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Experimental research on bond performance between GFRP bar and concrete under single-ended pullout conditions

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ABSTRACT

Fiber Reinforced Plastic bars (FRP bars) are widely used in structural engineering. Bonding performance between GFRP bars and concrete is the key problem to both working together. In this paper, the bonding properties between GFRP bars and concrete were studied by single-ended pullout test method. Studies show that: The bonding force of GFRP bars and concrete consist of chemical glue force, interface friction force and mechanical bite force; the failure mechanism of ribbed GFRP bars and plain GFRP bars in the process of the experiment were analyzed respectively in this paper; the GFRP bars and concrete bond failure modes include load-side GFRP bars brittle fracture and FRP bars pull failure; The influence factors such as diameter of GFRP bars, bonding length, strength grade of concrete and loading speed on bonding strength between FRP bars and concrete were analyzed.

1. INTRODUCTION

The durability problem of reinforced concrete structure is mainly manifested in the concrete cracks and crisp cracks. The cracks make steels exposed to the environment and lead to steel corrosion, and eventually weaken the bond anchoring effect between steel and concrete, so the core problem of durability is the corrosion of steel. In order to completely solve the reinforcement corrosion problem, in the 1980s a new material rose in the construction field - fiber reinforced polymer, FRP for short.

FRP bar is fiber-reinforced polymer which is made from multi-strand fibers strengthened by pulling-extrusion after gluing the matrix material, which high-strength fibers include carbon fibers, glass fibers and aramid fibers, and the matrix materials include various resins such as polyamide resin, vinyl resins and epoxy resins. The surface forms mainly have sticky sand, around the ribs, deformation and fabrics. The advantages of FRP bars are lightweight, high strength, corrosion resistance, fatigue resistance, strong binding capacity with materials, etc. Now it widely used in hydraulic engineering, bridge engineering, marina engineering, etc. Whether as a force tendon or reinforcement, the bonding properties between FRP bars and concrete are the key issues to determine the

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two materials coordination working.

2. SINGLE-ENDED PULLOUT EXPERIMENT

2.1 Experiment materials

FRP bars in the experiment were made by Huainan Jinde Industry Limited Company, where in the glass fiber volume fraction is about 70% and the resin matrix volume fraction is about 30%. The ultimate tensile strength of GFRP bar is 730MPa. Concrete strength grade is C20, C25 and C30, respectively, and the measured average compressive strength of the cube is 30.224MPa, 34.067MPa and 39.09MPa, respectively.

2.2 Experiment method

The instrument used to experiment is INSTRON universal testing machine, loading speeds are 0.2mm/min and 0.4mm/min. Test Specimens use 150mm × 150mm × 150mm cube standard test blocks and the single-ended pullout test was proceeded as shown as in Figure 1. In order to prevent the squeezing action of the ends of concrete when pulled GFRP bars, two plastic tubes were set in loading end and free end of bar which was embedded in concrete (shown in Figure 2). It can effectively avoid the impact of the concrete compression.

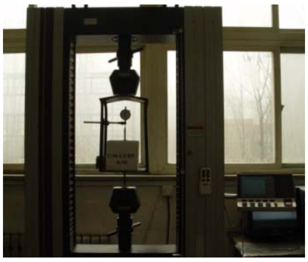

Fig. 1 The test device site diagram

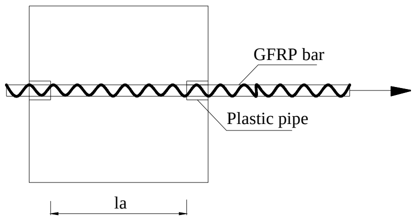

Fig. 2 Standard test block schematic diagram

3. ANALYSIS OF THE EXPERIMENT RESULTS

3.1 Failure mechanisms

As same as the bonding mechanism between steel and concrete, the bonding force of GFRP bars and concrete consist of chemical glue force, interface friction force and mechanical bite force. During the test, for different types of GFRP bars, the failure mechanism is different.

In the initial stage of test for plain GFRP bars, that is the straight up stage of load-displacement curve (F-S curve for short), chemical glue force plays a major role, meanwhile the bonding force may also include pressures generated by concrete shrinkage and expansion of GFRP bars. As the load increases, the chemical glue force gradually loses efficacy along the loading end to the free end of GFRP bars, the glue bond coefficient is the slope of the straight up stage. When the load reaches the maximum value Fu, the chemical glue force is completely ineffective, the curve gets into the downward stage, the bonding force is mainly interface friction force until entering the horizontal stage to destroy the specimen.

In the initial stage of test for ribbed GFRP bars, that is the curvilinear up stage of load-displacement curve (F-S curve for short), the bonding force mainly include chemical glue force and mechanical bite force generated between the rib and the concrete and the mechanical bite force plays a major role. As the load increases, the chemical glue force and mechanical bite force lose efficacy and the destruction of mechanical bite force is divided into two kinds: One is when the concrete strength is high, protruding ribs were stripping failure by concrete, mechanical bite force becomes ineffective; Another one is when the concrete strength is too low, the intercostal concrete splitting failure occurs, mechanical bite force becomes ineffective. Soon afterwards the F-S curve gets into downward stage, interface friction force plays a major role. After the destruction Due to the concrete residues on the interface of GFRP bars or remnants of the ribs, the unevenness of the interface increases, when the displacement increases, there may be slight mechanical occlusion phenomenon, making the F-S curve occurs residual rising stage. But for the most of specimens, as interface friction force decreases, the curve decreases slowly until entering the horizontal stage to destroy the specimens.

3.2 Failure modes

The single-ended pullout tests were carried out based on 68 test blocks. The failure modes include load-side GFRP bars brittle fracture and GFRP bars pull failure. GFRP bars pull failure includes ribs stripping failure and intercostal concrete splitting failure. Figure 3 to Figure 5 are several typical types of failure modes.

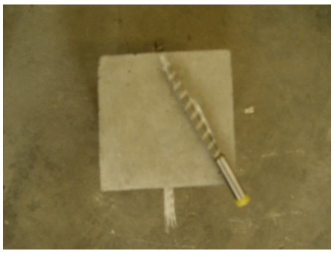

Fig. 3 The load-side GFRP bars brittle

Fig. 4 The ribs stripping GFRP bars

Fig. 5 The intercostal concrete splitting failure T

The characteristic of load-side GFRP bars brittle fracture is that GFRP bars rupture in the roots, the test ended with a loud noise "bang", and the slip of loading end and free end are very small, almost non-slip. This damage occurs for two reasons, firstly, GFRP bars in the production process exist flaw and tensile strength is very low, it can easily reach the ultimate tensile strength under a small force; secondly, the concrete strength is so high or bonding length is so long that the bond stress is higher than the ultimate tensile strength of GFRP bars. This damage occurs to the specimens with bonding length 120mm, diameter 10mm.

The characteristic of GFRP bars pull failure is that the slip of load-side increased accompanied by the testing process, GFRP bars slowly pulled out and eventually led to destruction. This damage will occur when the bonding length is too short or concrete strength is too low.

4. INFLUENCING FACTORS OF BOND STRENGTH

4.1 Diameter

The effect of diameter on the bonding strength is as shown in Figure 6, where L represents the bonding length, V represents the loading velocity, D represents diameter, τ represents the maximum value of bonding strength, the same below. Generally, with the increase of the diameter of GFRP bars, the relative bonding area between GFRP bar and concrete reduce, thus the bonding strength of GFRP bars and concrete decreases. In addition, when pouring concrete, concrete sinking due to weight, concrete bleeding and small bubbles or floating debris when vibrating concrete, etc., thus factors will make the beneath of ribs formed the gap layer. The larger the diameter, the more the laitance and bubbles, the greater the gap, so that the contact area between GFRP bars and concrete reduce, the bonding strength is reduced, and the slip of the loading end increases.

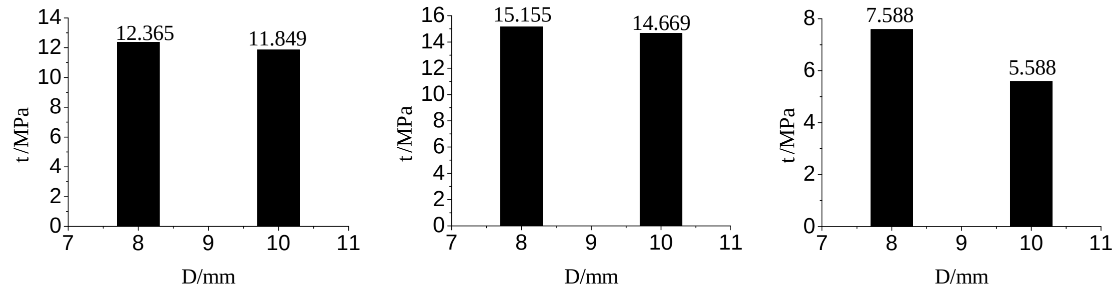

Fig. 6(a) L=90mm, V=0.2mm/min, C20

Fig. 6(c) L=120mm, V=0.4mm/min, C30

Fig. 6(b) L=40mm, V=0.2mm/min, C25

Fig. 6 Effect of diameter on bond strength

4.2 Bonding length

On the premise that diameter of GFRP bars is same, the bonding strength of GFRP bar and concrete decreases with the increase of the bonding length. The reason is that as the bonding length is longer, the distribution of bond stress along the length of GFRP bar is more uneven, the ratio of the average of bond strength at failure and the actual maximum bond strength is smaller, so the bond strength is reduced. The final reason is that the distribution of bond stress along the length of GFRP bar is nonlinear. Figure 7 is the Effect of bonding length on bond strength.

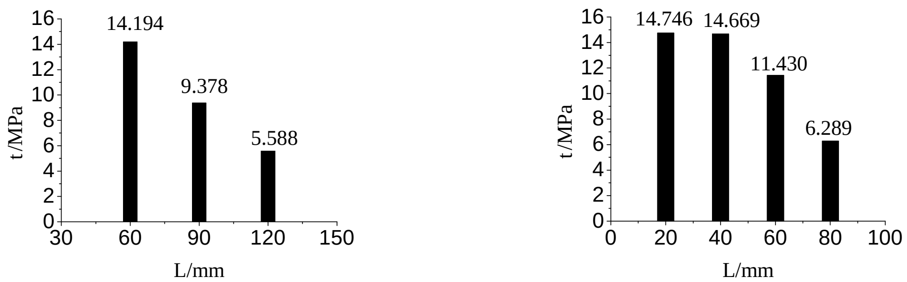

Fig. 7(a) D=10mm, V=0.2mm/min, C30

Fig. 7(b) D=10mm, V=0.2mm/min, C25

Fig. 7 Effect of bonding length on bond strength

4.3 Strength grade of concrete

The effect of strength grade of concrete on bonding strength between GFRP bar and concrete is shown in Figure 8. If the compressive strength of concrete improves, the chemical glue force and mechanical bite force between concrete and GFRP bar will increase. Meanwhile the tensile strength of concrete increases, it can delay the development of cracks inside the concrete, thus it can increase bond stress and bond stiffness of the structure.

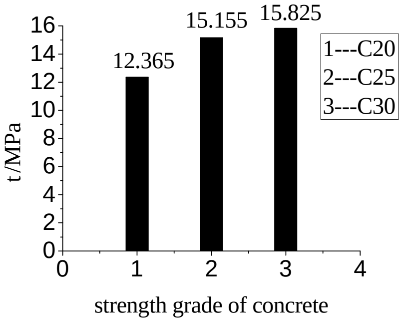

Fig. 8(a) D=8mm, V=0.2mm/min, L=40mm

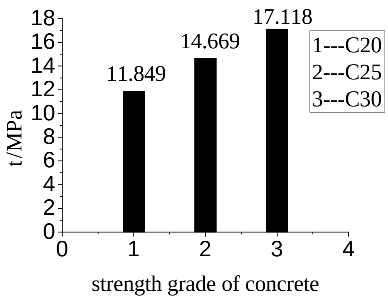

Fig. 8(b) D=10mm, V=0.2mm/min, L=40mm

Fig. 8 Effect of strength grade of concrete on bond strength

4.4 Loading speed

The same as steel tensile test and concrete compression test, as the loading speed increases, the bonding strength between GFRP bar and concrete significantly increases. Because the faster the loading speed, the slower the speed of crack propagation, the measuring bonding strength increases. Figure 9 is the effect of loading speed on bond strength when the strength grade of concrete is C30.

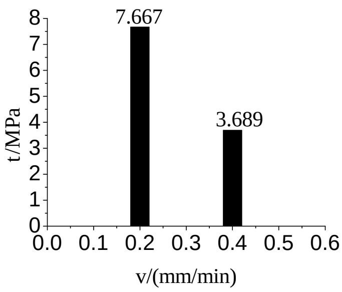

Fig. 9(a) D=8mm, L=90mm, C30

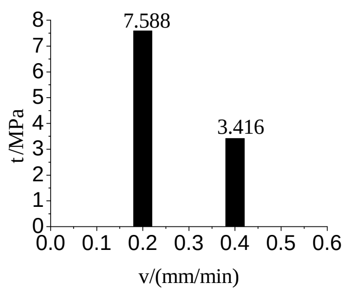

Fig. 9(b) D=8mm, L=120mm, C30

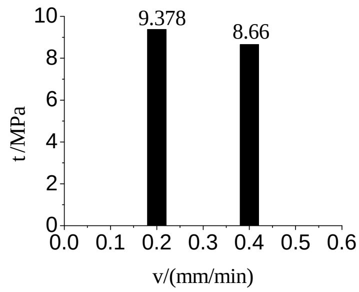

Fig. 9(c) D=10mm, L=90mm, C30

Fig. 9 Effect of loading speed on bond strength

5. CONCLUSIONS

The single-ended pullout experiment was proceeded based on 68 specimens, the bonding properties of GFRP bars and concrete was systematically studied, and the test results are analyzed. We can draw the following conclusions.

(1) The bonding force of GFRP bars and concrete consist of chemical glue force,

interface friction force and mechanical bite force. During the experiment, for different types of GFRP bars, the failure mechanisms vary.

(2) The GFRP bars and concrete bond failure modes include load-side GFRP bars brittle fracture and FRP bars pull failure. GFRP bars pull failure include ribs stripping failure and intercostal concrete splitting failure.

(3) The influence factors include diameter of GFRP bars, bonding length, strength grade of concrete and loading speed. The impacts of various factors were analyzed in this paper.

ACKNOWLEDGMENT

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