Experimental study on bonding performance of polypropylene fiber modified rubber concrete and deformed steel bar

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Abstract. In order to study the binding properties of deformed steel rods and rubber concrete modified with polypropylene fiber, four groups of bonding specimens were designed with polypropylene fiber volume ratio as a variable. The effect of polypropylene fiber on bond strength and bond slip curve was investigated by drawing test. It was found that the bond strength increased with the increase of polypropylene fiber volume fraction in the range of 0 ~ 1.5 %. Based on the experimental data, the constitutive relationship between deformed steel bar and polypropylene fiber modified rubber concrete was established. It provides a theoretical basis for further research on polypropylene fiber modified rubber concrete.

Keywords: Mekralon, Rubber concrete, Bond strength, Constitutive relation.

1. Introduction

The development of the automobile industry has brought rapid development to the national economy, and automobile tires are constantly produced as consumables. Waste rubber accumulates outdoors, which not only occupies land resources, but also breeds mosquitoes and spreads diseases. If the waste rubber is directly burned, it will release harmful gases such as CO and endanger the environment. The rubber concrete formed by replacing fine aggregate with rubber powder at a certain volume rate has excellent properties such as low elastic modulus, good crack resistance, heat insulation and impact resistance. However, the incorporation of rubber powder will reduce the strength, which limits the promotion and application of rubber concrete. Therefore, the incorporation of a certain volume rate of polypropylene fiber can effectively compensate for the strength defects of rubber concrete.

The bonding performance between concrete and steel bars is the basis for ensuring the joint work of the two. The experimental study of Professor Luo Lu Guoyun found the compressive strength was firstly increased and then decreased with the increase of fiber content[1]. With the increase of fiber content, the slump of rubber concrete is obviously reduced. The splitting tensile strength and bending strength are increased with the increase of fiber content. Fu Lipeng study found that the compressive strength and elastic modulus of linear regression[2]. Wang Huanyu believes that the fiber network structure formed by fiber in concrete can improve the mechanical properties[3]. Professor Pang Jianyong believes that the dynamic peak stress, dynamic peak strain and DIF value of rubber concrete specimens increase first and then decrease with the volume of polypropylene fiber[4]. Wen Jiang studied that polypropylene fiber can improve the frost resistance of rubber concrete, and established a quadratic freeze-thaw damage deterioration model[5].

In order to investigate the influence of polypropylene fiber volume ratio on bond strength, the bonding specimens were made to carry out pull-out experiment to research the bonding properties of deformed steel bars and polypropylene fiber modified rubber concrete.

2. Test survey

2.1. Raw materials

Using ordinary Portland cement, grade P.O42.5, 40 mesh rubber powder, particle size 5mm ~ 20mm graded continuous gravel, fineness modulus 2.7 natural secondary river sand, HRB400 rebar with a diameter of 14 mm, polycarboxylate liquid superplasticizer, polypropylene fiber performance parameters are shown in Table 1.

Table 1. Main properties of polypropylene fiber

Density(kg/m^3)	Elastic modulus(MPa)	Diameter(mm)	Tensile strength(MPa)	Tensile rate(%)
910	>4800	18~48	>486	>15

2.2. Mix proportion

According to the design method of fiber reinforced concrete, the rubber volume ratio of 5 % is used to replace the river sand, and the polypropylene fiber is replaced by 0.5 %, 1.0 % and 1.5 % respectively. The mix ratio is shown in Table 2. The strength grade of polypropylene fiber modified rubber concrete is designed as C30 and numbered uniformly. MmRRn, M and RR represent polypropylene fiber and rubber powder respectively, m and n represent their respective volume rates.

Table 2. Mix proportion(kg/m^3)

Number	Water	Cement	Flyash	River sand	Rubber powder	Pebble	mekralon	Water reducer
RR5	200	326	82	595.65	13.93	1165	0	4
M0.5RR5	200	326	82	595.65	13.93	1165	39.25	4
M1RR5	200	326	82	595.65	13.93	1165	78.5	4
M1.5RR5	200	326	82	595.65	13.93	1165	117.75	4

2.3. Specimen design

The central drawing specimens were designed according to the volume fraction of polypropylene fiber. The PVC pipe at both ends can not only control the anchorage length but also isolate the concrete from the steel bar, eliminate the end effect and restore the stress state of the steel bar in the actual structure. The specimen style is shown in Fig.1. The foam paper is wrapped between the PVC pipe and the steel bar to ensure that there is no relative slip between them. The PVC pipe port placed inside the test mold is sealed with rosin wax to prevent the concrete slurry from entering the pipe. After sealing, the rosin wax adhered to the steel bar anchorage section outside the casing is cleaned. All the central pull-out specimens were selected, the size of the 150mm cube was selected, the length of the steel bar was set to 500mm, and Free end reinforcement extension 30mm.

2.4. Test scheme

The clamp head on the universal testing machine clamps the high-strength screw on the top of the tester, and the end of the screw is provided with a ball hinge to ensure that the bonding specimen can fully fit the bottom of the gripping force tester. The steel bar of the specimen is clamped by the lower clamp head of the testing machine after passing through the center hole of the bottom steel plate. The free end is welded with iron sheet, and one displacement meter is placed at both ends of the iron sheet. A displacement meter is placed on the concrete surface, and the difference between the free end displacement meter and the reading of the concrete surface displacement meter is used as the relative slip. The displacement meter is arranged as Figure 2. The displacement and load are automatically collected by TDS-530 data acquisition instrument. When the specimen is damaged or the displacement exceeds 25 mm, the loading ends.

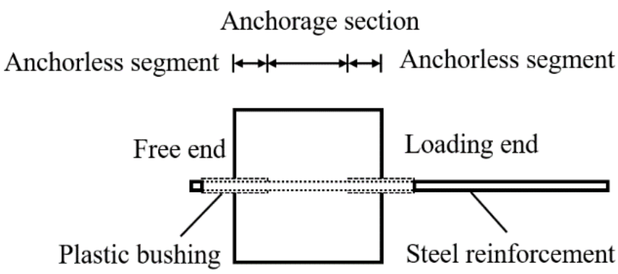


Fig. 1 Specimen design

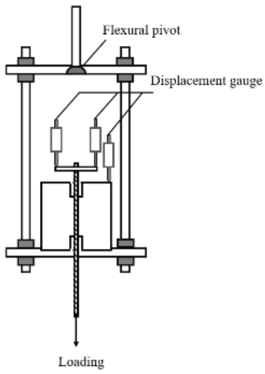


Fig. 2 Measuring Point Diagram

3. Experiment results and analyses

3.1. Bond strength and slip

The initial bond strength τ_b and ultimate bond strength τ_u are calculated by formula (1) and (2) respectively, and the test results are listed in the table 3.

$$\tau_b = F_{0.02}/\pi d l_a \quad (1)$$

$$\tau_u = F_u/\pi d l_a \quad (2)$$

Among them : $F_{0.02}$ is the drawing force when the slip is 0.02 mm, d is the diameter of the steel bar, l_a is the anchorage length of the steel bar, and F_u is the ultimate drawing force.

Table 3. Bond strength test results

Specimen number	Load(kN)		bond strength(MPa)		Free end slip(mm)
	$F_{0.02}$	F_u	τ_b	τ_u	S_u
C30RR5D14L70	15.395	35.263	5.424	15.865	0.8153
C30RR5M0.5D14L70	16.523	37.462	5.814	16.762	0.9347
C30RR5M1D14L70	17.435	40.136	6.214	18.326	1.2577
C30RR5M1.5D14L70	18.129	41.263	6.435	19.852	1.2637

Compared with the reference bond specimen, the initial bond strength increased by 0.390 MPa, 0.790 MPa and 1.011 MPa respectively for every 0.5 volume fraction of steel fiber, which increased by 7.19 %, 14.61 % and 18.64 % respectively compared with the reference specimen. The ultimate bond strength increased by 0.897 MPa, 2.461 MPa and 3.987 MPa for each 0.5 percentage point increase in the volume fraction of steel fiber, which increased by 5.65 %, 15.51 % and 25.13 % compared with the reference specimen. The slip increased by 0.1194 mm, 04424 mm and 0.4484 mm respectively, which increased by 14.64 %, 54.26 % and 55.01 % respectively. The data is drawn in Figure 3.

3.2. Bond-slip curves

According to the test data, the bond slip curve is drawn as shown in Figure 4. The unmodified rubber concrete specimen lacks the constraint effect brought by steel fiber, and the bond stress rapidly reaches the peak stress after splitting failure, and the bond slip curve only has an ascending section. When the instability of splitting internal cracks gradually develops outward, the development of cracks is limited and delayed until the steel fiber is pulled out with the steel bar because the steel fiber crosses the cracks and participates in the stress. At this time, the slip increases rapidly and the bond stress decreases. Therefore, the steel fiber modified rubber concrete specimens have complete ascending, descending and residual segments. The descending section becomes smoother and the curve is fuller. This shows that the bond stiffness and energy dissipation capacity of steel fiber modified specimens are better than those of unmodified specimens.

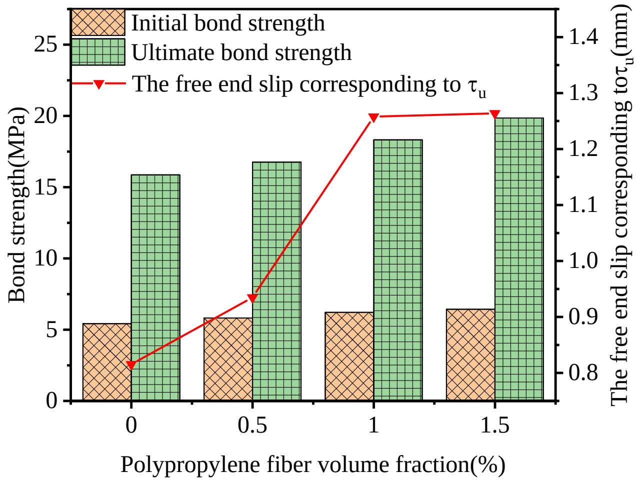


Fig. 3 Bond test results

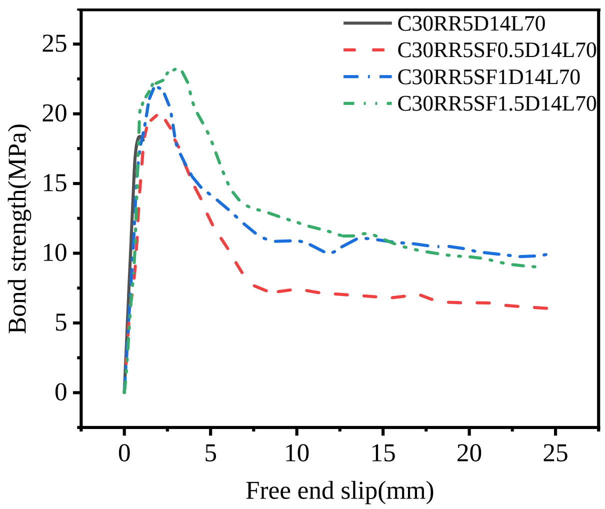


Fig. 4 Bond-slip curves

4. Bond-slip constitutive equation

Analyze the bond-slip curve drawn above, and the rising section is approximately in line with the growth law of the power function; in the descending section, the bond stress decreases linearly with the increase of slip. In the residual section, the bond stress changes little and remains basically stable. The bond-slip curve of steel bar and steel fiber modified rubber concrete can be described by Formula (3). The constitutive model is shown in Figure 5.

$$\tau=\begin{cases}\tau_{\mathrm{u}}\left(\frac{s}{s_{\mathrm{u}}}\right)^{\alpha} & s\le s_{\mathrm{u}}\\ \tau_{\mathrm{u}}-(\tau_{\mathrm{u}}-\tau_{\mathrm{r}})\left(\frac{\mathrm{s}-\mathrm{s_u}}{\mathrm{s_r}-\mathrm{s_u}}\right) & \mathrm{s_u}\le s\le s_{\mathrm{r}}\\ \tau_{\mathrm{r}} & s\ge s_{\mathrm{r}}\end{cases} \tag{3}$$

In the formula: τ_r is the residual bond stress, s_r is the free end slip corresponding to τ_r, α is the shape coefficient.

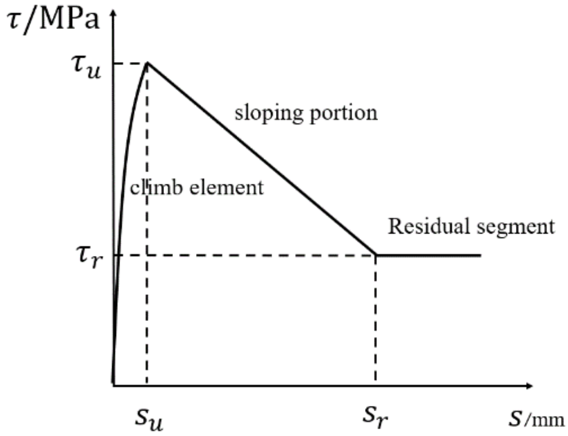


Fig. 5 Constitutive model

According to the experimental data, the undetermined coefficient α is fitted, and combined with the bond-slip constitutive model, the bond-slip constitutive equation with the deformed steel bar.
When ρ_f =0, the bonding specimen C30RR5D14L70 has split failure, only the rising section, the equation is as follows:

$$\tau=18.362s^{0.2655}\quad 0\le s\le 0.91 \tag{4}$$

When ρ_f = 0.5 %:

$$\begin{cases}\tau=19.917s^{0.3742} & 0\le s\le 0.935\\ \tau=-2.36\mathrm{s}+23.203 & 0.935<\mathrm{s}\le 8.211\\ \tau=6.967 & \mathrm{s}>8.211\end{cases} \tag{5}$$

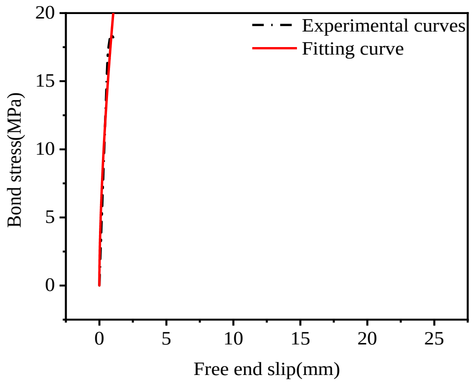
When ρ_f =1 %:

$$\begin{cases}\tau=27.333s^{0.3861} & 0\le s\le 1.128\\ \tau=-1.978\mathrm{s}+22.27 & 1.128<\mathrm{s}\le 7.706\\ \tau=10.041 & \mathrm{s}>7.706\end{cases} \tag{6}$$

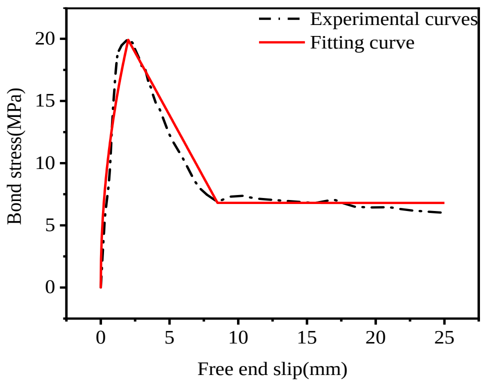
When ρ_f =1.5 %:

$$\begin{cases}\tau=19.496s^{0.2493} & 0\le s\le 1.26\\ \tau=-1.762s+25.315 & 1.26<\mathrm{s}\le 7.205\\ \tau=10.135 & \mathrm{s}>7.205\end{cases} \tag{7}$$

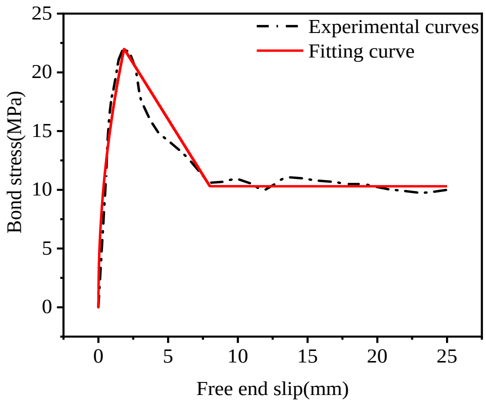
The fitted constitutive relation is shown in Figure 6.



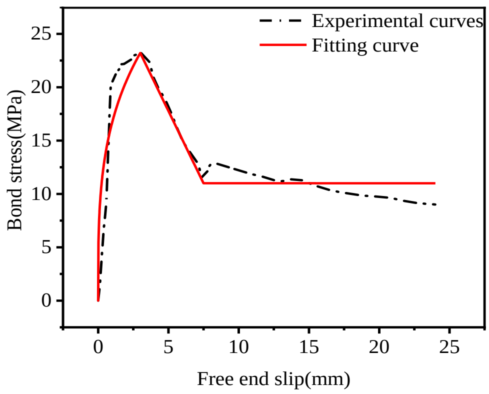
(a) C30RR5D14L70



(b) C30RR5M0.5D14L70



(c) C30RR5M1D14L70



(d) C30RR5M1.5D14L70

Fig. 6 The fitted constitutive relation

The relationship between the rising coefficient α of the bond slip curve and the volume fraction ρ_f of polypropylene fiber was fitted, and the fitting effect was shown in Figure 7. The functional relationship between the two is fitted as formula (8) :

$$\alpha = -0.246\rho_f^2 + 0.361\rho_f + 0.263 \tag{8}$$

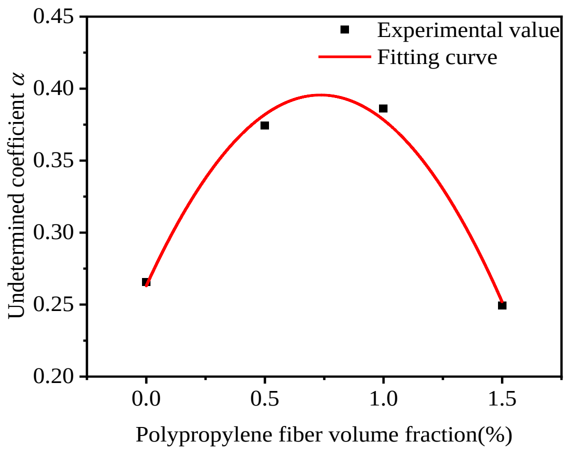


Fig. 7 Fitting results

The constitutive model expression considering the volume fraction of polypropylene fiber is as follows:

$$\tau = \begin{cases} \tau_u \left(\frac{s}{s_u}\right)^{(-0.246\rho_f^2+0.361\rho_f+0.263)} & s \le s_u \\ \tau_u - (\tau_u - \tau_r)\left(\frac{s-s_u}{s_r-s_u}\right) & s_u \le s \le s_r \\ \tau_r & s \ge s_r \end{cases} \tag{9}$$

5. Conclusions

The effect of polypropylene fiber with different volume ratios on the bonding properties of deformed steel bars and modified rubber concrete was investigated by drawing test. The specific conclusions are as follows.

(1)The initial bond strength and ultimate bond strength increase with the increase of polypropylene fiber volume fraction in the range of 0 ~ 1.5 %.

(2)In this paper, a three-stage constitutive model is proposed, and the parameters α in the constitutive relationship are nonlinearly fitted by experimental data. The regression analysis of α fitted under different steel fiber volume ratios is carried out, and the relationship between α and steel fiber volume ratio is given, so as to establish the average bond slip constitutive model of deformed steel bar and steel fiber modified rubber concrete.

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