Experimental Study on Failure Mode and Ultimate Shear Bonding Force of CFRP Plate-Steel Interface under Anchor Compression

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Abstract. In order to study the paste failure mode and ultimate shear bonding force of CFRP plate-steel interface anchor bonding, a single-sided shear test was carried out on a total of 15 carbon fiberboard (CFRP)-steel composite beam structure specimens in five groups. The test results show that for organic adhesives, the uniform anchoring method can improve the bearing capacity of the construction; for organic adhesives, the ultimate shearing when the specimen is peeled with inorganic glue is used. The bonding capacity is greater than that of specimens with organic adhesives.

1. Introduction
Fiber Reinforced Plastic (FRP) especially Carbon Fiber Reinforced Plastic (CFRP). CFRP as a new type of reinforcement material, Technology has been relatively mature in the field of concrete, it adopts adhesive carbon fiber for reinforcement and repair. However, the application of FRP as a new material in new structures is relatively lagging. The reason is that FRP materials have the disadvantages of poor elastic modulus, brittle failure, and inability to weld.

In order to make up for the shortcomings of FRP materials and give full play to their advantages, some scholars at home and abroad have put forward a solution to combine FRP-steel composite materials with steel in recent years. It is mainly to change the morphology of steel members through physical or chemical methods, such as anti-corrosion paint on rigid surfaces, sandblasting technology, laser ablation, groove treatment of rigid surfaces, etc[1]-[3]. All of which are aimed at increasing the roughness of the surface of steel structures and making steel components. There is a better bonding force between CFRP; or a certain amount of adhesive is treated to achieve a certain glue effect by changing the mixing ratio of the adhesive or adding a certain amount of fiber as a bridging medium in the adhesive[4].

The reinforcement structure of the prestressed CFRP plate has great advantages over the rest of the methods, giving full play to and utilizing the excellent characteristics of the CFRP plate, without the anchorage system with excellent anchorage performance. At present, carbon fiber plate anchors abroad have been commercialized, and there are still some problems in China. It is of great significance to develop anchors that are simple to manufacture and easy to construct with good construction results. In view of this, a single-sided shear test of the carbon fiberboard (CFRP)-steel composite beam structure specimen was carried out. The bonding mechanical properties of the CFRP plate-steel composite interface were studied, including the failure mode of the CFRP plate-steel composite structure interface, the axial stress distribution law of the CFRP plate, and the load-displacement relationship. And ultimate bond shear force.
2. Test Design

2.1. Examination Profile

A total of five sets of CFRP plate-steel composite beam specimens were designed for the test, each with a number of three specimens. The specimen size is H-type steel with a size of 200mm ×200mm×8mm×12mm.

According to the test requirements, the length of H-type steel is 950mm. Due to the test needs, the wing edge and web 150mm of H-shaped steel are cut off to ensure that the specimen is clamped and fixed by the test machine.

During the preparation of the specimen, a polishing machine is used to remove stains and rust marks on the surface of the steel beams, and then clean them with alcohol. After the steel beam is dried, the CFRP plate is pasted with a manual smear adhesive. After the pasting is completed, the specimen is pressurized, and a fixed torque is applied to each bolt. The resulting specimen schematic diagram is shown in Fig1.

Among the bolts designed in the test, due to the use of two types of high-strength bolts, namely, 8.8-level high-strength bolts and 12.9-level high-strength bolts. In the process of combination, the components are mainly divided into the following five types:

- organic non-pressure, organic uniform pressure using 8.8-level high-strength bolts, organic uniform pressure-up with 12.9-level high-strength bolts, organic non-uniform pressured 8.8-level high-strength bolts, and inorganic uniform pressure-level 8.8-level high-strength bolts.

![Figure 1. Schematic diagram of single side cutting](image)
The specimen number is composed of four parts, the first part is the uppercase letters Y or W, Y stands for organic, and W stands for inorganic; the second part is composed of uppercase letters J, F and G, where J represents uniform pressure, F represents non-uniform pressure, and G stands for non-pressure; the third part is composed of numbers 0, 8.8 or 12.9. Composition. 0 represents no bolts, 8.8 stands for high-strength bolts, 12.9 stands for high-strength bolts of 12.9; the fourth part is composed of Arabic numerals 1, 2 and 3, representing 1, 2 or 3 specimens in the same group. For example, Y-J-8.8-1 stands for high-strength bolts for 8.8 levels of uniform pressure.

### Table 1. Main types of specimens

| Trial parts grouping | Bolt type | Sticking method | CFRP processing Method | Glue type | Numbers |
|----------------------|-----------|-----------------|------------------------|-----------|---------|
| A                    | None bolt | Paste directly  | Polish                 | Organic glue | 3       |
| B                    | High-strength bolt of 8.8 | Pressure evenly | Polish                 | Organic glue | 3       |
| C                    | High-strength bolt of 12.9 | Pressure evenly | Polish                 | Organic glue | 3       |
| D                    | High-strength bolt of 8.8 | Pressure unevenly | Polish                | Organic glue | 3       |
| E                    | High-strength bolt of 8.8 | Pressure evenly | Polish                | Inorganic glue | 3       |

2.2. *Test Materials*

The steel beam used in the test is H-shaped steel with yield strength of 235Mpa, stretch strength 400MPa, elastic modulus of 2.06×105MPa, Poisson ratio 0.28, fracture extension rate 40.5%. The selected CFRP plate width is 100mm and thickness is 1.4mm. The measured tensile strength of the CFRP plate is 2523MPa, the tensile strength is 2523MPa, the tensile elastic modulus measured is 1.69×105MPa, and the fracture elongation measured is 1.70%; organic glue and inorganic glue are used. Among them, organic glue adopts Nanjing Tianlixin Technology Industry Co., Ltd. to provide Tianlixin TLS-503B carbon plate glue with 41.3MPa tensile strength, 100.5MPa compression strength and elastic modulus of 6.855Gpa. Inorganic glue is used to paste carbon fiber board with magnesium chloride (MOC), and inorganic glue is a magnesium chloride cement (MOC) binder. The raw materials for the preparation of MOC are industrially lightly calcinated MgO, MgCl2·6H2O, combined with MgO MgCl2=10.75:1 (molar ratio), water: (MgO+MgCl2)=0.45:1 (mass ratio).

2.3. *Add-up Mode and Test Point Destruction*

The loading rate is 0.2mm/min by displacement control. A single strain gauge is arranged at the center line of the carbon fiber plate of the specimen to measure the CFRP bond layer under load. The variation of strain with CFRP board. The measured point strain adopts the DH3816N static strain data collector. The specimen loads the photo as shown in Fig 2.

![Figure 2. The picture of specimen under loading](image)
3. Test Results

3.1. Test Phenomenon and Destructive Form

The test results show that the ultimate bearing capacity of the CFRP plate-steel composite beam structure can be effectively improved by bonding anchoring pressure, and the degree of increasing the ultimate bearing capacity can also change with the different position of the anchor pressure and the change of the strength of the only bolt.

With the increase of displacement, the load increases to a certain extent, and the specimen emits a slight sound, accompanied by a slight peeling sound at the CFRP plate-steel bond interface. At this time, the bond interface at the loading end begins to crack, and the load-displacement curve will appear "serrated", indicating that the CFRP plate-steel composite interface adhesive layer is not very uniform.

As the loading displacement continues to increase, the load increase gradually becomes slow, and the sound made by the specimen is also gradually rapid. When the limit load is reached, the specimen will make a loud noise, the test load will suddenly drop, and the test will end.

In this test, the following types of damage patterns mainly appear: A: loading end failure, B: CFRP plate crack penetration, C: CFRP plate end head tearing, D: CFRP plate with fine lines, E: CFRP plate central extraction, F: CFRP plate/plate layer partial peeling, G: Complete peeling of the CFRP plate produces a large displacement, and the destructive forms in the test are shown in Figures 3, 4.

![Figure 3. Failure mode in test](image1)

(a) The loading end is broken  
(b) Local peeling of CFRP plate/glue layer  
(c) Whole destruction form

**Figure 3. Failure mode in test**

[Image of failure modes]
3.2. Experimental Results and Analysis of Ultimate Shear Bonding Force

The ultimate bearing capacity and final failure form of each group of specimens are shown in Table 2 and Figure 5.

| Test number | Extream shear bonding force(kN) | Average ultimate shear bonding force(kN) | Destructive form |
|-------------|---------------------------------|----------------------------------------|------------------|
| Y-G-0-1     | 53.82                           | 53.71                                  | A, B, F          |
| Y-G-0-2     | 55.92                           |                                        | A, B, F          |
| Y-G-0-3     | 51.40                           |                                        | A, B, F          |
| Y-J-8.8-1   | 97.95                           |                                        | A, B, E          |
| Y-J-8.8-2   | 102.71                          | 99.64                                  | A, B, E          |
| Y-J-8.8-3   | 98.28                           |                                        | A, B, E          |
| Y-J-12.9-1  | 103.42                          |                                        | A, D             |
| Y-J-12.9-2  | 110.52                          | 107.62                                 | A, D             |
| Y-J-12.9-3  | 108.93                          |                                        | A, D             |
| Y-F-8.8-1   | 118.56                          |                                        | A, C             |
| Y-F-8.8-2   | 115.34                          | 115.01                                 | A, C             |
| Y-F-8.8-3   | 111.12                          |                                        | A, C             |
| W-J-8.8-1   | 75.44                           |                                        | A, B, F          |
| W-J-8.8-2   | 70.02                           | 71.55                                  | A, B, F          |
| W-J-8.8-3   | 69.18                           |                                        | A, B, F          |

Figure 5. Ultimate shear bond strength of single shear test

It can be seen from Table 2 that the test results of each group of specimens, the ultimate bond shear bearing capacity are near the average value, and the fluctuation range is relatively small. Under the condition of direct bonding, the ultimate bearing capacity is 53.71 kN, and the ultimate bearing capacity can reach 99.64 kN under the case of 8.8-level high-strength bolts under uniform anchoring, which is 85.5% higher than the ultimate bearing capacity of non-anchorage; the ultimate bearing under 12.9-level high-strength bolts in uniform anchoring. The load can reach 107.62 kN, which is 100.4% higher than the ultimate bearing capacity of non-anchorage pressure, 8% higher than the 8.8-level high-strength bolts for uniform anchoring pressure; the ultimate bearing capacity is as high as 115.01kN when the non-uniform anchor pressure adopts 8.8-level high-strength bolts, which is higher than the ultimate pressure. The limit bearing capacity is increased by 114.1%, 15.4% higher than that of 8.8-level high-strength bolts for uniform anchor pressure, and 6.9% higher than 12.9-level high-strength bolts for uniform anchor pressure. Among them, the ultimate bearing capacity is 71.55 kN is about 71.8% of the ultimate bearing capacity when organic glue is selected under the same conditions.
4. Summary
(1) For organic adhesives, the adhesive is destroyed by uniform anchoring. The anchor pressure method can improve the bearing capacity of the members during the tensile process, and it is shearing and destruction between CFRP plates.
(2) The anchor pressure method makes the component not have a peeling stage, the damage specimen is short, the damage is completed instantaneously, and is brittle damage.
(3) For inorganic glue, the CFRP plate-steel interface bond-slip relationship is divided into ascending stage and descent stage; for organic glue, whether pressurized or not anchored, it is divided into three stages, namely, the ascending stage, the smooth stage and the decline stage.
(4) The ultimate bond shear bearing capacity can be increased by 85.5% to 114.1% by anchoring pressure, and the increase of ultimate bond shear bearing capacity is related to the anchor position and the size of bolting.

5. References
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