GFRP Reinforced Concrete Adhesion in Low Temperature Environment

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Abstract. In order to study the bond properties of GFRP reinforced concrete at low temperature, a test device for mechanical loading and strain testing at low temperature was designed and developed. The effects of temperature, diameter of GFRP bar and bond length of GFRP bar and concrete on the bond properties of FRP bar concrete were studied. The study shows that the temperature is reduced from -10 °C to -30 °C, and the bond performance of GFRP reinforced concrete is increased by 15.5 % to 40 %, and the bond performance is enhanced by the load. Adhesive properties also become smaller as the bond length and GFRP diameter increase.

1. Introduction
Reinforced concrete structure is widely used for its benefits, but it also has some shortcomings, such as high mass and fast corrosion, which brings great hidden trouble to construction projects1,2. Considering that the new material FRP bar has some advantages and similar properties with steel bars3,4, it can combine with concrete to form FRP bar concrete to adapt to a higher degree of complex and harsh environment. Scholars have carried out extensive research on FRP bars and has attracted much attention.

However, the related research is mainly carried out at room temperature at present, while the bond performance of FRP bar concrete components at special environment, especially at low temperature, is relatively less studied. The main reason is that the stable low temperature environment is not easy to be realized at the same time as the bond performance loading and test conditions, which brings difficulties to the test and analysis of the coupling effect between low temperature and load. Accordingly, through the design and development of a test device for mechanical loading and strain testing at low temperature, the bonding performance of FRP bar concrete components at low
temperature is studied by applying the coupling effect of low temperature loads, in order to provide references for expanding the performance research and application of FRP bar concrete components at low temperature.

2. Test survey

2.1. Design and fabrication of specimens
The purpose of this experiment is to explore the bonding performance of FRP bars to concrete at low temperature. The GFRP bars with good bonding properties are mixed with cement, sand and stone to form beam-type concrete members. The concrete ratio is shown in Table 1.

| Table 1 Concrete ratio |
|------------------------|
| Strength Level | Cement Grade | Sand Content | Cement | Water | Aggregate | Sand |
| C30 | 42.5 | 0.32 | 456 | 210 | 1179 | 555 |

In this test, two half-beams with one GFRP bar were used to carry out pull-out test. When making components, after pretreatment of the surface of FRP bars, a BX120-0.5AA strain gauge is pasted every 15 mm in the bonding section of components to ensure that the strain gauge can read all the slip of the bonding section of FRP bars. The PVC pipe is wrapped in the non-bonded section of the component and sealed at the junction of the bonded and non-bonded areas with adhesive tape. Horizontal pouring method is used for pouring components to keep the FRP tendons in the tension zone of beam components. The dimension and bond zone of beam members are shown in Figure 1. Four groups of specimens were designed by changing the test target temperature, FRP diameter and anchorage length, of which group 1 specimens were tested at room temperature. The information of the specimens is shown in Table 2.

| Figure 1 Beam test device |
|---------------------------|

| Table 2 Sample Model |
|----------------------|
| Group Number | Specimen Number | Test Temperature (℃) | Anchorage Length (mm) | FRP bar Diameter d (mm) | Average Bond Stress τ (MPa) | FRP bar Stress σ (MPa) |
|----------------|-----------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| 1             | T0-8-5D         | 0                    | 5d                   | 8                    | 9.85                 | 196.97               |
|               | T0-8-7D         | 0                    | 7d                   | 8                    | 7.03                 | 197.69               |
|               | T0-10-5D        | 0                    | 5d                   | 10                   | 6.37                 | 127.39               |
2.2. Low temperature loading device

A self-developed low temperature test device was used in this study. The external force was loaded and unloaded by the suspended external weight of steel. The device could realize the synchronous or independent application of temperature and external force, and is divided into three parts, as shown in Figure 2. The first part is the refrigeration device. The second part is the counterweight device. The third part is the temperature console.

Note: The τ and σ in the chart is carried out by calculation assuming that the external force is 10 KN, for this test, it needs to be converted proportionally.
3. Testing Methods and Principles

3.1. Average Bond Stress

According to the mechanical features of beam-type members, half-beam is taken as stress analysis, and its mechanical sketch is shown in Figure 3.

For point A moment balance equation, the relationship between external force and bonding force can be obtained as below:

$$\sum M_A = 0, \quad \frac{p}{2} \times a_1 = F \times a_2 \quad (1)$$

$$F = \frac{pa_1}{2a_2} \quad (2)$$

In the formula above, $p$ is counterweight gravity, KN; $F$ is bonding force between FRP and concrete, KN; $a_1$ is the horizontal distance from the support to point A, mm; $a_2$ is the vertical distance from force F to point A, mm.
Bond stress is usually not uniformly distributed along the length of FRP tendons. In order to simplify the calculation, it is usually expressed by the following formula:

\[ \tau = \frac{F}{A_b}, \quad \sigma = \frac{F}{A_s} \quad (3) \]

In the formula above, \( \tau \) is the average bond stress, MPa; \( \sigma \) is FRP bar stress, MPa; \( A_b \) is the contact area between FRP and concrete in the bonding section, mm\(^2\); \( A_s \) is the cross sectional area of FRP bars, mm\(^2\).

By introducing formula (2) into formula (3), formulas for calculating the average bond stress and FRP stress in this test can be obtained as below:

\[ \tau = \frac{p a_l}{2a_z A_b}, \quad \sigma = \frac{p a_l}{2a_z A_s} \quad (4) \]

### 3.2. Principle of In-situ Compensation

The strain measured by strain gauge contains some temperature information, for which temperature compensation is needed to compensate the effect of temperature on FRP bars. In the prophase research, the in-situ compensation method was proposed, which can realize the temperature self-compensation of strain gauge. The specific principle is as follows:

1. The strain gauge is connected to TDS-530 data acquisition instrument by 1/4 bridge connection method. The strain measured without applying force is as follows:

\[ \varepsilon_t = \varepsilon_R + \varepsilon_\beta \quad (5) \]

2. By applying the first-order weight to the component the strain measured is as follows:

\[ \varepsilon_f = \varepsilon_m + \varepsilon_R + \varepsilon_\beta \quad (6) \]

In the formula above, \( \varepsilon_t \) is the strain measured without applying force; \( \varepsilon_R \) is the strain caused by the deformation of the base material of the strain gauge; \( \varepsilon_\beta \) is the strain produced by the difference between the strain gauge and the thermal expansion coefficient of the test component; \( \varepsilon_m \) is the strain produced by applying external force.

3. By subtracting formula (6) from formula (5), the influence of temperature effect is eliminated, and the strain related only to external under each gradation weight force is obtained as below:

\[ \varepsilon_m = \varepsilon_t - \varepsilon_1 \quad (7) \]

### 4. Analysis of Test Results

#### 4.1. Validation of Test Methods

The test assumes that the effective test range of each strain gauge is 15 mm, and slippage values are obtained by integrating strain data. In order to rationalize the test method, two groups of tests are designed to compare the test results with different test methods at room temperature. One group of tests uses the test method mentioned in this paper, and the other group uses ruler to measure the slip directly, as shown in Figure 4. The results of the two tests are shown in Figure 5. It can be seen that the test values are close to each other and that it is feasible to use strain gauge to test the slip of beam members.
4.2. Effect of Temperature on Bonding Properties

Figure 6 shows the relationship between bond stress and slip of FRP concrete members at three ambient temperatures (-30, -20, -10). It can be seen from the figure that the slippage between FRP bars and concrete increases with the increase of bond stress at different low temperatures. Among them, the slope of bond stress-slippage curve is the largest at -30°C. It can be seen that the low temperature environment has an effect on the bonding properties of GFRP bar concrete. The concrete manifestation is that when the diameter and bond length of GFRP bars are fixed, the bond strength between GFRP bars and concrete increases with the decrease of temperature. The above results may be due to the decrease of temperature leads to the increase of mechanical properties such as elastic modulus and concrete strength of GFRP tendons, and thus the increase of mechanical biting force in bond stress. In addition, there are micro-holes in concrete, and the free water in the concrete solidifies with low temperature, which enhances the bonding performance of the specimens.

4.3. Effect of FRP Bar Diameter on Bonding Properties

Figure 7 and Figure 8 show the bond stress-slip curves of FRP concrete members with different diameters at -20°C and -30°C. It can be seen from the figure that the smaller the diameter, the faster the curve rises, that is, under same slip, the smaller the diameter, the greater the bond stress. It can be seen that the bond stress formed by the combination of smaller diameter GFRP bars and concrete is greater when the ambient temperature and bond length are the same. It is presumed that the reason for the improvement of the coagulation performance is the bleeding phenomenon between GFRP bars and concrete, which affects the compactness of concrete and the binding force between GFRP bars and concrete, thus affects the bonding performance between GFRP bars and concrete.
5. Conclusion
In this paper, the performance of different types of GFRP bar concrete specimens is tested by beam drawing test. The morphological characteristics of the failure of the specimens under the dual action of low temperature environment and loading are studied. Based on the data collected during the test, the slip-bond stress curve is drawn. The effects of temperature, bond length and diameter on the bond properties of GFRP bar concrete were analyzed in the charts. The concrete conclusions are as follows:

(1) Under the same load, the bonding performance of GFRP bar concrete at low temperature is higher than that at normal temperature. The average bonding stress growth rate is between 15.5% and 40% as the temperature drops by 10°C.

(2) With the same other factors, by lowering the temperature, the bond strength between GFRP bars and concrete will be enhanced, and the magnitude of reinforcement will be more obvious with the increase of load.

(3) If the bond length is taken as a variable only and ensure that the diameter and temperature of GFRP tendons are the same, the bond performance of GFRP bar concrete decreases with the increase of bond length.

(4) If the diameter of GFRP is taken as a single variable and the bonding length and temperature are controlled unchanged, the bonding performance of GFRP bar concrete will be better if the diameter of GFRP is reduced.

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