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Progress Analysis of Bonding Performance of GFRP Reinforcement to Concrete

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Abstract: The article briefly summarizes the latest progress of research on the bonding properties of GFRP bars to concrete at home and abroad. It analyzes three test methods for studying the bond properties of GFRP bars, namely: losberg test, standard specimen test, and beam test, and briefly introduces the pullout test device for the pullout test. The bonding mechanism and the influence of the surface form of GFRP bars, concrete strength, diameter size, anchorage length, protective layer thickness and other influencing factors on the bond strength are analyzed and summarized, among which the diameter size and anchorage length have a greater influence on the bond strength. Suggestions are also made to address the shortcomings of the existing research, which provide a basis for a more in-depth study of the bond strength of GFRP bars in the future.

Keywords: GFRP bar, Ultimate bond strength.

1. Introduction

Reinforced concrete structures have been widely used in various projects, such as bridge deck slabs, sidewalks, garages, wastewater treatment plants and some harbor and hydraulic structures. However, the corrosion problem of steel reinforcement seriously affects the durability of reinforced concrete structures. In order to solve the problem of steel corrosion and prolong the service life of concrete structures, scholars at home and abroad have conducted research in recent decades. FRP bars have various forms, which can be classified into GFRP bars, CFRP bars, AFRP bars and HFRP bars according to the composition of different types of fibers, and the application of CFRP bars in civil engineering is still very limited due to the high price and expensive cost, while the production process of AFRP bars and HFRP bars is more complicated, which affects their application in engineering, and the application of GFRP bars in civil engineering is more complicated. GFRP reinforcement has become the preferred new material for structural engineering due to its low price and convenient use. GFRP reinforcement has high tensile strength, good corrosion resistance, and small weight. The bonding performance is the key to ensure that these two materials work together, so it is necessary to carry out an in-depth study on the bonding performance of FRP bars and concrete. Organization of the Text

2. Research on Bonding Mechanism Between GFRP Bars and Concrete

2.1. Bond stress

Bond stresses transfer the stresses between the GFRP bars and the concrete, so that both are subjected to the same stresses. The bond test is a good way to check the bond stress.

2.2. Working mechanism of bond stress

The bond stress consists of several aspects.T Kanakubo[2] et al. classified the bond mechanism between GFRP bars and concrete into two categories, mainly by mechanical occlusion force and friction force, through their research.B Tighiouart experiments[3] concluded that the bond stresses of FRP bars and concrete mainly include friction, mechanical occlusion force, and chemical adhesive force between the FRP bars and concrete. Hao Qingduo [4] and others believe that the bond mechanism of FRP bars is different depending on the form of the bars: the transfer of bond stresses in ribbed bars mainly depends on mechanical occlusion, and friction and chemical adhesion play a very small role; the transfer of bond stresses in light round bars mainly depends on chemical adhesion and friction, and the role of mechanical occlusion is very small.

3. Test Method for Bond-slip of GFRP Bars

3.1. Test Methods

There are three test methods for GFRP reinforcement bond-slip test research, which are losberg test, standard specimen test and beam test. In the conventional single-end pullout condition, the standard bond specimen is designed according to the Canadian Standards Association (CSA) standard, and the specimen size is 150mm × 150mm × 150mm concrete specimen [5]; the specimen size of the beam test specimen is not standardized, and the specimen size is 150mm × 250mm × 1250mm, according to the recommendation of the RILEM/CEB/FIP.(1978). recommendations, the specimen size is 150mm × 250mm × 1250mm.

3.2. Drawing test device

The upper plate of the device basket used for the pull-off test is a threaded rebar, which can be fitted with the tester's threaded socket to minimize the effect of the upper use of the fixture on the travel of the tester. In the lower part of the tester, a fixture is installed to clamp the GFRP ribbed bars, and the movement direction of the tester is unidirectional downward. The penetrating ball hinge in the middle of the lower plate of the basket and the channel steel mat can ensure that the GFRP ribbed bars rotate freely in the middle of the penetrating ball hinge, avoiding the concrete tear damage caused by the tilting of the loading end and the deflection of the GFRP ribbed bars, and ensuring that the pull-out force is all along the axial direction. In order to measure the slip at the loading end and the free end, a displacement gauge is set at the free end of the GFRP ribbed bar to measure the slip at the free end of the GFRP ribbed bar, and two displacement gauges are fixed at the starting position of the unbonded section of the GFRP ribbed bar to measure the slip at the loading end of the GFRP ribbed bar, and the average value of the two gauges is taken to calculate the slip at the loading end, so as to eliminate the skewing deviation in the loading process. The average of the two displacement meters is taken to calculate the slip of the loaded end to eliminate the tilt deviation during loading.

3.3. A study of factors affecting bond-slip properties

There are a number of factors that influence the bond-slip performance, mainly focusing on conditions such as profile, diameter, anchorage length, concrete strength, and thickness of the protective layer.

3.4. Form factor

Xue Weichen and Zhang Peng from Tongji University [6-7] carried out a comparison of the bond strength of bare round bars and threaded bars, and the test showed that the bond strength of threaded bars was much higher than that of bare round bars. Hao Qingduo and Ou Jinping of Harbin Institute of Technology [8] studied different shapes of GFRP bars and proved that the parameters of transverse ribs on the surface of GFRP bars, such as rib height, rib spacing, etc., significantly affect the bond performance of GFRP bars, and found that the optimum rib spacing of GFRP bars should be taken as 1 times of its diameter; the optimum rib height of GFRP ribbed bars is taken as 6% of its diameter.

3.5. Effect of diameter

In the study of the diameter of GFRP, Hao Qingduo, Ou Jinping and others [9-11] reached a consistent conclusion through tests: the bond strength of GFRP ribbed reinforcement increases with the diameter, the bond strength of GFRP ribbed reinforcement and concrete decreases, the slip at the loading end increases continuously, and the bond performance is getting worse and worse. It is generally believed that the reason for this phenomenon is due to the Poisson effect and shear hysteresis of GFRP bars. The Poisson effect converts some of the radial force into longitudinal force and reduces the radial force. The degree of reduction of radial force increases with the increase of the diameter of the reinforcement. The reduction in radial force will weaken the mechanical occlusion of the tendon, resulting in a reduction in bond strength. The shear hysteresis effect is that when the surface of the tendon is tensile, there will be some difference in the amount of fiber deformation between its surface and center region. As shown in Fig. 4, this effect results in the fact that the bond stress max at the surface of the tendon determines the bond strength, while the average bond stress ave used in the calculation is smaller. The larger the diameter, the greater the difference between the two, which manifests itself as a reduction in bond strength.

3.6. Impact of anchorage length

Zenon Achillides study [12] found that other factors remain unchanged, the larger the bond length of GFRP bars, the more uneven the distribution of bond stresses after the force, and this uneven distribution of bond stresses will seriously affect the change of bond strength.The ultimate bond strength of GFRP bars to concrete decreases with the increase of bond length. Prof. Gao Danying of Zhengzhou University [13] specifically studied the anchorage length and found that under the condition that other factors remain unchanged, the larger the anchorage length of the GFRP bar, the more uneven the distribution of the bond stresses after the force, and this uneven distribution of bond stresses will seriously affect the change of the bond strength.The anchorage length of the GFRP bar in ordinary concrete and high-strength concrete can be taken to be approximated as 20 times the diameter of GFRP bar. The anchor length of GFRP bars in normal concrete and high strength concrete can be approximated as 20 times the diameter of GFRP bars.

3.7. Concrete strength effects

A large number of experimental studies on the bonding properties of reinforced concrete show that the chemical adhesive force between reinforcement and concrete increases significantly with the increase in concrete strength. At the same time, the mechanical occlusal force between the reinforcement and concrete also increases with the increase of concrete grade, but the frictional resistance is not much affected by the concrete strength grade. The fiber polymer reinforcement, regardless of its material composition and surface form are quite different from steel, and the modulus of elasticity of fiber polymer reinforcement is only about 1/4 of that of steel. These factors lead to the bond performance of fiber polymer reinforced concrete under different concrete strength conditions is quite different from that of steel reinforced concrete. Therefore, it is necessary to further investigate the effect of concrete strength class on the bond performance of fiber polymer reinforced concrete. Zheng Qiaowen [14] studied the effect of compressive strength of concrete on the bonding performance of FRP bars and concrete by using pull-out test. It was concluded that increasing the concrete strength level has a certain promotion effect on enhancing the bond strength, but the effect is not significant, and with the change of diameter also has obvious fluctuation.

3.8. Influence of the thickness of the protective layer

The thickness of the protective layer of concrete is the distance between the outer surface of the fiber polymer reinforcement and the surface of the concrete. The thickness of the protective layer of concrete is the main factor affecting the form of bond damage of fiber polymer reinforcement concrete. Increasing the thickness of the protective layer of concrete can increase the splitting resistance of concrete. Most specimens with too small a protective layer of concrete will experience concrete splitting damage, reducing the ultimate bond capacity of fiber polymer reinforced concrete. Increasing the thickness of the protective layer of concrete, the specimens no longer produce splitting damage, the damage form of the specimen is mostly fiber polymer reinforcement pull-out or pull-off damage, which increases the ultimate bond bearing capacity of fiber polymer reinforced concrete. Hao Qingduo and Wang Yanlei [15] found in the experimental study that the protective layer has a greater influence on the degree of wear of the cross ribs of the GFRP tendons, and the degree of wear of the cross ribs increases with the increase in the thickness of the protective layer of concrete, which in turn affects the bond strength of the GFRP.

3.9. Other factors

Other factors affecting the bonding properties of fiber-polymer-reinforced concrete are external constraints, test methods, the form of the bends, the depth of the concrete pour, temperature variations and environmental factors.

4. Findings

GFRP bars will play an important role in future projects, and the bonding performance between GFRP bars and concrete needs to be studied as follows:

(1) The influence factors of concrete strength on the bonding performance of GFRP bars are still unclear.

(2) The bonding performance of GFRP bars under high temperature and corrosive conditions should be fully considered.

(3) Strain gauges are pasted on the surface of GFRP bars and FBG smart GFRP bars are used to further study the distribution of bond stress within the anchorage length.

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