

Bond Behavior of Recycled-Fiber Recycled Concrete and Reinforcement

Yu Liu¹; Jinghai Zhou²; Tingyu Zhao³; Hong Sun⁴;
Tianbei Kang⁵; Shouyu Li⁶; and Bingyu Zhao⁷

Abstract: Recycling solid construction waste is an inevitable trend to be followed for the realization of sustainable economic development. The bond behavior of reinforcement and recycled-fiber recycled concrete is discussed in this paper based on the observations of a half-beam unidirectional pullout test. With different recycled aggregates replacement ratios and recycled fibers volume content as variables, the pullout behavior, ultimate bond stress, and bond-slip under monotonic loading are evaluated. The test comprises two parts: direct pullout test and pullout test after the attachment of strain gauges inside the reinforcement. The results show that the half-beam unidirectional pullout test can suitably reflect the bond performance between recycled-fiber recycled concrete and reinforcement. The replacement rate of recycled aggregates exhibits a significant effect on the bond behavior between reinforcement and concrete, and the bond stress reduces by 36.92% when the replacement ratio is 100%. Adding recycled fibers is proposed to improve the bond behavior between recycled concrete and reinforcement; more specifically, the addition of 0.12% recycled fibers can increase the bond stress by 11.34% when the replacement ratio of the recycled aggregates is 50%. Moreover, the bond-slip curve relationship model between recycled-fiber recycled concrete and reinforcement that suitably correlates with the experimental results is established. Finally, the bond stress distribution is nonuniform. With the increase in the pullout force, bond stress causes local stress concentration. The more recycled aggregates, the speedier the bond stress transfer; furthermore, a moderate amount of recycled fiber can alleviate the stress concentration phenomenon. This research proposes a novel method of bond behavior test; furthermore, a novel recycled-fiber recycled concrete material is proposed that could be utilized in actual construction, and the recommended dosages are provided. DOI: [10.1061/JMCEE7.MTENG-15027](https://doi.org/10.1061/JMCEE7.MTENG-15027). © 2023 American Society of Civil Engineers.

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Introduction

The construction industry is crucial for economic development (Dehestani and Mousavi 2015; Desnerck et al. 2015). However, the increasing scale of construction is gradually exhausting the natural resources, producing solid construction waste. According to statistics, more than 1.5 billion tons of solid waste are produced worldwide, and the figure continues to rise (Wu et al. 2019; Zhou et al. 2019a), severely affecting the environment (Wang et al. 2014; Shen et al. 2016; Zhou et al. 2019b). In recent decades, to reduce the consumption of natural resources, scholars have been committed

to recycling construction solid waste and have achieved suitable results (Ajdukiewicz and Kliszczewicz 2002; González-Fontebona and Martínez-Abella 2008; Prince and Singh 2013; Butler et al. 2013; Prince and Singh 2015; Kou and Poon 2015). Ultimately, owing to its eco-friendly, recyclable characteristics, recycled concrete will become an inevitable trend in the sustainable development of the construction industry (Xie et al. 2018; Rockson et al. 2020; Adesina and Das 2021; Tam et al. 2021; Coban et al. 2022).

Reinforced concrete is indispensable in the construction industry. Bond performance is an important parameter for ensuring structural reliability. Generally, concrete strength (Xiao and Falkner 2007), rebar type (Wang et al. 2018), stress state (Naderpour et al. 2018), and thickness of concrete cover (Moallemi Pour and Alam 2016) are the main factors that affect the bond behavior. Owing to the existence of old mortar, the interface transition zone between materials is complex in recycled aggregates; nonetheless, the influence factors of bond performance are diverse (Xiao and Falkner 2007). Numerous scholars have researched the bond behavior between recycled concrete and reinforcement: Butler et al. (2011) revealed a strong correlation between bond strength and the crushing index of recycled aggregates. Kim and Yun (2014) showed that the smaller the particle size of the recycled aggregates, the higher the bond strength. Seara-Paz et al. (2014) revealed that the greater the number of recycled aggregates, the lower the bond stress. Liu et al. (2020) provided equations for the bond-slip relationship for different recycled aggregates replacement ratios and reinforcement. Most studies have shown reductions in bond performance owing to the use of recycled aggregates (Zhao et al. 2013; Zhan et al. 2016; Abdallah et al. 2017; Aslani et al. 2019). Furthermore, it has also been shown that for the same aggregates content,

¹Doctoral Student, School of Civil Engineering, Shenyang Jianzhu Univ., Shenyang 110168, China. Email: liuyu@stu.sjzu.edu.cn

²Professor, School of Civil Engineering, Shenyang Jianzhu Univ., Shenyang 110168, China (corresponding author). Email: zhoujinghai@sjzu.edu.cn

³Master's Student, School of Civil Engineering, Shenyang Jianzhu Univ., Shenyang 110168, China. Email: 382269086@qq.com

⁴Doctoral Student, School of Civil Engineering, Shenyang Jianzhu Univ., Shenyang 110168, China. Email: sunhong1982@sjzu.edu.cn

⁵Associate Professor, School of Civil Engineering, Shenyang Jianzhu Univ., Shenyang 110168, China. Email: kangtianbei@sjzu.edu.cn

⁶Master's Student, School of Civil Engineering, Shenyang Jianzhu Univ., Shenyang 110168, China. Email: krasnyi20@stu.sjzu.edu.cn

⁷Master's Student, School of Civil Engineering, Shenyang Jianzhu Univ., Shenyang 110168, China. Email: zby_e-mail@stu.sjzu.edu.cn

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the obtained strength is different, and it is affected by the quality of the aggregates. The conclusions have primarily been drawn from the center pullout test, wherein the device is simple and the specimen can be easily manufactured. However, it cannot reflect the anchorage characteristics of the beam under the actual stress state. The size of specimens in the conventional methods of the beam test is exceedingly large, and the process is complicated. Advantages and disadvantages are prevalent in both. Therefore, scholars have actively pursued novel alternate methods.

Presently, more than 13 million tons of waste carpets, mainly chemical fiber carpets made of polypropylene fiber, are produced in China each year (Wu et al. 2019; Zhou et al. 2019b). However, the comprehensive recovery ratio is less than 20%. Waste carpets are generally treated by incineration and landfills, which seriously endanger the natural environment. The problem of recycling waste carpets has become highly prominent. It is extremely difficult to achieve carbon peaking and carbon neutrality. Favorably, recycled fibers extracted from waste carpets can improve the mechanical properties of concrete (Awal and Mohammadhosseini 2016; Xuan et al. 2018; Zareei et al. 2019). Nevertheless, there is no clear understanding of the influence of bond behavior (Wang 1997; Ucar and Wang 2011).

Most importantly, the bond behavior between recycled concrete and reinforcement must be considered when using construction solid waste. In the past, a full beam test was used to study the bond behavior of reinforcement in actual concrete structures. The specimen comprised two half-beams; the upper part was hinged, the bottom was connected by pulling reinforcement, and four-point bending loading was adopted. Despite continuous improvement, there are still a few deficiencies, such as large material consumption, difficult specimen fabrication, and complex loading process. Different from the previous test methods (e.g., RILEM-FIP-CEB 1973; Wang et al. 2018), this study designs and adopts a novel method of bond behavior test, that is, the half-beam test, considering the actual anchoring characteristics of beam, while saving half of the materials and ensuring convenient loading and simple operation. Adding recycled fibers is proposed to improve the bond behavior between recycled concrete and reinforcement. Accordingly, the bond behavior between recycled-fiber recycled concrete (RFRC) and reinforcement was studied. The replacement rate of recycled aggregates (0%, 50%, 100%) and recycled fibers volume (0%, 0.12%, 0.24%) were used as variables. A two-stage bond-slip relationship model between RFRC and reinforcement was established. In addition, 10 steel bars were grooved, and built-in strain gauges were used to study the law of local bond stress distribution of reinforcement. Recycled-fiber recycled concrete affords alternate approaches for utilizing construction solid waste and waste carpets that are promising in actual construction applications.

Experimental Program

Materials

In this study, ordinary portland cement PO 42.5 was used. Natural river sand with fineness modulus 2.7, mud content <2%, and apparent density 2,615 kg/m³ was used. The coarse aggregates were partly natural aggregates from crushed gravel and partly recycled aggregates from the structural laboratory of Shenyang Jianzhu University (Shenyang, China). The original strength was C40. Fig. 1 shows the grading curves of aggregates. The aggregate performance indicators are given in Table 1. The waste carpet was cleaned, disinfected, and manually split, and the recycled fibers were extracted, as shown in Fig. 2. Fibers were made of polypropylene, with a density

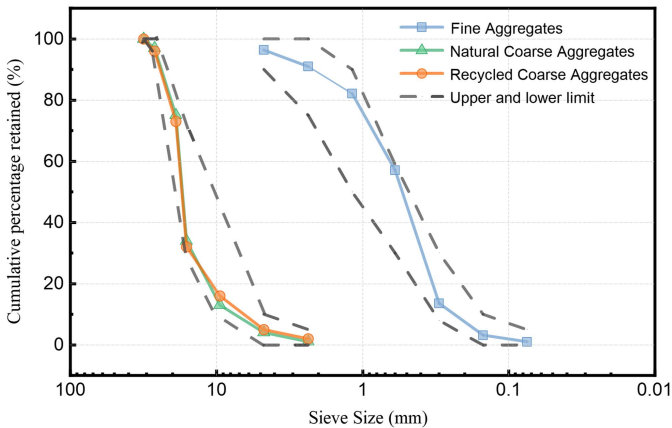


Fig. 1. Grading curves of aggregates.

Table 1. Performance indicators of aggregates

Type	Apparent density (kg/m ³)	Bulk density (kg/m ³)	Crushing index (%)	Water absorption (%)
Natural	2,730	1,850	6.4	1.12
Recycled	2,460	1,275	17.0	4.36

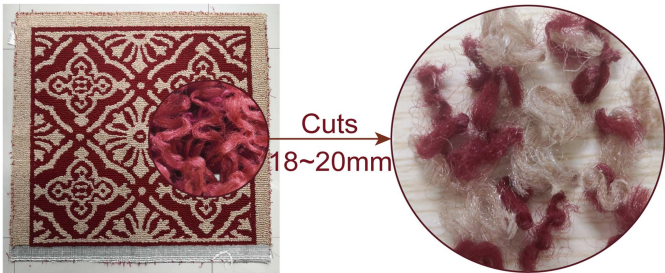


Fig. 2. Extraction of recycled fibers.

of 0.91 g/cm³, elastic modulus of 3.5 × 10³ MPa, and water absorption <0.1%; 16-mm deformed reinforcement was ensured, and ordinary tap water was used as the mixing water.

Concrete Mixture

According to the Chinese standard GB/T 25177-2010 (Chinese Standard 2010), the total water consumption of recycled concrete includes adequate water consumption involving hydration and additional water consumption absorbed by recycled aggregates. Water absorption and dosage determine the additional water consumption. The water absorption of recycled fibers is minimal and can be ignored. Specifications of the concrete mixture are provided in Table 2.

Pullout Test

In the half-beam test, unidirectional uniform loading and a speed of 100 N/s were ensured. Loading was performed using a computer-controlled piercing jack. The specimens were fixed with a steel beam during the loading process, and the test device is shown in Fig. 3. The study comprises two parts. First, the bond-slip relationship between concrete and reinforcement with 15 specimens was established; thereafter, displacement sensors (YWD-30 type, Liyang Instrument Factory, Liyang, China) were installed at the loading end and free end. The steel bar is considered whole and

Table 2. Concrete mixture

Notion	Recycled fibers (%)	Amount of material (kg · m ⁻³)				
		Cement	Sand	Natural aggregates	Recycled aggregates	Water
NC	0	390	709	1,156	0	195
RC50	0	390	709	578	578	205
RC100	0	390	709	0	1,156	215
RFRC50-12	0.12	390	709	578	578	205
RFRC50-24	0.24	390	709	578	578	205

Note: NC = natural concrete; RC50 = concrete with 50% recycled aggregates; RFRC50-12 = concrete with 50% recycled aggregates and 0.12% recycled fibers volume content; and RFRC50-24 = concrete with 50% recycled aggregates and 0.24% recycled fibers volume content.

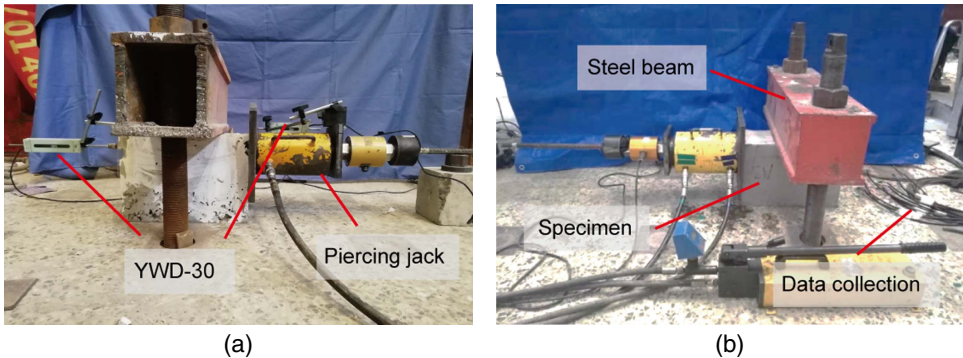


Fig. 3. Pullout test equipment: (a) bond-slip test; and (b) bond stress distribution test.

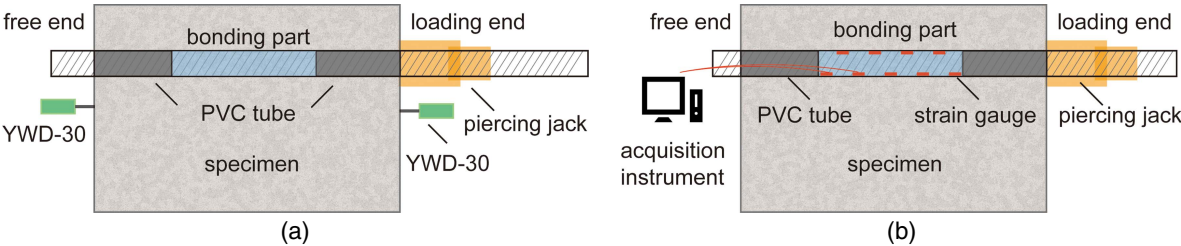


Fig. 4. Half-beam test: (a) bond-slip test; and (b) bond stress distribution test.

pulled out directly in this part. Second, another 10 reinforcements with a width of 4 mm and depth of 2 mm were considered and grooved along the axis. Nine strain gauges were arranged alternately at an interval of 20 mm; the schematic of the half-beam test is shown in Fig. 4, and the position inside the reinforcement is shown in Fig. 5. Waterproof treatment should be conducted before sealing. The static strain acquisition instrument (DH3816 type, Anshan Zhiyuan Technology Co., Ltd., Anshan, China) was connected to the embedded strain gauge of reinforcement to collect data. The each specimen's dimensions were 150 × 250 × 360 mm. As shown in Fig. 6, the pullout steel was HRB400 (Xiangsheng Machinery Mold Factory, Shenyang, China) and 16 mm in diameter, and anchorage length was 10 times the diameter of the reinforcement (160 mm). The unbonded section was covered with PVC pipe to eliminate the influence of the test results.

Results

Specimen Failure Modes

In the bond-slip relationship test, pullout-split failure occurred in all specimens. The cracks caused by failure were narrow and accompanied

by a weak sound. The specimens retained integrity even after failure. As shown in Fig. 7, there are two types of cracks in the test: the prominent cracks are consistent in the load direction, and the transverse cracks in the recycled concrete series are vertical to the main crack direction. The results show that although the failure mode remains unchanged, considerable serious damage and tortuous-shaped cracks are observed in recycled concrete. Because of recycled aggregates, the mechanical properties of concrete are reduced, and the concrete can be easily damaged under load. The concrete near the bond section is subjected to force, and transverse cracks appear: the larger the number of recycled aggregates, the more significant the crack (Kang et al. 2021). Compared with RC50, RFRC50-12 exhibits no transverse cracks. Recycled fibers hinder the generation and development of cracks because the random distribution of fibers improves the compactness of concrete, necessitates more energy to be damaged, and facilitates the generation and development of microcracks. Zhou et al. (2019b) and Liu et al. (2021) also concluded that a specific amount of fibers could improve the crack resistance of recycled concrete. However, secondary cracks appear at the end of RFRC50-24. The uniformity of fiber distribution is one of the critical factors affecting the performance of concrete, enabling agglomeration as the fiber content

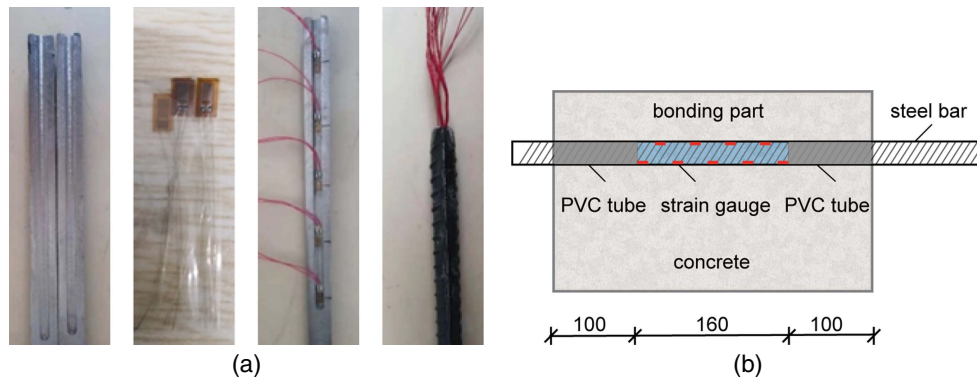


Fig. 5. Specimens of bond stress distribution: (a) reinforcement pretreatment; and (b) position of strain gauges.

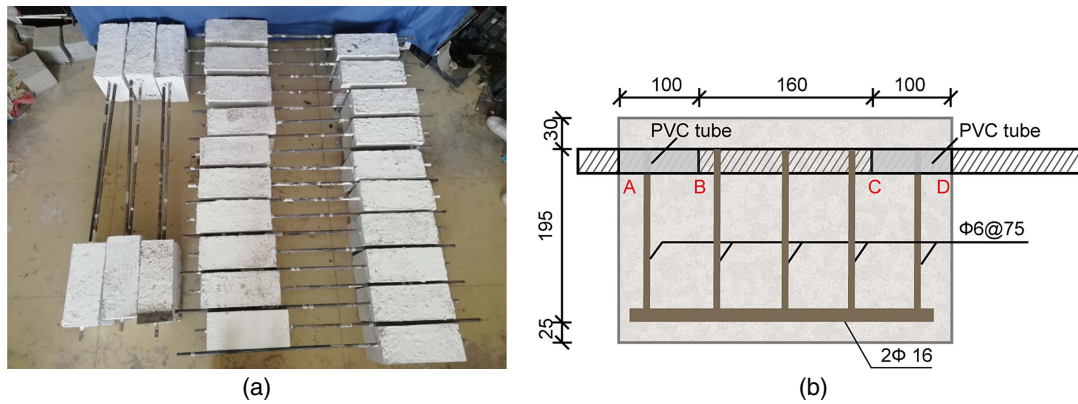


Fig. 6. Half-beam unidirectional pullout specimen: (a) specimen; and (b) reinforcement drawing.

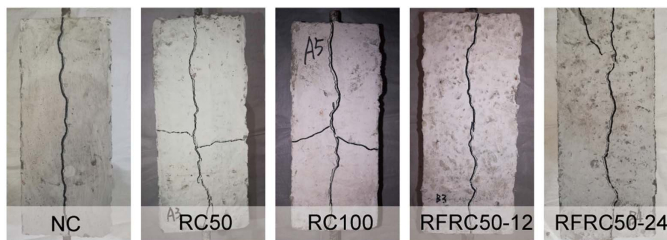


Fig. 7. Crack development of specimen.

increases during mixing, generating weak interfaces. In this zone, owing to the absence of aggregates and cementitious material, the interface is rapidly destroyed under stress.

As illustrated in Fig. 8, the occlusal surface wear of RC100 is more severe than that of natural concretes (NCs). During the preparation of recycled aggregates, due to the initial damage of recycled aggregates caused by crushing and sieving, the bond section is easier to crush under load. Fiber distribution has a crucial impact on the homogeneity of the concrete (Awal and Mohammadhosseini 2016). Excessive recycled fibers hardly disperse, and under stress concentration the mechanical properties decrease. Therefore, the occlusal surface of RFRC50-12 is more evident than that of RFRC50-24.

Bond-Slip Curves

The macro analysis of bond behavior is based on the widely accepted bond force assumptions. The bond force between concrete

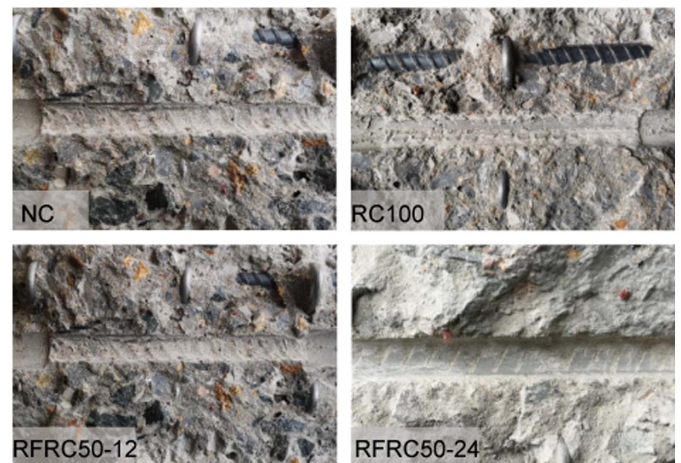


Fig. 8. Interfacial morphology between RFRC and reinforcement.

and steel reinforcement is evenly distributed along the anchorage section. Based on this assumption, the bond strength of each specimen is calculated using Eq. (1)

$$\tau = P/(\pi d l_a) \quad (1)$$

where τ = bond strength (MPa); p = pullout force (kN); d = reinforcement diameter (mm); and l_a = anchorage length (mm).

The slip obtained directly through the test is S_A and S_D , and the slip of the bonding section BC needs to be calculated. During the

loading process, the reinforcement is stressed and axial deformation occurs. Slight deformation was observed at the free end, whereas large deformation was observed at the load end. Therefore, AB is close to the free end and the deformation can be ignored, considering zero axial deformation in the AB section (Fig. 6) of the free end. In other words, A and B exhibit the same slip value ($S_A = S_B$). However, CD is close to the loading end and it exhibits axial deformation. The deformation of steel reinforcement is calculated using Eq. (2), and the actual slip of C can be calculated using Eq. (3). The average slip of the steel reinforcement in the anchored section (S_{BC}) can be calculated using Eq. (4)

$$\Delta S_{CD} = (P/E_s A_s) L_{CD} \quad (2)$$

$$S_C = S_D - \Delta S_{CD} \quad (3)$$

$$S_{BC} = (S_B + S_C)/2 \quad (4)$$

where E_s = elastic modulus of steel reinforcement; A_s = cross-sectional area of steel reinforcement (mm^2); L_{CD} = original length of the CD section (mm); S_C = relative slip value of C; and S_{BC} = average relative slip of the anchorage section.

Fig. 9 shows the bond-slip curve for the specimens. The development trend for the bond behavior of the half-beam test is similar to that observed in the center pullout test (Liu et al. 2021). All the bond-slip curves exhibit five stages: micro slip section, slip section, pullout section, descending section, and residual section.

In the micro slip stage, the pullout force was small, there was no apparent slip at the free end, the curve developed linearly, and chemical bonding force played a significant role. In the slip stage, as the pullout force increased, the free end of reinforcement started to slip. The interaction between concrete and steel bar cross ribs was evident, which indicated the reduction in the chemical bond force, and the bond effect was sustained by friction and mechanical interaction. Subsequently, the curve shows a transition into the stage of nonlinear development. In the pullout stage, the slip value increased significantly and the pullout force reached the peak. Cracks appeared in the concrete cover, the concrete on the occlusive surface was crushed, and the restraint effect was weakened. Subsequently, the curve shows a transition into the descending stage. In the descending stage, the bond-slip curve shows a transition into the descending stage following the pullout stage. The bond stress decreases continuously, and the slip value increases rapidly. The curve slope changed sharply, and the bond strength was significantly damaged. In the residual stage, as the slip value increased, the bond stress decreased gradually and stabilized at a specific value.

The addition of recycled aggregates reduced the bonding performance between concrete and reinforcement, consistent with the conclusions obtained from the central pullout test (Xiao and Falkner 2007; Liu et al. 2020). Before transitioning into the slip stage, the bond-slip curve of RC was similar to that of NC, and the recycled aggregates and recycled fibers did not affect the interaction between cement colloid and reinforcement. In the pullout stage, RC100 reached the ultimate bond strength first. The treatment of recycled aggregates inevitably generates internal microcracks and decreases the bearing capacity. The recycled aggregates in the bond section are easier to crush under load; therefore, the ultimate strength is reached first. However, in the descending and residual sections, the blocking effect and bond stiffness of the concrete fragments were reduced, and the reduction was most significant in the RC100 fragments. The residual stress exhibits negligible difference: 35.20%, 20.77%, and 36.24% of the ultimate stress, respectively. The slip value corresponding to NC is the smallest.

The ultimate bond strength of RFRC50-12 is the largest, close to that of NC. Compared with RC50, RFRC50-12 increased by 11.34%, while RFRC50-24 decreased by 16.17%, and the residual strength increased by 93.13% and 50.00%, respectively. On one hand, a moderate amount of fibers blocked the pores and increased the friction coefficient between concrete and reinforcement, that is, increased the friction force. On the other hand, it improved the uniformity and toughness of materials. The fibers at the cracks also perform the function of bridging and afford crack resistance. Therefore, the bonding stress of RFRC0-12 was higher than that of RC50.

The interface transition zone was the weakest area of the concrete material (Xiao and Falkner 2007). The more recycled the aggregates, the easily they are destroyed. The bond strength of RC100 was reduced by 36.92%, compared with that of NC. Eq. (5) establishes the relationship between recycled aggregates, recycled fibers volume, and bond strength, verified by both RC25 and RC75, with the R^2 over 0.97, as shown in Fig. 10

$$\tau = (-0.294\omega^2 - 0.577\omega + 13.54)(1 + 3.121a - 18.160a^2) \quad (5)$$

where ω = replacement rate of recycled aggregates (%); and a = recycled fibers volume (%). Considering the data presented by other scholars (Bravo et al. 2021; Liu et al. 2021), a similar trend is observed. Furthermore, an appropriate amount of recycled fibers can improve the bond strength that is comparable for both RFRC50-12 and NC. Recycled fibers improve the bond strength indirectly. Enhancing the mixing of aggregates and mortar improves the internal structure of recycled concrete, retards the generation and

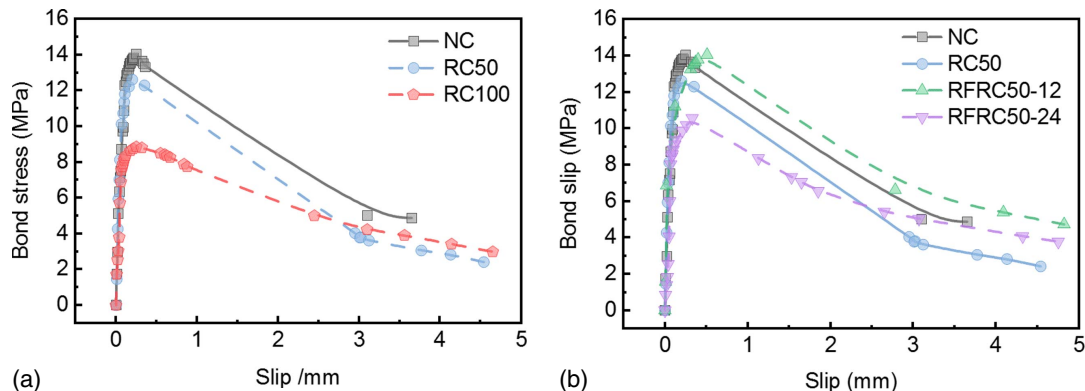


Fig. 9. Bond-slip curves of test: (a) RC series; and (b) RFRC series.

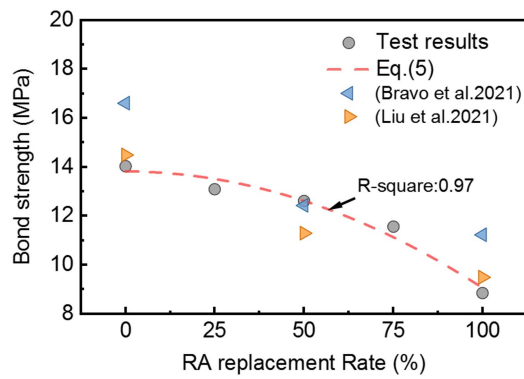


Fig. 10. Bond strength versus recycled aggregates replacement ratio.

Table 3. Fitting result of the parameter value

Type	Ascending sections			Descending sections		
	a	b	R^2	a	b	R^2
NC	20.494	0.092	0.98	23.647	1.419	0.98
RC50	16.894	0.054	0.98	14.987	0.941	0.97
RC100	11.640	0.053	0.94	22.157	2.058	0.92
RFRC50-12	14.871	0.035	0.97	30.076	1.634	0.95
RFRC50-24	15.807	0.102	0.88	26.585	2.152	0.92

Note: NC = natural concrete; RC50 = concrete with 50% recycled aggregates; RFRC50-12 = concrete with 50% recycled aggregates and 0.12% recycled fibers volume content; and RFRC50-24 = concrete with 50% recycled aggregates and 0.24% recycled fibers volume content.

development of microcracks, and plays a crucial role in dissipating the energy generated by force. Excessive recycled fibers adversely affect the uniformity of concrete and directly reduce the bond strength.

Bond-Slip Model for RFRC

The characteristics of the τ - s curve development trend are consistent and can be simplified into ascending and descending sections.

To further study the bond behavior between RFRC and reinforcement, the formula proposed by Liu et al. (2020) is modified, and the measured data are fit using Eq. (6). The results are given in Table 3

$$\frac{\tau}{\tau_u} = \begin{cases} \frac{a(S/S_u)}{S/S_u + b} & S \leq S_u \\ \frac{a}{S/S_u + b} & S > S_u \end{cases} \quad (6)$$

where τ_u = maximum bond stress along the embedded length; and S_u = corresponding slip.

The values of each parameter are obtained by nonlinear regression. In the ascending section, parameter a is related to recycled aggregates and decreases with its increase. The value of parameter b is 0.1 for NC and 0.05 for RC. The bond stress of RFRC50-12 increases, with the decrease in the value of parameter b , while the trend is opposite in the case of RFRC50-24. Compared with NC, the parameter b in case of RC100 is increased by 31.05% in the descending section, resulting in lower RC100 stress and a gentle downward trend in this section, while the addition of fibers increases the value of parameter a by more than 70%, and content of 0.24% is less than 0.12%. Pertaining to the accuracy of the instruments, the test data obtained in the descending section are limited. Furthermore, the steel bar slips to different degrees. Therefore, there is scope for further studies in the future. Fig. 11 compares the experimental and predicted results, which agree well and can suitably predict the bond behavior between RFRC and reinforcement.

Bond Stress Distribution

Bond stress cannot be measured directly through the test. Consider the microsegment of the reinforcement. Assuming that the shear stress on its surface is evenly distributed, the stress-strain relationship is established according to the stress balance conditions

$$\tau = \frac{dT}{A} = \frac{A_s d\sigma}{s dx} = \frac{(\sigma_{i+1} - \sigma_i) A_s}{\pi d h_i} = \frac{E_s A_s (\varepsilon_{i+1} - \varepsilon_i)}{\pi d h_i} \quad (7)$$

where dT = tension difference at both ends of the reinforcement microsegment (kN); σ_{i+1} and σ_i = reinforcement stress (MPa);

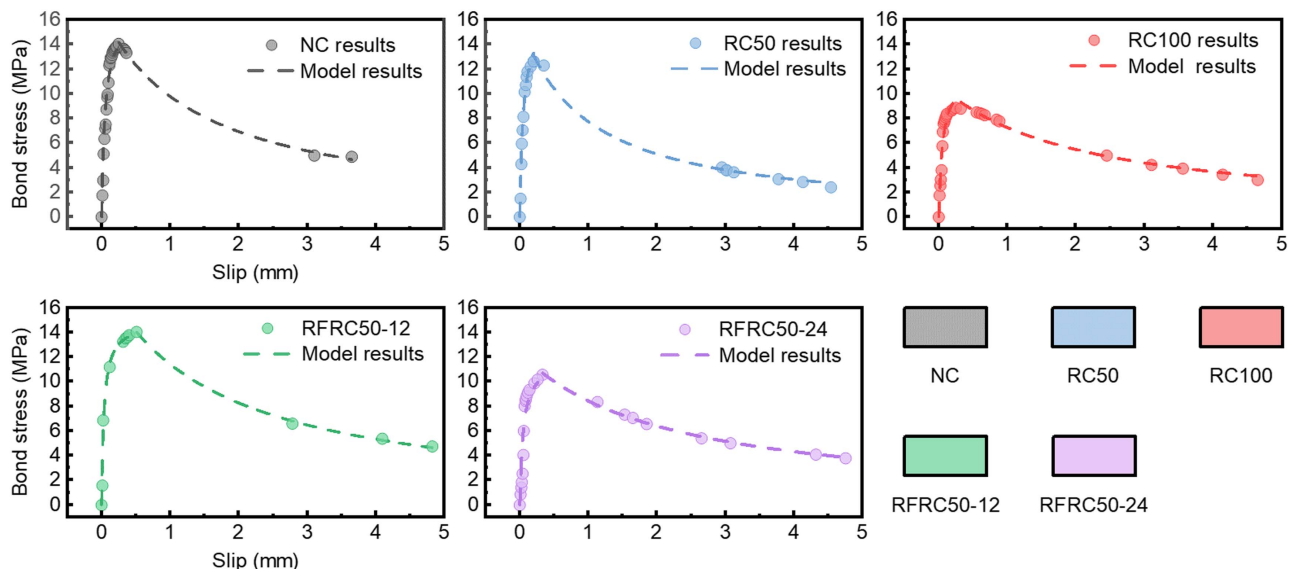


Fig. 11. Bond-slip curves of the test.

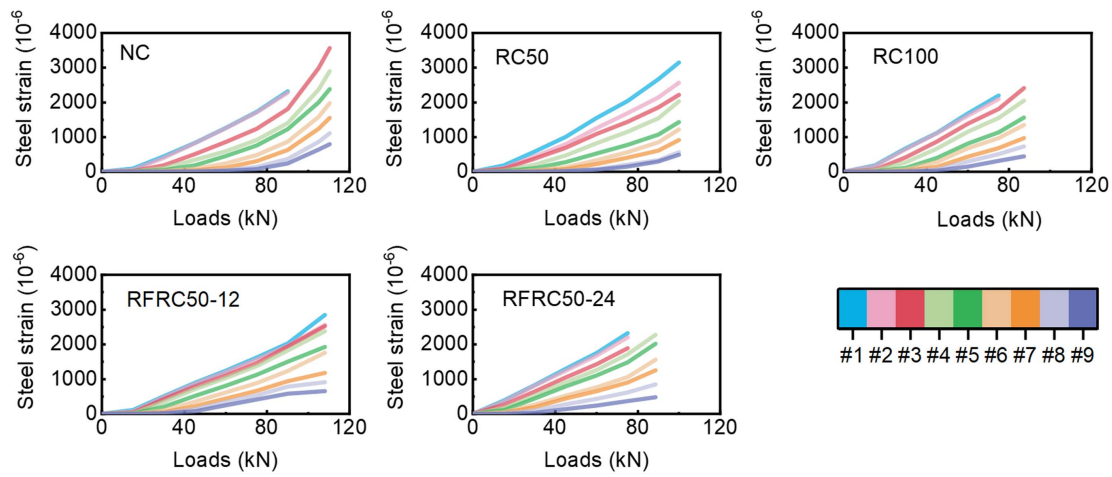


Fig. 12. Strain-load curves of reinforcement.

ε_{i+1} and ε_i = reinforcement strain; and h_i = distance between i and $i + 1$ (mm).

The variation of the reinforcement strain with load is shown in Fig. 12, and the strain gauges are numbered from the load end to the free end as 1 to 9. During the loading process, part of the reinforcement bond interface was broken and the strain gauges were debonded, causing some missing values. The strain increased with the increase in the load, and the entire strain changed linearly. The maximum strain appeared near the loading end and decreased gradually along the free end. This is consistent with the findings presented by Wang et al. (2018). With the increase in the pullout force, the strain difference between the load end and the free end increased.

The larger the number of recycled aggregates, the smaller the load required to generate strain at the free end, accelerating the stress transfer. Recycled fibers reduced the reinforcement strain near the load end and enhanced the uniformity of the strain transfer.

In addition, similar to recycled aggregates, excessive recycled fibers reduce the load the specimen can withstand.

The bond stress distribution curve is shown in Fig. 13. The bond stress is unevenly distributed in the anchorage section. Bond stress is slightly different in the initial loading stage. With the increase in the pullout force, bond stress concentration is observed, forming three or four peaks in the bond section. The peaks were prominent, and the position remained unchanged until the specimen was destroyed. The growth of the bond stress near the loading end was higher than that at the free end, consistent with the direction of stress transfer. The nonuniformity coefficient was proposed by Liu et al. (2020)

$$\mu = \tau_{\max} / \tau_{\text{aver}} \quad (8)$$

where $\tau_{\max}$ = maximum bond stress in the limit state; and τ_{aver} = corresponding average bond stress. The μ values of NC, RC50,

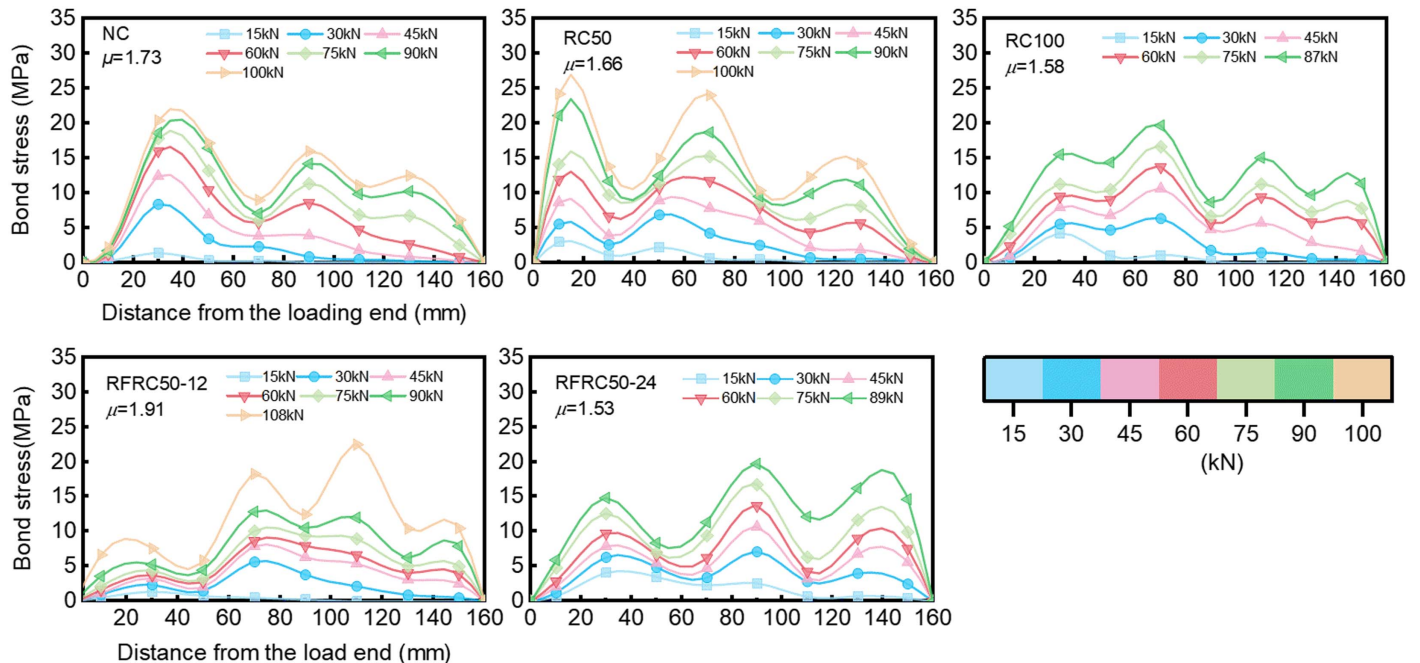


Fig. 13. Bond stress distribution along the embedded length.

RC100, RFRC50-12, and RFRC50-24 are 1.73, 1.66, 1.58, 1.91, and 1.53, respectively.

Contrary to the conclusion drawn by Liu et al. (2020), the closer μ is to 1, the higher is the uniformity of the bond stress distribution. Owing to the variation of the sources and contents of recycled aggregates, the bond stress of recycled concrete with different quality and content varies significantly, which affects the test results. Second, the freeze-thaw cycle conditions have been considered (Liu et al. 2020), which may weaken the influence of recycled aggregates on bond stress. Therefore, in this paper, μ is regarded as the residual coefficient of bond stress, that is, the larger the μ , the slower the bond stress loss and better the bond performance. Conversely, the lower the value of μ , the speedier the transference of bond stress and more significant the damage. The greater the number of recycled aggregates, the smaller the value of μ , the speedier the transference of stress, and the lower the bond performance. Recycled fibers are also influenced: μ increases at 0.12% and decreases at 0.24%, consistent with the previous conclusion.

The bond stress increases with the pullout force. NC exhibits three peaks at 30, 90, and 130 mm from the loading end. Along the loading direction, the peaks decrease sequentially. The peak positions of RC50 and RC100 move slightly toward the loading end. Near the free end, RC100 forms a new peak; the maximum peak appears in the middle of the bond section, and the stress curve is relatively flat. This indicates that the more recycled the aggregates, the speedier the transmittance of bond stress. With the addition of recycled fibers, the peak moves toward the free end. A new peak appears in the case of RFRC50-12, and the peaks in the case of RFRC50-24 are close. Recycled fibers cause the peak position to move to the free end and accelerate stress transmission.

Conclusions

This study used the replacement ratio of recycled aggregates and recycled fibers as the variable parameters. The failure modes, bond strength, bond-slip curve, and bond stress distribution law were obtained through the half-beam unidirectional pullout test. The main conclusions are as follows:

- The designed half-beam pullout test saves materials and simplifies operation and can reflect the bond behavior between RFRC and reinforcement.
- Recycled aggregates and recycled fibers do not alter the original failure modes of the specimen. With the increase in the number of recycled aggregates, the ultimate bond strength decreases gradually. In case of RC100, the ultimate bond strength decreased by 36.92%. The recycled fibers improve the bond properties between RFRC and reinforcement. The ultimate bond strength increased by 11.34% in the case of RFRC50-12, and decreased by 16.17% in the case of RFRC50-24; nonetheless, excessive addition of recycled fibers renders a negative impact.
- The development trend of the bond-slip curve of RFRC is similar to that of NC. The curve can be segmented into microslip, slip, pullout, descending, and residual sections. A segmented bond-slip model is proposed to describe the bond behavior between RFRC and reinforcement. The results correlate well with the experimental values.
- The bond stress is almost uniformly distributed under a small pullout force, but local stress concentrations are formed as the pullout force increases. Recycled aggregates and recycled fibers reduce the stress concentration and accelerate stress transfer. However, excessive recycled aggregates and recycled fibers negatively influence the load the specimen can withstand.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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