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Research On The Connection Property Of Bonded Steel Sleeve Connection For Full-scale Composite Member

Hongbo Li¹, Sitong Wei², Yiliang Peng¹ and Qing Sun²
¹Henan Electric Power Survey & Design Institute, Zhengzhou, Henan, 450007, China
²Department of Civil Engineering, Xi’an Jiaotong University, Xi’an, Shaanxi, 710049, China
*Corresponding author’s e-mail: sunq@mail.xjtu.edu.cn

Abstract. The glass fiber reinforced plastic (GFRP) possess excellent properties so as to be applied in many fields. In this paper, extrusion experiment of the connection property between full-scale composite member and steel sleeve has been conducted. Based on the test of the designed specimens, the failure process and failure characteristics were observed, the load-displacement curves and strain distribution of the specimens were obtained. The grout was utilized to strengthen the connection property and the experiment results showed the method could actually increase the connection strength of the joint. The connection performance of the component was analyzed to provide the basis for engineering application of bonded steel sleeve connection for composite member.

1. Introduction

With favorable characteristics such as higher specific strength and better insulation [1-4], glass fiber reinforced plastic (GFRP) plays an increasingly important role in power construction [5-8]. The utilization of GFRP instead of steel in the power transmission lines can meet the force requirements of components [9-10], decrease the material consumption and maintenance. Besides that, it could also greatly reduce the transportation, construction and installation and maintenance costs, so as to achieve good economic benefits and energy saving effect.

At present, there are few experimental studies on the actual application of GFRP members in larger sizes, and most of them are axial tension and compression strength studies. For composite components, there are two important research directions: connection performance and stability performance [11]. Research on the connection properties of glass fiber composites under large dimensions possesses important theoretical and engineering practical significance.

In this paper, the extruding test of bonded steel sleeve connection for full-scale GFRP component was carried out, the connection property of the composite component was studied as well. After that, the components were grouted, and the effect of pouring micro-expanded grouting material on the connection performance of the components was explored.

2. Experimental Condition

2.1. Specimen Details

The test piece is designed according to the actual full-scale dimensions and is mainly composed of two parts: a steel sleeve and a composite material pipe. The steel casing is made of Q345 steel, and the
composite material is made of glass fiber reinforced resin matrix composites. The position of the two contacts is connected by high-strength glue. The specimen size is shown in Figure 1.

2.2. Filling of Grouting Material
In order to enhance the connection performance of the component, the grouting material was poured at the joint of the composite material pipe and the steel pipe. The JY-60 high-strength non-shrinkage grouting material was adopted. The filling method is shown in Figure 2 and the final specimen component is shown in Figure 3.

![Figure 1. Specimen size](image1.png)
![Figure 2. Filling method](image2.png)
![Figure 3. Final specimen component](image3.png)

The strength and vertical expansion rate of grouting material was determined according to 《Technical code for application of cementitious grout》 and 《Code for concrete admixture application》 at the same time. According to test results, the flexural strength of the grouting material after 28 days is 10.7MPa, and the compressive strength is 69.9MPa and the expansion rate is 0.4%.

![Figure 4. The strength test of grout](image4.png)
![Figure 5. The vertical expansion rate test](image5.png)

2.3. Loading Scheme
Before loading, the ultimate bearing capacity of the component was estimated based on the strength of the composite material, which was approximately 1400kN. Prior to formal loading, a 10% limit load is preloaded to tightly connect parts of the specimen. At the time of formal loading, before 60% of the estimated ultimate load (840kN), each stage is loaded with a 10% ultimate load (140kN) and the loading rate is 70kN/min. After exceeding 60% of the ultimate load, each stage is loaded with a 10% ultimate load (140kN) and the loading rate is 50kN/min until it reaches 80% of the ultimate load (1120kN). After 80% of the ultimate load, the displacement loading was used, the loading rate was 2mm/min, the displacement for per stage was 1mm, and the interval for each stage loading was 30s.
The YAW-5000F pressure testing machine was used as the loading device. The bottom of the specimen and the loading board are shown in Figure 6. The specimen installation is shown in Figure 7.

![Figure 6. Bottom of specimen and board](image)

![Figure 7. Specimen installation](image)

### 3. Experimental Phenomenon

The phenomenon observed in the course of the experiment is shown in the Figure 8. During the loading process, the test piece made some noises, and there was no obvious appearance damage until destruction. Set specimen S-1 as an example to demonstrate how the figure shows. When the loading force was 436kN and 569kN, the specimen both made a faint sound. When the loading force was 620kN and 859kN, the specimen both made a medium sound. When the loading force was 950kN, the specimen made a continuous medium sound. When the loading force was 1045kN, the specimen made a medium sound. When the loading force was 1300kN, 1340kN, 1445kN and 1453kN, the specimen all made a faint sound. When the loading force was 1584kN, the specimen made a medium sound. When the loading force was 1637kN, the specimen made a faint sound. When the loading force was 1650kN and 1736kN, the specimen made a slightly larger sound. When the loading force was 1915kN, the specimen was broken with a very big sound.

The S-1 test piece appeared shear failure under impact, and the damage location was about 10cm from the junction between the upper steel sleeve and the composite material. The outer side of the upper and lower side of the adhesive layer were obviously damaged, and the composite material and the grouting material were pressed out about 5.5mm.

As we can see from the picture, the sounds occurred began about 300kN-400kN. It can be inferred that the adhesive part was beginning to break.

![Figure 8. The sound record](image)

The failure modes of the specimens included damage on the outside of the adhesive and destruction of the GFRP pipe. For the specimens filled with grouting material, the specimens tended to appear the damages of the GFRP pipe firstly, and the failure of specimens without grouting material generally occurred at the joints firstly. The failure modes of different specimens were collated, and the following results were obtained.
Table 1. Test specimen failure modes.

| specimen  | S-1   | S-2   | S-3   | K-1   | K-2   | K-3   |
|-----------|-------|-------|-------|-------|-------|-------|
| upper adhesive | no broken | no broken | no broken | broken | no broken | no broken |
| lower adhesive | no broken | broken | no broken |        |        |       |
| GFRP pipe    | broken |       | no broken |        |        |       |
| Extruding distance | 5.5mm | 0.5mm | 5.0mm | 8.5mm | 5.5mm | 1.0mm |

Figure 9. Destroyed specimens

4. Test result and analysis
The load-displacement curve of specimen is shown in Figure 10. When the composite material is pressed out of the test piece, the load decreases and then rises. When the load reaches limit finally, load-displacement curve falls sharply and specimen is damaged. Compared with specimens without grout, the specimens filled with grouting material have larger rigidity, higher ultimate bearing capacity and corresponding displacement, which indicates that the grouting material plays a positive role in the connection performance of the specimen.
The performance of the specimen is analyzed and summarized in Table 2. The critical load of the specimens without grout is between 1352kN and 1666kN, the mean value is 1465kN. The critical load of the specimens with grout is between 1863kN and 2001kN, the mean value is 1926kN.

If the adhesive area is supposed to be equivalent to the projection of the GFRP pipe to calculate the strength, the shear strength of the adhesive is 14.30MPa and 10.88MPa.

Table 2. Test specimen performance parameters

| specimen | section size (mm²) | bearing capacity (kN) | average bearing capacity (kN) | standard deviation | equivalent adhesive area (mm²) | adhesive strength (MPa) | average adhesive strength (MPa) |
|----------|-------------------|-----------------------|------------------------------|--------------------|--------------------------------|-----------------------|-------------------------------|
| S-1      | Φ217*10           | 1915                  | 1926                         | 56.91              | 134913.2                       | 14.19                 |                               |
| S-2      | Φ217*10           | 1863                  | 1342                         | 31.9               | 134231.9                       | 13.87                 |                               |
| S-3      | Φ217*10           | 2001                  | 1349                         | 13.2               | 14.83                          |                       |                               |
| K-1      | Φ217*10           | 1376                  | 1342                         | 21.9               | 10.25                          |                       |                               |
| K-2      | Φ218*10           | 1352                  | 1465                         | 142.70             | 135535                         | 9.97                  | 10.88                         |
| K-3      | Φ217*10           | 1666                  | 1342                         | 23.1               | 12.41                          |                       |                               |

As for all the specimens, the strain in the middle of the composite material is the largest. The load-longitudinal strain curves of middle of the specimens are shown in the Figure 11. As for the specimens without grout, the maximum strain is about 8000με, and for the ones with grout is about 10000με. The connection property of specimens with grout is better and the reinforcement method is useful. From applying load to the failure, the GFRP pipe remains in the elastic stage, the load and the strain maintain a linear relationship generally. The longitudinal strain values of the steel sleeve are less than 900με. Because the steel sleeve and the GFRP pipe are bonded together, the adhesive damages in the process of loading test and then sleeve will appear stress redistribution, stress situation was complex.

Figure 11. The GFRP load-longitudinal strain curve of middle of the specimens

Technical detail that it is necessary to include, but that interrupts the flow of the article, may be consigned to an appendix. Any appendices should be included at the end of the main text of the paper, after the acknowledgments section (if any) but before the reference list. If there are two or more
appendices they should be called appendix A, appendix B, etc. Numbered equations should be in the form (A.1), (A.2), etc, figures should appear as figure A1, figure B1, etc and tables as table A1, table B1, etc.

5. Conclusion

In this paper, the extruding test of bonded steel sleeve connection for full-scale GFRP component has been conducted. The connection property of grouted specimens and normal specimens were compared. The main conclusions are as follows:

(1) As for the normal specimens, the ultimate bearing capacity of the components is between 1352kN and 1666kN, the mean value is 1465kN. As for the grouted specimens, the ultimate bearing capacity of the components is between 1863kN and 2001kN, the mean value is 1926kN. The ultimate bearing capacity and stiffness of grouted specimens are better than the normal specimens.

(2) As for the normal specimens, failure occurred on the joint firstly and the maximum of the longitudinal strain of GFRP pipe is about 8000με. As for the grouted specimens, failure occurred on the GFRP pipe firstly and the maximum of the longitudinal strain of GFRP pipe is about 10000με. From this point of view, it also shows that the grouted specimen is stronger than the normal specimen.

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