ISSN 1027-5495. Functional Materials, 26, No.4 (2019), p. 784-788.
doi:https://doi.org/10.15407/fm26.04.784

Experimental study of mechanical properties of basalt fiber concrete with nano-SiO_2

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Received July 1, 2019

The compressive and tensile strength of fiber-reinforced concrete with different contents of SiO_2 nanoparticles and basalt fibers was studied. When the content of basalt fibers is 2 kg/m^3 and the content of nano-SiO_2 is 1.5 %, compressive strength and splitting tensile strength of the concrete are improved by 11.66 % and 45.16 %, respectively, compared with unmixed concrete, the brittleness resistance of concrete is highest, and the ratio of the splitting tensile strength to compressive strength is 30 % higher than that of unmixed concrete.

Keywords: basalt fiber, nano-SiO_2, compressive strength, splitting tensile strength.

Исследована прочность на сжатие и на растяжение фибробетона с разным содержанием наночастиц SiO_2 и базальтовых волокон. При содержании базальтовых волокон 2 кг/м^3 и 1,5 % наночастиц SiO_2 прочность на сжатие и растяжение бетона повышается на 11,66 % и 45,16 % по сравнению с обычным бетоном, хрупкость бетона минимальна, отношение прочности на растяжение к прочности на сжатие на 30 % выше, чем у обычного бетона.

Експериментальне дослідження механічних властивостей базальтового фібробетону з наночастками SiO_2. *Cao Hai, Wang Chao, Shao Cong, Zhu ling.*

Досліджено міцність на стискання і на розтягнення фібробетону з різним вмістом наночастинок SiO_2 і базальтових волокон. При вмісті базальтових волокон 2 кг/м^3 і 1,5 % наночастинок SiO_2 міцність на стискання і на розтягнення бетону підвищується на 11,66 % і 45,16 % у порівнянні зі звичайним бетоном, крихкість бетону мінімальна і відношення міцності на розтягнення до міцності на стискання на 30 % вище, ніж у звичайного бетону.

1. Introduction

Concrete is the most widely used building material in civil engineering due to its advantages such as good moldability, good durability and fire resistance [1, 2]. However, concrete also has the disadvantages of low tensile strength, high brittleness and easy to produce cracks, which obviously shorten the service life of concrete structure [3, 4]. For a long time, many scholars have been exploring ways and means to improve the performance of concrete. Compounding is the main way of high performance of cement-based materials [5–7]. Authors [8] studied the effects of nano-SiO_2 dispersion on concrete fracture toughness. The results show that the highest fracture toughness in both mode I and II was obtained at 0.5 % of nano-SiO_2 blended concrete. In [9] studied the modification effect of nano-SiO_2 with different dosage on the strength and durability of lightweight aggregate concrete. The results show that nano-SiO_2 can effectively improve the mechanical properties of lightweight aggregate concrete with appropriate dosage. In [10] carried out a comparative impact test study on recycled concrete and recycled concrete modified by

1 % ~ 2 % nano-SiO_2 or nano-$CaCO_3$ by Hopkinson compression bar (SHPB). The experimental results show that the impact strength of nano-modified recycled concrete is generally higher than that of recycled concrete without nano particles under dynamic impact load. Authors [11] studied on the basic mechanical properties of basalt fiber concrete through experiments. The results show that the flexural and tensile strength increased obviously. In [12] studied the influence of basalt fiber and basalt fiber and fly ash on the mechanical properties of concrete. Adding basalt fiber into concrete can reduce the brittleness of concrete and improve its toughness and crack resistance. At the same time, when the right amount of basalt fiber and fly ash composite, it can further improve the mechanical properties of basalt fiber concrete. Authors [13] studied the influence of fiber incorporation mode and rapid curing mode on the compressive strength of basalt fiber concrete (BFRC), and concluded that 6 kg/m^3 basalt fiber can effectively improve the compressive strength and deformation of concrete under compression. However, the above research focuses on the influence of single variable on the mechanical properties of concrete. The methods of concrete modification are described in the article.

This paper will study in concrete both with nano-SiO_2 and basalt fibers, which is called basalt fiber concrete with nano-SiO_2. The compressive and splitting properties of concrete with different contents of basalt fiber and nano-SiO_2 were tested.

2. Experimental

2.1. Test materials

– Cement: conch brand P. O42. 5 ordinary Portland cement.

– Coarse aggregate: grading crushed stone with particle size of 5 ~ 10 mm.

– Fine aggregate: common river sand of Huangshan city, fineness modulus is 2.8.

– Water: ordinary tap water.

Basalt fiber: the main performance indexes of short-cut basalt fiber produced by a company in Shanghai are shown in Table 1.

Nano-SiO_2: the main physical performance parameters of nano-SiO_2 are shown in Table 2. The design grade of concrete strength is C30, and the test mix ratio is shown in Table 3.

2.2. Test method

Concrete specimens were manufactured in accordance with the standard for test methods for mechanical properties of ordinary concrete. Concentrations of nano-SiO_2 were 0 %, 0.5 %, 1.0 %, 1.5 % and 2 %, content of basalt fiber was 0 kg/m^3, 1 kg/m^3, 2 kg/m^3 and 3 kg/m^3 according to the volume ratio of fiber, and 20 groups were designed according to the orthogonal test. 150 mm×150 mm×150 mm concrete specimens were made according to the mix proportion of the test, and the specimens were cured for 24 h and then removed from the mold. The specimens were raised for 28 days before mechanical properties tested. Pressure testing machine was used to conduct compressive strength and splitting tensile strength tests on the specimens. Three specimens in each group were tested, and the average value of the test results was taken.

Table 1. The main performance indexes of short-cut basalt fiber

Length, mm	Filament diameter, μm	Density, g·cm^{-3}	Tensile modulus, Gpa	Tensile strength, MPa	Elongation at break, %
12	15	2.65	90 ~ 110	3800 ~ 4800	3.2

Table 2. The main physical performance parameters of nano-SiO_2

Appearance	The main elements content, %	Average particle size, nm	Specific surface area, m^2·g^{-1}	Tap the density, g·cm^{-3}
White powder	$SiO_2 \geq 99.9$ %	15±5	600±50	0.0035

Table 3. The test mix ratio of C30 concrete, kg/m^3

Cement	Water	Limestone rubble	Sand
434	221	1235	615

3. Results and discussion

3.1. The compressive strength

According to the experimental design, the compressive strength and splitting tensile strength of basalt fiber concrete with nano-SiO_2 were measured respectively, and the specific results are shown in Table 4. The NS in the Table 4 represents nano-SiO_2 concrete, and the following figure represent nano-SiO_2 content. The BF in the table 4 stands for basalt fiber concrete, and the following figure represents the content of basalt fiber. For example, NS0.5-BF1 means the content of nano-SiO_2 is 0.5% and the content of basalt fiber is 1% in the basalt fiber concrete with nanometer SiO_2. The results of compressive strength measurements are presented in Fig. 1, 2.

As can be seen from Fig. 1, the compressive strength of concrete specimen increases with increase of nano-SiO_2 content up to 1.5 % and then decreases. Maximum value of compressive strength is reached when nano-SiO_2 content is 1.5 %, at this nano-SiO_2 content the compressive strength of the specimen is 7.51 % higher than that of the unmixed concrete.

The compressive strength depends on the content of basalt fibers as well with maximum value at 2 kg/m^3 (Fig. 2). At this content of basalt fibers the compressive strength of the specimen is 5.18 % higher than that of the unmixed concrete. When the basalt fiber content is 2 kg/m^3 and nano-SiO_2 content is 1.5 %, the compressive strength of the specimen is 11.66 % higher than that of the unmixed concrete.

3.2. The spliting tensile strength

As can be seen from Fig. 3 the splitting tensile strength of the concrete specimen reaches the maximum value at the nano-SiO_2 content of 1.5 %. When the basalt fiber content is 0 kg/m^3 and the nano-SiO_2 content is 1.5 %, the splitting tensile strength of the specimen is 19.35 % higher than that of the unmixed concrete.

As can be seen from Fig.4 the splitting tensile strength of the concrete with basalt fibers reaches the maximum at basalt fiber content of 2 kg/m^3, the splitting tensile strength of the specimen is 22.58 % higher than that of the unmixed concrete. When the basalt fiber content is 2 kg/m^3 and the nano-SiO_2 content is 1.5 %, the splitting tensile strength of the specimen is 45.16 % higher than that of the unmixed concrete.

Table 4. The test results of basalt fiber concrete with nano-SiO_2

No.	Compressive strength, MPa	Splitting tensile strength, MPa	The ratio of the splitting tensile strength to compressive strength
NS0-BF0	38.6	3.1	0.0803
NS0.5-BF0	39.4	3.3	0.0838
NS1.0-BF0	40.6	3.5	0.0862
NS1.5-BF0	41.5	3.7	0.0892
NS2.0-BF0	40.7	3.6	0.0885
NS0-BF1	39.5	3.4	0.0861
NS0.5-BF1	40.8	3.5	0.0858
NS1.0-BF1	42.0	3.7	0.0881
NS1.5-BF1	42.6	3.9	0.0915
NS2.0-BF1	41.9	3.8	0.0907
NS0-BF2	40.6	3.8	0.0936
NS0.5-BF2	41.7	4.0	0.0959
NS1.0-BF2	42.5	4.3	0.1012
NS1.5-BF2	43.1	4.5	0.1044
NS2.0-BF2	42.6	4.4	0.1033
NS0-BF3	39.7	3.5	0.0882
NS0.5-BF3	41.0	3.6	0.0878
NS1.0-BF3	41.8	3.7	0.0885
NS1.5-BF3	42.7	4.0	0.0937
NS2.0-BF3	41.5	3.8	0.0916

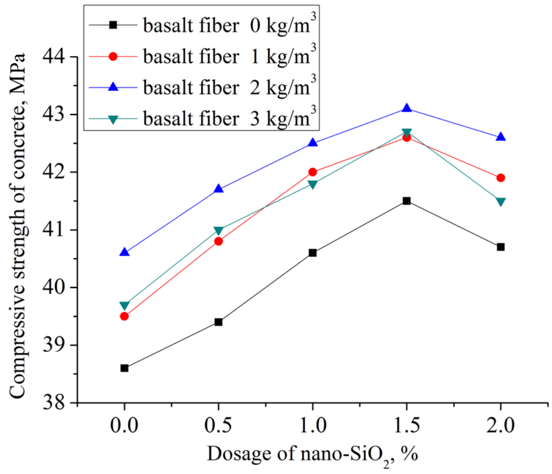

Fig. 1. Dependences of the compressive strength of the concrete on nano-SiO_2 content.

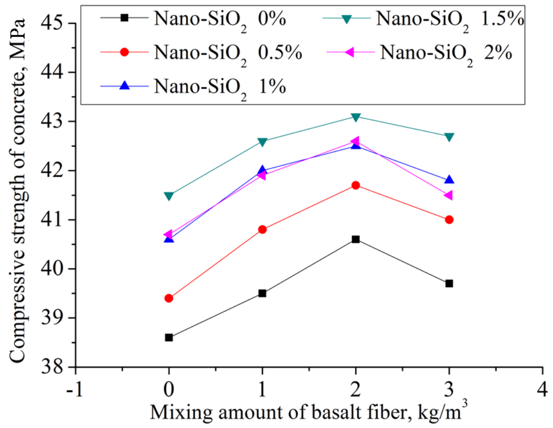

Fig. 2. Dependences of the compressive strength of the concrete on the content of basalt fiber.

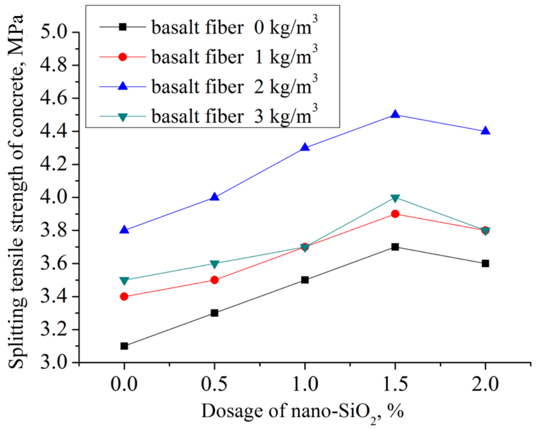

Fig. 3. The dependences of splitting tensile strength of the concrete on nano-SiO_2 content.

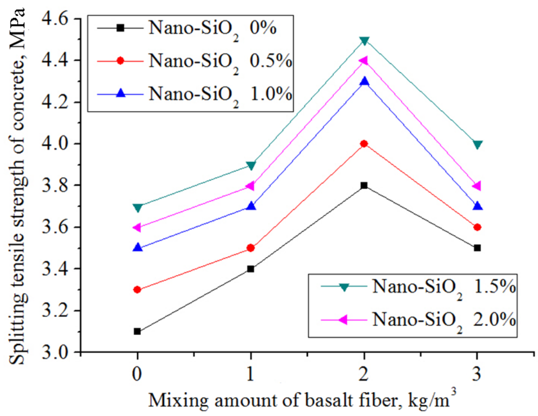

Fig. 4. The dependences of splitting tensile strength of the concrete on the content of basalt fibers.

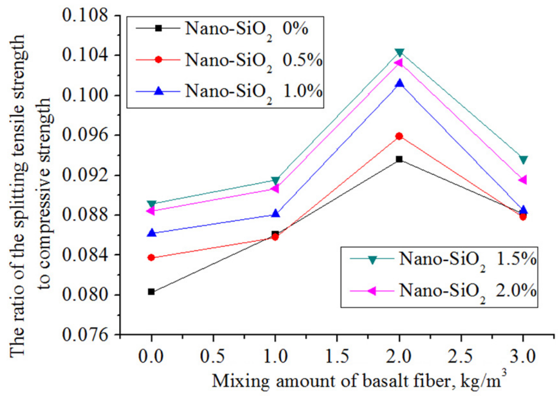

Fig. 5. The ratio of the splitting tensile strength to compressive strength.

3.3. The ratio of the splitting tensile strength to compressive strength

The brittleness resistance index of concrete can be reflected by the ratio of the splitting tensile strength to compressive strength. The greater the ratio of the splitting tensile strength to compressive strength of concrete, the more significant the brittleness resistance. As can be seen from Fig. 5, when the nano-SiO_2 content is 1.5 % and the basalt fiber content is 2.0 kg/m^3, the ratio of the splitting tensile strength to compressive strength of basalt fiber concrete with nano-SiO_2 reaches the maximum being 30 % higher than of the unmixed concrete.

3.4. Strengthening mechanism analysis

When nano-SiO_2 and basalt fiber are mixed in concrete, they can fill smaller holes in the gap, which can effectively compensate the excessive incorporation of basalt fibers to improve matrix compactness due to the small size of nano-SiO_2 particles. Moreover, the specific surface energy of nano-SiO_2 is very high, which can not only react with

$Ca(OH)_2$ quickly, but also release a large amount of hydration heat to promote the hydration reaction of cement, and generate more hydration products leading to improvement of concrete strength. When the concrete matrix is subjected to load, the supporting system composed of a proper amount of basalt fibers distributed evenly in random directions within the concrete cooperate with nano-SiO_2. On the one hand, the fiber will deform and consume part of the energy. On the other hand, they work together to hinder the formation of cracks and delay their development [14, 15]. Therefore, nano-SiO_2 and basalt fibers can work well together in concrete significantly improving the mechanical properties of concrete.

4. Conclusions

– For nano-SiO_2 concrete, adding nano-SiO_2 can effectively improve the splitting tensile strength and compressive strength of concrete. When the nano-SiO_2 content is 1.5 %, the concrete has better compressive strength and splitting tensile strength. At this time, the compressive strength and splitting tensile strength of concrete are 7.51 % and 5.18 % higher than that of unmixed concrete, respectively.

– For basalt fiber concrete, the addition of basalt fiber can effectively improve the splitting tensile strength and compressive strength of concrete. When the content of basalt fiber is 2 kg/m^3, and the compressive strength and splitting tensile strength of basalt fiber are 19.35 % and 22.58 % higher than that of unmixed concrete, respectively.

– A proper amount of basalt fiber and nano-SiO_2 composite incorporation can improve the compressive and splitting tensile strength of concrete. When the content of basalt fiber is 2 kg/m^3 and the content of nano-SiO_2 is 1.5 %, its compressive strength and splitting tensile strength are improved by 11.66 % and 45.16 %, respectively compared with unmixed concrete.

– A proper amount of basalt fiber and nano-SiO_2 composite incorporation can improve the brittleness resistance of concrete. When the content of basalt fiber is 2 kg/m^3 and the content of nano-SiO_2 is 1.5 %, the brittleness resistance of concrete is the best, and the ratio of the splitting tensile strength to compressive strength is 30 % higher than that of unmixed concrete.

Acknowledgements. The authors acknowledge the talent launch project of Huangshan university of Anhui province in China (2018xkjq012), the national innovation training project for college students (201810375027, 201810375035, 201810375048) and the scientific research project of Huangshan university of Anhui province in China(2017xhwh004).

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