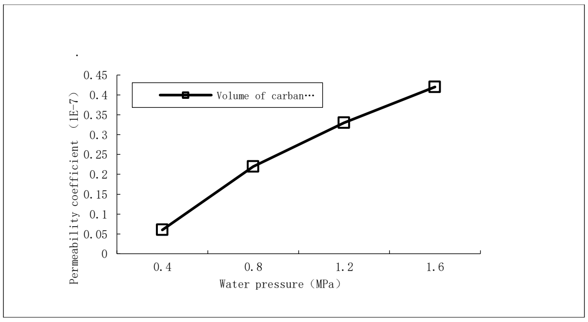


Figure 3: Permeability coefficients of carbon fibre reinforced concrete (C30) under different hydraulic pressures

Figure 3 shows the permeability coefficient of the specimens under different hydraulic pressures. It can be seen that, with the hydraulic pressure increasing, the permeability coefficient of plain concrete also increases gradually and its impermeability is weakened.

4 Conclusions

By using the orthogonal test method, this paper designs the mix proportion of carbon fibre reinforced concrete, analyzes the effects of carbon fibre content, methylcellulose, and silica fume on the impermeability of concrete, and obtained the order of all factors in terms of their effects on impermeability, which is: carbon fibre content>silica fume>methylcellulose>carbon fibre length. According to the orthogonal test results of the first test, the mix proportion was redesigned. The carbon fibre content was set at 0.5%, 0.6% and 0.7%, the methylcellulose content at 0.019%, 0.022% and 0.025%, and the silica fume content at 0.12%, 0.15% and 0.18%, respectively. The test results show that when the carbon fibre, methylcellulose, and silica fume content were 0.5%, 0.019%, and 0.18%, respectively, the permeated height of concrete was the smallest - 2.7cm, which was 3cm less than that of the standard concrete, a reduction of 52.6%.

Acknowledgments

Experimental study on macro mechanical properties and microstructure of foam concrete self insulation block, Project code: 2018HX003

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