ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101

Research on Anchorage of GFRP Anchor Bolts and Heads

Tong Wang[1, a], Zhaochao Huang[1, b] and Xiang Zhang[1, c]

[1] Shandong University of science and technology, Qingdao 266000, China
[a]845606557@qq.com, [b]1368252445@qq.com, [c]604506874@qq.com

ABSTRACT. *GFRP is an abbreviation of Glass Fiber Reinforced Polymer. It is an inorganic non-metallic material made of glass fiber reinforced material, synthetic resin as matrix material, and compounded by a certain process. Although the glass fiber reinforced polymer anchor can fundamentally solve the problem of poor corrosion resistance of the steel bar anchor, in the anchor system, the force on the surface layer or the waist beam needs to be transmitted to the shaft through the anchor head. At present, the pull-out strength of domestic GFRP anchors is far away from the tensile strength of GFRP tendons. This may cause the anchorage system of anchors to fail due to anchorage failure, and the tensile strength of GFRP tendons cannot be fully exerted. When ordinary clip-type anchorages are used, there is a huge clamping force on the ribs in the anchorage zone, which may result in the shear failure of ribs.Based on this, this article uses a high-strength impregnated reinforcement material to carry out the tensile failure test of a GFRP anchored anchorage with a diameter of 18cm. The study found that the use of high-strength reinforced concrete can make the GFRP anchor achieve the maximum tensile strength, and with the increase of curing time, the ability of the high-strength reinforcement to limit the displacement of the anchorage end is stronger.*

KEYWORDS: *GFRP anchor bolt, Bonding anchorage, Ultimate tensile strength*

1. Introduction

The geotechnical engineering mainly focuses on the research of complex geologic bodies. Anchor bolts are often adopted to reinforce the rock and earth mass for the purpose of effectively controlling the deformation of rock and earth mass and avoiding their landslide and collapse. Generally, the solid steel materials are the first choice to make anchor bolts. However, if the steel materials are adopted, we have to face the problem of corrosion of steel, and the corrosion is the prominent problem that affects the safety and durability of the anchorage system, especially in mountainous areas with severe corrosion problems and soft soil areas with abundant underground water. FRP tendons, as the alternative reinforcement material, is an innovative solution to overcome the steel corrosion problem. GFRP is an

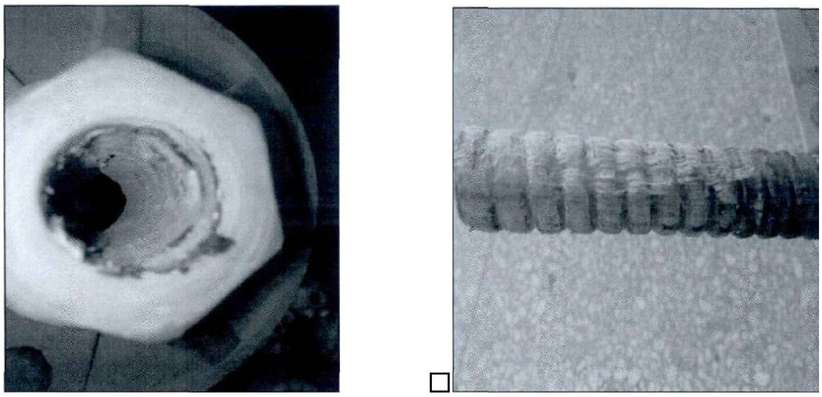
ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101

abbreviation of Glass Fiber Reinforced Polymer. It is an inorganic non-metallic material made of glass fiber reinforced material, synthetic resin as matrix material, and compounded through a series of manufacturing processes, including pultrusion, winding thread, curing and once forming and so on. It is featured with the light weight, high tensile strength, corrosion resistance, fatigue resistance and strong anti-electromagnetic interference capability, and can be used for fiber monitoring [1]. In the engineering, the glass fiber reinforced polymer with so many technical features has attracted much attention, and has been applied in the reinforcement of roads, bridges and concrete [2]. But, the shear strength of GFRP tendons is not very good, which is far below its tensile strength. And it has a poor bending strength, and can't be bent and anchored like a steel anchor bolt. Therefore, when a common clamp anchor is adopted, it will have a huge clamping force for the reinforcement materials in the anchorage zone, and will be highly possible to cause the shear damage of the reinforcement materials, which will make it greatly difficult for the anchor head anchorage of GFRP anchor bolts. Compared with the reinforcing steel bar, the performance of GFRP tendons is of anisotropy and good axial tensile property, but it has a low transverse compressive strength and shear capacity, which makes GFRP anchorage devices can't exert the excellent tensile property of GFRP tendons. Some tests indicated that when GFRP anchors reach the ultimate load, the internal thread of GFRP nuts will be seriously damaged and accompanied by small area local damage on the reinforcement surface. Thus, one of the key factors that GFRP anchor bolts can be widely used is to enhance the anchoring strength of GFRP anchor bolts and anchor heads. This present paper is aimed to make more people involved in engineering know about the GFRP anchor bolts, achieve the purpose of reducing project costs and the durability of anchoring engineering, and provide some reference for GFRP anchor bolts to better serve the rock and earth mass anchorage engineering.

2. Test Scheme Design

Although the glass fiber reinforced polymer anchor can fundamentally solve the problem of poor corrosion resistance of the steel bar anchor, in the anchor system, the force on the surface layer or the waist beam needs to be transmitted to the shaft through the anchor head. At present, the pull-out strength of domestic GFRP anchors is far away from the tensile strength of GFRP tendons. This may cause the anchorage system of anchors to fail due to anchorage failure, and the tensile strength of GFRP tendons cannot be fully exerted. Thus, one of the key factors affecting the extensive application of GFRP anchor bolts is to enhance the anchoring strength of GFRP anchor bolts and anchor heads. The early tests indicated that when the domestic GFRP anchors reach the ultimate tensile load, the internal thread of GFRP nuts will be seriously damaged and accompanied by small area local damage on the thread of anchor body (as shown in Figure 1). Because of the damage of dual interface, there is no way to reasonably analyze the shear strength of the anchor head position.

ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101



(a) Internal Thread Damage of GFRP Nuts (b) Surface Damage of GFRP Tendons

Figure. 1 Damage to GFRP Anchor

Therefore, the bond-type anchors with steel sleeves were adopted in this test. The shear strength of GFRP tendons is low. And in order to prevent that the two ends of reinforcement materials are clamped badly when the tensile strength of GFRP steel materials is not exerted. In this test, the steel sleeves were used to cover the two ends of GFRP tendons, and the high strength filling and reinforcing materials were adopted to fill the gap between GFRP tendons and the steel sleeves. In order to make the bonding between GFRP tendons and steel sleeves stable, threads can be made on the inner wall of the steel sleeves.

So, in order to explore when the bond-type anchors with steel sleeves and the high strength filling and reinforcing materials were adopted, whether it is applicable to the GFRP anchors with the diameter of 18 CM, and whether its largest tensile strength can be exerted.

2.1 Testing equipment

The WAW-1000 Computer Control Electro-hydraulic Servo Universal Testing Machine produced by Jinan Tianchen Testing Machine Manufacturing Co., Ltd. was adopted as the experimental equipment. Such testing machine can realize the automatic loading of the fixed rate under the control of computer, and automatically record the test data. The equipment can provide the maximum test force of 1000KN.

2.2 Test scheme

In this test, a total of two bonding test specimens with GFRP steel sleeves. F61-18 ordinary high torque anchors produced by Nanjing Fenghui Composite Material Co., Ltd. were adopted as the GFRP tendons. With the reference to the provisions of Technical Specification for Grout Sleeve Splicing of Rebars (JGJ355-201) and

ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101

existing experimental literature about FRP tendons concrete, two ends of the GFRP tendons were inserted to the steel sleeves, and the high strength filling and reinforcing materials were adopted to fill and bond the gap. After a period of curing, the WAW-1000 Computer Control Electro-hydraulic Servo Universal Testing Machine was used to conduct the drawing test.

The test was divided into two groups, and two groups of GFRP anchor bolts were conducted according to the above process. But their difference was that, the first group of GFRP anchor bolts was cured for 14 days; while the second group of GFRP anchor bolts was cured for 21 days.

This test, as the destruction test, is aimed to measure the anchoring strength at the anchoring ends of GFRP tendons and the tensile strength of GFRP tendons during the different curing stages. When the GFRP tendons are broken or pulled out from the anchor ends, the test is stopped.

3. Test Results and Analysis

3.1 Test results

During the test process, the test specimen was only broken in the glass fiber part in the middle part of the test specimen and cracked in the resin part (Figure 2). Because the reinforced ends were wrapped with steel sleeves and high strength filling and reinforcing materials, there was no invalid damage at the ends of the test specimen, for example, the part of clamping part were broken or the test specimen was broken away from the clamping chuck, which basically achieved the test purpose.

The drawing test was set as the low-speed loading with the loading rate of 5mm/min. From the test, it could be seen that when the maximum loading tension of GFRP tendons anchor bolts S1 was 181.75KN, the displacement was 11.33cm; while the maximum loading tension of S2 was 185.90KN, the displacement was 11.11cm.

(a) Breakage during the Test Process (b) Destruction Mode of Test Specimen

Figure 2 Breakage of GFRP Test Specimen

In this present paper, the bonding length of the destructive drawing test was 170mm. It is assumed that the bonding force was distributed evenly, and the failure load and peak slip was *, then the ultimate bonding strength of GFRP tendons anchor bolts and high strength filling and reinforcing materials can be calculated according to the following formula:

$$\tau = N/\pi dl(MPa) \quad (1)$$

d - Diameter of GFRP tendons (mm);

1 - Bonding length of tendons (mm);

N - Ultimate drawing force (N).

The results of this drawing test are summarized as below.

Table 1 Result Table of Drawing Test

Test specimen No.	Diameter of test specimen (mm)	Bonding length (mm)	Ultimate load (KN)	Bonding strength (MPa)	Peak slip
S1	18	170	181.75	18.92	11.33
S2	18	170	185.90	19.35	11.11

ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101

3.2 Analysis of test results

3.2.1 Analysis of damage mode

The test specimen was only broken in the glass fiber part in the middle part of the test specimen and cracked in the resin part, and the test specimen was broken into two parts. There was no pull-out damage of anchors at its reinforced ends. It indicated that the bonding force of GFRP tendons and high strength filling and reinforcing materials at the anchoring ends of sleeves met the condition of exerting the ultimate tensile strength of the anchor body itself, and the sleeve bond-anchorage is the effective anchoring method.

On the basis of loading analysis of GFRP anchor bolts, the glass fibre and resin were jointly born the tension during the preliminary stage of loading. Then, the resin yielded firstly, and after its yield point, the resin entered the plasticity strengthening status. At this time, the increment of imposed load was mainly born by the glass fibre. The GFRP anchor bolts lost its bearing capacity after the load bearing of glass fibre reached its breaking strength.

3.2.2 Analysis of Load-displacement Curve

The used test software is the MaxTest Universal Testing Machine developed by Langjie Company. The MaxTest is a king of control and analysis software for the general and special static testing machines, which is suitable for different types of material testing machines through setting different configuration parameters, including computer screen display universal testing machine, computer control electro-hydraulic servo universal testing machine, computer control electro-hydraulic proportional universal testing machine and computer control electronic universal testing machine and so on. There are more than 300 test standards developed for the system.

Based on the actual results of the whole process of two test specimens, S1 and S2, measured by MaxTest, the Load-displacement Curve of GFRP tendons and anchors was drawn (Figure 3 and 4).

ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101

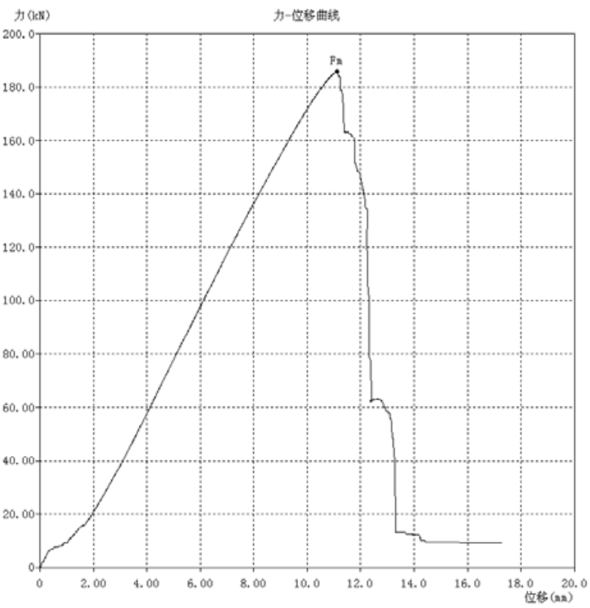


Figure. 3 Load-displacement Curve of Test Specimen S1

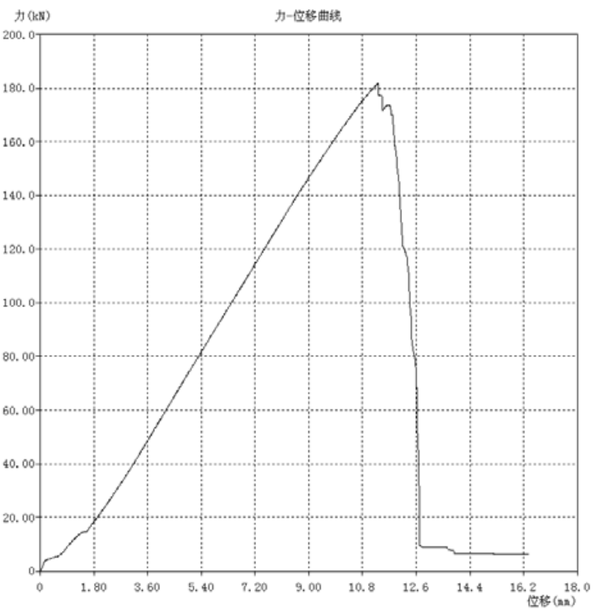


Figure. 4 Load-displacement Curve of Test Specimen S2

ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101

It can be seen that, from the above figure, GFRP tendons are skew lines passing through the original point at the initial stage of loading. During the whole process from the initial loading to the ultimate load, the GFRP tendons basically show the elastic deformation. After reaching the ultimate load, the test specimen was broken, which is a kind of brittle failure. Although the diameters of GFRP tendons in two groups of test specimens are 18cm, their ultimate load values are different, which is affected by the processing environment, material components and other factors. There are some defects in the internal random distribution, resulting in the different tensile strength. But the error is not large, which is in the acceptable range and has no influence on the test results.

The load bearing process of GFRP anchors is divided into two stages.

The first stage is the microslip line elastic stage: when beginning to increase the load, the chemical adhesive force plays a leading role, and there is little or no slip at the loading end. At this time, the load-displacement is in the line elastic stage.

The second stage is the nolinear slip stage: when the load is close to the ultimate tensile strength of GFRP tendons, the chemical adhesive strength begins to lose, and an obvious slip phenomenon appears. The friction force and mechanical interaction play a leading role, instead of the chemical adhesive force. At this time, the curve shows nonlinearity. As the continuous increase of the load, the slip growth is accelerated. The curve tends to be gentle before reaching the ultimate load, and the test specimen is broken after reaching the ultimate load.

4. Conclusion

1) The application of bond-type anchors with steel sleeves as well as pouring the high strength filling and reinforcing materials enable GFRP tendons to reach the ultimate tensile strength, which is the effective anchoring method.

2) During the load bearing process of GFRP anchor bolts, the stress-strain curve is a skew line passing through the original point, which belongs to linear elastic materials.

3) The bonding strength of GFRP tendons and steel sleeves increases with the increase of the curing time, and the displacement of load segment decreases. During the project construction process, anchor bolts with long curing time shall be adopted, which can ensure the bonding strength at the anchoring ends of anchor bolts.

References

[1] MALVAR L J. Tensile and bond properties of GFRP reinforcing bars [J]. Materials Journal, 1995, 92 (3): 276−285.

[2] SEBASTIAN W, GEGESHIDZE G, LUKE S. Positive and negative moment behaviors of hybrid members comprising cellular GFRP Bridge decking epoxy-bonded to reinforced concrete beams [J]. Composites, Part B: Engineering, 2013, 45 (1): 486−496.

ISSN 2663-1563 Vol. 3, Issue 1: 1-9, DOI: 10.25236/AJAGE.030101

[3] LIU H.D., YU X.Z., LI G.W. Experimental Study on Tensile Mechanical Properties of GFRP Anchor Bolts [J]. Chinese Journal of Rock Mechanics and Engineering, 2005, 24 (20): 3720-3721.
[4] LI G.W., GAO L., HUANG Z.H., Et al. Drawing Model Test on Failure Mechanism of Full-length Bonded Glass Fibre Reinforcement Polymer Anchor Bolts [J]. Chinese Journal of Rock Mechanics and Engineering, 2007, 26 (8): 1653 - 1663.
[5] JIANG T.Y., FANG Z. Experimental Study on Anchoring Performance of CFRP Tendon Compound Anchorage [J]. China Civil Engineering Journal, 2010, v.4302: 79-87.
[6] BAI X.Y., ZHANG M.Y., ZHANG S.Q. Experimental Study on Creepage of Full-length Bonded Threaded Glass Fiber Reinforced Polymer Anti-floating Anchors [J]. Chinese Journal of Rock Mechanics and Engineering, 2015, 04: 804-813.