Experimental Study on Basic Mechanical Properties of BFRP Bars

Xiaochun Fan¹, Ting Xu¹², Zhengrong Zhou¹ and Xun Zhou¹
¹School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan 430070, China
²Corresponding author. Tel.: 13027183668, E-mail: 2267296315@qq.com

Abstract. Basalt Fiber Reinforced Polymer (BFRP) bars have the advantages of corrosion resistance, high strength, light weight, good dielectric properties, and they are a new type of green reinforced alternative material. In order to determine the mechanical properties of BFRP bars, the tensile strength of basalt fiber bars was necessary to be studied. The diameters of the basalt fiber bars were compared by means of uniaxial tensile test in this article. Then the stress-strain curve can be drawn out. The results show that the stress-strain curve of BFRP bars present straight line relation, and there is no sign before failure; there is no yield platform on the stress-strain curve of BFRP bars, which are typical brittle material; the tensile strength of BFRP bars is about 3 times higher than that of ordinary steel bars, and the elastic modulus is about 1/5 of that of ordinary steel; the ultimate tensile strength of BFRP bars varies little with the increase of diameter, but there exist some differences in modulus values.

1. Introduction
Basalt continuous fiber is the fiber that used basalt ore as raw material, and melt the basalt stone under the temperature of 1450 ~ 1500°C, then formed through the platinum and rhodium alloy wire drawing slab at the high-speed. Basalt Fiber Reinforced Polymer (BFRP) bar is a new kind of non metal composite reinforced material, which is composed of the basalt fiber as reinforced material, synthetic resin as base material and mixed with appropriate auxiliary agent, formed by pultruded process and special surface treatment. This kind of new composite material has the advantages of corrosion resistance, high strength, light weight, anti-fatigue and insulation, which can replace reinforced steel for concrete structure. It can fundamentally solve the problem of steel corrosion, and has wide application prospect in civil engineering[1-2].

However, there are few researches on the basic mechanical properties and failure modes of BFRP bars[3-6]. In this paper, the tensile tests of BFRP bars with diameters of 10mm, 12mm and 16mm were tested. The failure modes of BFRP bars and the phenomena during the test were observed. The mechanical properties such as ultimate tensile strength and elastic modulus were measured, and the stress-strain curves of BFRP bars were drawn according to the test results.

2. Test Design

2.1. Test Material
This experiment uses the deep thread BFRP bars provided by Jiangsu Green Materials Valley New Material T&D Co., Ltd (GMV), and the diameter is 10mm, 12mm and 16mm. In order to ensure the reliability of the test results, each kind of bars is made of 5 specimens, and the parameters of the specimens are shown in table 1:
Table 1. Parameters of tensile specimens

| Surface form | Specimen number | Diameter/mm | Single length/mm | Number of test pieces |
|--------------|-----------------|-------------|------------------|-----------------------|
| Deep thread  | BFRP10          | 10          | 1300             | 5                     |
|              | BFRP12          | 12          | 1300             | 5                     |
|              | BFRP16          | 16          | 1300             | 5                     |

\[^a\] BFRP: Basalt fiber reinforced polymer;
\[^b\] BFRP**: ** indicates the diameter of the bar.
\[^c\] Refer to ACI440.3R-04 “Guide Test Methods for Fiber-Reinforced Polymers (FRPs) for Reinforcing or Strengthening Concrete Structures”: The length of the test section should not be less than 100mm, nor should it be less than 40 times the diameter of the FRP bar.

2.2. Production of the Specimens

The shear strength of BFRP bars is low, in order to avoid the shear failure at both ends of the tensile specimen due to the clamp action, the seamless steel sleeve with length 400mm is used for anchoring at both ends of the BFRP bars in the tensile test. Seamless steel sleeve needs to have a certain wall thickness to withstand compressive stress produced by the instrument at the end of the test piece. The wall thickness chosen in this experiment is 4mm. The anchoring procedure is as follows:

1. The pressure sensitive adhesive tape is wrapped from the bottom of 400mm so that it can block one end of the steel sleeve to prevent leakage of resin glue, it can also ensure that BFRP bars can be centered in the seamless steel sleeve;
2. The tensile specimen at both ends of 400mm anchorage length need to be handled by sticky sand to increase its adhesion with the resin glue;
3. The inner wall of the steel sleeve need to be derusted, and use hand to block one end of seamless steel sleeve, pour resin glue into the other side of the sleeve, then make the BFRP bars rotated into the steel sleeve so that the bubbles in the sleeve can be avoided and the effective bond between them can be ensured;
4. The resin glue on the sleeve surface need to be wiped off after inserting, and then reverse the material to ensure the full bonding between the resin glue and the reinforcing bar;
5. The resin glue in the sleeve need to be replenished in time to ensure that it is fully bonded, and place it for about 5 days until the resin glue is fully hardened, the other end of the anchor is the same as above.

Enlargement of BFRP bars’ ribs shown in Figure 1, the preparation of BFRP bars before tensile test shown from Figure 2 to Figure 7.

**Figure 1.** Enlargement of ribs
**Figure 2.** Wrapping tape
**Figure 3.** Enlargement of the sticky sand
**Figure 4.** Sand sticking at both ends
The tensile test was carried out on the Servo hydraulic Dynamicigue Testing System Series (LFV-1000kN) in the Civil Engineering Structural Laboratory of Southeast University (see Figure 8). The strain in the testing process is measured by the extensometer. Specific steps are as follows:

1. Place the tensile specimen on the test machine, adjust the extensometer’s position, set the parameters of the test machine, record and take photos in real time;
2. Using displacement control to load, set the maximum displacement value of 50mm, loading rate of 0.12mm / s;
3. Observe the test phenomena during loading, loading to the specimen damage, record the maximum load value and the mode of damage;

3. Test Results and Analysis

3.1. Typical Test Phenomenon of BFRP Bars
In the process of stretching, the surface appears adhesive peeling firstly, issued the sound of fiber stripping resin, followed by part of the fiber breaks and produces burrs. As the loading continues, the noise of fiber peeling becomes larger and larger, and white spot cracks appear on the surface of BFRP bars. As the load increases further, the fiber was constantly being pulled off and issued the "crackling" sound, the sound is getting more and more frequent, accompanied by a loud sound, the fiber broke suddenly, The middle of the BFRP bar is pulled off and the appearance is like explosive. The details can be seen from Figure 9 to Figure 11. (The number in the figure is the tensile force and fatigue displacement when the first wire broken.)
3.2. Mechanical Properties
The tensile strength and elastic modulus of the BFRP bars were calculated by the following methods.

The tensile strength is calculated according to formula (1):

\[ f_u = \frac{F_u}{A} \]  

Where \( f_u \) - the tensile strength (MPa); \( F_u \) - the maximum tensile strength (N) of the BFRP bars tested; \( A \) - BFRP tendons cross-sectional area (mm²).

The elastic modulus is calculated according to formula (2):
Where $E$ - tensile elastic modulus (MPa); $F_1$ - 50% maximum load (N); $F_2$ - 20% maximum load (N) $\varepsilon_1$ - the strain corresponding to 50% of the maximum load; $\varepsilon_2$ - the strain corresponding to 20% of the maximum load

According to the data measured in the tensile test, the tensile strength and modulus of elasticity are calculated according to formula (1) and formula (2). The test results are summarized in Table 2:

| Specimen number | Bottom diameter /mm | Maximum pulling force /kN | Ultimate strength /Mpa | Average ultimate strength /Mpa | Elastic Modulus /Gpa | Average elastic modulus /Gpa |
|-----------------|---------------------|----------------------------|-------------------------|-----------------------------|---------------------|-----------------------------|
| BFRP10-1        | 8.8                 | 79.16                      | 1302                    | 1275                         | 44.00               |                            |
| BFRP10-2        |                     | 77.99                      | 1283                    |                             | 43.16               |                            |
| BFRP10-3        | 8.8                 | 75.16                      | 1236                    | 1275                         | 43.16               | 43.37                       |
| BFRP10-4        |                     | 77.34                      | 1272                    |                             | 43.75               |                            |
| BFRP10-5        |                     | 77.98                      | 1283                    |                             | 43.75               |                            |
| BFRP12-1        |                     | 109.09                     | 1246                    |                             | 43.62               |                            |
| BFRP12-2        |                     | 105.83                     | 1209                    |                             | 47.11               |                            |
| BFRP12-3        | 10.56               | 106.88                     | 1221                    | 1230                         | 50.32               | 46.11                       |
| BFRP12-4        |                     | 109.13                     | 1247                    |                             | 44.76               |                            |
| BFRP12-5        |                     | 107.24                     | 1225                    |                             | 44.73               |                            |
| BFRP16-1        |                     | 196.11                     | 1260                    |                             | 41.10               |                            |
| BFRP16-3        | 14.08               | 188.94                     | 1214                    | 1212                         | 42.95               | 44.17                       |
| BFRP16-4        |                     | 191.26                     | 1229                    |                             | 49.45               |                            |
| BFRP16-5        |                     | 178.26                     | 1145                    |                             | 43.19               |                            |

* The second specimen in the 16mmBFRP bar has a sleeve slippage after the tensile force up to 140kN, so its sample data is invalid.

It can be seen from Table 2 that the tensile strength of BFRP bars is more than 1100MPa, about 3 times of HRB400 ordinary steel (tensile strength design value = 360MPa), the elastic modulus is about 1/5 of that of HRB400 ordinary steel (elastic modulus = 200GPa). The tensile strength of the materials with different diameters is similar, but there is a big difference in the elastic modulus, the larger the diameter, the more discrete the data measured.

3.3. Stress - Strain Curve

According to the tensile load and strain values collected in the experiment, the stress-strain curves of the BFRP bars are plotted (Figure. 12 to Figure. 14). From the figure we can see that the stress-strain
curves are straight line, that is to say, the stress and strain of the BFRP bars are in good linear relationship. BFRP bars are linear elastic materials, there is no sign before failure and there is no plastic yield platform, which is completely different from ordinary steel bars.

Figure 12. Stress-strain curve of BFRP bars with diameter of 10mm

Figure 13. Stress-strain curve of BFRP bars with diameter of 12mm

Figure 14. Stress-strain curve of BFRP bars with diameter of 16mm

4. Conclusion

(1) BFRP bar is a typical brittle material, it has no sign when it breaks and the fracture is abrupt.

(2) In this experiment, the tensile strength of BFRP bars is about 1212 ~ 1275MPa, the elastic modulus is about 43.37 ~ 46.11GPa, the tensile strength is about 3 times higher than that of ordinary steel bars, and the elastic modulus is about 1/5 of the ordinary steel bars or so.

(3) The BFRP bars are basically linear elastic deformed before they are destroyed, and their stress-strain relationship is approximately a straight line and there is no yield platform in the curve.

(4) The tensile strength of the fiber bars produced by the same raw material type, the same processing conditions and methods depends mainly on the performance of fiber itself, so BFRP bars with different diameters have similar ultimate tensile strength.

(5) Because with the diameter increases, the unit volume of fiber content is reduced, and the defects inside specimen increased, resulting in a large deviation of data for a set of 5 specimens in elastic modulus.

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6. References

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