Study on The Mechanical Properties of Steel - Basalt Fiber Composite Reinforcement (SBFCBs)

Lei Zhao[1, *], Shengjiang Sun[1], and Wei Qi[1]

[1]Highway College, Chang'an University, Xi'an 710054, China

Abstract. Steel bar and Basalt Fiber are combined to obtain a new structural material with high strength, high elastic modulus, high toughness, corrosion resistance, low cost and other excellent comprehensive performance: Steel Basalt Fiber Composite Bars (SBFCBs). In this paper, three different types of composite bars were tested by monotonic tensile tests, and the failure patterns of steel bars were introduced in the process of stretching, and the yield strength, ultimate strength, elastic modulus and stress-strain curves of steel bars were obtained. Test results showed that the stress-strain curve of SBFCBs was obviously double-folded, and SBFCBs exhibited stable post-yielding stiffness after the reinforcement yielded. The stress-strain curve model of SBFCBs under uniaxial tension was derived according to the material's compounding rule. By sorting the experimental data and comparing it with theoretical values, we could prove the accuracy of the model.

1 Introduction

Wu Zhi-shen and Wu Gang proposed a new composite material. Its inner core is ordinary steel bars and the oute r cover is steel fiber composite bars (SFCBs). SFCBs co mbine the advantages of FRP and steel bars: the role of s teel bars in the initial stage SFCBs will be guaranteed to have a higher elastic modulus; FRP is linear elastic, and t he steel bar is elastoplastic. FRP continues to function aft er the steel bar yields, and the stress-strain relationship o f SFCBs at this stage has obvious secondary stiffness[1]. Gu Xing-yu and Shen Xin studied the mechanical prope rties of high modulus basalt fiber-steel wire composite b ars, analyzed the mechanical mechanism of basalt fiber-s teel wire composite bars, and concluded that the stress-st rain relationship curve of basalt fiber-steel wire composit e bars has double Linear feature[2]. Xiao Tong-liang and Qiu Hong-xing proposed a steel-basalt fiber composite t endon curve and hysteresis rule for the asymmetry of ten sion and compression of steel-basalt fiber composite ten dons, and gave a suggested value for the modulus of unl oading modulus[3].

BFRP bars have the advantages of high strength, goo d durability, light weight, etc. The disadvantages are mai nly reflected in low elastic modulus and poor ductility; t he main advantages of steel bars are high elastic modulu s and good ductility, so we can combine the two to get a new materials with good comprehensive properties such as high strength, high elastic modulus, and corrosion resi stance[4-7]. In order to study the mechanical properties of SBFCBs, this paper conducted unidirectional tensile t ests on 3 different types of SBFCBs, and derived the stre ss-strain constitutive model of SBFCBs.

2 Theoretical analysis of mechanical properties of SBFCBs

In this paper, the composite rule is used to analyze the str ess-strain relationship of steel-basalt fiber composite bar s (SBFCBs). This rule holds that the interface between th e inner core of the steel bar and the outer layer of the co mposite bar fiber can be well bonded, and deformation c oordination under load[8-9]. The structural diagram of S BFCBs is shown in figure 1. The stress σ -strain ε of st eel-basalt fiber composite bars is shown by the following formulas (1) and (2).

$$\varepsilon = \varepsilon_b = \varepsilon_s \tag{1}$$

$$\sigma = \left(\sigma_b A_b + \sigma_s A_s\right) / \left(A_b + A_s\right) \tag{2}$$

In the formula: σ_b is the fiber stress; ε_b is the fiber strain; A_b is the area of fiber cladding in the cross section of the composite rib; σ_s is the reinforcement stress; ε_s is the steel strain; A_s is the area of the inner core of the composite reinforcement.

* Corresponding author: 735038027@qq.com

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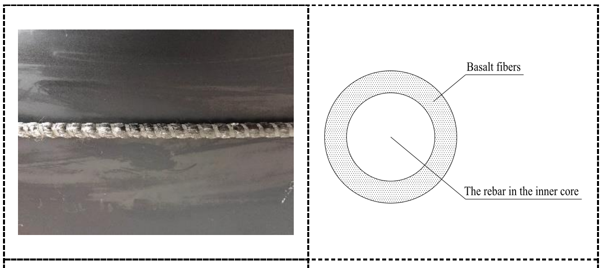
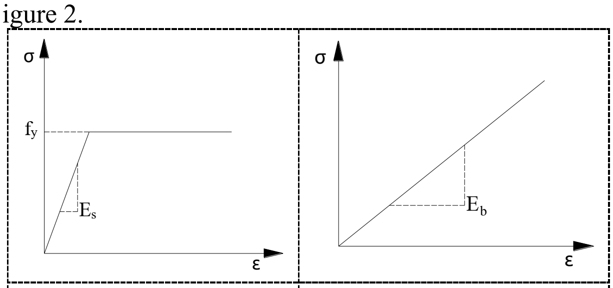


(a) SBFCBs facade	(b) SBFCBs cross-section

Fig.1. SBFCBs construction diagram

The stress-strain curve of the inner core steel bar in SBFCBs was simulated by the double-fold ideal elastic-plastic model, and the stress-strain curve of BFRP was simulated by the complete linear elastic model, as shown inf igure 2.



(a) stress-strain model of reinforcement	(b) elastic model of the stress-strain relationship line of BFRP

Fig.2. Stress-strain relationship model of SBFCBs materials

During the tensile test, since the yield strength of the reinforcement is 400MPa, when the strain value of the composite reinforcement is around 0.002, the reinforcement begins to yield, which specifically shows that the stress growth rate slows down[10]. It is considered that the reinforcement after yield is not considered, and the core reinforcement cannot continue to bear higher loads, so the subsequent increased loads are all borne by the composite reinforcement and basalt fiber, which is called secondary stiffness. During the entire tensile test, it is assumed that the core steel bar is a completely elastic plastic material, the steel bar is completely elastic at the initial stage, and completely plastic after yielding. The basalt fiber is completely elastic throughout the process.

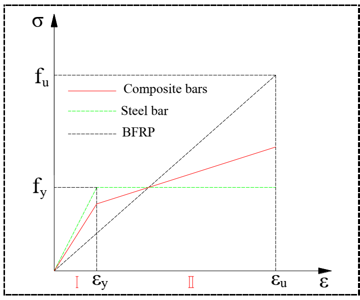


Fig.3. The stress-strain relation curve diagram of SBFCBs

It is assumed that the section area of the reinforcement is A_s, the elastic modulus is E_s, and the yield strain is ε_s. The area of the outer layer basalt fiber is A_b, the elastic model is E_b, and the ultimate strain is ε_{bu}. Compound bar area $A = A_s + A_b$. As shown in figure 3, from the beginning loading to the composite reinforcement yield for the first I stage, this stage the elastic modulus of composite reinforced remember as E_{I}, yield stress for f_y; Composite reinforcement to yield to the outsourcing of basalt fiber fracture failure, to remember the first II stage, the stage of elastic modulus to remember as E_{II}, limit stress to f_u. The stress expression of SBFCBs in monotone stretching process (3) is deduced according to the compound rule.

$$\sigma = \begin{cases} E_{\mathrm{I}}\varepsilon \rightarrow E_{\mathrm{I}} = \left(E_s A_s + E_b A_b\right)/A \\ E_{\mathrm{I}}\varepsilon_y + E_{\mathrm{II}}\left(\varepsilon - \varepsilon_y\right) \rightarrow E_{\mathrm{II}} = E_b A_b / A \end{cases} \quad (3)$$

3 SBFCBs tensile test and its analysis

3.1 Specimen size

The models and materials of SBFCBs are shown in table 1. In this test, the outer layer of composite reinforcement is basalt fiber, and the inner core is 8mm threaded reinforcement. To account for different steel-basalt fiber content ratios, different fiber dosages (20beam, 30 beam, 40 beam,) were used. The basic physical and mechanical properties of BFRP and steel bars are shown in table 2. The number and size of the specimen in the test are shown in table 3.

Table.1. Model of SBFCBs specimen

Type of composite reinforcement	The rebar in the inner core	Fiber types	Fiber dosage (beam)
S8-B20	HRB400（Ø8）	BFRP（528tex）	20
S8-B30			30
S8-B40			40

Table.2. Basic physical and mechanical properties of composite reinforcement

Material	Tensile/yield strength (Mpa)	Modulus of elasticity (Gpa)	Elongation (%)
HRB400 threaded reinforcement	400	200	16
BFRP（528tex）	1800	80.7	2.0

Table.3. SBFCBs specimen number and size

Serial number	model	Specimen diameter (mm)	The length of the specimen (m)
B1	S8-B20	10.1	1.7
B2	S8-B30	10.8	1.7
B3	S8-B40	12.0	1.7

3.2 Test methods and equipment

To ensure the normal conduct of the tensile test, the SBFCBs must be anchored at both ends before the test. BFRP is a typical anisotropic material. The transverse and longitudinal strength ratios of basalt fiber are small. If traditional clip anchors are used, BFRP will fail early in the anchoring area. So the straight barrel bonded anchorage (Steel pipe specification: 50mm×5mm, length is 350 mm, as shown in figure 4) was used in this test. The SBFCBs specimens in this test were shown in figure 5.

Fig.4. Straight barrel bonded anchorage

Fig.5. SBFCBs specimen

This test used jacks for loading (as shown in figure 6, 7). Using a pressure ring to measure the tensile force of SBFCBs. Using Y-B-15 handheld strain gauge display(as shown in figure 8)and Strain gauge to measure the tensile strain of SBFCBs. This test uses DH3817 dynamic and static strain test system to collect data.

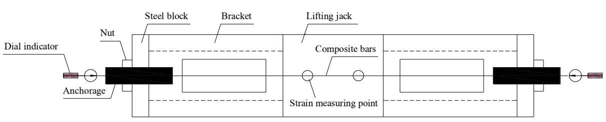


Fig.6. Schematic diagram of loading test device

Fig.7. Test apparatus

Fig.8. YB-15 handheld strain gauge display

Installing SBFCBs, pressure rings, jacks, reaction frames, etc. before starting the test. This test used the method of tension control, the loading rate was 0.05 t/s.

3.3 Test results and analysis

3.3.1 The failure process and failure pattern of the specimen

The entire test process is based on the yield of the steel bars in SBFCBs. It can be divided into two stages: at the beginning of loading, the steel bar is in an elastic working state and has not yet yielded, and the core of the steel bar and the outer basalt fiber share the load; The core steel bar yields first and cannot continue to bear higher loads. The additional load is borne by basalt fiber, which manifests as the strain growth of the reinforcement material accelerates. With the continuous increase of the load, the basalt fiber eventually breaks down and its bearing capacity. When it reaches the maximum value, its bearing capacity drops rapidly and the test ends. It can be found that SBFCBs have the following main characteristics during the stretching process.

(1) The failure part of the test piece is concentrated in the middle area of the reinforcement, and there is almost no fiber failure in other places.

(2) Before the test, the anchorage was blocked to prevent the reinforcement from being pulled out before it was damaged. After the test, through observation, there was no obvious deformation and crack at the orifice of the anchorage, indicating that the anchorage effect of the anchorage on the composite reinforcement was very good.

(3) The damage of SBFCBs started from the breakage of the outer basalt fiber. During the loading process, th

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e harsh sound of the gradual break of the fiber will be heard. When the ultimate load is reached, the outer basalt fiber is suddenly broken and accompanied by a loud noise. The morphology of SBFCBs failure is filamentary blasting, as shown in Figure 9.

Fig.9. SBFCBs failure pattern

3.3.2 Test results and analysis

According to the formula (3) derived from the law of composite materials, combined with the physical properties of materials in table 2 and table 3, the material characteristic values of SBFCBs can be calculated. The theoretical yield strain ε_y of SBFCBs takes the yield strain ε_s of the inner core reinforcement, and the ultimate strain ε_u takes the ultimate strain ε_{bu} of the basalt fiber. The test data were processed to obtain the strain, elastic modulus, strength and other parameters of SBFCBs of the following three specifications, as shown in table 4 below.

Table.4. SBFCBs monotone tensile test values and corresponding theoretical values

Specimen number		The yield strain (%)	The yield strength (MPa)	E_{I} (GPa)	Ultimate strain (%)	Ultimate strength (MPa)	E_{II} (GPa)
B1	Test results	0.1949	327.73	168.15	1.84	857.14	32.18
	Theoretical value	0.20	310.06	155.03	2.0	857.62	30.42
	error(%)	2.55	5.69	8.46	8.00	0.06	5.79
B2	Test results	0.1934	309.28	159.92	1.82	898.38	36.22
	Theoretical value	0.20	291.66	145.83	2.0	951.12	36.64
	error(%)	3.30	6.06	9.66	9.00	5.55	1.15
B3	Test results	0.1945	285.27	146.66	1.78	974.68	43.48
	Theoretical value	0.20	266.54	133.27	2.0	1079.06	45.14
	error(%)	2.75	7.03	10.0	11.00	9.67	3.68

The stress-strain curves of different SBFCBs specimens in this test are shown in figure 10 below.

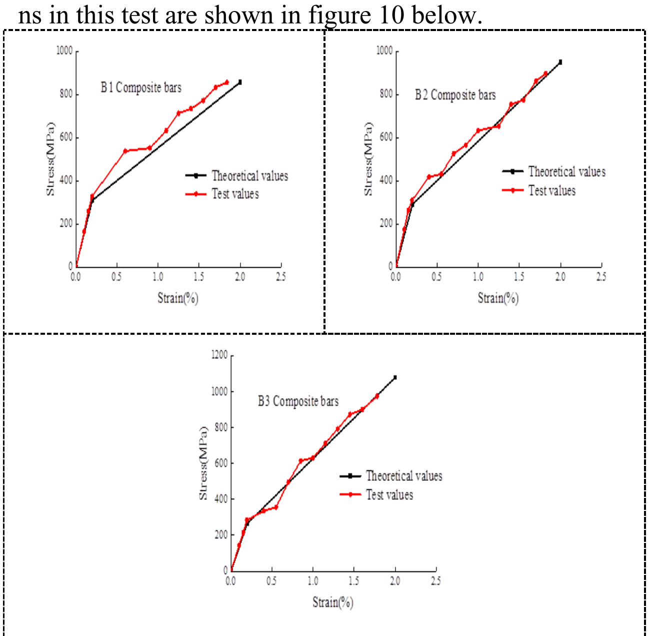

Fig.10. The stress-strain curve of SBFCBs specimen

It can be clearly seen from Fig. 10 that the stress-strain curves of SBFCBs all show obvious double-folded lines. After the steel bar is yielded during the stretching process, the composite bars have obvious secondary stiffness. It agrees well with the theoretical curve.Through the comparison and analysis,wo can find some facts.

(a) The measured yield strain of composite bars is very close to that of ordinary steel bars.

(b) The measured ultimate strength of the composite bar is less than the theoretical value. It can be judged from the ultimate strength of SBFCBs that the core reinforcement and basalt fiber are effectively bonded, and they are jointly stressed, but it cannot guarantee that all basalt fibers and the core reinforcement deform synchronously when bearing the load, which results in the composite reinforcement ultimate strength below theoretical value.

(c) The ultimate strain of composite reinforcement is slightly smaller than the elongation of basalt fiber

4 Conclusion

In this paper, three different types of SBFCBs were subjected to tensile tests,and the test values were compared with theoretical values to draw the following conclusions:

(1) During the tensile test, the failure of SBFCBs began with the fracture of the outer basalt fiber. During the loading of the specimen, the core steel bar yielded first. As the load increased, the outer basalt fiber assumed a larger load. When the ultimate strength was

reached, the composite reinforcement fiber burst suddenly.

(2) The stress-strain curve of SBFCBs was obviously double-folded. Taking the steel bar yield as the dividing point, the test process was divided into the initial stage a nd the post-yield stage: when the steel bar was yielded, it could withstand larger loads and exhibit a clear "post-yi eld stiffness", which was called secondary stiffness.

(3) The stress-strain curve model of SBFCBs under uniaxial tension was derived according to the material's compounding rule. By sorting the experimental data and comparing it with theoretical values, we could prove the accuracy of the model.

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