Bond behavior between BFRP bar and recycled aggregate concrete reinforced with basalt fiber

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Abstract: This study investigated the effect on the bond behavior between BFRP bars and recycled aggregate concrete (RAC), which a total of 54 specimens for pull-out test and 162 specimens for mechanical properties were conducted. The parameters including RAC strength grade, chopped basalt fiber volume content and length, based on orthogonal test the bond stress-slip constitutive were proposed. According to the main results of experiment, the strength of RAC was higher than the other two factors in the effect of mechanical performance and ultimate bonding stress. Similarly, the influence of these factors on the free end slip that the length of chopped basalt fiber was the weakest, then the chopped basalt fiber volume percent was higher compared to RAC strength grade. Application of non-linear regression analysis in the bond stress-slip constitutive relationship with the experimental results and referred to the engineering practice.

Keywords: BFRP rebar; recycled aggregate concrete; the pull-out experiments; bond stress-slip relationship; the multiple nonlinear regression model

1. Introduce

In recent decades, the recycled concrete aggregates (RCA) were produced by demolition waste which were used to replace the nature aggregate in concrete structures [1] and regarded the results of recent LCA analyses conducted about the life cycle of natural and recycled aggregates [2-3]. RAC was used to reduce energy consumption and available natural resources consumption, thus solving some of the problems in construction engineering. However, some limitation was still existed which made people reluctant to use the RAC in constructions. The main problem with high water absorption capacity and inside macro cracks that RCA in structural concrete, which leading to decrease in the mechanical properties of concrete.

Fiber reinforced polymer has good chemical stability, thermal stability, resistance to acid and alkali, electric insulation, corrosion, high temperature resistance and other properties. Existing researches showed that chopped fiber reinforced concrete has

been widely applied in the field of hydraulic engineering, building construction, highway and other projects for its excellent tensile strength, bonding strength and crack resistance ability, impact resistance properties and excellent impermeability, frost resistance and other properties [3-7]. In addition, FRP bars were used to replace steel rebar in structures to solve the corrosion problem effectively [8-9].

In recent years, a lot of researches about FRP by many scholars had been made. In 1991, Pleimann [10] first proposed the calculation formula about anchorage length of GFRP bar. Ehsani, et al. [11] had studied anchorage length, concrete strength, cover thickness, diameter of FRP reinforcement effect on bond behavior based on 102 static loading tests of GFRP tendons, and derived the calculation formula of GFRP reinforcement anchorage length with hook or without hook. Roman and Robert [12] researched the bonding strength of AFRP reinforcement with concrete according to the center pullout test. Tests results showed that bond strength of AFRP reinforcement was 40%-100% of ordinary steel bar.

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Xu et al. [13] studied bond behavior between deformed bars and steel-pp hybrid fiber reinforced concrete, and experimental results showed that the ultimate bonding strength raised 18.4%, 17.4% and 50.5% and the peaking slip raised 39%, 38% and 31% respectively with the increasing of the steel fiber volume ratio, steel-fiber long-diameter ratio and concrete strength.

Xue et al. [14] studied the bond performance among 4 different bond mediums with composite reinforced AFRP through 48 standard tension strength tests. Experimental studies had shown that the bond strength of AFRP reinforcement with concrete was about 0.79-1.11 times more than the bond strength of deformed bar, higher around 10% for it compared to the high performance concrete. In addition, bond strength of AFRP reinforcement with epoxy resin was higher and AFRP reinforcement with cement was low.

Yazcizi et al. [15] had studied the bond behavior of deformed bars and concrete due to steel fiber volume by pullout test. Four variables each concrete series, steel fiber content, length-diameter ratio, concrete strength and cover thickness were prepared. The results of test showed that the bonding strength which was higher 7%-16% for mixing the fiber compared to without fiber. All mechanical properties of fiber reinforced concrete increased as the factors increased, and with great effect of length-diameter ratio 80 comparing to length-diameter ratio 40.

Mazaheripour et al. [16] investigated bond behavior between steel fiber reinforced self-compacting concrete and GFRP bars by 36 pull-out tests. The factors were the diameter of GFRP reinforcement, surface characteristics of GFRP reinforcement, bond-anchorage length, and self-compacting concrete cover thickness. Test results showed that most of the specimens failure mode were the pullout failure, and bond length, cover thickness both affected its bonding strength in a larger degree. Different surface characteristics of GFRP tendons performed the different failure modes ultimately.

Ganesan et al. [17] researched the bond constitutive relation of hybrid fiber reinforced high performance concrete and steel bar through pullout test.

Tests showed that when the steel fiber volume content was 1% and polypropylene fiber volume content was 0.1%, the corresponding bond strength was the maximum.

At present, current research focuses on bonding properties between ordinary concrete and FRP bars, but the research of basalt fiber recycled concrete with BFRP bar bonding properties is almost none. In this paper, performance of bonding studied by pull-out test and non-linear regression model was used to study stress bond-slip constitutive.

CFRP and GFRP bars reinforced concrete have been studied [18-20]. However, research on the more cheap BFRP bars were limited.

Bond performance was one of the most important requirements in reinforced concrete constructions which determine the cooperatively ability between reinforcement and concrete matrix. Therefore, evaluating that bond behavior between the BFRP bar and RAC matrix was an essential requirement when employing RAC structures.

This paper investigated the effect on the mechanical properties of fiber RAC and bond-slip behavior between BFRP bars and fiber recycled concrete when different fiber content (0%, 0.2%, 0.3% and 0.4%) and fiber length (6mm, 12mm and 18mm). For the recycled coarse aggregates which were applied to three different concrete grades (C40, C50 and C60). The study focused on the influence of different recycled concrete grade, fiber contents and different length of fiber RAC performance according to the orthogonal test.

2. Experimental Programs

2.1. Materials

The recycled aggregate concrete(RAC) was made up of cement, fly ash, fine aggregate, recycled coarse aggregate, water and additive. The *BoHai-brand* P.O 42.5 cement was used in this test. Fly ash (Grade II) was used to improve the performance of the RAC. The fine aggregate in the experiment came from the *Ling* river in *JinZhou*, and its bulk density was 1.6g/cm^3 and apparent density was 2.7g/cm^3 , fineness modulus was 2.46. Recycled coarse aggregate was derived from

abandoned building concrete (the original strength grade of the concrete was C30, $f'_c = 34.2$ MPa). The basic properties of coarse aggregates were based on the “Standard for technical requirements and test method of sand and crushed stone (or gravel) for ordinary concrete” (JGJ 52-2006) and shown in Table 1. The water reducing rate of the water reducing agent (poly carboxylic acid, PCA) was 35%. The cement, fly ash, fine aggregate and recycled coarse aggregate were dry mixed in the cement mix in the first. Then, the PCA water reducing agent was diluted in half of the

sample’s water allotment and the resulting solution was gradually added to the dry mix in the running spiral stirrer. Finally, the blended chopped basalt fiber and remaining water were then gradually mixing the dry mix manually. Four kind of RAC grades were considered (C40, C50, C60), and the mixes proportion of concrete were shown in Table 2.

The relevant indexes of the chopped basalt fibers (see Fig.1), as well as BFRP bars (see Fig.2) are shown in Table 3 and Table 4.

Table 1

Basic mechanical properties of recycled aggregates

Aggregate type	Particle size range /mm	Bulk density /(kg/m ³)	Apparant density /(kg/m ³)	Water absorption /%	Crushing indicators /%	silt content /%
Recycled coarse aggregate	5-20	1400	2600	3.8	18.1	0.2

Table 2

Mixing proportions of recycled aggregate concrete

Mix design	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Recycled coarse aggregate(kg/m ³)	Fly ash (kg/m ³)	Water educing agent (kg/m ³)	Water (kg/m ³)
C40	378	618	1052	162	2.16	190
C50	362	733	1099	90	1.81	163
C60	414	625.68	1112.32	138	2.208	160

Table 3

The performance metrics of chopped basalt fiber yarn

Diameter /μm	Density /g/cm ³	Tensile strength /Mpa	Elongation at break/%	<i>E</i> /Gpa	Maximum applicable temperature /°C	Fiber type	Length /mm
13	2.65~3.05	3000~3500	3.2	90~110	650	Chopped	6、12、18

Table 4

The basic performance indexes of BFRP bar

Name	Diameter /mm	Area /mm ²	Tensile strength /MPa	<i>E</i> /GPa	Density /g/cm ³
BFRP bars	16	201	1123	51.3	1.94

Fig.1. Chopped yarn of basalt fiber

Fig.2. BFRP bars

2.2 Test Design

In order to explore the influencing factors of the bond performance between RAC and BFRP bar, the method of orthogonal test method was used in this paper. The parameters and values of orthogonal test were shown in Table 5. A total of 9 group of fiber reinforced RAC specimens was designed (specimens named K1-K9), which considered three factors such as the grade of RAC (A), the fiber volume quantities (B),

Table 5

Factors of orthogonal test

Test case	Factors		
	A (Grade of fiber recycled concrete /MPa)	B (The volume content of basalt fiber / %)	C (The length of fiber chopped yarn /mm)
1	C40	0.2	6
2	C50	0.3	12
3	C60	0.4	18

2.3 Specimens

At present, there is no standard test procedure for fibers cooperated RAC. For each mix, three 150mm cubic specimens and prism specimens with 150mm×150mm in cross section and 300mm in height were casted in steel moulds and demoulded, marked and once again transferred to the curing room which was set at $20 \pm 2^{\circ}\text{C}$ with approximately 95% humidity. The prismoids were used to determine the tensile splitting strength (f_{ct}), and the cubic specimens were used to determine the compressive strength ($f_{c,cub}$) at 28 days. The specimens were produced and maintained, and after a period of 28 days according to standard methods, the mechanical properties of the specimens

and the length of chopped fiber (C). 6 groups of basalt chopped fiber reinforced RAC specimens were designed (specimens named K10-K15) for analyzing the bonding performance. And three groups of recycled concrete specimens without chopped fibers were designed (specimens named A16-A18) as the comparative group. The details of the specimens as shown in Table 6.

were measured and complete according to the Chinese code “Standard for test method of mechanical properties on ordinary concrete” (GB/T50081-2002) and the test results were showed in Table 6.

As the pull-out specimens with dimensions of 150×150×150 mm, the diameter of BFRP bar was 16mm, and the length of bond zone [21] between BFRP reinforcement and RAC was 80mm (five times the rebar diameter). A 70 mm PVC pipes was placed at the loading end to segregate RAC and BFRP bar. 20mm BFRP bar was reserved at the free end of the cubic specimen in order to measure the relative slip to RAC and BFRP bar. The specimen details in the pull-out test were showed in Fig. 3.

2.4 Methods of Test

The pull-out test is conducted under an electro-hydraulic servo testing machine of 300 kN capacity. The test specimens were placed in a conventional tensile loading frame, as shown in Fig. 4. With the frame that two assembled steel plates (Brand 1045 in ASTM) in both ends with the thickness of 25mm meet the requirements of Chinese standard “Concrete Test Method Standard Structure” (GB50152-2012). Note that the “loading end” refers to the location of the applied load and “free end” refers to the direction opposite to the load application. The load was applied by a force control method at a rate of 0.08kN/s. At the free end of BFRP bar, in order to measure the displacements within the range of 10 mm due to 4 linear variable differential transformer (LVDT) were installed, and an automatic data acquisition system was used to record the relevant data.

Fig. 3. Diagram of pull-out specimens (unit: mm)

Fig. 4. Testing machine

2.5 Test results

The compressive strengths, splitting tensile strengths and axial compressive strengths of the specimens at 28 days are shown in Table 6.

Thus, the relationship of bond stress-slip with rebars and concrete was used to analyze the bond behavior of pullout test of BFRP bars and fiber RAC and was divided two modes (Table 6). The bond stress can be determined from the tensile pull-out load applied during the test. According to ACI 440.1R-06 [American Concrete Institute (ACI) 2006] the average

bond stress (τ) can be defined as:

$$\tau = \frac{P}{\pi d l_a} \quad \text{eq.(1)}$$

Where P is the tensile load, d is the diameter of FRP bar, l_a is the bond length (equal to $5d$).

The results were shown in Table 6.

Table 6

Test program and results

serial NO.	Mix design	Volume of chopped fiber (%)	Length of chopped fiber(mm)	Strength of cube compressive (MPa)	Strength of splitting tensile (MPa)	Strength of axial compressive (MPa)	Ultimate bond strength $\tau_{\max}$ (MPa)	Slip of free end $S_{\max}$ (mm)	Failure modes
K1	C40	0.2	6	42.3	3.15	34.3	13.32	4.57	2p1s
K2	C40	0.3	12	42.2	3.07	33.7	11.59	4.92	3p0s
K3	C40	0.4	18	42.5	2.94	32.6	10.65	4.89	2p1s
K4	C50	0.2	12	53.6	3.59	41.9	13.12	4.30	1p2s
K5	C50	0.3	18	54.4	3.49	41.9	11.6	4.99	3p0s

K6	C50	0.4	6	50.1	3.43	42.1	12.22	4.26	3p0s
K7	C60	0.2	18	60.9	3.99	57.6	17.36	2.67	2p1s
K8	C60	0.3	6	62.5	4.04	57.8	14.88	5.79	2p1s
K9	C60	0.4	12	61.2	3.86	51.0	13.97	3.77	3p0s
K10	C40	0.2	18	42.5	3.18	33.8	11.11	3.47	3p0s
K11	C50	0.2	18	55.5	3.6	43.7	14.81	4.92	3p0s
K12	C60	0.4	6	63.9	4.14	52.9	13.63	3.69	3p0s
K13	C60	0.4	18	58.5	3.58	49.1	12.29	4.80	2p1s
K14	C50	0.2	6	51.7	3.57	40.2	13.84	3.13	2p1s
K15	C50	0.3	6	52.7	3.61	42.6	12.83	3.54	3p0s
K16	C40	--	--	41.9	2.88	32.1	13.28	2.08	3p0s
K17	C50	--	--	52.8	3.3	40.3	13.84	4.18	2p1s
K18	C60	--	--	61.2	3.89	52.5	13.2	3.39	2p1s

Failure modes: p=pullout failure; s=splitting failure; such as: 2p1s=pullout failure of two specimens and Splitting failure of one specimen. $\tau_{\max}$, $S_{\max}$ is the ultimate bond strength and maximum slip between free end of bars and the surface of concrete, respectively.

3. Analysis of results

3.1 Failure mode

Two types of failure mode for the specimens, pull-out damaged of BFRP bar and splitting failure of RAC, were observed in the experiment.

As the main failure mode of specimens in the test, pull-out failure mode was shown in Fig. 5a. At the initial of loading, bond-slip measured inapparent due to adhesive stress between BFRP bar and RAC was provided mainly by the chemical adhesion effect. The relative slip is not significant between the free end of BFRP bar and recycled concrete block. With the increasing of loading, the chemical adhesion had weakened gradually due to the growing slip between the BFRP bar and RAC matrix. Finally, the bond capacity was mainly attributed to the friction force until the BFRP bar was pulled out from the RAC block eventually, and serious damage could be observed on the surface of the bars.

In contrary, splitting failure mode could be observed in some specimens (see in Fig. 5b). At the

beginning of loading, it can be seen that splitting failure specimens when compared with pull-out failure ones were similar. And then, while the load was closed to the ultimately, tiny cracks could be clearly seen on the upper surface of specimens, and accompany by a slight cracking sound. As the result, the specimen cracked along the direction of bar and the block was divided into two or more pieces by the star-ray style crack. At last, the specimen was splitting suddenly with brittleness characteristic.

Fig.5. Failure pattern:(a) pull-out failure; (b) splitting failure

3.2 Range analysis

Based on the orthogonal test method, influence of the recycled concrete strength, content of basalt fiber and the length of chopped fiber respectively to the bonding performance were analyzed. In addition, the value of range (R) which indicated the degree of impaction of the factors on the mechanical and bond behaviors of the specimens were listed see in Table 7.

Table 7

Range analysis

Results of test	Value of range(R)
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	Grade of recycled concrete (A)	Content of basalt fiber (B)	Length of Chopped strand fiber(C)
Compressive strength of cube	19.1	1.9	1.54
Strength of Splitting and tensile	0.87	0.23	0.19
Compressive strength of Axial	20.18	5.34	2.78
Ultimate bond strength	2.23	1.43	0.50
Slippage of free end	0.71(0.20)	1.59	0.17

From Table 7 it was known that the value of parameter A was the biggest in the three parameters, that concluding compressive strength of cube, strength of splitting and tensile, compressive strength of axial and ultimate bond strength. This indicated that, the strength of RAC mostly affected in the three mechanical behaviors and ultimate bond strength among the parameters. Similarly, the slippage of free end was affected by the content of basalt fiber among the three parameters that was the most. Compared to the influence of RAC, bond strength of basalt fiber bars in basalt fiber concrete could limit the contraction of concrete, contraction decreasing of concrete decreased the bond stress with basalt FRP bars. The order of the parameters affected the property of mechanical of recycled concrete and the ultimate performance of bond was B (content of basalt fiber)> A (strength grade of recycled concrete)> C (length of chopped strand fiber). Simultaneously, for the slippage of free end, the order changed to B (content of basalt fiber)> A (strength grade of recycled concrete)> C (length of chopped strand fiber).

As shown in Table 6, It also could be found that, on one hand, the fiber was the main contributor to the bond performance. To balance of the beneficial and adverse effect of fiber and the improvement of bond grade, thus the bond stress of RAC bonding was the best under a fiber volume content of 0.2% and increased with the level of RAC increasing [22], so the best combination was A3B1C3; On the other hand, in terms of the slippage, when the content of fiber was 0.3% with the length of 6mm for RAC by mix 3, the amount of slip of free end achieved the maximum.

3.3 Analysis of bond stress-slip relationship

According to Eq.(1), the bond stress between BFRP bar and RAC could be converted by the loading force. Fig. 6a, Fig. 6b and Fig. 6c were the bond-slip curves of RAC specimens with and without fiber under different conditions.

(1) The effect of recycled concrete strength

In this section, the experimental results on bond-slip curves from the three different target concrete compressive strengths (C40, C50 and C60) were analyzed. As shown in Figure 6a, specimens (K10, K11, K7) incorporated with 18mm-length fiber at 0.2% volume content for different RAC strength were selected to study the varies regulation. From the curves of K10, K11, K7 it was said that, strength of ultimate bond increasing with the increase of RAC grade. The increase amplitude decreased with the increase of RAC strength, especially when the RAC grade was C60 the peak bond stress seemed inapparent chang. In addition, compared with the maximum slips of the specimens with fiber were greater than the specimens without fiber and the scope of increasing was 17.7% to 66.8%.

The study showed that basalt chopped fiber have the capacity to enhance the cracking resistance ability of concrete, it will prevent shrinkage of concrete [23] and that closed to the BFRP bar led to a declination of the wrapping force of concrete, which reducing the friction and bonding strength between bars fiber and the matrix.

Due to the existing of basalt chopped fiber, development of crack inner concrete was delayed and the splitting strength of RAC specimen was greater than that of specimen without fiber. So that the maximum slippage of fiber reinforced RAC specimen

was greater than the specimens non-incorporated fiber, and the slope of down segment for the RAC specimen decreased with the incorporation of the fibers.

(2) The influence of fiber volume content

In Fig. 6b, compared the relationship between the bond-slip curves in three groups that had the same concrete grade (C50), fiber length (6mm) and three different volume fiber content (0.2%, 0.3%, 0.4%) at the influence of bonding strength and slip. For specimen K14 (0.2%), K15 (0.3%), and K6 (0.4%), in one hand, the ultimate bonding strength decreased with the increasing of the fiber content. In another hand, the maximum slips were also increased with increasing of the fiber volume content, the scope of reducing was 20.1%-36.1%. Simultaneously, the bond strength was decreased compared the RAC specimen without fiber (K17) with the incorporating of chopped basalt fiber and the maximum slip was increased. The investigations reveal that the ductility of the specimen

was improved due to the contribution of fibers bridging the crack although decreased the bond strength of these specimens.

(3) The influence of length of fiber

Bond-slip curves for three different fiber length specimens(K12, K9, K13) were shown in Fig. 6c. Test results showed that the ultimate bond strength was decreased and the value of maximum slip was increased with the increasing of fiber length. While, to compare the RAC specimen (K18) without fiber and the fiber RAC specimens (K12, K9, K13), not only the ultimate bond strength of the fiber RAC specimens higher than specimen K18 except K13, but also slip amount of the fiber RAC specimens increased as well. As a result, it would appear that control the length of the fiber reasonably could improving the bond stress of fiber RAC and BFRP bars effectively due to increase the ductility of the concrete matrix [24-25].

(a)

(b)

(c)

Fig.6. The bond stress – slip curve: (a) different strength specimens of recycled concrete; (b) different volume content of fiber specimen; (c) different length of fiber specimen.

4. The regression model of bond stress – slip

According to the studied method of literature

[26-27], the effect of these multiple factors to the target property was analyzed. The bond stress of specimens could be obtained by nonlinear regression analysis, and the regression equation was :

$$Y=6.9098+0.1316X_1-75.6202X_2-23353.3X_2^2+0.239X_3-0.00315X_3^2-66.727X_2X_3 \quad \text{eq.}(2)$$

where X_1 is RAC strength, X_2 and X_3 are the volume content and length of fiber.

In Eq.(2), on one hand, the coefficients of one degree term X_1 and X_3 were positive which indicated that the strength of RAC increasing could promote the bond stress between the RAC and BFRP bars,

Table 8

Fitting value comparison with the experimental value of bond strength

Test No.	Fitted values	Test values	Test value/Fitted values
K1	12.44722	13.32	1.070118
K2	11.74539	11.59	0.98677
K3	9.969322	10.65	1.068277
K4	12.80297	13.12	0.867767
K5	12.1738	11.6	1.090867
K6	14.0545	12.22	0.933509
K7	12.7255	17.36	0.911555
K8	12.53102	14.88	0.97518
K9	14.11897	13.97	1.048943
K10	13.76322	11.11	1.005578
K11	13.17047	14.81	0.974149
K12	13.4898	13.63	1.02596
K13	15.43497	12.29	1.124718
K14	14.48647	13.84	1.027165
K15	13.33757	12.83	1.047417
K16	13.84702	13.28	0.984327
K17	12.60132	13.84	0.975294
K18	14.8058	13.2	0.891543

It can be concluded from Table 8 that, ultimate bond strength values calculated from the regression equation fit well with the experimental results, in addition, their ratios had a smaller gap and the range of the fluctuation was 0.6% -13.3%. Tab.8 also indicated that, Eq.2 was not only fit well for RAC specimens with chopped fiber, but also well for RAC specimens without fibers.

5. Conclusion

coefficient of one degree term X_2 was negative which indicated the fiber volume content involved in decreasing the enhanced of bond strength of specimens. On the other hand, the more the fiber volume content the lower bond strength, the longer fiber length the lower bond strength, by the coefficients of quadratic term X_2 and X_3 were negative. In addition, regression results with the interaction terms of X_2 and X_3 was negative which indicated that produced negative effects with the interaction effect of fiber volume content and fiber length. The ultimate bond strength obtained by fitting analysis and the experiment were listed in Table 8.

In this paper, the effect of including chopped fiber on the mechanical properties and bond behavior between BFRP bars and RAC was investigated with a total of 54 specimens for pull-out test and 162 specimens for mechanical properties. Based on the experimental results and discussion the following conclusions can be drawn:

(1) Based on the bond strength of basalt fiber bars in basalt fiber concrete could limit the contraction of concrete, contraction decreasing of concrete decreased

the bond stress with basalt FRP bars. The strength of RAC was the main influence factor to the compressive strength of cube, strength of splitting and tensile, compressive strength of axial and ultimate bond strength. Meanwhile, the content of basalt fiber had the greatest impact on the slippage of free end among the three influence factors. The sequence of the influence factors that affected the mechanical property indicators of concrete regeneration and ultimate performance of bond was: $A > B > C$. And the sequence on the slip amount of free end was: $B > A > C$.

(2) An increase in ultimate bond strength was observed with increasing of recycled concrete and the maximum increasement rate was 56.3%. While, an decrease in bond strength occurred when the chopped fiber was incorporated into the RAC specimens. Furthermore, the bond strength was decreased with the increasing of fiber volume content. Experimental results confirm the tendency of the ductility of RAC specimens by incorporating chopped fiber with an proper fiber length and RAC grade.

(3) With the increasing of RAC strength, the maximum slip value of BFRP bar and RAC was increased, and the situation was more obvious in the specimens with chopped fiber compared with the without fiber ones. With the increase of the fiber volume content, the maximum slip increased as well. With the incorporation of chopped fiber, the slope of decreasing segment in bond-slip curves decreased. With the increase of fiber length, the maximum slip gradually increased, compared to specimens of non-doped fiber recycled concrete.

(4) An equation was proposed to predict the ultimate bond strength for RAC specimens (both for with and without chopped fiber) reinforced with BFRP bars. Due to the limit of the small amount of data available on this topic, this equation could be modified with further study.

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