International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Annales de Chimie - Science des Matériaux
Vol. 44, No. 6, December, 2020, pp. 427-432
Journal homepage: http://iieta.org/journals/acsm

Influence of Basalt Fiber on the Physical and Mechanical Properties of Aerated Ceramsite Concrete

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https://doi.org/10.18280/acsm.440609

Received: 18 July 2020
Accepted: 7 October 2020

Keywords:
Aerated Ceramsite Concrete (ACC), lightweight wallboards, Basalt Fiber (BF), physical and mechanical properties

ABSTRACT

In order to improve the technical performance of Aerated Ceramsite Concrete (ACC) so that it could better meet the requirements of lightweight wallboards for prefabricated buildings, this study mixed 0%, 0.05%, 0.10%, 0.15% and 0.20% of the Basalt Fiber (BF) by volume ratio into the ACC of 100mm-thickness LC15 lightweight wallboards, and conducted experiments to test the apparent density, compressive strength, splitting tensile strength, and flexural strength on the 7d, 14d, and 28d of the experiment; then, the microstructure and failure forms of the BF-improved ACC material were observed and analyzed, and the results showed that adding BF can effectively improve the physical and mechanical properties of ACC, and the optimal BF content in the ACC of lightweight wallboards is 0.10%-0.15%.

1. INTRODUCTION

China is now vigorously developing wallboards for prefabricated buildings and promoting the application of green and energy-saving building materials in prefabricated buildings. The ACC wallboard is a new type of lightweight wall board [1]; its main raw materials include ceramsite, cement, fly ash, water, and foaming agent; after battery-mold modeling and casting, and autoclave curing and other processes, these materials are fabricated into ACC wallboards, which have many merits such as light weight, high strength, good impermeability, thermal insulation, high fireproof performance, and strong earthquake resistance, etc. [2]; moreover, the ceramsite material is a green lightweight aggregate made by roasting silt, sludge and other pollutants. However, ACC has the same shortcomings as ordinary lightweight aggregate concrete, such as easy cracking, high brittleness, and low elastic modulus, which have severely restricted the promotion and application of ACC wallboards [3]. In view of these problems, in order to improve the splitting tensile strength and flexural strength of concrete and effectively control the development of cracks, researchers at home and abroad have conducted a series of studies, they tried to mix appropriate amounts of polypropylene fiber, steel fiber and basalt fiber into concrete to fabricate the fiber concrete, which has improved the physical and mechanical properties of concrete [4-6]. However, now there are few studies on the influence of fibers on the mechanical properties of the ACC lightweight wallboards. Since basalt fiber has the characteristics of high durability, high elastic modulus, good electrical insulation, high heat absorption coefficient, and it has good dispersibility, strong bonding force, and close thermal expansion and contraction coefficients with cement and concrete [7, 8], this paper proposed to incorporate basalt fiber into ACC and test its compressive strength, splitting tensile strength, flexural strength, and apparent density [9], in the hopes of improving the physical and mechanical properties of ACC lightweight wallboards, so that it could meet both the requirements of the prefabricated buildings and green and energy-saving buildings in China, which also has an important practical significance for China's economic and social development.

2. EXPERIMENTAL MATERIALS

2.1 Ceramsite, ceramic sand

The ceramsite and ceramic sand used in the experiment were produced by Jinhua Jiechen Building Material Technology Co., Ltd. Their physical properties are shown in Table 1 and Table 2.

2.2 Cement

The experimental adopted the Hailuo (Brand name) 42.5R ordinary Portland cement, its physical properties are shown in Table 3.

Table 1. Physical properties of ceramsite

Particle size /mm	Pass rate/%				Bulk density/ (kg/m^3)	Apparent density /(kg/m^3)	1h Water absorption %	Cylinder compression strength /MPa
	2.36 mm	4.75 mm	9.50 mm	19.00 mm				
2.00~20.00	0.7	3.5	40.4	99.1	726	1443	8.05	6.8

Table 2. Physical properties of ceramic sand

Particle size/mm	Fineness modulus	Bulk density/(kg/m^3)	Apparent density /(kg/m^3)	1h Water absorption %	Cylinder compression strength /MPa
0.16~2.00	3.4	775	1519	8.15	7.7

Table 3. Physical properties of cement

Apparent density /(kg/m^3)	Fineness /%	Water consumption for standard consistency/%	Setting time/min		Flexural strength/MPa		Compressive strength/MPa	
			Initial setting	Final setting	3d	28d	3d	28d
3115	2.5	27.6	135	258	4.6	6.8	26.7	48.5

2.3 Fly ash

The fly ash used in the experiment was Grade-II fly ash produced by Quzhou Juhua Electric Heating Plant; its physical properties are shown in Table 4.

2.4 Foaming agent

The foaming agent used in the experiment was the high-efficiency composite foaming agent produced by a catalyst factory in Shangyu. The main properties of the foaming agent were: pH 6-7, stability 40s, foam expansion ratio 3.6, and density 1.130 kg/L.

2.5 Admixture

Admixture adopted the JS-3 naphthalene sulfonate superplasticizer, in powder form, the mixing amount accounted for 1.0% of the cement mass, water reduction rate 25%.

2.6 Fiber

The fiber used in the experiment was basalt fiber; its physical properties are shown in Table 5.

Table 4. Physical properties of fly ash

Apparent density /(kg/m^3)	Fineness /%	Water demand /%	Water content/%
2028	25.3	101.8	0.3

Table 5. Physical properties of fiber

Fiber type	Density /(kg/m^3)	Length /mm	Diameter /mm	L/D ratio	Tensile strength /MPa	Elastic modulus /GPa
Basalt fiber	2645	18	0.015	1200	3356	81～92

3. EXPERIMENT SCHEME

3.1 Design of reference mix ratio

According to the requirements of *Reinforced Ceramsite Concrete Lightweight Wallboard* (JC/T 2214-2014): the surface density of 100mm-thickness lightweight wallboard ≤10 kg/m^2; hollow rate of prepared wallboard 31% [1, 2]; density of solid board≤1594 kg/m^3; standard water content of wallboard 0%-10%; the maximum density of ACC (calculated under water content 7%)≤1706 kg/m^3; compressive strength of wallboard≥7.5 MPa; compressive strength grade of the experiment LC15.

According to the *Technical specification for lightweight aggregate concrete* (JGJ 51-2002) and related literatures [2, 3], the mix design of the lightweight wallboard matrix ACC adopted: cementitious material≥36%, fly ash content 20%, water-binder ratio 0.35, sand ratio 37%. The basalt fiber was incorporated at ratios of 0%, 0.05%, 0.10%, 0.15% and 0.20% of concrete volume, respectively [10, 11], the obtained test mix ratios are shown in Table 6.

Table 6. Test mix ratios

No.	Fiber volume content/%	Ceramsite /(kg/m^3)	Ceramic sand/(kg/m^3)	Cement /(kg/m^3)	Fly ash /(kg/m^3)	Water /(kg/m^3)	Foaming agent /(m^3/m^3)	Water reducing agent/(kg/m^3)
N1	0.0	478	281	436	109	191	0.1	4.4
N2	0.5	478	281	436	109	191	0.1	4.4
N3	1.0	478	281	436	109	191	0.1	4.4
N4	1.5	478	281	436	109	191	0.1	4.4
N5	2.0	478	281	436	109	191	0.1	4.4

3.2 Experimental method

The ceramsite and ceramic sand were pre-wetted 24 hours before the experiment, and the water content of the wetted ceramsite and ceramic sand was measured to adjust the water consumption during mixing. Then, dry materials such as cement, fly ash, water reducing agent, and basalt fiber were mixed by a mechanical mixer for 2 minutes, then water and foaming agent were added and mixed for another 1min, after that, ceramsite and ceramic sand were added and mixed for 2 more minutes [3, 12].

Test pieces were fabricated according to the *Standard for Test Method of Mechanical Properties on Ordinary Concrete* (GB/T 50081-2002). The size of test pieces for the tests on apparent density, compressive strength, and splitting tensile strength was 100mm×100mm×100mm; and the size of test pieces for the tests on flexural strength was 100mm×100mm×400mm. For the above mentioned 5 mix ratios, 4 test items were performed for each mix ratio; for each test item, the test pieces had 3 ages; for each age, there're 3 groups of test pieces; and 3 test pieces in each group; there're a total of 180 test pieces in the experiment. After the test pieces were formed for 24 hours, the molds were removed, and the test pieces just removed from the molds were immediately placed in a standard curing room with a temperature of (20±2)°C and a humidity of 95%. Then, the apparent density, compressive strength, splitting tensile strength, and flexural strength of the test pieces on 7d, 14d, and 28d were measured and tested respectively. The compressive strength loading speed was 0.5MPa/s; and the loading speed of the splitting tensile strength and the flexural strength was 0.05MPa/s. The measured compressive strength values were multiplied by a size conversion factor of 0.95; the measured splitting tensile strength values and tensile strength values were multiplied by a size conversion factor of 0.85. For the three test pieces in each group, the representative value was determined according to the specified method; for each test item, the average value of the representative values of the three test piece groups was taken as the test result.

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1 Physical and mechanical properties

In lightweight wallboard matrix ACC, BF was mixed at the ratios of 0%, 0.05%, 0.10%, 0.15% and 0.20% of the concrete volume. Based on the test results of the apparent density, compressive strength, splitting tensile strength and flexural strength on 7d, 14d, and 28d, the influence of BF on the physical and mechanical properties of ACC were plotted as shown in Figure 1, Figure 2, Figure 4, and Figure 6. Also, the matrix ACC, the compressive failure form, splitting tensile failure form, and the flexural failure form of the BF-improved ACC (mixed with 0.15% BF) are shown in Figure 3, Figure 5, and Figure 7.

(1) Influence of BF content on apparent density

It can be seen from Figure 1 that, for BF-improved ACC, under a same age, the apparent density gradually decreased with the increase of the BF content; under a same BF content, the apparent density gradually decreased with the increase of the age. In short, adding BF will make the lightweight wallboard ACC lighter.

(2) Influence of BF content on compressive strength

According to Figure 2, at different ages, the compressive strength of ACC increased with the increase of BF content within a certain range, and the optimal content was 0.15%. When the volume content of BF was 0.05%-0.15%, the compressive strength increased with the increase of BF content. When BF content was 0.15%, the compressive strength improvement was the most obvious, and the compressive strength of ACC on 28d had increased by 5% compared with matrix ACC. When BF content exceeded 0.15%, the enhancement effect of compressive strength was obviously weakened.

According to Figure 3, during the compressive test, matrix ACC test piece exhibited macro cracks and damaged quickly. When ultimate load was reached, the test piece lost its bearing capacity and collapsed on all sides, obviously, the damage type was brittle failure. As shown in Figure 3-a, during the compressive test, when macro cracks appeared on the surface of the BF-improved ACC, it's observed that, compared with matrix ACC, the cracks of BF-improved ACC were narrower, and the test piece still had certain bearing capacity, which had improved the brittle failure of the test piece. When the loading continued and the test piece completely lost its bearing capacity, multiple penetrating cracks were generated, but the test piece remained as a whole piece and showed no obvious collapse [13], see Figure 3-b.

(3) Influence of BF content on splitting tensile strength

According to Figure 4, adding an appropriate amount of BF in ACC can significantly improve the splitting tensile strength. With the increase of BF content, the splitting tensile strength first increased and then decreased later. When the BF content was 0.15%, the splitting tensile strength reached the maximum value, the splitting tensile strength on 28d was 1.91MPa, which was 17.18% higher than that of matrix ACC. When BF content reached 0.15%, the increase in strength decreased.

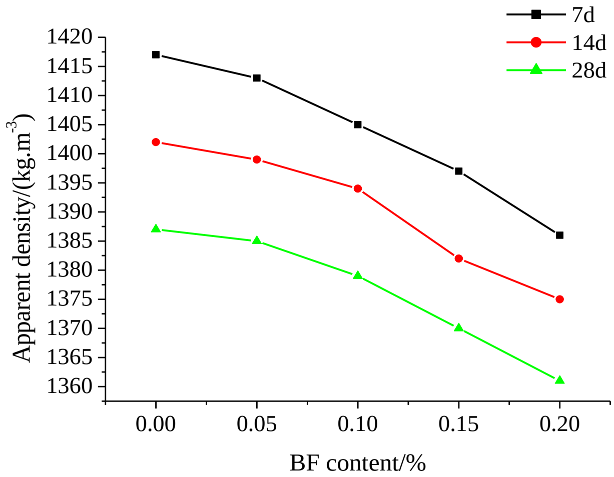


Figure 1. Influence of BF content on apparent density

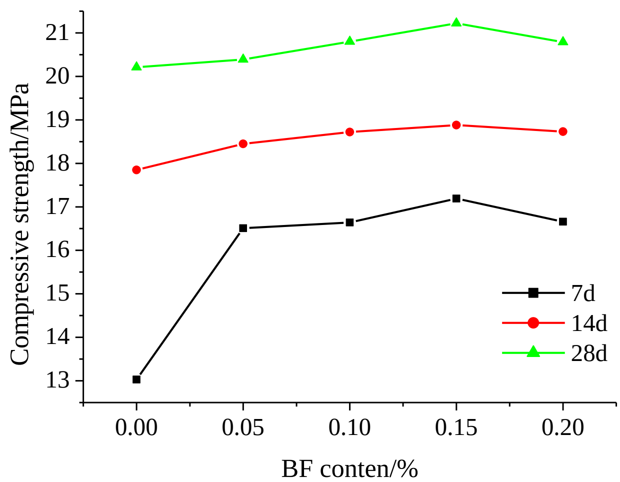
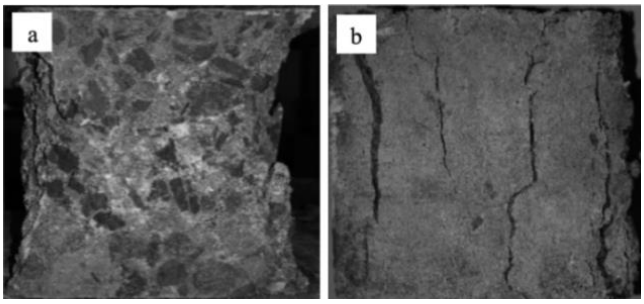


Figure 2. Influence of BF content on compressive strength



a. Matrix ACC **b.** BF-improved ACC

Figure 3. Compressive failure

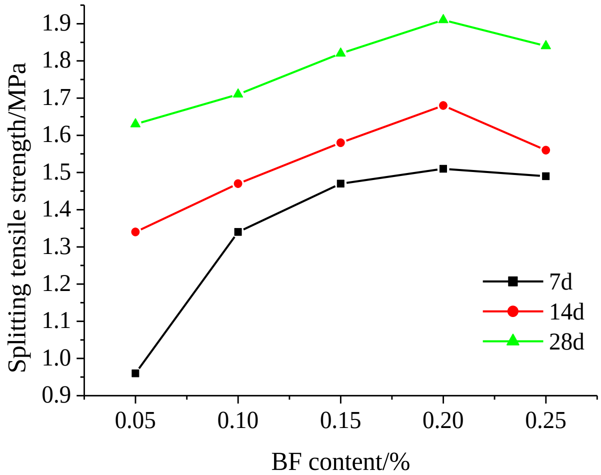
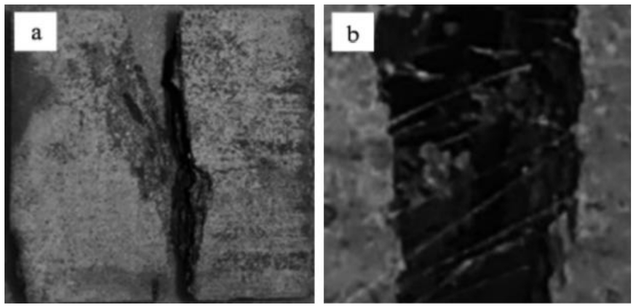


Figure 4. Influence of BF content on splitting tensile strength



a. Matrix ACC **b.** BF-improved ACC

Figure 5. Splitting tensile failure

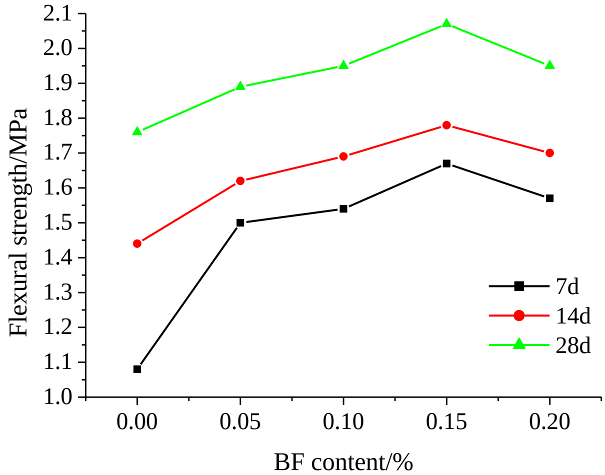


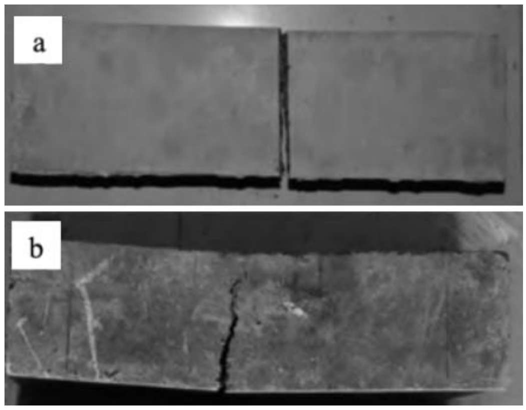
Figure 6. Influence of BF content on flexural strength

According to Figure 6, the splitting tensile failure process of the matrix ACC was relatively fast. When the ultimate load was reached, longitudinal macro cracks appeared on the surface of the test piece. The test piece was instantly damaged and split into two halves and showed wide sections, as shown in Figure 5-a. The splitting tensile failure process of BF-improved ACC was relatively slow, when ultimate load was reached, accompanied by a low sound, thin cracks appeared on the surface, at this time, the BF mainly bore the tensile strength, and the test piece still maintained integrity. After that, the load continued to increase, and the cracks expanded gradually until the BFs were pulled out and the test piece lost its bearing capacity [14, 15], see Figure 5-b.

(4) Influence of BF content on flexural strength

It can be seen from Figure 6 that BF can significantly improve the flexural strength of ACC. With the increase of BF content, the flexural strength increased first and then decreased later. When BF content was 0.15%, the flexural strength reached the maximum value. At this time, the flexural strength on 28d was 2.07MPa, which was 17.61% higher than that of the matrix ACC.

According to Figure 7, during the loading process, matrix ACC test pieces showed no obvious cracks, only when the ultimate load was reached, cracks appeared and quickly penetrated the entire section; the test piece underwent brittle failure, as shown in Figure 7-a. During the loading process, the cracks of BF-improved ACC expanded slowly, and the tensile force at the cracks was borne by the BF growing across the cracks until the BF was pulled out from the slurry, it was exhibited as that the flexural strength of the BF-improved ACC had been significantly improved [16, 17], see Figure 7-b.



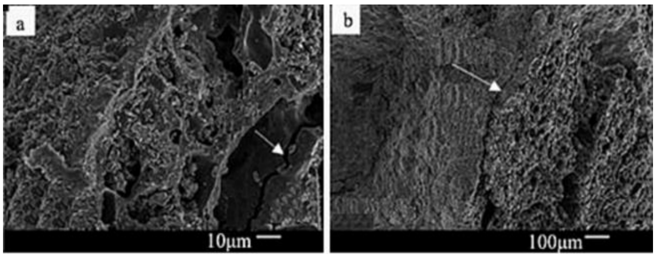
a. Matrix ACC **b.** BF-improved ACC

Figure 7. Flexural failure

4.2 Microstructure observation and analysis

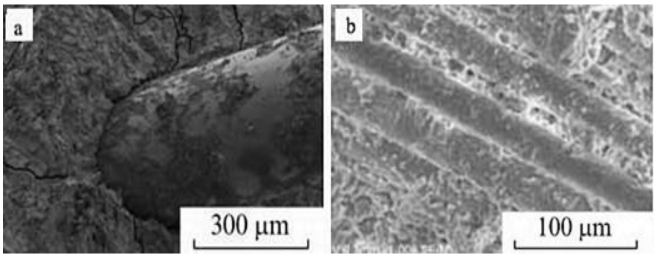
Under normal circumstances, aggregate properties, slurry strength and cross-section cohesion have a great impact on the strength of concrete. After BF had been added into ACC, its microstructure became more complicated. In the experiment, scanning electron microscope (SEM) was used to observe the microstructures of the ceramsite-slurry interface and the BF-slurry interface of the test pieces, as shown in Figures 8-9.

It can be seen from Figure 8 that the pre-wet ceramsite released water when ACC was set and hardened, which made the slurry hydration in the ceramsite-slurry interface area relatively sufficient; the slurry and hydration products can penetrate the ceramsite to a certain depth, there is no obvious boundary between the ceramsite and the cement slurry, the ceramsite and the slurry were tightly combined, forming a good interface, on which the cracks were not easy to appear, and the performance of ACC had been improved [18], as shown in Figure 8-a. However, the water absorption of ceramsite with a smooth surface was relatively low, which reduced the water release of the ceramsite and weakened the hydration reaction in the ceramsite-slurry interface area, thus forming a weak interface, on which cracking failures would occur easily [19, 20], see Figure 8-b.



a. Dense interface area **b.** Weak interface area

Figure 8. Ceramsite-slurry interface



a. BF at the crack **b.** BF clumping

Figure 9. BF-slurry interface

It can be seen from Figure 9 that after the BF was pulled out from the slurry, a large amount of hydration products remained on the surface of BF, as shown in Figure 9-a, which indicated that the BF and cement slurry had a high bonding strength; within a range of 200μm around the BF, there're many micro-cracks in the slurry and ceramsite, and this indicated that during the pulling out process, the basalt bore a large bonding force, the BF and the ACC had good compatibility, and the internal pore structure of the concrete was improved. When ACC cracked, the FB growing across the cracks can exert a good tying effect on the concrete on both sides of the cracks, which is helpful to inhibit the development of cracks and improve its brittleness [21]. Therefore, adding BF can improve the compressive strength, splitting tensile strength and flexural strength of ACC. However, with the increase of BF content, during the mixing process of ACC, it is not easy to mix the FB evenly, and BF clumping appeared, which reduced the fluidity of the mixture, and microstructures formed in the matrix easily, as shown in Figure 9-b, pores appeared between BFs, which increased the defects of the structure, and the decrease in the compactness led to the decrease in the apparent density, and at the same time, it affected the bonding force between the BF and the slurry. After that, as the load continued to increase, relative sliding would occur between BFs, and the compressive strength, splitting tensile strength, and flexural strength decreased accordingly [22]. In summary, the microstructure performance of the BF-improved ACC was consistent with the physical and mechanical test results of the test pieces.

5. CONCLUSION

By adding 0%, 0.05%, 0.10%, 0.15% and 0.20% BF by volume ratio into the ACC of 100mm-thickness LC15 lightweight wallboards, and conducted experiments to test its apparent density, compressive strength, splitting tensile strength, and flexural strength on the 7d, 14d, and 28d, this paper studied the influence of BF content on the physical and mechanical properties of lightweight wallboard ACC, and the following conclusions were obtained:

(1) Under external force, the FB added to ACC could cooperate with the concrete and bear the force together, which can effectively improve the ductility and plastic deformation performance of the concrete, and control crack development and failure forms, thereby improving the physical and mechanical properties of ACC.

(2) At a same age, with the increase of BF content, the apparent density of ACC gradually decreased, and the compressive strength, splitting tensile strength, and flexural strength increased first and decreased later. Under a same FB content, with the increase of age, just as ordinary concrete, the FB-improved ACC showed gradual decrease in apparent density, and increase in compressive strength, splitting tensile strength, and flexural strength.

(3) When 0.05%~0.20% BF (volume content) had been mixed into lightweight wallboard ACC, the BF-improved ACC outperformed the matrix ACC in all physical and mechanical properties; after comprehensively considered the four technical performance indicators of apparent density, compressive strength, splitting tensile strength and flexural strength, this paper proposed that the recommended BF content in lightweight wallboard ACC is 0.10%-0.15%.

ACKNOWLEDGMENT

Fund Projects: Scientific Research Project of Zhejiang Provincial Department of Education (Grant No.: Y201941603; Y202043269); Scientific Research Project of Zhejiang Provincial Department of Construction (Grant No.: 2019K163).

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