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Experimental Research on Calculation Parameters of GFRP Bars Tensile Strength

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Abstract. A tensile test on the 18mm diameter (φ18) and 25mm (φ25) GFRP bars was conducted to observe the tensile apparent characteristics and failure strength. The value calculated by failure strength fomula and the experimental value were ,contrasted to study the parameters and value of the strength calculating formula,, and drawn the conclusions as follows: The φ18 and φ25 GFRP bars' failure strength is effected by fiber materials, enhance materials itself and interface performance. The φ18 bars' failure strength is about 10% higher than φ25 bars'. The deviation between the calculated value and the actual value is more than 30%. k is the correction parameter in theoretical formula, $k_{\varphi 18}$=0.76, $k_{\varphi 25}$ = 0.68 is appropriate. Based on statistical intensity distribution model of GFRP bars' failure strength, reference stresses value of the φ18 and φ25 GFRP bars are different and the diameters of GFRP bars increases to weaken the strength of the composite material. The reducing rate of the reference stresses is significantly affected by the diameters. The diameters effect is greater than the fiber content effect.

Introduction

GFRP bars have high strength, light weight, corrosion resistance and other excellent properties, especially used in soil nailing. In harsh environment, GFRP bars have more advantages than traditional reinforced. The soil nailing gives full to the role of tension, and bending and shearing performance requirements are relatively low, so the study on tensile mechanical properties of GFRP soil nailing is crucial [1-7]. For different engineering, the tensile strength formula was established from a macro perspective. GFRP bars are consisted of glass fibers and macromolecule substrate material, which belongs to one-way of the composite material. The tensile strength has a relationship with the component, and The damage of whole material always start from the most weak point to the whole failure[8]. The failure criterion of the strength calculation formula of the composite material is determined by ailure phenomena. Not all the strength factors of the composite material can be presented by the formula in calculating strength, which fails to consider the microstructure defect, so. It can be adjusted by additional parameters based on general theoretical formula. In this paper, for the tensile strength theoretical formula, some parameters in the tensile strength theoretical formula were corrected by the tensile test strength.

GFRP Bars' Strength Calculation Formula

A parallel model is constituted by the substrate and the reinforcing body (the fibers or particles) . Most physical parameters of composites will fulfill the hybrid law of composite materials when the boundary stress and the boundary displacement of each unit are symmetrical and the amount of stress gradient and strain gradient are not too large only considered by the average stress and mean strain of composite volume.

$$\overline{\sigma}_c = \overline{\sigma}_f v_f + \overline{\sigma}_m v_m \tag{1}$$

Here : v_f—Fiber volume fraction； v_m—Substrate volume ratio.

Considering the bonding of fiber and substrate, the following formula can be used:

$$\sigma_L = K\sigma_f V_f + \sigma_m(1-V_f) \tag{2}$$

Here: *k*——Constant less than 1.

Generally, the failure strain of substrate is much higher than the fiber's. Before the breakage of fiber's the tensile strength is controlled by fiber strength. After the crack of substrate, before the destruction of fiber, the stress of composite should be:

$$\sigma_L = \sigma_f V_f \tag{3}$$

The largest value of stress should be:

$$\sigma_L = \sigma_{fu} V_f \tag{4}$$

Rosen utilized statistical intensity distribution model to get the longitudinal tensile strength：

$$\sigma_{L\max} = \sigma_{ref} V_f \left(\frac{1 - V_f^{\frac{1}{2}}}{V_f^{\frac{1}{2}}} \right)^{-\frac{1}{2\beta}} \tag{5}$$

Here:

σ_{ref} refers to reference stress, It is a function of the fiber and substrate properties

β refers to statistical parameter of fiber strength which conform Weibull Distribution

The equation can be approximated as in the general 10%~70% content of the fiber ：

$$\sigma_{L\max} = \sigma_{ref} V_f \tag{6}$$

Eq.6 is the same as the equation that ignores the substrate stress. The only difference between the two equations is that the fiber stress in Eq.6 is the reference stress rather than average stress because the strength of brittle fibers is discrete[8,9].

Experiment Plan and Test

In the test, GFRP bars with 18mm and 25mm diameter (φ18, φ25) were used. According to GB/T 2577-2005 standard, resin content in GFRP bars was calculated ,and glass fibers volume fraction of two diameters GFRP bars(φ18, φ25) can be obtained with 65.72% and 66.30%. The tensile test was done by universal testing machine and loading with speed of 2mm/min.

Experimental Phenomena and Results. In φ18 and φ25 GFRP bars' tensile tests, when the tensile force reached 20kN, crackling sounds appeared, and the sounds continued until the bars damage. After tensile tests were suspended and unloaded, then were loaded again, crack sound appeared again and at the same time the stress-strain curve became less steep. Crack sound came from glass fibers. After the sound, cracks appeared on the surface of the bars. It can be found that GFRP bars didn't necked as reinforced during the failure. The bars didn't destructed suddenly as well,while the fibers were broken firstly, the numbers of broken fibers increased with load increasing. At last, GFRP bars were broken down.

In tensile tests, it was observed that GFRP bars' effective destruction expressed as resin fracture and parts of fibers fracture. The bars' fracture surface show a "explode type" damage form. GFRP bars' tensile strength was shown in Table 1.

Table 1. GFRP bars' tensile strength

Serial number	Diameter （mm）	Cross-sectional area （mm^2）	Ultimate load （kN）	Ultimate load （MPa）
Average value	18.0	254.3	193.0	755.7
Average value	25.0	490.6	338.0	688.9

Test Results. According to destruction description, the force was main borne by the substrate or the substrate and fibers ,and fibers do not break before crack sound appeared. According to the Table.1, the load of bars crack was about 10% failure load. Crack sound appeared when the second load reach the unload load to prove the local fiber were broken or substrate were cracked.

From test results, φ18 GFRP bars' failure strength is 755.7 MPa, and φ25 bars' is 688.9 MPa. φ18 bars' failure strength is about 10% higher than φ25 GFRP bars'. However, The bearing capacity increase with the increase of diameter, instead of the change of the stress. It also can be shown that GFRP bars have significant size effect. It is different from the steel. So GFRP bars' bearing capacity and stress should be considered in the application and design calculations.

Analysis Calculation Parameters. According to fiber and the composition of the substrate material which GFRP bars selected, and then strength calculation were analyzed. In this test,the fibers of GFRP bars are glass fibers.The longitudinal tensile elastic modulus is 70 GPa, and the tensile strength is 1500 MPa.The substrate used high polymer, and its longitudinal tensile elastic modulus is 8.4 GPa and the tensile strength is 23 MPa.

According to Eq.1, GFRP bars' longitudinal tensile failure strength was shown in Table 2.

Table 2. GFRP bars' longitudinal tensile failure strength

Specimen Type	φ18	φ25
Experimental values	755.7	688.9
Calculated values	993.7	1002.3
Error（%）	31.5	45.5

According to Table 2, the calculation value are much higher than the experimental value,and the error reached 30%. As bars' size increases, the calculation error increase more significantly. Therefore, it was necessary to consider bonding properties between glass fibers and substrate material, and put forward to calculation parameters *k*. Focusing on calculating fiber strength and volume reduction scores to reflect the impact of the bond performance. Considering the bonding between the fiber and the substrate.according to the experimental values inverse the parameters *k*,calculation parameters of φ18 and φ25 GFRP bars were $k_{\varphi 18}$=0.76,$k_{\varphi 25}$=0.68 by Eq.2.

According to statistical intensity distribution model and reference stress of the bars which calculated by Eq.6, $\sigma_{L\max}$ is taken as experimental values to calculate , σ_{ref} of φ18 and φ25 are 1150MPa ,1039 MPa. Compared to the strength of the glass fiber (1500 MPa), σ_{ref} decreases 23.3%, 30.7% respectively, the bigger bars' size is , the smaller its strength becomes. The difference of fiber volume fraction between φ18 bars and φ25 bars is within 1%, it is shown that volume change of the fiber is significantly greater than strength reduction. More fibers would result in a lower tensile failure strength, so bars' size has greater effect than fiber content. In the calculation of the tensile strength , fiber size and content should be discussed separately and set up different affecting parameters, while they also have relevant with each other. In the parameters, a combination of parameter calculation should be contained, at the same time the corresponding proportion also should be reflected. But for the size of the proportion, it should be studied further.In addition, other factors cannot be evaluated by a simple test, for example, processes, materials, microstructure and other aspects , and these aspects need further study in future.

Conclusions

(1) The failure strength of GFRP bars with different diameters is affected by fibers material and reinforced material and the bonding interfacial properties. The φ18 bars' failure strength is about 10% higher than φ25 GFRP bars'.

(2) The deviation between the calculated value and the actual value of bars' strength is more than 30%. The fiber reinforcement items in the theoretical formula are corrected and used the correction parameter k. The different diameters have different correction parameter k. kφ18 = 0.76, kφ25 = 0.68, they are appropriate.

(3) Based on statistical intensity distribution model of GFRP bars' failure strength,reference stresses σ_{ref} of φ18 and φ25 are calculated to indicate that different diameters of GFRP bars have different reference stress. If the diameter becomes larger, GFRP bar strength will reduce.The reduction of reference stress σ_{ref} significantly affected by the size,and the size effect is greater than the fiber content effect as well.

(4) The corresponding weight should be reflected the bars' tensile strength influence on GFRP bars' size and fiber content, while the weight requires further study. GFRP bars' production processes and materials microstructure also need further research.

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