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Research Status of Bond-slip Behavior between Rebar and Recycled Concrete

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Abstract

The bond force between steel bar and concrete can be divided into three kinds: chemical adhesive force, friction force and mechanical bite force. According to the developing process of bond-slip curve, the curve is divided into 5 sections, which are micro-slip section, slip section, crack section, decline section and residual section. The bond performance between reinforcement and concrete is affected by concrete strength, reinforcement performance, anchorage length, thickness of protective layer and so on. The bond behavior between rebar and recycled concrete is consistent with that of ordinary concrete. The trend of bond-slip curve is similar to that of development. The failure modes of drawing specimens are pull-out failure, split-pull failure and split failure.

Keywords

Bonding Properties; Bond Slip Curve; Failure Mode of Specimen.

1. Bond Mechanism between Steel Bar and Concrete

The bond force between steel bar and concrete is one of its basic properties as building and engineering materials. The adhesive force can be divided into three kinds: chemical adhesive force, friction force and mechanical bite force. The chemical adhesive force mainly forms on the surface of cement gel and Steel Bar, which is a kind of adsorption force, only exists in the initial stage of steel bar subjected to external load. Once the steel and concrete slip, the chemical bond will disappear and cannot be restored. There are two main sources of friction: The first is from the shrinkage effect of cement hydration, and the second is the corresponding friction resistance when the steel bar is subjected to external forces, the friction force is formed on the contact surface between the steel bar and the concrete, and the magnitude depends on the roughness of the contact surface. Mechanical bite force is an important component of good anchoring effect between steel bar and concrete, which is related to the type and roughness of steel bar. Once the bite force fails, the steel bar will slip a lot and the concrete specimen will be destroyed. The bond-slip curve is shown in figure 1. According to the bond-slip developing process, the curve is divided into 5 stages:

1. Micro-slip stage (o-s) : in this stage, the corresponding load is small, micro-slip occurs at the loading end, and the steel bar in the specimen does not slip. The stress starts to transfer from the loading end to the free end, and the chemical adhesive force is the main component of the bond force of steel bars.

2. Slip section (s-cr) : the stress transmits to the free end, and the load at the loading end increases, the internal slip quantity also increases gradually, the chemical adhesive force disappears, and the friction force becomes the main part of the adhesive force. At this stage, micro-cracks appear in the specimen and the slip increases gradually.

3. Crack-increasing section (cr-u) : the micro-cracks in concrete develop with the increase of load. The cracks extend from the specimen to the specimen surface.

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4. Down Section (u-r) : after reaching the peak, the crack develops rapidly, the specimen appears through the crack, the slip quantity increases rapidly, and the bond stress decreases rapidly. At this stage, the mechanical bite force and the friction force act together.

5. Residual section (after R) : after the steel reaches a certain amount of slip, the stress basically no longer decreases and gradually tends to stability.

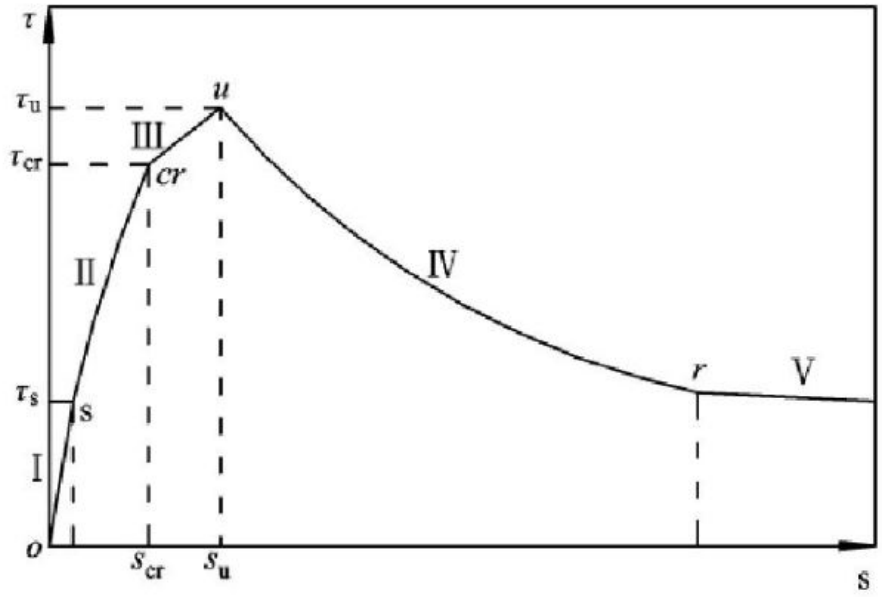

Fig 1. Diagram of Bond slip curve

2. Factors Affecting Bonding Properties

(1)Strength of concrete

It has been shown that the bond strength of rebar-recycled concrete increases with the increase of the strength grade of concrete and decreases with the increase of the replacement ratio of recycled aggregate. Table 1 shows the formulas for calculating different bond strength proposed by many scholars.

Table 1. The formulas for calculating different bond strength proposed by many scholars

Scholars	Calculation formula of bond strength
Charles Rockson[1]	$\tau_0=1.44\sqrt{f_c}+0.84\left(\frac{c}{d}\right)-2.84$
Musab Alhawat[2]	$\tau_0=\sqrt{f_c}\left[1.2+3.0\left(\frac{c}{d}\right)+50(\frac{d}{l_a})\right]$
Danying Gao[3]	$\tau_0=\sqrt{f_{cu}}\left[3+0.36\left(\frac{c}{d}\right)-0.31\left(\frac{l_a}{d}\right)+0.2V_{sf}+0.1V_{pf}-0.003r_g\right]$
Youlin Xu [4]	$\tau_0=f_t(0.82+0.9\frac{d}{l_a})(1.6+0.7\frac{c}{d}+20\frac{A_S}{cS_V})$
ZhimingTeng[5]	$\tau_0=f_t(1.14+1.81\frac{d}{l_a})\ \frac{c}{d}$
Darwin David[6]	$\tau_0=\sqrt{f_c}\left[1.06+2.12\left(\frac{c}{d}\right)+75(\frac{d}{l_a})\right]$

Note: τ0-bond strength; fc-cylinder compressive strength; fcu-cube compressive strength; c-coating thickness; d-reinforcing bar diameter; anchoring length of la-reinforcing bar; Vsf-steel fiber volume ratio; Vpf-polypropylene fiber volume ratio; Rg-replacement rate of recycled aggregate.

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In addition to the formula for calculating the bond strength proposed by the above scholars, studies by Li Yujun [7] and others have found that when the anchorage length is equal to 5 times the diameter of the steel bar, the bond strength between steel bar and high strength ceramsite concrete is 25% higher than that between steel bar and ordinary concrete. Cao Wanlin [8] and others found that when the replacement rate of recycled coarse aggregate was 100%, the bond strength between rebar and concrete decreased obviously, which was lower than the bond strength of 33% -66% of recycled coarse aggregate, moreover, the bond strength between deformed steel bars and concrete is higher than that between plain steel bars.

(2)Performance of reinforcement and anchorage length

An mingzhe [9] found that the bond performance between reactive powder concrete (RPC) and deformed rebar is much higher than that between RPC and plain rebar, and the bond performance of different rebar specimens is much higher than that between RPC and plain rebar, the failure mode of round bar is pull-out failure, while that of deformed bar is tensile failure or split failure of concrete. Hu Qiong [10] and others found that with the increase of anchorage length of steel bar, the ultimate load corresponding to the failure of the specimen increased, but the average bond stress decreased. Dong Hongying [11] and others through a study of 15 beam-type specimens, found that compared with plain steel bars, the bond performance of rebar and recycled concrete was greatly improved, and the increase was 100%, the bond property between steel bar and concrete decreases with the increase of steel bar diameter and anchorage length. Zhao Jun [12] studied the effect of different types of reinforcement on bond strength between reinforcement and concrete, and found that the higher the strength of the reinforcement itself, the higher the surface roughness, and the higher the ultimate bond strength.

(3)Other influencing factors

In addition to the above two factors, the bond performance between reinforcement and concrete is also affected by other factors. Such as: protective layer thickness, stirrups and other factors. Increasing the thickness of protective layer can delay the cracking failure of concrete to some extent and improve the average bond strength of specimens, while stirrups can restrain the cracking development of concrete and increase the bond stress between steel bars and concrete. Chen Gangwen [13] studied the bond behavior of steel bar-seawater sea sand concrete under lateral restraint. The results show that the thicker the concrete relative protective layer is, the greater the ultimate bond strength of the interface is, the ultimate bond strength is obviously higher than the specimens without stirrup restraint. It is found [14] that stirrups can change the failure mode of some specimens, and can effectively limit the development of cracks, and increase the thickness of concrete cover, resulting in an average increase of the ultimate bond stress of specimens by 36%, the crack bond stress of the specimen also increases correspondingly.

3. Research Status of Bond-slip between Rebar and Recycled Concrete

The research on the bond behavior between recycled concrete and steel bar is beneficial to perfect the theory of recycled concrete and promote the development and application of recycled concrete. It has been concluded [15] that the failure process of bond between recycled concrete and steel bar consists of 5 stages, which is basically consistent with that of ordinary concrete. Liu Kai and others[16] found that the bond strength between rebar and recycled concrete decreases with the increase of the replacement rate of recycled coarse aggregate, and that when the anchorage length meets the design requirements, the bond strength between rebar and recycled concrete decreases with the increase of the replacement rate of recycled coarse aggregate, and the bond strength between rebar and recycled concrete decreases with the increase of the replacement rate of recycled coarse aggregate, the bond performance between recycled concrete and steel bar depends on the strength of steel bar. Song Guojie [17] studied the effect of recycled coarse aggregate substitution rate, concrete strength and loading rate on bond performance of recycled concrete by central pull-out test, the ultimate bond strength of recycled concrete increases with the increase of loading rate, but the increase is not

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significant. Zheng Jianlan [18] and others studied the effect of the corrosion rate of fine carbonized aggregate and rebar on the bond performance of recycled concrete under the condition of 70% replacement rate of recycled coarse aggregate, the maximum bond stress can be increased by 75.6%, and the corresponding replacement rate of recycled fine aggregate is 30%, the range of promotion showed the trend of first increasing and then decreasing. Wang Jiang [19] studied the influence of high temperature and the replacement ratio of recycled coarse aggregate on the bond stress of recycled concrete, it is found that the compressive strength and ultimate bond stress of recycled concrete decrease with the increase of the replacement ratio of recycled coarse aggregate, and the corresponding peak slip increases The compressive strength and ultimate bond stress of recycled concrete decrease with the increase of temperature, and the corresponding slip increases. Li Rongxia [20] studies the bond behavior of recycled concrete under unilateral pressure. The results show that the larger the diameter of steel bar, the smaller the ultimate bond strength of recycled concrete under unilateral pressure, the lateral pressure can increase the anchorage strength of steel bar. Qin Yongjun [21] studied the influence of the diameter of steel bar, the content of lithium slag and the replacement ratio of recycled coarse aggregate on the bond strength of recycled concrete by drawing test, the bond strength increases with the increase of the replacement ratio of recycled aggregate, and the appropriate amount of lithium slag can also increase the bond strength. The results of Ma Yanni [22] test show that the bond strength of recycled concrete increases with the increase of strength grade, and the bond stress corresponding to the peak value of bond slip curve increases with the increase of loading rate.

4. Conclusion

(1) the bond force between rebar and concrete is mainly composed of three parts: chemical adhesive force, friction force and mechanical bite force. The bond-slip curve can be divided into 5 parts: micro-slip section, slip section, crack-increasing section, falling section and participating section.

(2) The main factors affecting the bond-slip between reinforcement and concrete are: concrete strength, diameter and type of reinforcement, anchorage length of reinforcement, thickness of concrete cover, According to the measured data, different formulas for calculating the bond strength have been put forward by different scholars.

(3) The failure modes of bond-slip specimens of rebar and recycled concrete are the same as those of ordinary concrete, which are pull-out failure, split-pull-out failure and split failure.

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