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Study on mechanical properties of FRP connectors for precast sandwich insulation wall

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Abstract

In this paper, the FRP connectors commonly used in composite thermal insulation shear wall are studied. Three kinds of FRP connectors are designed, and their pull-out performance, failure mode and load-displacement curve are studied. Through the test results, it is found that the main failure modes of the three anchorage forms of FRP are concrete anchorage failure, and the pull-out bearing capacity is above 15 kN. According to the calculation formula of pull-out bearing capacity, the tensile bearing capacity of FRP connectors is calculated and compared with the test results. The test values of pull-out bearing capacity are more than 1.5 times of the calculated values, and the pull-out specimens of FRP connectors have a good safety reserve.

Keywords

Thermal insulation composite shear wall ; FRP connectors ; pull-out bearing capacity ; mechanical properties.

1. Introduction

At present, the connectors used for the connection of thermal insulation composite shear wall panels in China mainly include steel bar connectors and stainless steel connectors. Both steel bar connectors and stainless steel connectors are isotropic materials. The two materials have good thermal conductivity and are easy to form cold and hot bridges [1], resulting in energy consumption, which is not conducive to the promotion of energy saving and environmental protection concepts. In 2016, the State Council issued the ' Nogan Opinions on Further Strengthening the Management of Urban Planning and Construction ', and the Ministry of Housing and Urban-Rural Development successively issued the ' 13th Five-Year Plan for Building Energy Conservation and Green Building Development '. The two documents clearly define the path of sustainable green building development and reduce pollution [2-3]. As the disadvantages of steel and stainless steel connectors are becoming more and more obvious, fiber reinforced polymer (FRP) connectors are more and more widely used, and there will be no hot and cold bridge phenomenon such as steel and stainless steel. Exploring the mechanical properties of FRP connectors on the whole thermal insulation composite shear wall can provide theoretical and technical support for the application of FRP connectors in thermal insulation composite shear wall [4-5]. In 2011, Frankl studied the insulation layer material, the thickness of the precast layer and the number of connectors of the sandwich wall connected by 6 CFRP plates. It shows that increasing the number of connectors and the thickness of the precast layer can significantly improve the stiffness of the specimen and reduce the overall damage degree of the specimen [6-7]. Insub studied the 18-sided composite shear wall and studied the mechanical properties of different insulation materials and the number of FRP connectors under the influence of wind load. The results show that when the number of GFRP connectors is small, the shear fracture of the connectors occurs. When the number of GFRP connectors is large, the overall bending of the wall occurs. When the number of connectors is appropriate, the shear tear of the insulation board occurs, and the bond failure occurs between the insulation board and the concrete. At the same time, it is found that the friction between the insulation board and the concrete has a certain contribution to improving the integrity of the wall [8]. Tomlinson [9] studied the horizontal and vertical combination of wall connectors, and studied the parameters such as the angle, diameter and force form of the connector inserted into the wall. The research shows that the connector is easy to be pulled out in the tension state and is easy to be crushed in the compression state. The connector with smaller diameter breaks in the tension state and buckles in the compression state. The stiffness of the specimen increases with the increase of the insertion angle and diameter of the connector.

2. Experimental Design

2.1. Specimen Design

According to the " Handbook of Practical Mechanical Engineering Materials " [10], " Technical Standards for Composite Shear Walls with Built-in Thermal Insulation Cast-in-place Concrete " [11] and literature 12, the commonly used connectors are FRP connectors and stainless steel connectors. In this paper, GFRP connectors are used. The three kinds of GFRP used are shown in Figure 1, and the relevant material parameters are shown in Table 1.

Fig. 1 GFRP connectors

Table 1 Relevant mechanical parameters of GFRP

GFRP Type	Tensile Strength / MPa	Tensile Modulus / GPa	Shear Strength / MPa	Bending Elastic Modulus / GPa	Bending Strength / MPa	Cross-sectional Area / mm2
Thread LW	907	62.0	73.9	50.2	1170	78.5
Rectangle R	907	62.0	73.9	50.2	1170	90
Star ST	943	49.0	58.0	38.3	840	160.4

The size of the concrete specimen is 600 × 400 × 150mm, and the depth of GFRP embedded in concrete is 30mm.Three specimens are made for each GFRP connector, and the strength of the concrete used is C40. According to the code for design of concrete structures GB50010-2015, a cube test block with a side length of 100 mm should be made while making concrete specimens, and the test blocks should be cured under the same conditions. The mechanical parameters of the standard test block are shown in Table 2, and the schematic diagram of the designed drawing specimen is shown in Fig.2.

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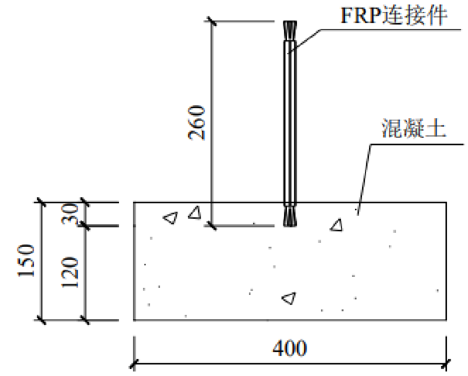
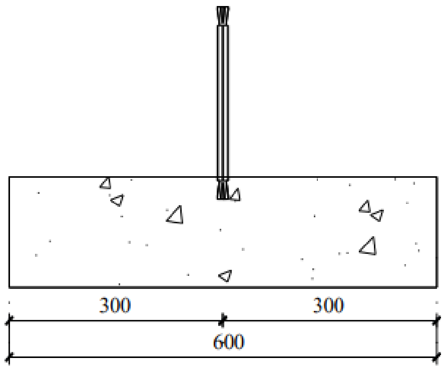
Table 2 Measured mechanical parameters of concrete

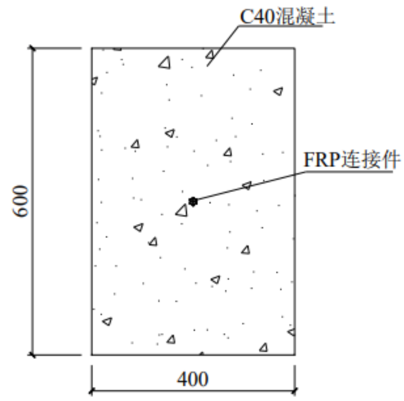
Concrete Strength	Axial Compressive Strength f c / (N / mm2)	Axial Tensile Strength f t / (N / mm2)
C40	27.55	2.35



(a)Front View



(b) Side View



（c）Vertical View

Fig. 2 Drawing Specimen Schematic Diagram

2.2. Test Device and Loading Scheme.

The pull-out test is carried out on the electro-hydraulic servo testing machine, and the loading rate is set to 100N / s. The load-displacement curve of the specimen during the loading process is directly obtained on the computer. In order to ensure that the testing machine clamps the connector in the middle, the steel plate clamping device shown in Figure 3 is used to fix the specimen. The test device is shown in Figure 4.

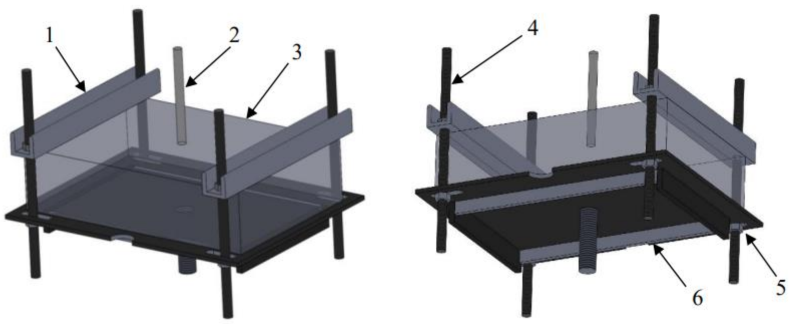


Fig.3 Steel Plate Clamping and Fixing Device

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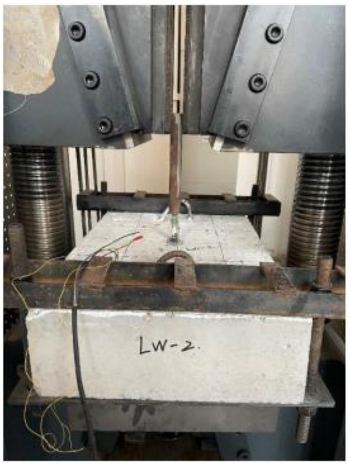

Fig.4 Test Loading Device

2.3. Measurement Content.

(1) Pull-out bearing capacity of the specimen

Directly obtained by the computer system of electro-hydraulic servo testing machine.

(2) Slip of connectors

Directly derived from the computer system of the testing machine

(3) Connector strain

The strain gauge is pasted on the anchorage section of the connector 50 mm in advance, and the tensile strain of the connector during the test is measured by the acquisition instrument.

3. Test Result

3.1. Failure Mode of Specimens.

There are three main failure modes of GFRP connectors : concrete cone anchorage failure, bond failure and concrete splitting failure. Anchorage failure is that obvious cracks are formed around the concrete with the connector as the center. With the further increase of load, the cracks penetrate into the closed area, and the connector is connected with a conical body pulled out. The whole process of bond failure is relatively quiet, there is not much noise, and the connectors are pulled out from the concrete. The phenomenon of concrete splitting failure test is more intense, accompanied by a great noise. Concrete forms a relatively large penetrating crack from the middle, and concrete splits.

The thread LW-1 and LW-2 are concrete anchorage failure, and LW-3 is bond failure. There was no obvious phenomenon in the three specimens of threaded FRP at the initial stage of loading. When the load of LW-1 is added to 13 kN, the concrete has a ' hiss ' sound, and the concrete cracks, and then the concrete is pulled out when the load is loaded until the peak load is 13.4 kN. There is no obvious sound in LW-2 and LW-3, and the whole loading process is relatively calm. Compared with LW-2, the area of concrete pull-out is relatively small in LW-2. The damage phenomenon of LW-1 ~ 3 is shown in figure 5.

Fig.5 LW Failure Phenomenon

The anchorage failure of concrete occurred in both rectangular R-1 and R-2, and the bond failure between R-3 and concrete occurred. There was no obvious phenomenon in the initial stage of R-1 and R-2 loading. When the loading continued, cracks appeared in the concrete around the connector, forming a cone and being pulled out from the concrete. There is no obvious phenomenon in the whole loading process of R-3, and it is pulled out from the concrete calmly at the end of loading. The experimental phenomena of R1 ~ 3 are shown in Fig.6.

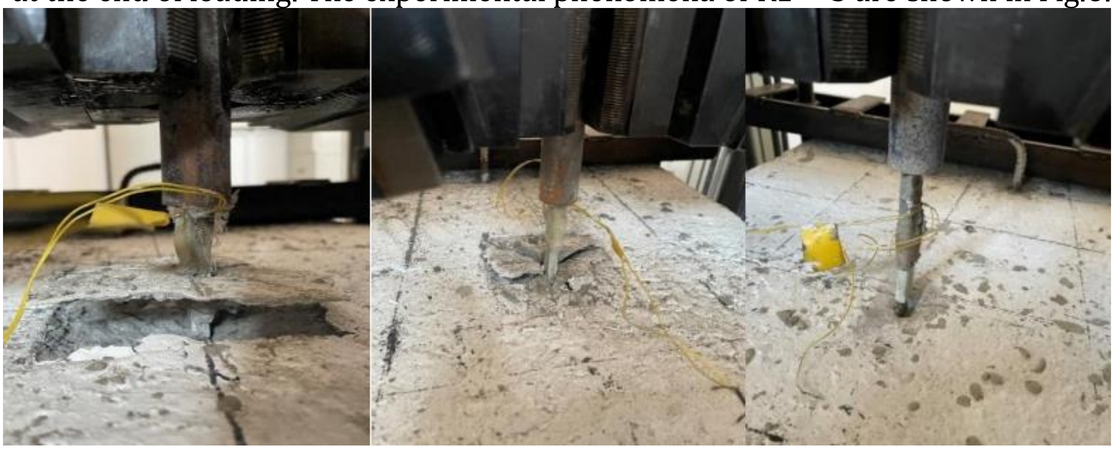

Fig. 6 R1 ~ 3 Failure Phenomenon

The failure modes of star-shaped GFRP are mainly anchorage failure and concrete splitting failure. Among them, ST-1 appeared a dull sound during the loading process, and the testing machine stopped loading. The specimen was observed to find a penetrating crack in the middle of the concrete, and the test was completed. When ST-2 is loaded to about 14 kN, the concrete cracks appear. Continue to load, the cracks further expand, and finally close to form a cone pull out. Tiny cracks appeared in ST-3 when it was loaded to 10 kN. When it was further loaded to 12 kN, the concrete cracks formed a closed area, and the test was completed. The destruction phenomenon of ST1 ~ 3 is shown in Figure 7.

3.2. Load-settlement Curve.

According to the load-displacement curve of each specimen obtained by the computer system of the testing machine, as shown in Figure 8, the load-displacement curve shows a straight upward trend at the initial stage of loading, indicating that the specimen is in the elastic stage at the initial stage of loading, and the slip of all specimens is less than 8mm.When the load is added to 0.95 times of the peak load, the cracks form a closed area, and the concrete forms a cone and is pulled out. During the test, the load-displacement curve has a slight fluctuation or a drop section is caused by the slip between the connector and the fixture of the test machine.

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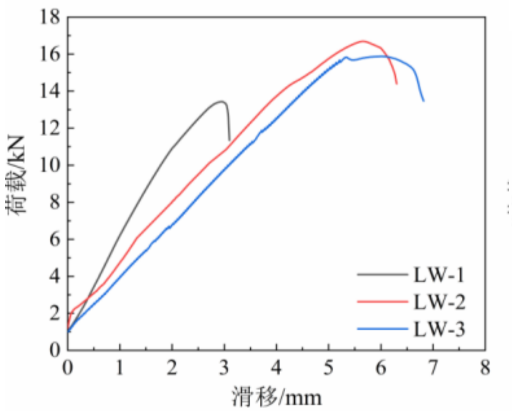
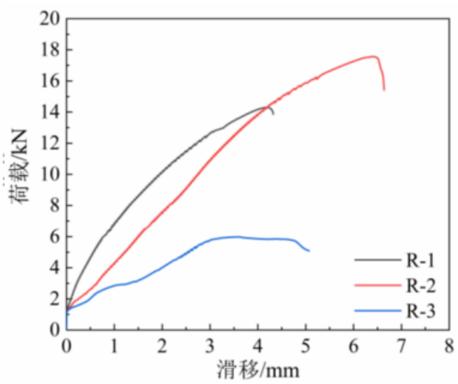
According to Reference [13], FRP belongs to fiber composite material, and there is no obvious yield point. According to the test, the ultimate tensile strain of GFRP is 14629με. The strain data collected by the acquisition instrument in this test show that the strain is less than the ultimate tensile strain of GFRP, indicating that all specimens do not reach the ultimate strain.

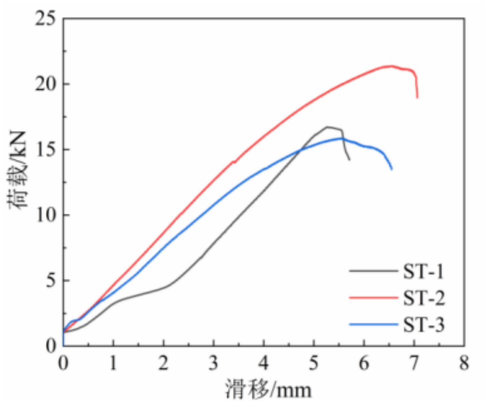
Fig. 7 ST1 ～ 3 Damage Phenomenon



(a)LW-1~3



(b)R-1~3



ST-1~3

Fig.8 Load Displacement Curve

4. Analysis of Mechanical Properties of Connectors

According to the concrete design code GB50010-2010 and Reference [14], the pull-out bearing capacity of the conical body of the connector is equal to the sum of the concrete pull-out force on the horizontal projection area of the quasi-shaped body. The simplified model for calculating the pull-out bearing capacity is shown in Fig.9 and the calculation formula (1).

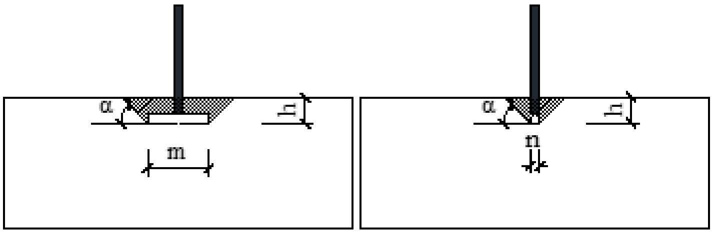


Fig.9 Conical Body Failure Calculation Diagram

$$T_i = f_t \frac{\pi\left(m+2h\cot\alpha\right)\left(n+2h\cot\alpha\right)}{4} \quad (1)$$

T_i is the pull-out bearing capacity (kN), f_t is the design value of concrete tensile strength (N / mm2), m and n are the long and short axes (mm) at the end of the connector, h is the embedded depth, α is the pull-out angle of cone failure, generally π / 4. According to the above calculation model and calculation formula, the calculated value of the pull-out bearing capacity of each specimen is 8.45 kN. The test value and theoretical value of each specimen are listed in Table 3.Among them, R-3 is not considered due to the error of specimen making.

Table 3 Calculated and Experimental Values of Specimens

Test Piece	Calculated value(kN)	Test value（kN）	Safety factor
LW-1		13.44	1.59
LW-2		16.69	1.98
LW-3		15.88	1.88
R-1		14.31	1.69
R-2	8.45	17.57	2.08
R-3		/	/
ST-1		16.73	1.98
ST-2		21.69	2.57
ST-3		15.86	1.88

According to the data in the table, the minimum pull-out bearing capacity of each specimen is 1.59 times of the calculated value, so the connector has sufficient safety reserve, but the test value is larger than the calculated value. The main reasons for the analysis are as follows :

In the calculation process, the failure angle is π / 4, and the actual test failure angle is greater than π / 4, that is, the horizontal projection area of the actual concrete cone is greater than the calculated value.

The actual strength of concrete is greater than the design strength.

In the process of specimen production, due to settlement and other reasons, the actual embedded depth of the connector is greater than 30 mm at the time of design.

5. Conclusion

The main failure modes of the three kinds of GFRP connectors are concrete cone anchorage failure, bond failure and concrete splitting failure. Individual premature pull-out failure such as R-3 belongs to the error of making specimens.

In general, the pull-out performance of the three kinds of GFRP is good. The pull-out bearing capacity is between 13.44-21.69 kN, and the minimum safety factor is 1.59.The pull-out bearing capacity calculated by the theoretical formula has a large safety reserve and can be applied to actual safety production.

The small drop section in the load-displacement curve is caused by the slip between the connector and the fixture of the electro-hydraulic servo testing machine.

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