Experimental Study on Rheological Properties of Basalt Fiber Polymer Concrete

Yinghua Yu[1], Jiaxing Shen[1], Ping Xu[1]and Guoyue Ruan[1]
[1]*Department of Mechanical Engineering, Liaoning Technical University, Fuxin, China*

Keywords: Basalt fiber polymer concrete; rheology; resin proportioning; aggregate; fly ash; basalt fiber.

Abstract: In order to explore the basalt fiber polymer concrete (BFPC) rheology change law on the main component content, the four-factor and five-level proportion orthogonal scheme is designed. The change laws of yield stress τ_0 and viscosity coefficient η with the E44 and E51 mass ratio, the amounts of aggregate, fly ash and basalt fiber were studied. It is shown that significant influence on τ_0 and η from large to small are the amount of aggregate, the E44 and E51 mass ratio, the amount of basalt fiber and the amount of fly ash. τ_0 and η reduce monotonously with the reduction of the amount of aggregate and basalt fiber as well as increasing of the amount of fly ash but reduce with the reduction of E44 and E51 mass ratio firstly then increases when it is sufficiently small.

1 INTRODUCTION

Basalt fiber polymer concrete (BFPC) is also called polymer mineral concrete. It is a new type of fiber-reinforced composite material that has been surface treated basalt fiber incorporated into the resin concrete in accordance with the appropriate mass ratio and length-to-diameter ratio, after being stirred, formed and maintained. Compared with other fiber polymer concrete, it can not only further improve the damping and thermal stability of the concrete, but also make the concrete commutable, environmentally friendly and economical. Therefore, BFPC is considered to have good application prospects in machine tool manufacturing and construction (mine construction, civil construction, highway bridge construction, tunnel construction, etc.) [1-3].

The rheological properties of the studied materials are the basis of materials, structural design, manufacturing processes, and tooling design [4-9]. At present, the research on BFPC mainly focuses on the optimization of the material grouping ratio and the study of its mechanical properties, but the research on the rheological properties of BFPC is rarely reported [1-3]. Therefore, it is of great theoretical and practical significance to study the rheological properties of BFPC. In this paper, the influence of aggregate ratio, fly ash, E44 and E51 mass ratio and basalt fiber content on rheological properties of BFPC is studied by means of experimental method in BFPC. This study lays the foundation for the optimization design, mechanical structure design and manufacturing process design of BFPC, and even promoting its application in engineering.

2 BFPC RHEOLOGICAL MODEL

The fresh wet BFPC concrete can be regarded as a viscoplastic Bingham (Bingham) fluid whose rheological equation is

$$\tau = \tau_0 + \eta\gamma' \quad (1)$$

Where $\tau$is the shear stress, Pa;$\tau_0$is the yield stress, Pa; η is the plastic viscosity coefficient,Pa·s;γ’ shear rate,s-1. Among them, the yield stress$\tau_0$and plastic viscosity coefficientη are the basic rheological parameters that determine the rheological properties of BFPC [4-8].

3 EXPERIMENTAL

3.1 Experimental Instruments

The test device is shown in Figure 1. It is an inverted truncated inverted fall barrel, which is welded from a stainless steel plate, where D_0=300 mm, d_0=100 mm, and H=100 mm. The bottom portion of the device can control the outflow of the BFPC material. The top of the device is equipped with a scale for recording the descending height of the BFPC material.

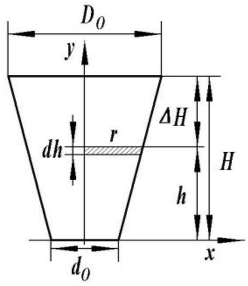

Figure 1: Collapsed down tube and test principle diagram.

3.2 Test Methods and Principles

This article adopts the two-points method to determine the rheological properties of BFPC materials[9]. The measurement principle is as follows.

Establish a coordinate system as shown in Figure 1, the height h and radius r have the following relationship:

$$r = \frac{d_0}{2} + \frac{(D_0 - d_0)h}{2H} \tag{2}$$

When pour the concrete into the collapsed down tube, and the height is reduced by dh, the reduced volume of the concrete in the collapsed down tube is equal to the volume of flowing out of the collapsed down tube.

$$\pi r^2 dh = v \cdot dt \cdot \frac{\pi}{4} d_0^2 \tag{3}$$

Wherev is the speed which the concrete flows out from the bottom of the collapsed down tube, m.

When the falling height of concrete in the collapsed down tube is ΔH, and the time is Δt, the formula 3 is integrated, as showed in formula (4).

$$\int_H^h \pi r^2 dh = v\Delta t \cdot \frac{\pi}{4} d_0^2 \tag{4}$$

Whereh and ΔH can be measured by experiments, and only v is an unknown quantity. Therefore, the shear rate can be obtained.

$$\gamma' = \frac{\Delta v}{\Delta H} \tag{5}$$

When the height of concrete in the slump is h, the shear stress is

$$\tau = f \cdot \rho \cdot h \tag{6}$$

Where f is friction coefficient of concrete; ρ is specific gravity of concrete, 2530kg/m^3 [1].

Combining equations (2) to (6) and bringing in the relevant parameters, the τ, τ_0, and γ' of the BFPC material can be obtained, andηcan be obtained by inverse calculation[4].

3.3 Preparation of Experimental Raw Materials

Aggregate size, filler, diluent, curing agent, toughening agent and adhesive are the same as those in document [1]~[3]. The length and diameter of fiber and the way of processing fiber are also the same as those in document [1]~[3]. In order to investigate the rheological behavior of BFPC with its content of main components, there are 4 factors, namely the aggregate content, mass ratio of E44 and E51, fly ash content, and basalt fiber content, each of which Take 5 levels. BFPC's yield stress and plastic viscosity coefficient were used as evaluation indicators.

Table 1: Factor level.

Level	A (mass ratio of E44 and E51)	B (aggregate content /%)	C (fly ash content /%)	D (basalt fiber content /%)
1	70:30	81	10	0.2
2	60:40	80	9.5	0.3
3	50:50	79	9	0.4
4	40:60	78	8.5	0.5
5	30:70	77	8	0.6

4 RESULTS AND ANALYSIS

4.1 Orthogonal Test Results

The results of the orthogonal experiment are shown in table 2.

Table 2: Orthogonal experimental designs and results.

Number	A	B	C	D	Yield stress /Pa	Viscosity coefficient /Pa·s
1	1(70:30)	1(81)	1(10)	1(0.2)	455.7	1841.2
2	1	2(80)	2(9.5)	2(0.3)	486.3	2256.3
3	1	3(79)	3(9)	3(0.4)	472.2	2848.2
4	1	4(78)	4(8.5)	4(0.5)	429.3	2280.9
5	1	5(77)	5(8)	5(0.6)	466.3	2362.4
6	2(60:40)	1	2	3	488.4	2128.2
7	2	2	3	4	479.2	2454.3
8	2	3	4	5	443.3	2246.6
9	2	4	5	1	408.4	1756.3
10	2	5	1	2	340.2	1635.5
11	3(50:50)	1	3	5	490.2	2312.5
12	3	2	4	1	458.2	2206.2
13	3	3	5	2	408.2	1874.1
14	3	4	1	3	409.0	1595.5
15	3	5	2	4	386.4	1574.3
16	4(40:60)	1	4	2	479.4	2311.0
17	4	2	5	3	426.4	2082.5
18	4	3	1	4	368.0	1465.5
19	4	4	2	5	348.5	2254.5
20	4	5	3	1	325.7	961.0
21	5(30:70)	1	5	4	464.3	2621.2
22	5	2	1	5	472.2	1855.3
23	5	3	2	1	383.4	1900.2
24	5	4	3	2	328.2	1867.2
25	5	5	4	3	306.9	1407.6

4.2 Range Analysis

The yield stress and viscosity coefficient of BFPC are analyzed by range analysis. The results are shown in Table 3. It can be seen that the order of the factors affecting the yield stress and the viscosity coefficient is B>A>D>C, that is, the amount of aggregates is the main factor affecting the rheological properties, and the influence of the mass ratio of E44 and E51 and the amount of fiber used is the second, and the amount of fly ash is the least.

Table3: Results of range analysis.

	Yield stress				Viscosity coefficient			
	A	B	C	D	A	B	C	D
K1	462.0	475.6	409.0	406.3	2317.8	2242.8	1678.6	1733.0
K2	431.9	464.5	418.6	408.5	2044.2	2170.9	2022.7	1988.8
K3	430.4	415.0	419.1	420.6	1912.5	2066.9	2088.6	2012.4
K4	389.6	384.7	423.4	425.4	1814.9	1950.9	2090.5	2079.2
K5	391.0	365.1	434.7	444.1	1930.3	1588.2	2139.3	2206.3
R	72.4	110.5	25.7	37.8	502.9	654.6	460.7	473.3

4.3 Effect Curve Analyses

Based on the results of table3, the effect curves of four factors on yield stress τ_0 and viscosity coefficient η are plotted, respectively, as showed in Figure 2 and 3.

As shown in Figure 2 and 3, the influence of four factors on τ_0 and η is as follows:

(a) The effect of E44:E51 mass ratio(Factor A): with the decrease of factor A, both $\tau_0$and η decrease, but when factor A decreases to a certain value, $\tau_0$and η increase with the decrease of factor A.The reason is that E44 and E51 have the same structure of two phenolpropane (DPP) and epichlorohydrin (ECH) polymerized bisphenol A epoxy resin. However, because of the different ratio of DPP to ECH and different reaction conditions, their molecular weight is different. E44 has a larger molecular weight, a longer molecular chain, and more polar parts throughout the chain. When the long molecular chains are tangled together, the internal friction is large and the corresponding viscosity is large, but the adhesive layer has a poor wettability with the surface of the adherend and the adhesive force is small. The situation in E51 is the opposite[2]. Therefore, when the factor A is large, the stickiness of the E44 accounts for the major factor. As the factor A decreases, both the yield stress and the viscosity coefficient decrease. When factor A decreases to a certain value, the relative content of E51 increases. As a result, the wettability of the entire surface of the binder and the adherend is increased. For this reason, even if the amount of E44 is reduced, theτ_0 and η of the entire fresh BFPC increase.

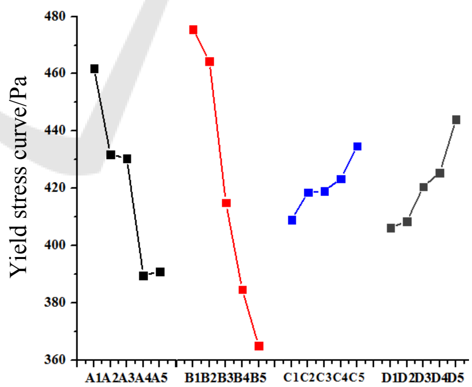

Figure 2: Yield stress curve.

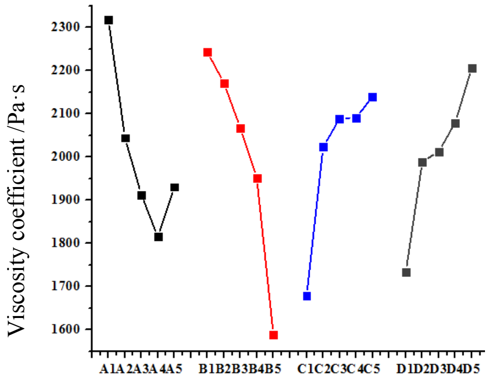

Figure 3: Viscosity coefficient curve.

(b) The effect of aggregate content (factor B):within the scope of changes in the aggregate content of this study, both $\tau_0$and η decreased as the aggregate content decreased. Because with the decrease of aggregate content, the accumulation of particles is sparse, and the spacing of the aggregates becomes large, so that the interparticle interaction force is reduced. As a result, the flow resistance is reduced, so $\tau_0$and η are reduced.

(c) The effect of fly ash content (factor C):within the scope of this study, both τ_0 and ηdecreased with increasing fly ash content. This is because fly ash is a mineral admixture. The main components of fly ash areSiO_2、Al_2O_3、$Fe_2O_3$and CaO. It is a glassy particle, which has low hydration activity, low density, and requires less water or glue. Appropriate increase of fly ash content can increase the volume ratio of concrete slurry, which is beneficial to the flow of concrete. In addition, fly ash can play a "ball effect" and it can lubricate all parts. For this reason, properly increasing the amount of fly ash can lead to a decrease in the $\tau_0$and η of fresh concrete.

(d) The effect of fly ash content (factor D):within the scope of this study, bothτ_0 and η increased with increasing fiber content. When the fiber content increases to a certain value, the network structure formed between the fibers will limit the rheology of the matrix. With the gradual increase of fiber content, the fiber network will become more secret. The fiber network will have greater restrictions on the rheological properties of concrete.

5 CONCLUSIONS

The effect of various factors on the yield stress and viscosity coefficient of BFPC from large to small is the following: aggregate content, mass ratio of E44 and E51, content of basalt fiber and fly ash content.

The yield stress and viscosity coefficient of BFPC decreased monotonically with the decrease of aggregate content and fiber content, and the yield stress and viscosity coefficient of BFPC decreased with the increase of fly ash content.The yield stress and viscosity coefficient of BFPC decrease with the decrease of E44:E51 mass ratio. However, when the mass ratio of E44:E51 decreases to a certain value, the yield stress and viscosity coefficient of BFPC increase with the decrease of E44:E51.

ACKNOWLEDGEMENTS

The work of this paper is supported by the National Natural Science Foundation of China (Grant No. 51375219).

REFERENCES

1. Xu P, Shen J. X, Yu Y. H,et al, 2017. Study on damping properties of basalt fiber reinforced polymer concrete.*Non-Metallic Mines*, 40(1):39-32.
2. Xu P, Shen J. X, Yu Y. H,et al, 2016. Influence of coupling time on strength of basalt fiber reinforced polymer concrete. *Non-Metallic Mines*, 9(5):39-48.
3. Yu Y. H, Shi R. R, Xu P,et al, 2015. Experiment research on optimization of component in polymer mineral concrete reinforced by basalt fiber. *Non-Metallic Mines*, 38(3):16-18,39.
4. Song W. M, Yi J, 2012. Summary of the rheology performance of the fresh-mixed fiber-reinforced concrete.*Coal Ash*,(2):41-44.
5. Huang F. L, Li H. J, Xie Y. J, et al, 2015. Research progress on the correlation between workability and rheological parameters of fresh concrete.*Concrete*, (10):41-44.
6. Tomasz P, 2013. Rheological properties of self-compacting concrete with chosen steel fibers.*Pragu: Czech Republic*:1-12.
7. Tomasz P, 2011. The rheological of fresh steel fibres reinforced self-compacting mixtures. *Rchitecture Civil Engineering Environment*,(2):65-72.
8. Gao X. J, Sun B. C, Ye H, et al, 2016. Influence of mineral admixtures on the rheological behavior of self-compacting concrete.*Journal of Jilin University* ,Engineering and Technology Edition ,46(2):439-444.
9. Cao M. L, Zhang C, Han L.D, 2012. Experimental study on the rheological properties of fresh mineral powder concrete based on two-point method. *Concrete*, 267(1):138-141.