Experimental study on bonding properties of fiber woven net with concrete

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Abstract. The high-strength carbon fiber braided net does not require a steel protective layer, making the TRC component lighter and thinner. However, the interfacial bonding properties of fiber woven net and concrete matrix directly affect the mechanical properties of TRC plates. In this paper, the mechanical properties of fiber braided net are studied to determine its exact mechanical properties. The results show that the embedding length and surface treatment method can improve the bonding performance.

1. Preface

The structure of fiber woven net Texture Reinforced Concrete (TRC) is to arrange the multiaxial fiber braid in the direction of the concrete to enhance the mechanical properties of the concrete. Since the fiber braid does not require a concrete protective layer, the TRC sheet can be as thin as 1 cm. At the same time, the structure of TRC has good bearing capacity, crack limiting, impermeability and corrosion resistance, which makes it commonly used in structural reinforcement.

Xu and Raupach [1,2] and other studies used fiber woven net to impregnate liquid polymer to improve the synergistic ability of fiber bundles, thereby improving the bonding properties of fiber woven net and matrix, and improving the mechanical properties of TRC. From 2003 to 2005, Yu Qiaozhen conducted research on the interfacial properties of textile and cement matrix materials, which shows that the properties of the fibers used in the fabric have a great influence on the interfacial adhesion between the fabric and the cement matrix [3].

The interfacial adhesion properties of fiber woven net and concrete matrix directly affect the mechanical properties of TRC plates. This paper studies the mechanical properties of carbon fiber net materials.

2. Test material

2.1. Cement-based composite materials

The fine aggregate used river sand with an apparent density of 2.738 g/cm³, a bulk density of 1.6 g/cm³, and a fineness modulus of 2.7. The measured maximum particle size of the sand is 2 mm, which is medium size, with 0.94% mud and 2.04% water. 42.5 grade silicate cement of the brand “Conch” produced by Conch was utilized. Grade II fly ash produced by Yancheng Power Plant was selected. And
the JM-PCA(I) polycarboxylate superplasticizer produced by Nanjing Subote New Material Co., Ltd. (water reducing capacity is 18-22 %) was used.

In this test, a high-performance cement matrix was prepared, and its mixing ratio is shown in Table 1. According to the "Code for Design of Masonry Mortar Mixing Ratio" (JGJT 98-2010) and "Test Method for Mechanical Properties of Mortar for Steel Wire Net" (GBT7897-2008), 40*40*160mm test pieces were made to test the bending resistance of cement matrix. Firstly, the cement electric bending test machine was used to carry out the bending test, and keep a constant rate of loading until the test piece was broken. Then the residual residue of the bending test was used to test the compressive property and the splitting tensile property of the cement matrix, with the cross-sectional dimension of 40×40mm. And the flexural strength and the compressive strength turned out to be 12.3 MPa and 76.2 MPa, respectively, proving that the cement matrix prepared with the mixing ratio above meets the strength requirements.

Table 1. The mix ratio of matrix cement

| mix ratio (kg/m³) | cement | fly ash | silica fume | 0~2mm sand | superplasticizer | water |
|------------------|--------|---------|-------------|------------|------------------|-------|
|                  | 800    | 100     | 80          | 1200       | 30               | 256   |

2.2. fiber fabric

The carbon fiber fabric reinforcement material produced by Hongguang Carbon Fiber Factory in Yixing city was employed in this paper. The grid size was 10*10mm as shown in Figure 1. The reinforcing effect is mainly carried by the warp fiber bundle, and the parameters are shown in Table 2.

Table 2. Carbon fiber fabric performance parameters

| Type          | Cross-section/mm² | Tensile strength /MPa | Young's Modulus /GPa | extensibility |
|---------------|-------------------|-----------------------|----------------------|--------------|
| carbon fiber  | 0.218             | 2900                  | 230                  | 1.95         |

In order to avoid damage to the fibers during transportation and use before the test, a tensile test of the fiber web was also required. The shape, size and method of the test piece are determined according to "Testing methods for tensile properties of oriented fiber reinforced plastics" GB/T3354-1999. The test piece was impregnated with epoxy resin, and in order to prevent the fiber bundle from being damaged in advance due to the stress concentration of the clamp, the fiber sheet was used as the reinforcing gasket at both ends of the fiber bundle before the test, and the gasket and the fiber bundle were fixed by epoxy resin glue. Its dimensions are shown in Figure 2. The tensile strength, ultimate
strain and elastic modulus of the fiber bundle were measured by a quasi-static test of the MTS universal testing machine. The cross-sectional area of the fiber bundle was obtained by dividing the linear density 800 by the bulk density, which was 0.218 mm$^2$. The fiber bundle test piece has a gauge length of 100 mm, a tensile rate of 2.5 mm/min, a 1 KN force sensor, and a data acquisition frequency of 20 Hz. The test also measured that the 40 mm wide fabric strip has an ultimate tensile load capacity of 2.53 KN and a tensile strength of 2893.78 MPa.

![Figure 2. Diagram of tensile strength of carbon fiber fabric](image)

### 3. Test design and production

#### 3.1. Test plans
In this test, the bond performance between carbon fiber and concrete was studied mainly by controlling epoxy resin impregnation, concrete thickness and fiber embedding length. The test grouping was as follows:

| Number | plates thickness (mm) | embedding length (mm) | treatment methods |
|--------|-----------------------|-----------------------|-------------------|
| 15-20-1 | 15 | 20 | Epoxy resin |
| 15-40-1 | 15 | 30 | Epoxy resin |
| 15-50-1 | 15 | 40 | Epoxy resin |
| 15-60-1 | 15 | 50 | Epoxy resin |
| 20-20-1 | 20 | 20 | Epoxy resin |
| 20-40-1 | 20 | 30 | Epoxy resin |
| 20-50-1 | 20 | 40 | Epoxy resin |
| 20-60-1 | 20 | 50 | Epoxy resin |
| 20-40-3 | 20 | 40 | Epoxy resin+solid |
| 20-40-0 | 20 | 40 | -- |

#### 3.2. Test piece production and loading program
Two sets of 120 x 80 mm x 12 molds (thickness of 15 mm and 20 mm) as shown in Fig. 3 were produced. When the test piece was made, the thickness of the protective layer was controlled for quality. Firstly, half quality of the concrete was poured in the mold, then the fiber net was fixed on the upper part, and finally the remaining part of the concrete was poured, and the plastic film was covered and sprayed for 24 hours. After that the mold was removed, and the standard curing was carried out for 28 days. In order to eliminate the influence of the clamp holding test piece on the bonding performance test results, the clamp holding part was designed as plain concrete, with length of 60mm, and there were 3 pieces in each set. One end of the fiber bundle was made of a fiber sheet as a reinforcing gasket, and another end was buried in the concrete and its length was shown in Table 3 to ensure that the test phenomenon will be the pulling or breaking of a single fiber bundle.
4. Analysis of test results

4.1. Effect of carbon fiber bundle embedding length on bonding performance

The bonding properties of carbon fiber and concrete were directly related to the embedding length of carbon fiber. When the embedding length of the carbon fiber was short, the broken form of the carbon fiber was mainly represented by the pulling out of carbon fiber. However, when the embedding length of the carbon fiber was long, the broken form of the carbon fiber was mainly represented by the breaking of carbon fiber. As the fiber bundle grows in the depth of the concrete, the contact area was increased, so that the friction was also greater. Therefore, when the embedding length was shorter, the fiber was pulled out and destroyed, and when the embedding length was longer, the fiber was broken. The load-displacement curves for different fiber embedding lengths with a plates thickness of 15 mm as shown in Figure 4. It can be observed from the figure that as the burial length increases, the ultimate load increases from 1114N to 1537N, an increase of 38%. As the embedding length increases, the displacement corresponding to the ultimate load decreases. When reaching the ultimate load, the loads of embedding length of 40 mm and 50 mm decrease more than that of 30 mm.

4.2. Influence of plates thickness on bonding performance
Comparing Fig. 4 with Fig. 5, the ultimate load of 15mm and 20mm corresponding to different fiber embedding lengths differs by about 5%, which shows that when the plates thickness was 15mm, the fiber bonding performance can be fully exerted. Compared with reinforced concrete, the thickness of the TRC is much thinner.

4.3. Effect of fiber bundle surface treatment on bonding performance

Figure 6. Load displacement of different surface treatment methods

It can be seen from Fig. 6 that the carbon fiber bundle treated by the epoxy resin had a greatly improved carrying capacity, which was about 42.2% higher than that of the untreated one. The bearing capacity of the grit-treated material was increased to 1338N, but when the fiber bundle entered the yielding stage, the bearing capacity decreased rapidly due to the sand sliding of the surface, and the late-stage force was lower than that of the epoxy-treated carbon fiber bundle.

When the untreated carbon fiber bundle was buried in the concrete, only the outermost carbon fiber filament and the concrete can effectively rub, and the inner fiber filament cannot be combined with the outermost fiber filament. When the force was too large, the fiber filaments in the fiber bundle were gradually broken to reduce the load bearing capacity of the fiber bundle.

The epoxy resin glue with extremely strong impregnation will bond the carbon fiber bundle into a whole. The fiber bundles were combined with force, and the carrying capacity was stably and greatly improved.

The adhesion of a layer of fine sand to the outer surface of the carbon fiber bundle impregnated with epoxy resin can significantly improve the friction with the concrete, thereby improving its load carrying capacity.

5. Conclusions

Through the experimental study on the tensile properties of carbon fiber and the bonding properties of
carbon fiber and concrete, the following conclusions can be drawn:

1. Epoxy resin impregnated carbon fiber fabric will have some damage during transportation, but it can be used directly if there is no obvious damage on the surface.

2. The bond performance between carbon fiber bundle and concrete has little relationship with plates thickness. The bond performances of concrete thickness of 15mm and 20mm are not much different, and the thickness of 10mm can exploit the concrete restraint performance.

3. The embedding length of the carbon fiber bundle can significantly improve the bonding performance. For example, when the thickness of the plates is 15 mm, the embedding length is increased from 20 mm to 50 mm, and the load carrying capacity is therefore increased by 38%.

4. The carbon fiber bundle is improved by 42% after bonding with epoxy resin. Although it can be improved by the use of grit, it is easy to generate brittle damage after destruction.

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