

Influencing Factor Analysis on Bond Behaviors of FRP Bars and Concrete

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Abstract. Fiber reinforced composite (FRP) bars have the advantages such as anti-corrosion, high strength and reducing the weight of components. Applying them to concrete structures instead of ordinary steel bars can improve the stability of the whole structures and enhance the corrosion resistance of the structure, therefore the application of components will expand. The bond behavior between FRP bars and concrete is an important indicator to show its working performance, hence, the researches of the bond behaviors are significance. This paper summarizes the research status of previous researches on the bond behaviors of FRP bars and concrete under different conditions. Firstly, the commonly used test methods for testing the bonding properties are introduced. Secondly, the main research results are analyzed and compared from three aspects: concrete type, FRP bar surface shape and surface treatment method, and environmental factors. Finally, the shortcomings of the existing research are expounded, and the feasible further research directions in the future are also proposed.

Keywords: FRP bars; concrete type, Bond behavior; Environmental factors; Surface shape and treatment method.

1. Introduction

For steel concrete structure that has been exposed to severe cold or saline-alkali environment for a long time, the corrosion of steel bars is very serious. The survey data, in the investigation of 967 components of marine buildings in Zhenhai, Zhejiang, nearly 56% of total bridge structures had been seriously corroded and affected the use [1]. It is estimated that nearly 600,000 bridges in the United States had nearly 100,000 bridges steel bars are severely corroded [2]. In the UK, one-third of the steel concrete structures need to be rebuilt due to the corrosion of steel in the marine environment [3]. The durability problem of concrete structures in China is also very prominent. According to statistics, the dangerous bridges in the existing highway bridges in China account for about 35.4%. To address the severe corrosion of bar, a new material called Fiber reinforced composite bar was developed to replace bar within a certain range. FRP (Fiber Reinforced Polymer) bar is a kind of bar without metallic materials that is formed by gluing multiple strands of long fibers and base materials and then drawn by a specific mold. Compared with ordinary rebars, FRP bars have the properties of corrosion resistance and high strength, but their elasticity modulus is relatively small. Therefore, FRP reinforced concrete has great application prospects in freeze-thaw, saline and other environments. Similar to reinforced concrete, the study of the bond behaviors between reinforcement and concrete is one important factor to measure the working performance of FRP concrete, which is related to the failure behavior and various mechanical properties of FRP concrete. It is of great significance to research the bonding performance among concrete and FRP bars. After consulting the relevant experiments and literature of predecessors, it is found that the research on the bonding properties of FRP bars and concrete is very extensive, and the influencing factors of the bonding properties between the two are an important study direction. In the research experiments of Xu and Shen, the bonding performance can be affected by the following factors, including the properties of the reinforcement, the type of concrete, the structure of the reinforcement and the concrete, and the use environment of

the concrete components [2-3]. However, after summing previous studies, it was found that most of the research experiments used different concrete components and there was no relatively uniform standard at the moment for the selection of reinforcement and concrete, which made the results of different studies not have strong comparison and difference. It is difficult to summarize the influencing factors of FRP bars. Thus, this article briefly introduction the common test methods for the determination of bonding properties, and focus on three factors that influence the bonding properties of concrete and FRP bars, then analyze and compare them, summarize the common problems and give improvement suggestions of the current research for subsequent analysis and research.

2. Experiment methods

The bonding stress can transmit the stress between the FRP reinforcement and the concrete, so that they can be stressed together, and it is a significant index to measure the bonding property of the FRP reinforcement concrete. Due to the inhomogeneity of the concrete itself and the influence of many factors on the bonding position of FRP bars, it is difficult to have a bonding test method that can reasonably and accurately reflect the bond behaviors among FRP bars and concrete. At present, there are three main test methods: pull-out test, axial tension test and beam test.

2.1 Pull-out test

The pull-out test (The pull-out test device is shown in Figure 1) method is convenient and simple to operate, clear in theory, low in cost, and easy to analyze data. It is widely used in the research of the bond behaviors of FRP bars and concrete. However, due to different stress states of the FRP bars at the free and loading end in this method, the test data will deviate from the actual stress at the FRP end to a certain extent; and the concrete is prone to splitting during the pull-out test, so it cannot reflect the whole process of bond behaviors among concrete and FRP bars.

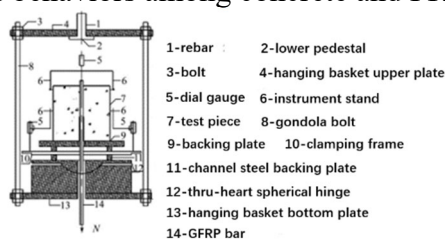


Figure 1. Pull out test [4]

2.2 Axial tension test

The axial tensile test (The axial tensile test device is shown in Figure 2) can measure the local bond force and relative slip in cracks, which is good for simulating the bond characteristics of the main crack of the pure bending section of the concrete and the bond characteristics of the lap joint of the steel bar. effect, so the application is very common. However, due to the existence of a pair of axial balance tensions in this method, it is difficult to satisfy them at the same time, so errors are prone to occur.

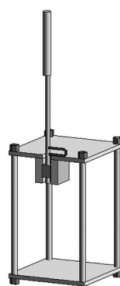


Figure 2. Axial tension test [5]

2.3 Beam test

Beam test (The beam test device is shown in Figure 3) is divided into full beam type and half beam type test. This method is more connected with the actual stress state of the component, and can simulate the real stress state of the component well with high precision. However, the size of this method is too large, the production is difficult and the cost is high, so it is rarely used. At present, many tests use the semi-beam type, which is also highly consistent with the actual stress state of the member and the force transmission is simple.

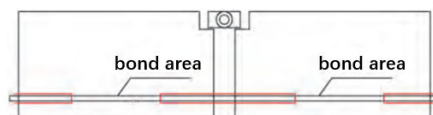


Figure 3. Beam test [6]

3. Influencing factors of the bond behaviors between concrete and frp bars

3.1. Type and strength of concrete

3.1.1. Concrete Strength

Shi et al. [7] studied that increasing the strength level of concrete can improve the shear and tensile strength of concrete, and has a certain promotion effect on enhancing the bond strength. But the effect is not significant. With the change of factors such as the diameter of FRP bars, it also has a certain effect [7]. Through experimental research, Zhang et al., found that within a certain range, the bond intensity of AFRP (Aramid Fiber Reinforced Polymer) bars increases with the enhancement of concrete strength. When the concrete strength is high, the bond strength does not change significantly [8]. It can be seen from the above that the conclusion that the bonding performance increases with the enhancement of concrete strength is partly established for the concrete structural members of FRP bars. However, there is a certain range limit, and the effect of promotion is not obvious.

3.1.2. Concrete Type

Yang et al. [9] thought that the bond failure form of BFRP (Basalt Fiber Reinforced Polymer) bars and coral concrete and the bond failure form of ordinary concrete did not show obvious difference through the central pull test.

Gao et al. discovered that the bond strength of PVA fiber reinforced concrete and FRP bars was above 23MPa, which was higher than the bond strength of BFRP bars and general concrete, and the residual bond strength was greater [10].

It can be seen from the above that there is no accurate conclusion about the change of the bonding performance with the different types of concrete. There are some types of concrete that can promote the bonding performance of FRP reinforced concrete, but there are also changes in the type of concrete that affect the bonding strength. In the case where the influence is not obvious, more research and experimental analysis of different specimens are required.

3.2. Surface shape and surface treatment methods of FRP bars

3.2.1. Surface shape of FRP bars

The research of Zhang obtained the main factors affecting the bond strength of FRP bars and concrete with threaded surface through the experimental study of 20 FRP bars pulled out [11]. It is found that the shape of the surface could impact the bond strength, and a calculation method model of FRP reinforced concrete members bond stress with threaded surface is further established. Figure 4 shows that the relationship of shear stress and slip distance, the figure shows that a slip distance exists lead to the maximum shear force.

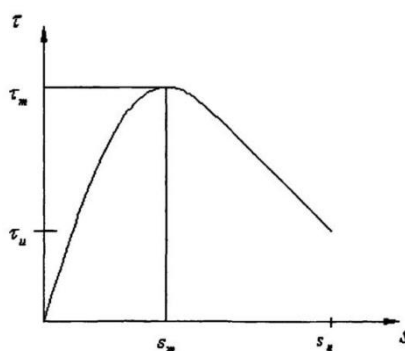


Figure 4. The bond-slip relationship model between concrete and threaded surface with sand of FRP bar [11]

Specifically, for the FRP reinforced concrete pull-out specimen, before the free end slips, the bond between the reinforcement FRP and the concrete is influenced by the chemical adhesive force and initial Slip loads are close. In order to better analyze the pull-out test, the test of FRP bars is divides by the author into four parts: micro-slip section, slip section, descending section and residual section. The adhesion force of the FRP bar with the threaded surface is mainly provided by the friction force and the mechanical bite force, but relatively speaking, the friction force plays the main role. In the pull-out experiment, the damage of the outer rib of the FRP bar or the peeling of the FRP bar at the core is not the reason for the failure mechanism, but the shear slip between the thread bulge on the surface and core of the FRP bar is the reason, resulting in longitudinal shearing. cut damage. This failure mechanism can effectively explain the direct effect of the surface shape of FRP bars on the bonding properties.

3.2.2. Surface treatment methods of FRP bars

The research of Fahmy showed that the reinforcement surface treatment has a significant influence on the bonding properties of BFRP reinforcement and concrete [12]. Figure 5 shows the tester of this experiment. The different surface treatment methods have different phenomena and mechanisms, the BFRP bars coated with sand have the advantage of improving bond stiffness. And the increase of the compressive strength of concrete also leads to the bond strength increased, and less impact on the other bond-slip behavior properties. The bond-slip relationship of sand-dipped BFRP bars is also closely related to the bar surface shape. In addition, the geometric details such as the width and the height distance of the rib spacing can affect bond-slip characteristics.

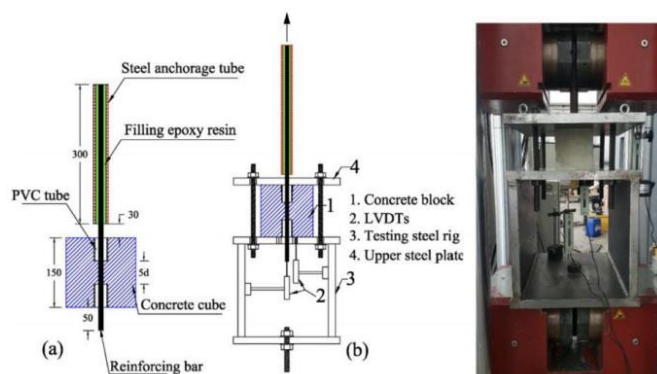


Figure 5. Bonding performance tester (left: schematic diagram; right: actual image) [12]

As show in Figure 6, bond stress and the slip at free end with different surface treatments has different relationship. The smooth BFRP bars with surface treatment has a significant influence on all aspects of bonding properties. Overall, the surface treatment of BFRP bars has higher bond and residual bond strength. The wound FRP bar greatly improves its bond strength, and improved degradation rate of bond stress. The sand coated method strengthens the chemical bonds and prolongs the bond capacity, but has no impact on the strength. The wound FRP bars has bond-slip relationship

different from different surface treatments, and has small impact on the bond properties. Finally, the experimental results of FRP bars with different diameters show that the bond strength is impacted by the diameter of the FRP bars, while the geometric details of the surface shape of the FRP bars have a greater influence on the bond properties.

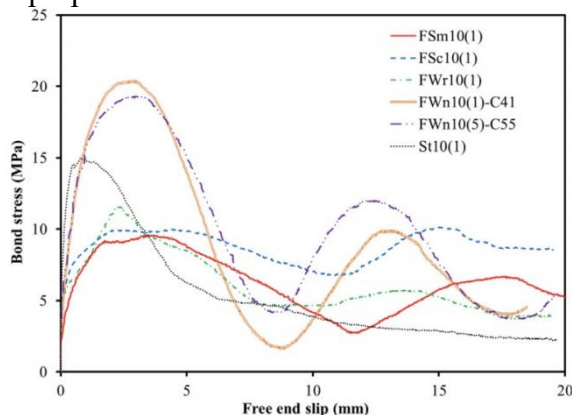


Figure 6. Relationship between bond stress and the slip at free end with different surface treatments [12]

The bond-slip relationships for wound BFRP bars are directly effected by surface shape of the bars, shown by the anti-bond mechanism of wound BFRP bars. The height and width of rib spacing could be other factors that affect bond performance.

3.3. Environmental factors

The service environment of FRP reinforced concrete has an important influence on its bond behavior. Relevant studies have done several experiments on the bond behavior under various unfavorable factors such as freeze-thaw cycle, high temperature, low temperature, chloride salt, lye, dry-wet cycle.

3.3.1. Bond behavior under high temperature

A high temperature environment refers to an ambient temperature where it exceeds the comfort level of the human body. In some extreme situations such as fire situations, the environment can also be called a high temperature environment.

Liu and Zhu [13] studied the bond behavior of basalt fiber reinforced plastics (BFRP) bars and hybrid fiber recycled aggregate concrete (HFRAC) through central pull-out test after high temperature. The target temperatures for the experimental setup were 20, 100, 200, 300, 400, and 500 °C. As Figure 7 shows, recycled concrete's bond elastic modulus progressively declines as temperature rises, and peak bond strength initially rises and then falls as temperature rises. The peak bond behavior between BFRP and regular aggregate concrete (RAC) is, however, steadily declining. Concrete performance is the dominant factor before 300°C, while after 300°C it is mainly influenced by the performance of BFRP bars.

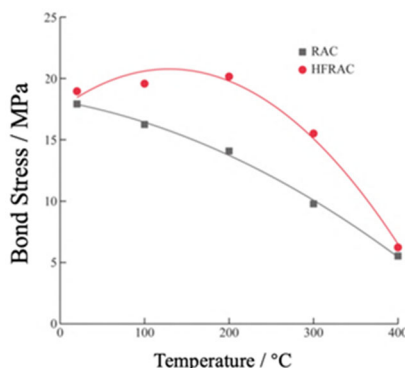


Figure 7. Peak bond strength curves for specimens made of RAC and HFRAC [13]

Wang et al. [14] carried out the pull-out test on the surface sandblasted glass fiber reinforced plastic (GFRP) bars and basalt fiber reinforced plastic (BFRP) bars at high temperature and obtained the bond strength and slip curves with temperature between 20~350 °C. The findings of the study demonstrate that the bond behavior between FRP bars and concrete deteriorates noticeably as temperature rises. As Figure 8 illustrates, the attenuation of the bonding force is concentrated in the epoxy resin's glass transition temperature range at 60 to 120 °C, and at 200 °C, the bonding force is just 15% as strong as it is at ambient temperature.

Overall, the binding behavior of FRP bars and concrete is greatly influenced by the high temperature environment, and as temperature rises, so does performance. Although extreme conditions like fire may occur in real-world circumstances, the temperature chosen for high temperature research is typically modest. Therefore, more research into the behavior of bonds in situations with greater temperatures is required.

3.3.2. Bond behavior under freeze-thaw cycle

Freeze-thaw cycles refer to the alternating occurrence of freezing and thawing of the moisture contained in the surface and interior of a structure. This phenomenon is very common in plateau areas, and it is easy to cause diseases on reinforced concrete structures.

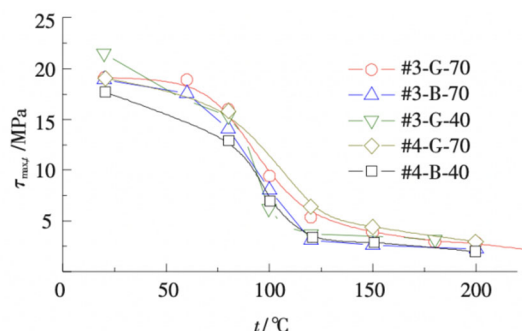


Figure 8. Attenuation of bond strength with temperature [14]

Jin and Yang [5] used a basalt fiber reinforced plastic (BFRP) bars structure with embedded reinforcement. Through the cube compressive test, the static tensile test of BFRP reinforcement and the pull-out test of embedded FRP reinforcement concrete before and after freezing and thawing, the bond behavior of embedded BFRP reinforcement and concrete under the action of freezing and thawing cycle was studied. The research results show that the increase of the number of freezing cycles will have a deteriorating effect on the concrete, resulting in the degradation of the bond behavior of FRP and concrete. Under the influence of different degrees of deterioration of concrete and bonding materials, the failure mode of concrete will change. Meanwhile, within 50 cycles, the bond behavior decreased to a lesser extent.

Liu et al. [15] studied the bond strength between glass fiber reinforced plastic (GFRP) bars and concrete through the material property test of GFRP bars and concrete before and after freezing and thawing, as well as the adhesion test of different diameters and buried depths. The test findings demonstrate that under the influence of restricted freeze-thaw cycles, the ultimate bond strength of GFRP bars and concrete reduces by around 10%. Meanwhile, for GFRP bars with smaller diameters, its mechanical properties are greatly affected by freezing and thawing.

In conclusion, the bond behavior between FRP bars and concrete will decrease as the quantity of freeze-thaw cycles grows. However, with a short number of cycles, the drop in bond behavior is rather minor. The mechanical characteristics of concrete and FRP bars themselves are more impacted by the freeze-thaw cycle.

3.3.3. Bond behavior under low temperature

Zhou et al. [15] independently developed a temperature-load integrated test chamber for low-temperature, to study the effect on bond behaviors in low temperature. The research results show that in the range of -10~-30 °C, with the decrease of temperature, the bonding strength of the two tends

to increase obviously. Meanwhile, by controlling variables, it is concluded that the bond strength will increase if the FRP bars have a larger diameter or shorter bond length as Figure 9 shown. (8-5D-20 represents that the diameter of FRP bars is 8mm, the bond length is $8 \times 5 = 40$ mm, and the experiment temperature is -20 °C)

Li et al. [6] devised a test device for low temperature that can realize mechanical loading and strain testing to conduct beam pull-out tests on FRP reinforced concrete specimens. On the bond behavior of FRP bars and concrete, the effects of temperature, FRP bar diameter, and FRP bar-concrete anchorage length were tested. According to the study's findings, the bond behavior between reinforcement and concrete is improved by 15.5% to 40% as the temperature drops from -10 °C to -30 °C. It also degrades with longer anchoring lengths and smaller FRP diameters.

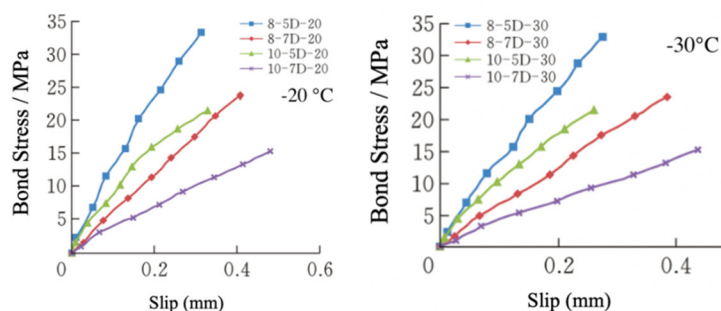


Figure 9. Bond stress and slip curves of each specimen at -20 °C and -30 °C [15]

In conclusion, in the range of -10 ~ -30 °C, the results are basically the same: the bond behavior increase with the temperature decreasing and will also increase if the FRP bars have a larger diameter or shorter bond length.

Relevant studies generally have little research on the low temperature environments, and most of the research devices are independently developed and designed. In addition, the temperature range of experimental research is also limited. It is necessary to further improve and unify the experimental methods and devices, and the research at lower temperatures should be conducted.

4. Conclusion

Regarding the influence of various factors on the bonding properties of FRP bars and concrete, scholars around the world have conducted a large number of experimental researches and analysis on theories. This paper summarizes and analyzes several main influencing factors. Through the analysis of the current domestic and foreign research results in this area, the suggestions are put forward

(1) The central pull-out experiment is generally used in most conditions, which is different from the stress of components in actual engineering, and the experimental method needs to be further improved.

(2) Currently, there have been a lot of researches on the impact of environmental factors all around the world, but the experimental environment and conditions are still different from the actual engineering application scenarios, and there are few studies on some extreme high and low temperature situations. In addition, most of the experimental equipment in the low temperature environment is independently developed, and there is no more general and universal experimental equipment used, and the experimental temperature is also relatively limited.

(3) There is a basic consensus on the influence of concrete types on the bonding performance of FRP bars and concrete. Within a certain range, the improvement of concrete strength will enhance the bonding performance, and the change of concrete types will also promote the bonding performance. However, the results of some experimental examples are not obvious, and more and more comprehensive studies on the effect of concrete performance on the bond behaviors are needed.

(4) On the basis of the research on the bond behaviors of concrete and FRP bars, the stress experiment of FRP bars and concrete can be further taken as the research object of the next stage. It

is meaningful to link the specific mechanism of bond behaviors between concrete and bars and the mechanics of concrete Performance for deeper analysis.

(5) When studying the bonding properties of FRP bars after surface treatment, the specific proportions of friction force, chemical bonding force and mechanical occlusal force can be analyzed, and further analysis can be taken in the specific effects of the three forces on bonding properties.

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