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Experimental study on compressive strength of basalt fiber reactive powder concrete

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--***ABSTRACT***--
To investigate the effect of the basalt fiber on the mechanical properties of the active powder concrete, the BF-RPC compression test was carried out under the hot water curing condition. The test results that the addition of BF could improve the mechanical properties of RPC, and with the increase of BF content the compressive strength of RPC showed a trend of first increasing and then decreasing. Besides, the optimal BF content is 0.15%, which increases the strength by 20.2%, And a prediction equation of compressive strength was proposed by analyzing the influence of BF on RPC mechanical properties with different BF content.
KEYWORDS;- *Hot water curing; BF; RPC; mechanical properties; prediction equation*

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I. INTRODUCTION

Reactive Powder Concrete (RPC) is a new type of cement-based composite material with high strength, toughness, and durability, and it was first developed by French company BOUYGUES at the end of the 20th century [1,2]. RPC replaces coarse aggregates in ordinary concrete with well graded quartz sand, and is composed of cement, silica fume, quartz powder and water reducing admixture. Because of its excellent performance, it is widely used in long-span bridges, hydraulic engineering and military defense engineering [3-5].

RPC has the characteristic of brittleness in ordinary concrete and is prone to cracking [6]. At present, adding fiber is the most common way to improve the performance of PRC, as steel fiber can easily lead to corrosion of RPC and internal steel fiber and reduce the load-bearing capacity and service life of the structure. As a non-metallic material - Basalt Fiber (BF) has a positive effect on improving the crack resistance and corrosion resistance of concrete [7-12], and has the advantages of being more environmentally friendly and corrosion-resistant. There are various methods of PRC curing, among which hot water curing can greatly raise the mechanical properties of concrete [13-16] and freeze-thaw resistance [17], and also contribute to the improvement of the mechanical properties of RPC [18-21]. By studying the influence of BF on the mechanical properties of RPC under hot water curing conditions and the optimal fiber content, a compressive strength prediction equation for BF-RPC was proposed, it provide reference for the application design of RPC in practical engineering.

II. TEST PROGRAM

Material Properties

The test materials：

(1) Cement used is P.0.52.5 cement produced by Nanfang Cement Plant；

(2) Quartz sand and quartz powder are produced by Jinan Qingtian Chemical Technology Co., Ltd. The particle size of quartz sand is 10-20 mesh, and the particle size of quartz powder is 350 mesh；

(3) Micro silicon powder is produced by Chengdu Jinhe Technology Co., Ltd., with a particle size of 2000 mesh and a silicon content of ⩾ 94 (%)；

(4) Basalt fiber: Select chopped basalt fiber with a length of 18mm；

(5) Water reducing admixture: Select AN3000 type water reducing admixture with a water reducing efficiency of 29%.

In order to study the influence of BF-RPC compressive strength, Table 1 concrete mix proportion was used. In this research plan, BF volume content of 0.0%, 0.10%, 0.15%, 0.20%, and 0.25% were selected, and a total of 15 sets of 45 specimens were produced. The concrete specimens adopted hot water curing, and the test materials are shown in Figure 1.

Materials (Kg/m^3)						
P.0.52.5 cement	Silica fume	Quartz sand	Quartz powder	Water	Water reducing admixture	Fiber volume fraction /（%）
935	265	900	180	285	23.6	0-0.25

Table 1 RPC Mix proportion

(a) BF (b) Silica fume (c) Quartz sand (d) Quartz powder (e) cement

Figure 1 materials

Details Of Specimens

In order to ensure BF uniform distribution in RPC matrix, BF-RPC specimens were prepared by the following steps：

(1) Mixing: mixing and stirring the weighed quartz sand and BF for 2 - 3min, and dispersing BF evenly through friction between sand particles; then silicon powder and cement are poured into a mixer and stirred for 1 to 2 minutes, so that quartz sand and gelling materials can be fully fused and contacted. Dissolving the high range water reducing admixture in water, adding half of the high range water reducing admixture solution and stirring for 2 minutes, then adding the rest of the water reducing admixture solution into the mixture, adding in batches to play the role of the water reducing admixture more effectively, stirring for 3 minutes and discharging.

(2) Forming: the stirred BF-RPC discharge material is put into a mold of 150mm*150mm*150mm at one time and slightly higher than the mold, and then the mold is placed on a vibration table for vibration until slurry appears on the upper surface of the BF-RPC, and then the mold is placed into a standard curing room for curing after leveling with a spatula.

(3) Demoulding: After curing for 24 h, the samples were demoulded by demoulding gun.

(4) Cuing: Putting three demolded test blocks into a self-made hot water bucket, control the temperature at 90 centigrade, and curing for 48 hours before taking them out.

Test Phenomena

Compressive strength was tested by 5000kN electro-hydraulic servo pressure tester. According to the relevant literature [23] and the "Concrete physical and mechanical properties test method standard" loading scheme selection: using equal rate stress control method, compressive strength test loading rate of 1MPa/s.

III. RESULT VIEW

Compressive Strength

The failure forms of RPC and BF-RPC specimens are shown in Figure 2：

（a） RPC （b） BF-RPC

Figure 2 Failure forms of compressive strength of specimens

Figure 2 shows the failure modes of compressive strength for RPC and BF-RPC. RPC showed obvious brittleness in the test, and the specimens exhibited a sudden rupture shape during the failure process. At the moment before the end of failure, there were fragments splashing, and the strength was between 80-83 MPa. Irregularities appeared between the failure sections, and the failure approached the center from both sides, Cracks mostly appeared around the edges.

During the failure process, BF-RPC could hear distinct sound of concrete cracking. Compared with RPC specimens, the concrete mixed with BF has better plastic characteristics and better overall integrity after failure, without the phenomenon of splashing of fragments; The strength was significantly better than that of RPC specimens.

Data Analysis

The compressive strength test results of RPC specimens and BF-RPC specimens are shown in Table 2

BF volume fraction	Specimen strength /MPa			Concrete strength, /MPa	Improvement rate /%
	1	2	3		
0	81.8	81.4	82.2	81.8	0
0.10%	93.6	92.1	91.5	92.4	13
0.15%	99.7	97.6	97.7	98.3	20.2
0.20%	92.3	95.3	93.5	93.7	14.5
0.25%	89.7	89.2	87.7	88.9	8.6

Table 2 BF-RPC cube compressive strength test results

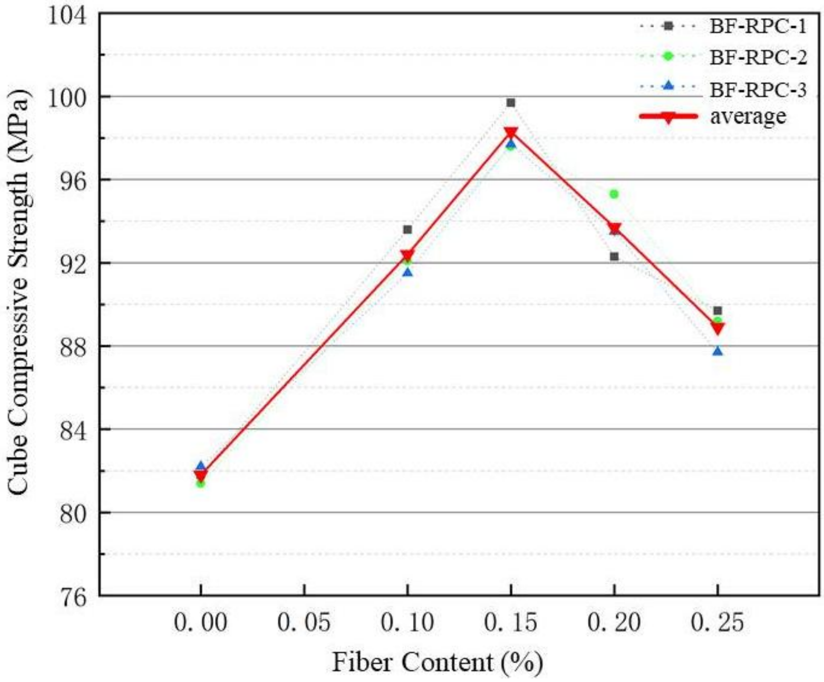

Figure 3 BF-RPC cube compressive strength

From Figure 3, it can be seen that BF has an improving effect on the compressive strength of RPC cubes, and the rate of strength improvement shows a trend of first increasing and then decreasing with the increase of BF content. The optimal BF content is 0.15%, with a maximum increase of 20.2%.

The BF-RPC Prediction Equation Of Compressive Strength

In order to study the relationship between BF content and RPC compressive strength, the correlation equation (1) between compressive strength and BF content in reference [22] was used:

$$f_{cu} = (1 + \lambda_c / 100)\ f_0 \quad (1)$$

In equation (1), λ_c is the increase in compressive strength of BF-RPC, according to the improvement value of BF-RPC compressive strength relative to RPC, equation (2) is obtained by modifying it:

$$\lambda_c = -808.394V_f^2 + 239.659V_f - 0.454 \quad (2)$$

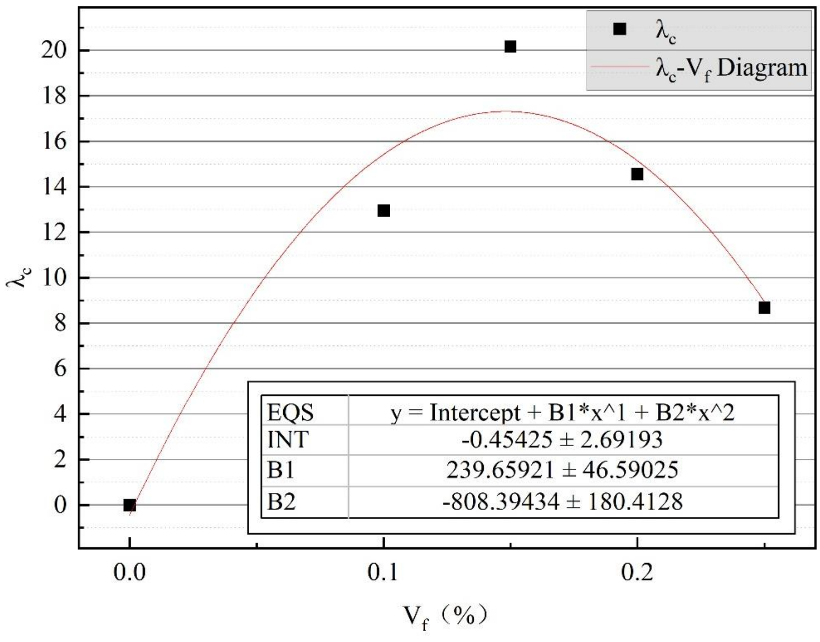

Figure 4 BF-RPC λ_c - V_f diagram

Substitute RPC compressive strength value f_0 and fiber content V_f into (1) and (2) for calculation, and the calculation results are shown in Table 3:

BF volume fraction	Actual compressive strength	Calculated compressive strength value	Error value /%
0.1	92.4	94.4	2.16
0.15	98.3	95.9	-2.44
0.2	93.7	94.2	0.53
0.25	88.9	89.1	0.22

Table 3 BF-RPC predicted compressive strength

The results show that the error value between the predicted compressive strength and the measured value is less than 10%, and the predicted results of this formula have high reliability. Due to the significant influence of fiber length and curing conditions on the test, this formula can only predict the compressive strength of BF-RPC with a BF length of 18mm under hot water curing conditions.

Mechanism Analysis

Due to the presence of defects such as pores and microcracks inside the material, external loads could resulted in an increase of the pores and cracks, ultimately leading to failure. As a brittle material, RPC has size differences, and cracks and pores of different sizes will cause which not being able to fully function.

According to the fiber spacing theory and composite material theory [23-25], when adding BF, there will be a composite between BF and the cementitious material, and BF will play a role in inhibiting and preventing, improving the overall failure limit of the matrix. At the beginning of crack development, the direction of its development was unknown, and BF mixed in RPC was distributed in every corner. After being blocked by BF, the micro cracks in BF-RPC would form closed cavities or very small pores inside, which had no negative impact, thereby constraining the extension of BF-RPC cracks and achieving the effect of increasing strength and toughness; When the crack extends to a certain extent and BF-RPC is about to fail, BF plays a pulling effect internally and prevents the matrix from failing. BF-RPC failure will occur before BF slip or fracture, thus achieving positive suppression effect and improving the strength of the matrix. The damage and destruction of BF-RPC were prevented from within the matrix. In the absence of BF, as the strength increases, the brittleness of plain RPC also increases, and its ability to resist fracture decreases. Moreover, plain RPC is prone to cracking and failure under external tensile stress. Due to the presence of BF, the characteristic of brittle failure in RPC is changed, and its strength is enhanced, improving the toughness and tensile crack resistance of the matrix.

IV. CONCLUSION

Through the compressive strength test of BF-RPC under hot water curing conditions, the influence of BF and hot water curing conditions on the mechanical properties of RPC was studied. The test results were compared with the calculated values of the prediction equation, proving the rationality of the test results. The analysis results are as follows:

(1) Under hot water curing conditions, the compressive strength of BF-RPC is higher than that of standard RPC. When the BF content is in the range of 0% to 0.15%, the strength shows an upward trend. When the BF content is in the range of 0.15% to 0.25%, the strength shows a downward trend. The optimal BF content is 0.15%, and the compressive strength is increased by 20.2%, respectively.

(2) Taking into account both economy and constructability, the optimal BF length is 18mm, and a compressive strength prediction equation with a volume content of BF-RPC ranging from 0% to 0.25% was proposed.

(3) According to the fiber spacing theory and composite material theory, it is analyzed that BF doping is helpful to improve the mechanical strength of RPC.

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