Experimental Study on Bonding Performance of Basaltic Fiber Reinforced Polymer and Inorganic Polymer Concrete

Xin Li[1,a], HaiQin Xu[1,*,b], YongHao Qian[1,c], Tao Wang[1,d], DanDan Xiao[1,e]and XiaoChun Fan[1,e]
[1]*School of Civil Engineering and Architevture,WuHan Technology of University, LuoShi Road 122, WuHan, China*

**Corresponding author：TEL +86 13638644921*

Keywords: Inorganic polymer concrete, basalt fibre reinforced polymer, bond performance, pull-out test.

Abstract: Inorganic polymer concrete (IPC) and basalt fibre reinforced polymer(BFRP) has good durability. This paper presents a bond durability test for BFRPbar to the IPC. The test in this article chose BFRP bars in diameter of 10mm, 12mm and 16mm, with two kinds of IPC in different strength, through experiment, the bond property between the IPC and BFRP bars is studied systematically. In this paper, the bond-slip curves of the IPC-BFRP are obtained by the tensile test between them, which proves that they have good bonding property and provide reference for the application of the IPC-BFRP structure in the engineering.

1 INTRODUCTION

The bond strength between the steel and concrete plays a key role in their cooperative work [1]. In response to the requirements of the green building that the country advocates, the research community and construction industry have expanded their horizons to new building materials[2]. In this paper, the bonding performance between the new concrete-IPC and the composite bar- BFRP is studied. The raw material composition of IPC derived from solid industrial waste is environmentally friendly building materials. The BFRP raw materials are derived from natural basalt ore which are not easy to rust. It is a natural Inorganic non-metallic material. The structural system composed of the two new materials can solve the problems of environmental pollution of reinforced concrete materials and the reduction of structural mechanical properties caused by steel corrosion [3].

There are many factors that affect the bond strength between BFRP and IPC, similar to reinforced concrete components, mainly by the following [4-9]: (1) Strength grade of IPC; (2) The position of BFRP in concrete; (3) When there are multiple BFRP in a member and they are in a row, the net distance between the BFRP has an important influence on the bond strength. The smaller net distance, the lower bond strength will be. (4) Thickness of protective layer of IPC; (5) Surface form and diameter of BFRP; (6) Bond length between IPC and BFRP, etc. At present, there is still a lack of in-depth research on the bonding properties between IPC and BFRP. This article mainly explores the effect of two different mix ratios of IPC and BFRP on the Bonding performance. Through the center pull-out test, the ultimate bond strength of the test piece and bond stress-slip curve are obtained[5], to explore the bonding properties between the two.

2 EXPERIMENTAL WORK

2.1 Materials Properties

2.1.1 Inorganic Polymer Concrete

The compressive strengths of Inorganic Polymer Concrete were determined by using 150mm cube specimens through Compression test. The concrete mix design is shown in Table 1. Concrete cube and pull-out specimens were removed from the moulds after 24h.And after being cured with water for 28 days, all the specimens and cubes were ready.The28-day compression strengths of IPC20 was 20.5MPa, and the 28-day compression strengths of IPC30 was31.3MPa.

Table 1the mix design of IPC（kg/m3）

	Fly ash	Powder	Sodium hydroxide solution	Sodium silicate solution	Water reducer	Fine aggregate	Coarse aggregate	Total mass
IPC20	320	80	53.33	106.67	4	649.9	1206.96	2420.86
IPC30	300	100	53.33	106.67	4	649.9	1206.96	2420.86

Note:In Table 1,the concentration of Sodium hydroxide solution is 10mol/L,and in Sodium silicate solution,SiO2/Na2O=2.

2.1.2 BFRP Reinforcing Bars

Three types of BFRP bars with a diameter of 10mm、12mm and 16mmused in this paper were made by Jiangsu Green Materials Valley New Material T&D Co., Ltd (GMV). The tested properties of BFRP is summarized in Table 2.

Table 2 Physical and mechanical properties of BFRP reinforcing bars

Bar Type	Diameter/m	Maximum pulling force/kN	Ultimate tensile strength/MPa	Average tensile Strength/MPa
BFRP10	10	79.16 77.99 75.16	1302 1283 1236	1274
BFRP12	12	109.09 105.83 106.88	1246 1209 1221	1225
BFRP16	16	196.11 188.94 191.26	1260 1214 1229	1234

2.2 Test Specimens

In accordance with GB50152-9218 Standard methods for testing of concrete structures, 18 pull-out specimens were produced[7]. As shown in Fig 1, BFRP reinforcing bars with a diameter of 10mm、12mm、16mm. And two kind of Inorganic Polymer Concrete were used to test bond strength. The total length of the BFRP reinforcing bars is 800mm, and bond length is five times of diameter(5*10mm、5*12mm、5*16mm).The length of free end is 50mm[2].Plastic tubes were adopted to make up un-bond area. Considering about the poor shear strength of BFRP bars, steel casing of 300mm length and resin glue were used to fix the loading end of bars to prevent the too much power given[10-13].Schematic diagram of the pull-out specimens are shown in Fig.2.

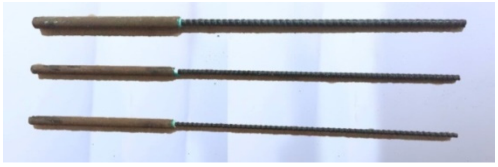


Figure1： BFRP reinforcing bars (already fixed)

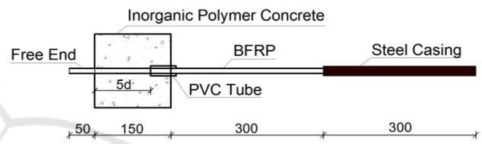
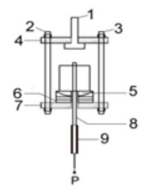


Figure2：Schematic diagram of the pull-out specimens

2.3 Test Setup and Test Method

The tests were carried out with Electro-hydraulic servo universal testing machine（1000KN/SHT4106-G）in Wuhan University of Technology, Materials Research and Test Centre at a rate of 1 mm/min. The pull-out specimen was put in pull-out shelve. Loading statistics were recorded by Electro-hydraulic servo universal testing machine, and the displacement on the free end of the BFRP transducer. The details of pull-out shelve are shown in bar was measured with a displacement Fig.4.The pull-out test setup and instrumentation are shown in Fig.3.



1-thread steel rod, 2-bolt, 3-threaded steel rod with diameter 20, 4-upper steel plate, 5-ball hinge, 6-310*310 steel plate, 7-lower steel plate, 8-BFRP, 9-steel

Figure 3:The test equipment. Figure 4: The pull-outshelve.

3 RESULTS AND DISCUSSION

3.1 Mode of Failure

3.1.1 Pull-out Damage

The BFRP were pulled out and damaged in the specimens numbered B10C20, B10C30 and B12C30. During the loading process, due to the chemical bonding force, mechanical anchorage force of BFRP and the elastic deformation of bars, the displacement of free end fell behind the loading end. As the loading continues, the displacement of free end and the loading end were found to be developing gradually. When the pull-out force reached its peak, the pull-out force began to decrease. At this time, the slip of free end and the load-end developed at about the same time, but the displacement of free end still fell behind the load-side's displacement. Finally, the displacement of the free-end and the displacement of the loading end were synchronized, and the chemical bonding between BFRP and IPC could be declared invalid.

By observing the extracted bars, it was found that the cross ribs of BFRP were seriously worn out. The BFRP of 10 mm diameter were slightly worn and relatively well-preserved. And there were a small amount of inorganic polymer concrete chips between the cross ribs. The pull-out force would be larger when use BFRP of 12mm diameter, even leading to the shear failure of the entire cross ribs and stacking more IPC debris between the cross ribs. The specific situation is shown in Figure 5.

Figure 5: pull out damage

3.1.2 Splitting Damage

In this test, concrete specimen splitting failure occurred on the drawing specimens numbered B12C20, B16C20, and B16C30. During the test process, as the pulling force increased, the cross ribs were wear away, the residual ribs piled up to the free ends, and the hoop stress of IPC was increasing. The concrete cracked when the concrete's tensile strength was insufficient to resist the hoop stress. When a splitting failure occurred, the load dropped sharply

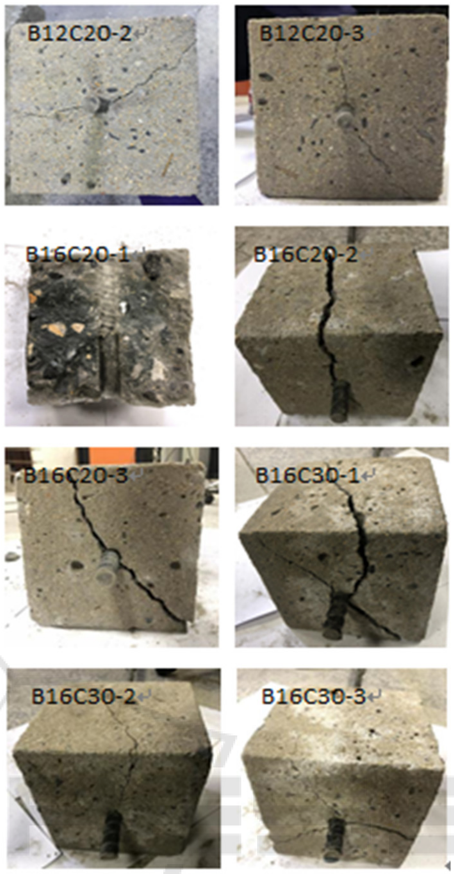


Figure 6: Concrete splitting failures

and the chemical bonding between BFRP and IPC failed. The specific cracking of each specimen is shown in Figure 6.

3.2 Bond Strength

This test assumes that the bond stress is distributed equably along the depth of BFRP, and the bonding stress between the IPC and BFRP can be calculated by Equation (1) [10]:

$$\tau = F/(\pi d l a) \qquad (1)$$

In the formula, τ is the average bond stress; F is the loading force of the testing machine; d is the basalt bar diameter; l_a is the effective bond length.

Specimen	Peak load (kN)	Adhesion stress τ max. (MPa)	Average adhesion stress τ (MPa)	mode of failure
	22.86	14.55		Bar pull-out
B10C20	23.93	15.23	14.48	Bar pull-out
	21.46	13.66		Bar pull-out
	---	---		---
B12C20	36.24	16.02	15.02	Concrete splitting
	31.69	14.01		Concrete splitting
	41.31	10.27		Concrete splitting
B16C20	40.44	10.05	10.06	Concrete splitting
	39.61	9.85		Concrete splitting
	17.90	11.40		Bar pull-out
B10C30	24.51	15.60	13.07	Bar pull-out
	19.16	12.20		Bar pull-out
	24.74	10.93		Bar pull-out
B12C30	23.09	10.21	11.21	Bar pull-out
	28.28	12.50		Bar pull-out
	41.94	10.43		Concrete splitting
B16C30	44.57	11.08	10.71	Concrete splitting
	42.67	10.61		Concrete splitting

Note: 20, 30 represents the design strength of the IPC, B represents basalt bars, 10, 12 and 16 represent the diameters of the BFRP, and the specimens with the number B12C20 have one and the other two specimens of the same group with the failure modes and bonding. There is a significant difference in strength and it is determined that the data is invalid and discarded.

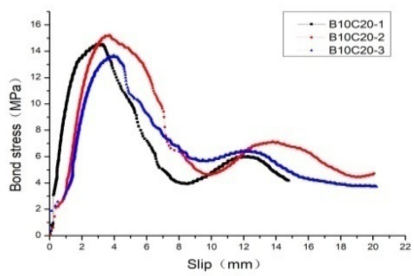
By analyzing the data in the table: (1)Under the premise that the bond length was five times the diameter of the reinforced material, the pullout of the reinforcing material was easy to occur when the IPC with the strength of 20MPa and BFRP with the diameter of 10mm work together. When BFRP with the diameter were 12mm and 16mm,the concrete splitting failures were easy to occur. When IPC with the strength of 30 MPa worked together with basalt reinforcements with diameters of 10 mm and 12 mm, specimens tended to be pulled out and broke out. When combined with basalt reinforcement with the diameter of 16 mm, the concrete splitting failures were easier to occur.

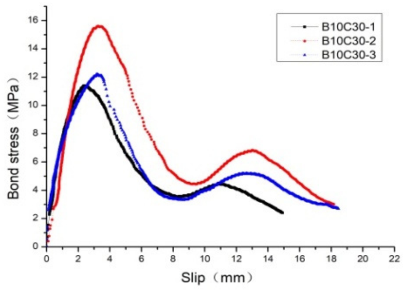
(2) Comparing the test data of the bond strengths of B10C20, B12C20and B16C20, the average bond strength between IPC and 10 mm BFRP was 14.48 MPa. When diameters of BFRP increased to 12 mm, the bond strength increased 3.73%, and when the diameter of BFRP increased to 16 mm, the bond strength decreases by 30.52%.Comparing the test data of the bond strengths of B10C30, B12C30and B16C30, the average bond strength between IPC and 10 mm BFRPwas13.07 MPa. When diameter of BFRP increased to 12 mm, the bond strength decreased by 14.23%, and when BFRP increased to 16 mm, the bond strength decreased by 18.06%. (3)Comparing the test data of the bond strength of B10C20 and B10C30, the average bond strength of 20MPa IPC and 10mm BFRP was 14.48Mpa.The bond strength decreases by 9.74%, when the strength of IPC was increased to 30MPa. The average bond strength of 20MPa IPC and 12mm BFRP was 15.02Mpa.When the strength of IPC is increased to 30MPa, the bond strength is reduced by 25.37%.And the average bond strength of 20MPa IPC and 16mm BFRPwas10.06Mpa.When the strength of IPC was increased to 30MPa, the bond strength is increased by 6.46%.

3.3 Bond Stress-Slip Responses

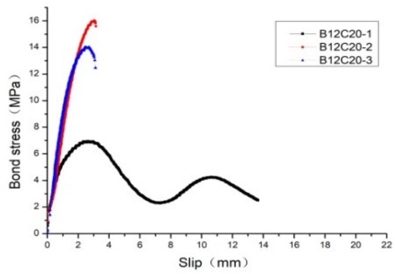
The BFRP would be stretched during the loading process, making the sliding of the loading end inaccurate, so the test adopted a displacement meter to test the free end displacement, and the displacement data collected at the free end was used as the slip value. From the obtained load data, the bond stress was calculated by formula (1), so we can draw a more realistic bond stress-slip curve.

（a）B10C20

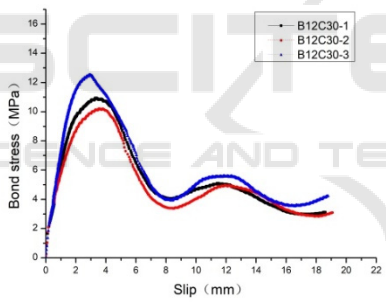




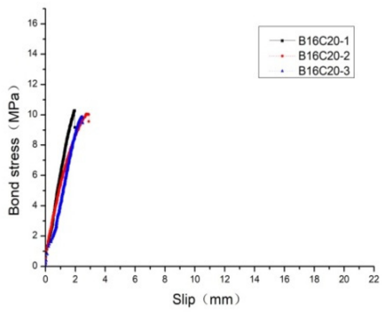
（b）B10C30



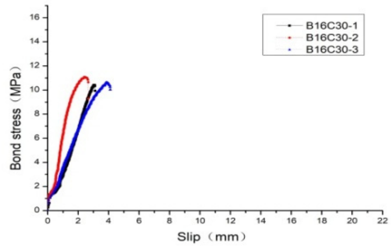
（c）B12C20



（d）B12C30



（e）B16C20



（f）B16C30

Figure 6: Bond stress-slip curves

By analyzing the bond stress-free end slip curve, wefound:

(1) For the pull-out test specimens with BFRP pulled out from B10C20, B10C30and B12C30, the bond slip curve exhibited a cyclic decay pattern. As the cross ribs of the BFRP were successively damaged when they were pulled out, the load-displacement curve presented alternate peaks and valleys, and showed a gradually decreasing trend. The process of BFRP and IPC bond-slip: At the initial stage of loading, the bond between BFRP and IPC was mainly provided by chemical bonding force. The duration of this process was short, because the chemical adhesion force was small. Afterwards, there was a slight displacement at the free end, and the chemical bonding force disappears. Then the pull-out force was provided by the friction force and the mechanical bite force. And on the slip curve, the pull-out force and the slip were all increasing, presenting the certain nonlinearity. As the load and slip continued to increase, the pull-out force slowly rose, the displacement increased sharply and the curve became more nonlinear. The pull-out force reached the peak and then gradually decreased, because the ribs of BFRP were worn out. The cross ribs were destroyed one after the other, because the cross ribs of BFRP had a certain distance. The peaks and valleys appeared on the curve in order, and they appeared cyclically decaying.

(2) For specimens with concrete splitting failure of B12C20, B16C20 and B16C30, when the pull-out force gradually increased to reach the first peak, the concrete was split and broken due to the tensile strength of the concrete that could not resist the tensile force. Unlike the specimens with basalt bars were pulled out, the pull-out force rapidly dropped after the pull-out force reached the first peak. Concrete creaked due to insufficient tensile strength to resist tensile stress in the hoop force. On the curve, the bond stress quickly disappeared after reaching the first peak and the test stops.

4 CONCLUSIONS

In this paper, based on 18 pull-out test specimens, the bonding properties between BFRP and IPC are experimentally studied. The main conclusions are as follows:

(1) There are two main failure modes for the BFRP-IPC pull-out test: BFRP are pulled out and IPC is split and destroyed .
.

(2) When 20Mpa of IPC works together with BFRP with the diameter of 12mm or more, it is prone to occurconcrete splitting damage. When 30MPa of IPC works together with BFRP with the diameter of 16mm or more, it is prone to occurconcrete splitting damage.

(3) IPC and BFRP have good bonding properties, and their bond strengths are between 9.85 MPa and 16.02 MPa.

REFERENCES

1. Yuan Xiaohui, Lu Zhean, Fan Xiaochun. Inorganic Polymer Concrete-steel Bar Pullout Test Study [J]. Journal of Wuhan University of Technology, 2013, 35(6):117-122.
2. Jin Yun-dong.Research on short-and long-term mechanical propertiers of BFRP bar reinforced marine sand concrete beams [D]. Nanjing: Southeast University, 2016.
3. Li Zhongxi. BasaltReinforced Concrete[J].Engineering Quality, 2010(2): 76-78.
4. Niu Jiangang, HaoJi, Sun Li-bin, etc al. Research on Bond-anchorage Behavior between Deformed Bars and HPP Fiber Reinforced Lightweight Aggregate Concrete. Engineering Mechanics, 2017,34(2):42-49.
5. Yan Ying-xin. Research on Bonding Properties of Reinforced Steel, FRP Reinforced, Bamboo Reinforced and Concrete [J]. Jiangxi Building Materials, 2016,(7):2-4.
6. Wang Yi-lin. Research on Some Issues of Bond Performance Between Steel bar and Concrete [D]. Wuhan: Huazhong University of Science & Technology, 2005.
7. Lu Xilin, Zhou Changdong, Jin Ye. Test study on bond behavior between GFRP bar and concrete in high temperature [J]. Joumal of Building Structures, 2017, 28(5):42-49.
8. GB 50010-2010, Code for design of concrete structures [S]. Beijing: China Architecture & Building Press, 1999.
9. Chen Jian. The Experimental Research on Bond-Slip Performance of GFRP Bars Embedded in Fiber Reinforced Concrete [D]. Dalian: Dalian University of Technology, 2007.
10. Sun Zeyang, Wu Gang, Wu Zhisheng, etc al. Experimental Study on the Bond Behavior between Steel Fiber Composite Bar (SFCB)and Concrete [J]. Earthquake Resistant Engineering and Retrofitting, 2009,31(1):21-27.
11. Wei Jun, Wang Yilin, LuoXiaohui. Curve fitting method of bond stress distribution in steel bar pull-out test [J]. Journal of Railway Science and Engineering, 2005,2(2):22-24.
12. Hassan M, Benmokrane B, ElSafty A, etcall.Bond durability of basalt-fiber-reinforced-polymer(BFRP) bars embedded in concrete in aggressive environments [J]. Composites Part B, 2016(106):262-272.
13. Wang HZ, Belarbi A. Flexural durability of FRP bars embeddedin fiber-reinforced-concrete [J]. Construction and Building Materials, 2013(44):541-550.