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Experimental study on Early Desiccation Cracking Behabior of Short-cut Basalt Fiber Concrete

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Abstract: *Early desiccation cracking of concrete would directly affect the durability of reinforced concrete structure. In order to improve the early desiccation cracking behavior of concrete, the concrete specimens mixed with basalt fibers were prepared. Based on the indoor and outdoor exposure test methods, the effects of short-cut basalt fiber content on early desiccation cracking of concrete and were analyzed by using initial crack time, crack number, maximum crack width and total crack area as evaluation indexes. The test results show that the total crack area of the basalt fiber concrete with a volume fraction of 0.05%, 0.1%, and 0.15% increased by -5.0%, 73.6%, and 86.5% respectively after the outdoor exposure test. The total crack area of reinforced concrete specimens with a volume fraction of 0.1% increased by 63.6% after the outdoor exposure test. The early desiccation cracking behavior of concrete and reinforced concrete could be improved by adding the content of short-cut basalt fiber.*

Keywords: *concrete, basalt fiber, early desiccation cracking behavior, outdoor exposure test*

1. Introduction

With the steady development of Chineses economy, civil engineering projects in planning and design have been constructed one after another, causing the use of concrete materials increase year by year. As one of the important building materials in engineering, the early hydration reaction of concrete materials would caouse the temperature to rise sharply, makes the water evaporate on the surface, and leads to the early desiccation cracks of concrete. If the concrete or reinforced concrete cracks, it will accelerate the deterioration process of the structure, thereby reducing the safety performance and durability of the structure. Therefore, effective measures should be proposed to improve the early desiccation cracking behavior of concrete. Scholars at home and abroad have put forward many methods to improve the early desiccation cracking behavior of concrete through a large number of experimental studies. Chen Lifu [1] mixed polypropylene fiber and steel fiber in concrete, thus improving the early desiccation cracking behavior of concrete. Wang Wei [2] add glass fiber in concrete to improve the early desiccation cracking behavior of high-performance concrete. Basalt fiber is a new type of inorganic reinforcing fiber, is the characteristic of basalt fiber are not only economical price, environmental protection, more importantly, basalt fiber has high strength, electrical insulation, corrosion resistance, and high-temperature resistance etc. The early desiccation cracking behavior of concrete and reinforced concrete mixed with short-cut basalt fiber was study by indoor and outdoor exposure tests in this paper, and the results of exposure tests chould provide a reasonable dosage for engineering practice.

2. Materials and test methods

2.1. Raw materials and properties

(1) Fine aggregate: The medium sand was provided by the stockyard of CCCC Third Harbor Engineering Co., Ltd., and the sand had a fineness modulus of 2.89 and an apparent density of 2600 kg/m^3.

(2) Coarse aggregate: the limestone crushed stone was provided by the stockyard of CCCC Third Harbor Engineering Co., Ltd., and its nominal particle size was 5-20mm, and the particle size in general.

(3) Cement: The ordinary Portland cement P O 42.5R produced by Dalian Xiaoyetian Cement Co., Ltd..

(4) Water reducer: the polycarboxylic acid waterreducer was produced by Dalian Mingyuanquan

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Technology Development Co., Ltd.. The type used in this test were PC-1 and PC-4, The main technical parameters of the two type water reducer are shown in Tab. 1, The solid content of the mother liquid of the PC-1 type water reducer is 40%, and the mixing ratio of the mother liquid and water is 1:2, The solid content of the mother liquid of the PC-4 type water reducer is 60%, and the The total ratio is 1:4.

(5) Fiber: short-cut basalt fiber was produced by Shanxi Jintou Basalt Development Co., Ltd.. The specifications of the fiber are shown in Tab. 2.

Table 1: Technical parameters of water reduce

model	PC-1	PC-4
Chemical composition	Copolymer of polyethylene glycol methyl allyl ether and acrylic acid	Copolymer of polyethylene glycol allyl ether with acrylic acid and maleic acid
Solid content (%)	38~40	58~60
Total alkali content (%)	< 2	< 2
Chloride ion content (%)	< 0.1	< 0.1
Sulfate content (%)	< 0.5	< 0.5
PH value	5~7	3~5

Table 2: The specifications of Short-cut Basalt Fiber

Representative symbol	Fiber monofilament diameter (μm)	Fiber single filament number	Fiber length (mm)
18	15	200	18

2.2. Design of mix ratio

The design strength grade of the concrete used in the test was C30, the water-cement ratio of the concrete was 0.53, and the sand ratio was 0.45, According to the existing literature research results [3-6], the content of basalt fiber should be between 0.5% and 2%, In between, considering the cost of basalt fiber, 1~1.5% is acceptable volume content in engineering field. The volume content of short-cut basalt fiber were respectively 0.05%, 0.1%, and 0.15% in this paper, The water-reducing rate of the water reducer is 18%, It is necessary to adjust the content of water reducer to ensure the workability of concrete, since the incorporation of short-cut basalt fiber would reduce the slump of concrete to a certain extent, The mix proportion of one cubic meter of concrete is shown in Tab. 3, the amount of fiber and water reducer is shown in Tab. 4.

Table 3: Mix proportion of concrete/per cubic meter

Material	Stone	Sand	cement	Water	Water reducer
Dosage(kg)	998.473	816.933	367.453	194.75	3.675

Table 4: Content of fiber and water reducer (PC-4/PC-1)

Fiber volume fraction (%)	0.05	0.1	0.15
Fiber consumption(kg)	1.325	2.65	3.975
PC-4 type water reducer dosage (kg)	3.675	5.511	6.614
PC-4 type water reducer accounts for the proportion of cementitious (%)	1	1.5	1.8
PC-1 type water reducer dosage (kg)	4.409	5.511	-
PC-1 type water reducing agent accounts for the proportion of cementitious materials (%)	1.2	1.5	-

3. Test results and analysis

3.1. Indoor exposure method

According to the standard CECS 13:2009, the size of the specimens was 600mm×600mm×63mm in the early desiccation cracking behavior test, The first test was conducted by indoor exposure method, There were two reference concrete specimens and two basalt fiber concrete specimens with volume content of 0.1% for the test, The average nominal total area of cracks in each reference concrete specimen (A_{mcr}), the average nominal total area of cracks in each basalt fiber concrete specimen (A_{fcr}), and the crack reduction coefficient (η_{cr}) for the comparison of early desiccation cracking behavior are shown in Tab. 5, The symbol N represents the reference concrete, and X1-0.1% represents the basalt fiber concrete mixed with 0.1% in the indoor exposure test.

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Table 5: Comparison for the early desiccation cracking behavior

Test number	A_{mcr} (mm^2)	A_{fcr} (mm^2)	η_{cr}
N	20.7	4.9	0.76
X1-0.1%	1789.8	521.4	0.71

It can be seen from the results in Tab. 5 that the addition of short-cut basalt fiber could well control the early cracks of concrete, and the results of the two groups were similar, Compared with the reference specimens, the cracks of specimens with 0.1% volume content basalt fiber concrete reduced by 76% and 71%, Through the indoor exposure method required by the standard, the cracks of concrete was not obvious, which make it difficult to compare the crack area, Relevant experience shows that using the same large plate mold, when the specimen was molded directly to the outdoor, and suing light and natural air drying, the test effect would be more significant. Therefore, the second experiment was carried out in this paper.

3.2. Outdoor exposure method

The early desiccation cracking behavior test of the specimens under outdoor exposure was adopted. The specimens were poured when the surface temperature was between 40-50℃, and immediately after the specimens were molded, they were exposed outdoors for 6h under the action of appropriate temperature and natural wind. Mark and read the length and width of the crack.

(1) Contrast test between 18mm-0.05% and reference specimens

The highest surface temperature in this test reached 50℃, so the cracks were relatively wide. The results of 18mm-0.05% specimens and reference specimens are shown in Tab. 6. The symbol X2-0.05% represents the basalt fiber concrete mixed with 0.05% in the outdoor exposure test.

Table 6: Test result of 18mm-0.05% and reference specimens

serial number	Maximum split Seam width (mm)	Average split Crack width (mm)	Total crack length (mm)	Total area of cracks (mm^2)	Reduction coefficient of cracks
N	1.33	0.553	773.5	428.1	-5%
X2-0.05%	1.21	0.552	710.5	449.4	

The test result shows that when the volume content of basalt fiber was 0.05%, the improvement effect of fiber on crack resistance of concrete was not obvious, and even the total frontal crack area is slightly higher than that of ordinary concrete. The average crack width and total crack length of reference concrete and fiber concrete were basically the same, but the fiber concrete was better than the reference concrete in terms of cracking behvior as a whole. Both of the two reference concrete specimens have partial cracks through to the bottom of the specimen, while only one fiber specimen has partial cracks through to the bottom of the specimen.

(2) Contrast test between 18mm-0.1% and reference specimens

The test results of 18mm-0.1% concrete and reference concrete are shown in Tab. 7.

Table 7: Test result of 18mm-0.1% and reference specimens

serial number	Maximum split Seam width (mm)	Average split Crack width (mm)	Total crack length (mm)	Total area of cracks (mm^2)	Reduction coefficient of cracks
N	1.76	0.644	1098.5	707.2	73.6%
X2-0.1%	0.7	0.263	710.5	187	

The test result shows that the incorporation of basalt fiber had played a significant role in improving the early desiccation cracking behavior of concrete, and the crack reduction coefficient was 73.6%, which was similar to the result of the indoor exposure test. The reslut also shows that the 18mm basalt fiber concrete mixed with 0.1% could effectively reduce the early cracks of the concrete, and the cracks could be reduced by about 70%.

(3) Contrast test between 18mm-0.15% and reference specimens

The test resluts of 18mm-0.15% concrete and reference concrete is shown in Tab. 8.

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Table 8: Test result of 18mm-0.15% and reference specimens

serial number	Maximum split Seam width (mm)	Average split Crack width (mm)	Total crack length (mm)	Total area of cracks (mm^2)	Reduction coefficient of cracks
N	1.61	0.79	2778	1098.6	86.5%
X2-0.15%	0.48	0.37	471	173.0	

The test results of shows that the crack width and crack length of the fiber concrete specimens were relatively small compared with the reference concrete specimens. The bottom surface of the reference concrete specimens all have cracked penetrating from the top surface, while the fiber concrete specimens have no penetrating cracks. It can be seen that fibers could not only effectively reduce the area of concrete shrinkage cracks, but also hinder the development of fibers in the depth direction.

(4) Contrast test between 18mm-0.15% and reference specimens

The reinforcement forms of the early desiccation cracking behavior test of reinforced concrete are all adopts Φ8@100×100mm, and the volumecontent of 18mm fiber is 0.1%. The early desiccation cracking behavior of reinforced concrete is shown in Tab. 9. Where symbol G represents the reference reinforced concrete, GX2-0.1% represents the basalt reinforced concrete mixed with 0.1% in the outdoor exposure test.

Table 9: Test result of reinforced concrete

serial number	Maximum split Seam width (mm)	Average split Crack width (mm)	Total crack length (mm)	The total area of cracks (mm^2)	Reduction coefficient of cracks
G	0.36	0.169	1098.5	129.6	63.6%
GX2-0.1%	0.22	0.128	368.5	47.2	

Comparing the test results, it can be seen that the incorporation of basalt fiber has less effective in reducing the cracks of reinforced concrete than the reference concrete because the steel bar itself has a limiting effect on the cracking of concrete. However, from the overall results, the fiber was still very effective in limiting the cracks of reinforced concrete, which could reach about 60%, and the crack width was also effectively reduced.

3.3. Mechanism analysis

(1) During the shrinking process, when the specimens was restrained from the outside, shrinkage stress would be generated inside the concrete. When the shrinkage stress exceeded the tensile strength of the concrete, cracks would occur on the surface or inside. Therefore, the cracks could be prevented effectively by reducing the shrinkage stress of concrete. When the volume content of basalt fiber was 0.05%, the distribution of fiber in the concrete was relatively too small to form an effective three-dimensional network structure to reduce the shrinkage stress, which is greater than the tensile strength of the fiber concrete, so it can not prevent the cracking of concrete. Therefore, when the fiber content in concrete is relatively small, it could not effectively prevent the expansion of crack, but compared with the reference concrete, it could effectively control the extension of crack depth.

(2) Compared with other fibers, basalt fiber has the characteristics of large specific surface area and small-fiber spacing. After adding equal to or more than 0.1% of basalt fiber in concrete, a large number of fibers evenly dispersed in the concrete form a three-dimensional spatial network structure, which plays a role in supporting aggregate. In a certain extent, the settlement of coarse and fine aggregates is prevented, and the development of early desiccation crack of concrete has been delayed and prevented. At the same time, the micro-cracks inside the concrete would also be affected by the fiber, and the stress and the stress concentration at the tip of the conrete would also be reduced. The fiber could effectively absorb the energy generated by the shrinkage stress of the specimen, so as to improve the crack behavior of conrete. The monofilament fibers could be seen in the cracks in Fig. 1, which chould effectively control the concrete cracks.

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Figure 1: Partial enlarged photo of fiber concrete

4. Conclusion

(1) With the increase in the amount of short-cut basalt fiber, the early desiccation cracking behavior of concrete will be improved. The addition of fiber could not only reduce the width and length of the crack but also reduce the depth of the crack.

(2) When the volume content of basalt fiber was 0.05%, the crack resistance of concrete is not improved significantly. When the volume content was 0.15%, the increase in the crack coefficient was not significant compared to 0.1%. Therefore, short-cut basalt fiber concrete with volume content of 0.1% could be selected for engineering application.

(3) Because the steel bar itself has a limiting effect on the early desiccation cracking behavior of the concrete, the effect of basalt fiber on improving the early desiccation cracking behavior of reinforced concrete is not as good as that of plain concrete. However, from the analysis of the whole results, the basalt fiber is effective in restricting the crack of reinforced concrete, and the crack width is significantly reduced.

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