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Experimental and analytical investigation into the stress performance of composite anchors for CFRP tendons

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ABSTRACT

This paper presents a study of the internal stress distribution and its stress transfer mechanism of composite anchors for carbon fiber-reinforced polymer (CFRP) tendons. One set of static tensile test for composite anchor was introduced and carried out. Three zones designated as tension zone, holding zone and compression zone respectively were divided to analyze the stress distribution separately based on some assumptions. Test and analysis results show that the tensile stress and its variation on the steel tube surface will reflect the internal stress distribution of composite anchor. Peak tensile stress exists in the tension zone test points indicates the bonding failure occurs between adhesive and CFRP tendons. The radial clamping action of wedge could effectively enhance the anchoring effect. The obvious decrease of stress curve in the compression zone indicates the bonding damage of entire composite anchor occurs.

1. Introduction

In civil engineering, the employment of fiber reinforced polymer (FRP) materials is increasing due to their notably advantages over conventional materials inclusive of light weight, high mechanical properties and corrosion resistance [6,9,13,24]. Extensive studies have been made to examine the overall behavior of FRP-reinforced and strengthened concrete members [3,5,7,8,11,12,16,17,19,22,28–30]. In the field of external prestressing, FRP composites are promising to be widely used as external tendons for the rehabilitation and construction of various engineering structures [26,27]. Among the FRP composites, carbon FRP (CFRP) is considered as replacement for the conventional prestressed steel [1,4,20,21,26,27].

Currently, three anchor systems can be used to attach the tendon of composite material to the concrete structure: mechanical (wedge-type) anchors, adhesively bonded anchors and composite anchors. The first is based on the current anchors for steel tendons and is not considered entirely successful because the wedges tend to dig into the composite material causing premature failure [23,24]. For this reason, adhesively bonded anchorages are being investigated to attach composite material tendons to the anchor structure. An adhesive bond-type anchorage consists of a steel tube inside which single or multiple tendons are bonded with an adhesive. These joints are increasingly being utilized because of their recognized advantages over the mechanical anchorages [20,21]. The overall properties of a bond-type anchorage depend mainly on the geometry of the materials involved in the joint and the properties of the adhesive [2,18,25]. The third anchor system is composite anchor, which combine the advantages of adhesively bonded anchorages and mechanical clamping anchorages. Therefore, it has better anchoring performance [7,14,15]. This paper presents a test investigation conducted to evaluate the internal stress distribution and stress transfer mechanism in the composite anchor system.

2. Experimental work

2.1. Composite anchors

The sketch map of the composite anchor, as shown in Fig. 1, was tested under static tensile load in this study. The CFRP rod, which has a surface roughness, is 8 mm in diameter. The content of fiber is around 40% by volume. The tensile strength of the CFRP was 2720 MPa and the average limit breaking force is 138.6 kN. The adhesive used was a low viscosity polyamine cured epoxy. The modulus of elasticity of the adhesive was 260 MPa. The thickness of the adhesive is 2 mm. The tensile and compressive yield

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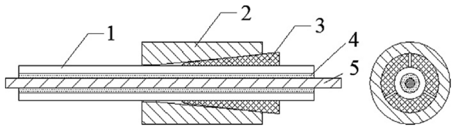

Fig. 1. Sketch map of the composite anchor (1-Steel tube; 2-Anchor ring; 3-Wedge clamping; 4-Adhesive; 5-CFRP rod).

stresses are 17.3 and 27.2 MPa respectively. The CFRP rods were set in No. 20 # seamless steel tubes through the adhesive epoxy. The length of the tube is 400 mm, and the tensile strength is 410 MPa and the modulus of elasticity 21.1 GPa. An anchor ring, which was clamped by mechanical wedge, was set outside the tube. The diameter of the anchor ring is 18 mm and the length of wedge clamping is 65 mm.

Compared to the mechanical anchors and adhesively bonded anchors, the composite anchors used in this study would be preferable since the wedge clamping can increase the friction force and improve the anchoring efficiency. Meanwhile, the steel tube and adhesive bonded to the CFRP rod can protect the tendon from damaging of wedge clamping.

2.2. Test setup

Fig. 2 shows the test up using the composite anchor, where 6 strain gauges were installed along the outer wall of steel tube. According to the strength performance of steel tube, three different zones can be observed, which were denoted as tension zone, holding zone and compression zone respectively. Gauges A-1, A-2 and A-3 were pasted in the tension zone and Gauges A-4, A-5 and A-6 were in the compression zone.

Static tensile load was applied in increments of 20 kN until the failure occurs to the CFRP tendon using center hole hydraulic jack with loading rate varying form 300 MPa/min to 400 MPa/min. When each incremental load was applied, allow 5 min between load increments and record the strain gauge reading.

2.3. Test results

During the test, when the tensile load was about 110 kN, a slight sound of fiber fracture can be heard. Finally a sliding failure between CFRP tendon and adhesive can be observed at the load of about 138.6.7 kN and the corresponding ultimate strength was 2720 MPa. The efficiency coefficient η_a of the CFRP tendon-anchorage assembly can be calculated according to the technical specification [10]. The calculated $\eta_a = 98.6\% > 95\%$ using the equation of $\eta_a = F_{apu}/(\eta_p F_{pu})$, where F_{apu} is the measured ultimate tensile force of tendon-anchorage assembly; F_{pu} is the ultimate tensile force of the tendons; η_p refers to the efficiency coefficient of the tendons, when the number of tendons or bars vary from 1 to 5, and here $\eta_p = 1$.

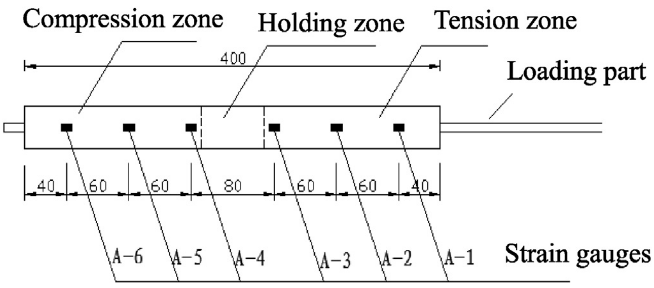

Fig. 2. Sketch map of test setup (in mm).

Based on the data of strain recorded by six strain gauges under different applied tensile load, tensile stress can be calculated. Fig. 3 shows the relationship between the tensile stress calculated and the applied tensile load. Under different load increments, designated as 20 kN, 40 kN, 60 kN, 80 kN, 100 kN, 120 kN, 130 kN, strains were measured and tensile stresses were calculated at different strain gauges. Fig. 4 shows the tensile stress distributions along the steel tube under different load increments.

3. Stress distribution analysis of composite anchor

The stress distribution of composite anchor is more complicated than mechanical anchors or adhesively bonded anchors due to its complicated structure, as shown in Fig. 5. It can be seen in Fig. 5 that three different zones inclusive of compression zone, holding zone and tension zone respectively were differentiated due to the load-bearing mechanism. In Fig. 5, F_r is the radial holding force of anchor ring and wedge clamping, F_t is the shear force between wedge clamping and steel tube, l_1, l_2 and l_3 are the lengths of tension zone, holding zone and compression zone, respectively. The stress performance at different zones was analyzed in the following sections.

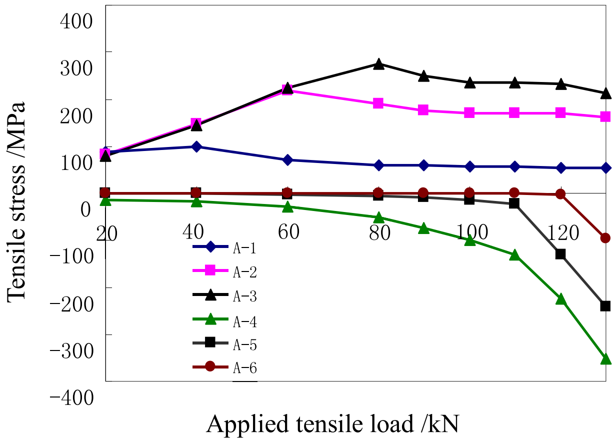

Fig. 3. Axial stress variation curves.

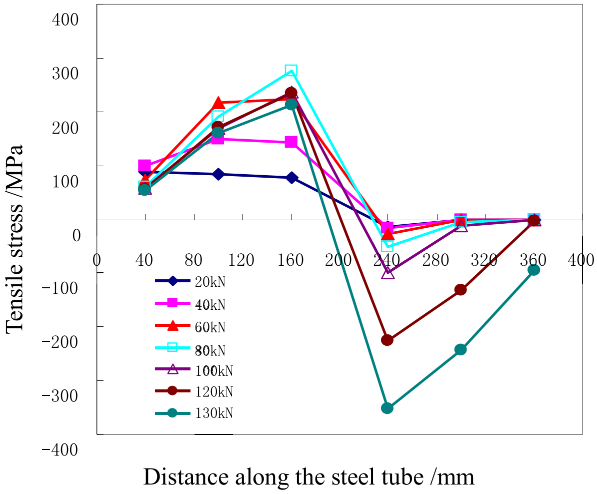

Fig. 4. Tensile stress distributions along the steel tube.