Experimental Study on the Strength of Coal Gangue Aggregate Concrete with Basalt Fiber

Guowei Yang and Wenhua Zha*

School of Civil and Architectural Engineering, East China University of Technology, Nanchang, Jiangxi 330013, China.
*Email: 1374988139@qq.com

Abstract. In order to study the effect of basalt fiber content, basalt fiber length and coal gangue activation on compressive strength and splitting tensile strength of concrete, 24 groups of orthogonal experiments were designed. The results show that the influence of various factors on the compressive strength and splitting tensile strength of concrete is coal gangue activation > basalt fiber content > basalt fiber length. The activation of coal gangue is conducive to the increase of concrete strength; the influence of fiber content on strength increases first and then decreases; the increase of fiber length is beneficial to compressive strength and unfavorable to splitting tensile strength; the best ratio of engineering practice is fiber content 0.10 %, fiber length 18 mm, activated coal gangue.

1. Introduction
Coal is the most important energy in China, accounting for about 94% of the basic reserves of fossil energy resources in China, much larger than oil and natural gas. Coal gangue is a solid waste produced in the process of coal mining and washing [1-2]. According to statistics, the normal mining of 1t coal produces about 0.2t coal gangue, and the washing of 1t coal produces about 0.65 ~ 0.7t coal gangue. As a big coal country, China mines a large amount of coal every year, so the amount of coal gangue produced is considerable. Such large-scale coal gangue emissions, if not reasonably used, will pose a huge threat to the environment and public health [3-4]. The use of coal gangue as concrete aggregate is an economic and environmentally friendly way of utilization. The preparation of concrete by coal gangue can not only utilize coal gangue in large quantities and with high added value, effectively solve the environmental and ecological problems caused by coal gangue accumulation, but also make up for the shortage of natural aggregate resources, reduce costs, save resources and energy, and reduce environmental load [5-6].

Coal gangue concrete has the characteristics of low tensile strength and high brittleness as ordinary concrete. Studies have shown that thermal activation can stimulate the activity of coal gangue. After calcination, coal gangue is dehydrated and decomposed to produce metakaolin, amorphous silica and alumina, and enhance its mechanical properties [7-8].

In recent years, the use of fibers to enhance the performance of concrete has attracted the attention of scholars. Basalt fiber is a kind of inorganic fiber made of natural basalt stone as the main raw material, which is melted at 1450-1500 °C and drawn at high speed by platinum rhodium alloy plate. Basalt fiber has the characteristics of high tensile strength, large elastic modulus, strong corrosion resistance and good chemical stability [9]. Adding basalt fiber into concrete can improve compressive strength and splitting tensile strength of concrete [10-11]. At present, there is a lack of research on the
incorporation of basalt fiber into aggregate concrete containing coal gangue. Therefore, this paper analyzes the influence of the amount and length of basalt fiber and the activation of coal gangue on the strength of basalt fiber coal gangue concrete through the mechanical properties test of basalt fiber coal gangue concrete with different materials. The orthogonal test scheme and variance analysis were used to determine the influence of these three factors on the strength of basalt fiber coal gangue concrete.

2. Test Scheme

2.1. Test Raw Materials
The cement was made of P. O42.5 ordinary portland cement of Hailuo brand. The natural fine aggregate was river sand with fineness modulus of 2.3, and the coarse aggregate was natural gravel and coal gangue after crushing and screening. Coal gangue coarse aggregate particle size 4.75 ~ 20mm, in order to get the activated coal gangue, the need for non-spontaneous combustion of coal gangue calcination treatment, select RX2-45-9 box resistance furnace for calcination, preheated to 300 °C, and then the grading good coal gangue coarse aggregate into, calcined 30 min, calcination temperature is 800 °C. After calcination, heat preservation 2h, and finally let it cool naturally. Natural coarse aggregate takes gravel with particle size of 4.75 ~ 20 mm, and coal gangue and natural gravel are continuously graded to meet the requirements of "cobble and gravel for construction" (GB / T14685-2011 ).Mixing and maintenance water is natural urban tap water. Basalt fiber selected from the same manufacturer of four different fiber length (6mm, 9mm, 12mm, 18mm) products, the basic performance parameters are shown in table 1.

| Elastic modulus (GPa) | Tensile strength (MPa) | Monofilament diameter(μm) | Material density (g/cm³) | Breaking elongation (%) |
|-----------------------|------------------------|---------------------------|--------------------------|------------------------|
| 35                    | 1050                   | 20                        | 2.7                      | 3.5                    |

2.2. Orthogonal Design
Orthogonal test design is another design method to study multi-factor and multi-level. It selects some representative points from the comprehensive test according to the orthogonality. These representative points have the characteristics of 'uniform dispersion, neat and comparable.' Orthogonal test can effectively arrange multi-factor test to achieve the purpose of high efficiency, rapidness and economy, and minimize test error. In order to explore the influence of basalt fiber content, basalt fiber length and coal gangue activation on the compressive strength and splitting tensile strength of basalt fiber coal gangue concrete, three factors were set up in the experiment. Factor A and basalt fiber mass concentration were set at six levels: 0.05 %, 0.10 %, 0.15 %, 0.20 %, 0.25 %, 0.30 %. Factor B, basalt fiber length set four levels: 6mm, 9mm, 12mm, 18mm; factor C, coal gangue activation set two levels: 1-non-activation, 2-activation.

2.3. Specimen Production and Maintenance
According to the standard of fiber reinforced concrete test method (CECS13: 2009), various materials were prepared in advance, and the basalt fiber coal gangue concrete was prepared by forced mixer. Firstly, basalt fiber, natural gravel coarse aggregate, coal gangue coarse aggregate and river sand were mixed evenly, and then water was added to continue stirring. In order to ensure the uniform dispersion of basalt fiber in concrete and prevent the agglomeration of basalt fiber, the stirring time was set to 4 min. The mixed mixture was added to the 100mm × 100mm × 100mm concrete test block mold to vibrate and compact. After 24 hours, it was demoulded and placed in the standard curing room for 28 days. The material consumption of the test piece is shown in table 2.
The compressive and splitting tensile strength of each specimen is shown in Table 2.

| Test piece | Orthogonal composite | Basalt fiber mass percentage (kg/m³) | Fiber length (mm) | Ceme nt (kg/m³) | Water (kg/m³) | Sand (kg/m³) | Natural gravel (kg/m³) | Coal gangue (kg/m³) | Activation of coal gangue |
|------------|----------------------|-------------------------------------|------------------|----------------|--------------|-------------|------------------------|----------------------|------------------------|
| G1 A1B1C1  |                      | 1.18                                | 6                | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G2 A1B2C1  |                      | 1.18                                | 9                | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G3 A1B1C2  |                      | 1.18                                | 12               | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G4 A1B2C2  |                      | 1.18                                | 18               | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G5 A2B1C1  |                      | 2.35                                | 6                | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G6 A2B2C1  |                      | 2.35                                | 9                | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G7 A2B1C2  |                      | 2.35                                | 12               | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G8 A2B2C2  |                      | 2.35                                | 18               | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G9 A3B1C1  |                      | 3.53                                | 6                | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G10 A3B2C1 |                      | 3.53                                | 9                | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G11 A3B1C2 |                      | 3.53                                | 12               | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G12 A3B2C2 |                      | 3.53                                | 18               | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G13 A4B1C1 |                      | 4.70                                | 6                | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G14 A4B2C1 |                      | 4.70                                | 9                | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G15 A4B1C2 |                      | 4.70                                | 12               | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G16 A4B2C2 |                      | 4.70                                | 18               | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G17 A5B1C1 |                      | 5.88                                | 6                | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G18 A5B2C1 |                      | 5.88                                | 9                | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G19 A5B1C2 |                      | 5.88                                | 12               | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G20 A5B2C2 |                      | 5.88                                | 18               | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G21 A6B1C1 |                      | 7.05                                | 6                | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G22 A6B2C1 |                      | 7.05                                | 9                | 406            | 185          | 610         | 610                    | 610                  | yes                    |
| G23 A6B1C2 |                      | 7.05                                | 12               | 406            | 185          | 610         | 610                    | 610                  | no                     |
| G24 A6B2C2 |                      | 7.05                                | 18               | 406            | 185          | 610         | 610                    | 610                  | no                     |

2.4. Experimental Process

After the specimens were cured to the age of 28 d, the compressive and splitting tensile tests were carried out by using the microcomputer-controlled electro-hydraulic servo long column pressure testing machine YAW-3000 according to the standard ' test method for physical and mechanical properties of concrete ' (GB / T 50081-2019). The compressive strength of three test blocks in each group was calculated by multiplying the measured compressive strength by the size conversion coefficient 0.95. The splitting tensile compressive strength is obtained by multiplying the arithmetic average of tensile measured values by the size conversion coefficient 0.95.

3. Test Result Analysis

The compressive and splitting tensile strength of each specimen is shown in figure 1. The results of compressive and splitting tensile range analysis are shown in table 3.
Figure 1. Compressive and splitting tensile strength of concrete.

Table 3. Analysis of Range Results of Compressive Splitting Tensile Strength.

| Index Factor | 28d compressive strength/MPa | 28d splitting tensile strength/MPa |
|--------------|-------------------------------|-----------------------------------|
|              | A | B | C | A | B | C |
| K_1          | 49.3 | 52.5 | 44.4 | 2.7 | 3.7 | 2.8 |
| K_2          | 54.5 | 51.5 | 59.8 | 3.9 | 3.2 | 4.2 |
| K_3          | 51.7 | 50.7 | 3.5 | 3.6 |
| K_4          | 54.4 | 53.6 | 3.7 | 3.4 |
| K_5          | 51.5 | | 3.3 |
| K_6          | 51.1 | | 3.6 |
| R            | 5.2 | 2.9 | 15.4 | 1.2 | 0.5 | 1.4 |

Influence degree: C>A>B

3.1. Compressive Strength of Specimens
As shown in figure 1 (a) and table 3, when measuring the compressive strength of basalt fiber coal gangue concrete, the activation of coal gangue has the greatest impact on it, and the range R is 15.4 MPa. The calcined coal gangue aggregate can effectively increase the compressive strength. The second is the basalt fiber content range, the difference R is 5.2 MPa. With the increase of basalt fiber content, the compressive strength increases first and then decreases. The compressive strength of 0.10 % and 0.15 % increases by 27.5 % and 16.0 % compared with 0.05 %. The compressive strength of 0.25 % and 0.30 % decreased by 5.3 % and 9.8 % compared with 0.20 %, respectively. The minimum influence is the length of basalt fiber, the range R is 2.9 MPa. With the increase of the length of basalt fiber, the compressive strength increases gradually, the compressive strength of 6mm to 9mm increases by 8.0 %, from 12mm to 18mm increases by 15 %.

3.2. The Splitting Tensile Strength of Specimens
As shown in figure 1 (b) and table 3, when the splitting tensile strength of basalt fiber coal gangue concrete is measured, the activation of coal gangue has the greatest impact on it, and the range R is 1.4 MPa. Calcining coal gangue aggregate is helpful to improve the tensile strength of the structure. The second is the basalt fiber content range, the range R is 0.5 MPa. With the increase of basalt fiber content, the splitting tensile strength also shows a trend of increasing first and then decreasing. The tensile strength of 0.10 % and 0.15 % increases by 19.6 % and 21.3 % respectively compared with 0.05 %. The compressive strength of 0.25 % and 0.30 % decreased by 3.3 % and 7.2 % compared with 0.20 %, respectively. The minimum effect is the length of basalt fiber, the range R is 0.5 MPa. With the increase of the length of basalt fiber, the tensile strength decreases, the tensile strength of 6mm to
9mm decreases by 17.4%, from 12mm to 18mm decreases by 6.0%.

3.3. Extreme Difference Analysis

It can be seen from Table 3 that for the compressive strength and splitting tensile strength of basalt fiber coal gangue concrete, the activation of coal gangue has the greatest impact, followed by the basalt fiber content, and the basalt fiber has the smallest impact. The optimal dosage of each factor of the compressive strength of the test block is $A_2B_4C_2$, and the optimal dosage of each factor of the splitting tensile strength of the test block is $A_2B_1C_2$.

4. Conclusion

Based on the orthogonal test method, this paper explores the influence of different incorporation of basalt fiber content, basalt fiber length and coal gangue aggregate activation on the mechanical properties of basalt fiber coal gangue concrete, and draws the following conclusions.

(1) The main order of influence of various factors on the 28d compressive strength of concrete is: activation of coal gangue > basalt fiber content > basalt fiber length; the main order of influence on 28d splitting tensile strength of concrete is activation of coal gangue > basalt fiber content > basalt fiber length.

(2) In the compressive test, with the increase of basalt fiber content, the strength increases first and then decreases. With the increase of basalt fiber length, the compressive strength increases gradually. In the splitting tensile test, with the increase of basalt fiber content, the tensile strength increases first and then decreases. With the increase of basalt fiber length, the tensile strength decreases gradually. The activation of coal gangue is helpful to the increase of compressive strength and splitting tensile strength.

(3) $A_2B_4C_2$ was selected as the optimal ratio of compressive strength and $A_2B_1C_2$ was selected as the optimal ratio of splitting tensile strength. In engineering practice, the main stress form of concrete is compressive, so the best ratio of basalt fiber coal gangue concrete is basalt fiber content 0.10%, basalt fiber length 18 mm, activated coal gangue.

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