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Experimental Study on Basic Mechanical Properties of SiO_2 Modified Basalt Fiber Concrete

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Abstract. The tensile performance of concrete is not good. In order to explore the improvement effect of highly active Nano-SiO_2 (NS) particles on the basic mechanical properties of Basalt fiber (BF) concrete. BF particles with high cost performance and NS particles with high activity were added into concrete in the way of single and mixed, respectively. The compression and splitting tensile test were performed, and the microstructure and failure mechanism of concrete were analyzed by electron microscopic experiment. The results show that the increase rate of compressive strength and splitting tensile strength of BF doped concrete is up to 4.31% and 13.41% respectively. The increase rate of compressive strength and splitting tensile strength of single-doped NS concrete is up to 8.9% and 5.43% respectively. The maximum increase rate of compressive strength and splitting tensile strength of BF and NS concrete is 16.29% and 23.91%, respectively. According to the results of microscopic microscopy, the mixing of BF and NS can greatly improve the mechanical properties of the foundation, because the integrity of concrete is enhanced after the incorporation of NS, which makes the bond between BF and cement mortar close, and thus improves the compressive and splitting tensile strength of basalt fiber concrete.

Keywords. Basalt fiber; Modified by Nano-SiO_2; Experimental research; Mechanical properties; The micro electron microscopy (SEM)

1 Introduction

Green new materials are recognized by various countries for their cheap but excellent properties [1-3]. The incorporation of basalt fiber into concrete can improve the number of bubbles and microstructure, so as to optimize the mechanical properties of concrete. Many studies have shown that a certain volume of fiber can improve the basic mechanical properties of concrete[4, 5], and can enhance the durability of cement based composite[6]and the grinding resistance of polypropylene fiber concrete[7]. Liu Qian found that the length ratio of BF is the key factor affecting the concrete performance. Li Fuhai et al.[8]found that adding basalt fiber to concrete can enhance the chloride ion permeability of concrete. Nanomaterials have a wide range[9]. Atmaca[10]It points out

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that the mechanical properties, permeability and durability of NS mixed in light concrete are improved, but its effect is not as good as the improvement effect of NS on ordinary concrete. Li[11]proposed that the enhancement of concrete was related to the water cement ratio. In addition, some studies[12, 13] have found that the addition of NS weakens the frost resistance of concrete. The smaller the NS particle size, the stronger the freeze and thaw resistance of the concrete[14].

At present, many scholars have mixed various kinds of fibers and nanomaterials into concrete to study their properties, and found that the effect of mixed tragedy is stronger than that of single mixing. Zhao Yawei[15]found that BF can improve the mechanical properties and fracture resistance of concrete. Shi He studied the properties[16] of concrete mixed with polypropylene fiber and NS particles, and improved the salt and freezing resistance performance of concrete. Guo Lin[17]mixed SiO_2 into polypropylene fiber concrete, and the freezing resistance was improved.

High active nanomaterials modified fiber concrete has many research results, Xu Hengqian[18] using chemical modification method developed high polymer fiber, greatly improve the hydrophilic fiber, wen-juan liu[19]will have high toughness, high activity GO into concrete, the results show that can improve the cement cement hole structure to improve the mechanical properties and frost resistance of concrete, liu[20]et al. in concrete mixed microcapsule phase change material (mPCMs)to improve the frost resistance of concrete, and use SiO_2 secondary modification to solve the shortcomings of microcapsule phase change material concrete strength.

However, few studies use nano SiO_2 modified basalt fiber concrete. It is necessary to study the combination of different NS and BS dosage, and obtain the comprehensive test results, which can provide some reference value for the selection of modifier dosage in actual engineering, and pave the way for further scientific research. Therefore, this experiment tested the basic mechanical properties of nano SiO_2 (0.5%, 1%, 1.5% and 2%) with different basalt fibers (0.08%, 0.16%, 0.24%, 0.32%), and analyzed the modification effect of nano SiO_2 on the basic mechanical properties of basalt fiber concrete from the microstructure and macroscopic mechanical properties.

2 Experiment

2.1 Experimental Material

For this experiment, 13mm basalt fiber, light tan with metallic luster, BF performance indicators are shown in Table 1, and nano SiO_2 performance parameters are shown in Table 2. Cement performance parameters are shown in Table 3; fine aggregate is medium sand; continuously graded coarse aggregate; water reducing agent is HS-DEFOAMER 567, and water uses standard water.

Table 1. Main performance indexes of Basalt fiber

length /mm	proportion /g/cm^3	diameter /μm	Modulus of elasticity /Gpa	Tensile strength /MPa	Ultimate elongation	T /°C
13	2.7	17.5	98	3500	3.2%	-250~630

Table 2. Performance parameters of Nano-SiO_2 material

Particle size /nm	Specific surface area /m^2/kg	Bulk density /g/cm^3	density /g/cm^3	The crystal type	Color	PH value
20	248	0.05	2.1-2.5	spheroidal	white	4~7

Table 3. Performance parameters of cement

Specific surface area	Ignition loss	setting time /min		Flexural strength/MPa		The compressive strength/MPa	
/m^2/kg	/%	initial	final	3d	28d	3d	28d
358	3.12	209	257	5.7	7.2	27.8	42.5

2.2 Design of the Specimen Mix Ratio

The reference concrete mix ratio of this test is shown in Table 4 below. The additional materials are fibers and nanomaterials, respectively, and BF and NS are added to the reference concrete in a certain proportion. BF is mixed into the concrete by the volume substitution method, and nano SiO2 is added into the concrete by the method of replacing the cement by equal mass. The test is based on the base concrete ratio, respectively equipped with 4 groups of BF dosage: 0.08%, 0.16%, 0.24%, 0.32%, and 4 groups of NS dosage: 0.5%, 1%, 1.5% and 2%. The specific material content of each group is shown in Table 5.

Table 4. Benchmark concrete mix ratio

Water cement ratio	Water /kg/m^3	Cement /kg/m^3	Sand ratio	Fine aggregate /kg/m^3	Coarse aggregate /kg/m^3	Water reducing agent /kg/m^3
0.42	178	416	0.38	719	1089	2.85

Table 5. Material content of each group of test pieces

Order number of the samples	number of the samples	Cement /kg/m^3	Water reducing agent /kg/m^3	Addition Percentage of BF material /%	Addition amount of BF material /kg/m^3	Addition Percentage of SiO_2 material /%	Addition amount of SiO_2material /kg/m^3
1	PC	416.00	2.85	0	0	0	0
2	BF1	416.00	2.85	0.08	2.24	0	0
3	BF2	416.00	2.85	0.16	4.48	0	0
4	BF3	416.00	2.85	0.24	6.72	0	0
5	BF4	416.00	2.85	0.32	8.96	0	0
6	NS1	414.92	2.85	0	0	0.5	2.09
7	NS2	412.83	2.85	0	0	1.0	4.17
8	NS3	410.75	2.85	0	0	1.5	6.26
9	NS4	408.66	3	0	0	2	8.34
10	BF1-NS1	414.92	3	0.08	2.24	0.5	2.09
11	BF1-NS2	412.83	3	0.08	2.24	1.0	4.17
12	BF1-NS3	410.75	3.33	0.08	2.24	1.5	6.26
13	BF1-NS4	408.66	3.33	0.08	2.24	2	8.34
14	BF2-NS1	414.92	3.33	0.16	4.48	0.5	2.09
15	BF2-NS2	412.83	3.33	0.16	4.48	1.0	4.17
16	BF2-NS3	410.75	3.67	0.16	4.48	1.5	6.26
17	BF2-NS4	408.66	3.83	0.16	4.48	2	8.34
18	BF3-NS1	414.92	3.7	0.24	6.72	0.5	2.09
19	BF3-NS2	412.83	3.83	0.24	6.72	1.0	4.17

20	BF3-NS3	410.75	3.83	0.24	6.72	1.5	6.26
21	BF3-NS4	408.66	4.53	0.24	6.72	2	8.34
22	BF4-NS1	414.92	4	0.32	8.96	0.5	2.09
23	BF4-NS2	412.83	4.16	0.32	8.96	1.0	4.17
24	BF4-NS3	410.75	5.23	0.32	8.96	1.5	6.26
25	BF4-NS4	408.66	7.33	0.32	8.96	2	8.34

2.3 Experimental Method

The tests used specimens with block size of 100×100×100mm, which were divided into 25 groups according to different dosage, with a total of 75 specimens. The impurities on the specimen surface shall be removed before the test, and the experimental equipment shall use the universal test machine. The ordinary test piece, nano test piece, fiber test piece and the small test blocks in the compression test are selected for microscopic test. The size of the test block is about 6-12mm. Will need to paste the end of the conductive film with cutting machine grinding flat, paste conductive film, and then paste the other end of the conductive film on the platform, using strong dust on the surface of the dust impurities, and then spray gold treatment, the end of the spray sample into the sample room, observe the microscopic morphology of the concrete in high vacuum mode.

3 Test results and Discussion

3.1 Concrete Compression Strength

Table 6 shows the compressive strength value of concrete cubes of BF and NS mixed materials, and Table 7 shows the improvement rate of compressive strength corresponding to different mixing amounts. It can be seen that the compressive strength of concrete cube increases first and then decreases with the increase of SiO_2 dosage, and the change law of basalt dosage also increases first and then decreases. The results are plotted as shown in Figure 1.

According to the statistics of the bar chart of Figure 1, the improvement rate of the compressive strength of concrete can reach 8.9%, while the maximum improvement rate of BF is only 4.31%. When BF and NS are mixed, the BF amount is less than 0.24%, and when the NS amount is less than 1.5%, the effect of the compressive strength is good, and the compressive strength effect is not obvious. BF 0.08% and 0.16%, NS 0.5% concrete compressive strength and 1%.

The modification effect of the highly active nano-SiO_2 on the compressive strength of basalt fiber concrete was further analyzed. Compression of basalt fiber concrete when SiO_2 excess (over 2.0%) The strength value is far lower than that of concrete without mixing or appropriate amount of SiO_2, which makes the integrity of basalt fiber concrete structure worse and the compressive strength value reduced. The appropriate amount of SiO_2 can enhance the compressive strength of basalt fiber concrete. When the amount of SiO_2 is 0.5%, the compressive strength of concrete with basalt fiber mixing of 0.32% is the most obvious, and the amount of fiber mixing should not be too small. When the SiO_2 dosage is 1.5%, the basalt fiber dosage should not be too much, and the compressive strength of concrete is optimal when the fiber dosage is about 0.08%.

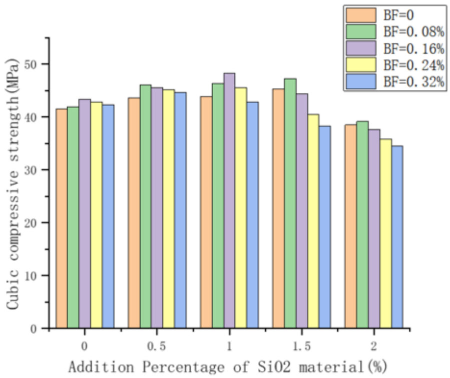


Figure 1. Columstogram of compressive strength of BF and NS concrete

Table 6. Compressive strength of concrete mixed with BF and NS concrete（MPa）

Nano-SiO_2 \ BF		Addition Percentage of BF material /%				
		0	0.08	0.16	0.24	0.32
Addition Percentage of SiO_2 material/%	0	41.56	41.98	43.35	42.89	42.37
	0.5	43.68	46.09	45.59	45.18	44.68
	1.0	43.85	46.38	48.33	45.51	42.85
	1.5	45.26	47.30	44.39	40.44	38.24
	2.0	38.48	39.15	37.61	35.87	34.45

Table 7. Improvement rate of compressive strength of mixed with BF and NS concrete（%）

Nano-SiO_2 \ BF		Addition Percentage of BF material /%				
		0	0.08	0.16	0.24	0.32
Addition Percentage of SiO_2 material/%	0	0.00	1.01	4.31	3.20	1.95
	0.5	5.10	10.90	9.70	8.71	7.51
	1.0	5.51	11.60	16.29	9.50	3.10
	1.5	8.90	13.81	6.81	-2.69	-7.99
	2.0	-7.41	-5.80	-9.50	-13.69	-17.11

3.2 Splitting Tensile Strength

The results of cracking tensile strength and strength improvement rate of concrete are shown in Table 8 and Table 9, and the data results are drawn in Figure 2.

According to the statistical results of the chart, the improvement effect of BF on splitting strength is better than that of SiO_2. The maximum increase was 13.41%, while NS was 5.43%.

When the fiber and nano materials are mixed in concrete, with the increase of BF content, the splitting tensile strength of the specimen increases first and then decreases. In the case of different NS content, the influence of BF content on the splitting tensile strength of the specimen is consistent, but the peak splitting tensile strength of the concrete is different. When the BF mixture is 0.08%, and the NS concentration is 1.5%, the maximum tensile strength of concrete can reach 3.15 Mpa, and the improvement rate is 14.13%. The other combinations were, 0.16%, 1.0%, 3.29,19.2%; 0.24%, 1.0%, 3.43,23.91%; 0.32%, 0.5%, 3.19,15.58%, respectively. Figure 4 shows that the tensile intensity of BF is 0.16% and 0.24%, and the NS is 0.5% and 1%.

The modification effect of the high activity nano SiO_2 on the splitting tensile strength of basalt fiber concrete was further analyzed. When the amount of SiO_2 is excessive (more than 1.5%), the compressive strength value of basalt fiber concrete is much lower than that of no or appropriate amount of SiO_2 concrete. The incorporation of excessive modifying agent makes the integrity of basalt fiber concrete structure worse and the split tensile strength value is reduced. Appropriate incorporation of highly active nano SiO_2 can improve the splitting tensile strength of different basalt fiber concrete.

The BF dosage should not be too large[21]. The split tensile strength of concrete specimens with BF mixture of 0.32% is lower than that of concrete specimens with BF mixture of 0.24%.

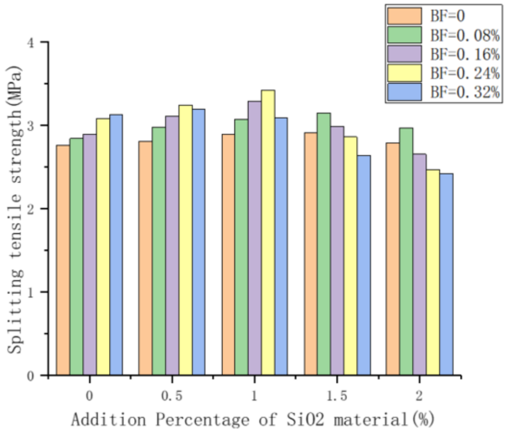


Figure 2. Bar diagram of split tensile strength of BF and NS concrete

Table 8. Split tensile strength of BF and NS concrete（MPa）

Nano-SiO_2 \ BF		Addition Percentage of BF material /%				
		0	0.08	0.16	0.24	0.32
Addition Percentage of SiO_2 material/%	0	2.76	2.84	2.89	3.08	3.13
	0.5	2.81	2.98	3.11	3.24	3.19
	1.0	2.89	3.07	3.29	3.42	3.09
	1.5	2.91	3.15	2.99	2.86	2.64
	2.0	2.79	2.97	2.65	2.47	2.42

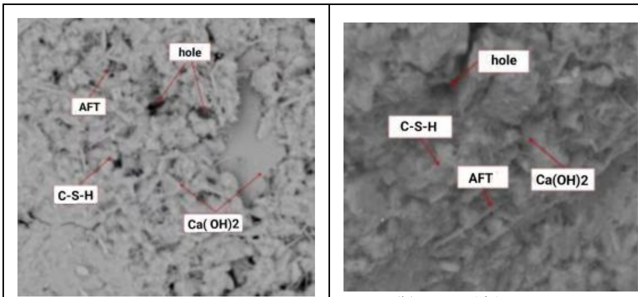
Table 9. Improvement rate of split tensile strength of BF and NS concrete（%）

Nano-SiO_2 \ BF		Addition Percentage of BF material /%				
		0	0.08	0.16	0.24	0.32
Addition Percentage of SiO_2 material/%	0	0.00	2.90	4.71	11.59	13.41
	0.5	1.81	7.97	12.68	17.39	15.58
	1.0	4.71	11.23	19.20	23.91	11.96
	1.5	5.43	14.13	8.33	3.62	-4.35
	2.0	1.09	7.61	-3.99	-10.51	-12.32

4 Analysis of the Microstructure and the Destruction Mechanism

The ordinary test piece, nano test piece, fiber test piece were selected for microscopic test, and the microscopic morphology of concrete was observed by 5000 times in high vacuum mode.

Adding SiO_2 molecules into ordinary concrete can accelerate the curing reaction of cement, reduce the reaction of C_3S molecules in cement slurry, and accelerate the hardening rate of concrete [22, 23]. Cement in the process of hydration will reflect the main hydration process and SiO_2 molecules and cement hydration products further reaction[24], through the SME electron microscope to observe the microscopic morphology of concrete, can observe the reaction generated the network structure of hydration of calcium silicate (C-S-H), sheets of $Ca(OH)_2$, irregular distribution of loose needle AFT crystal, and with the reaction, between the product holes and gaps. Compared with Figure 3 (a) and (b), it can be seen that the content of calcium silicate (C-S-H) in nano SiO_2 concrete is more, and the structure is larger and more dense than ordinary concrete. On the contrary, the number of voids in nano SiO_2 concrete is smaller, and the overall structure is more compact and compact. One is that NS itself can play a filling role, and the other is that it promotes the hydration reaction, changing the proportion of each product and increasing the compactness of the structure.

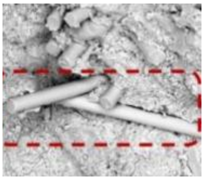


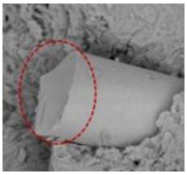
(a)common concrete (b)Nano-SiO_2 concrete

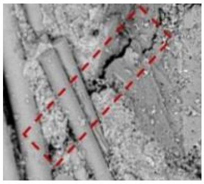
Figure 3. Microscopic morphology of concrete

Random lap basalt fiber can improve the density of concrete, as shown in Figure 5. And basalt fiber has a strong tensile capacity, in the concrete force, part of the stress in the tensile area concentrated tensile stress, basalt fiber can play a protective role in the concrete structure. Because the concrete structure contains a large number of space, and fiber and cement cement combination site is not close enough, when the concrete tensile damage, part of the fiber extraction damage, its tensile strength depends on the tightness of the fiber and the concrete connection, its effect is far lower than the fiber failure energy, as shown in figure 4 (b), (c), (d).

When the single fiber in concrete, its toughness can not reach the best state, and the modifier is added to enhance the bonding between the fiber and the glue, so as to achieve the effect of improving the performance of concrete.


(a)Basalt fiber randomly distributed grid structure


(b)Basalt fiber fracture plane


(c)Basalt fiber across cracks

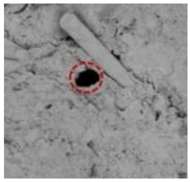
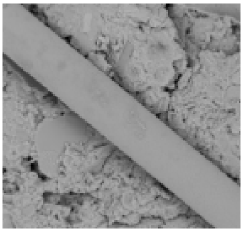

(d)Basalt fiber Pull-out damage

Figure 4. Microscopic morphology of BF concrete

BF can enhance the tensile strength of concrete, strengthen the skeleton structure of concrete, NS can improve the integrity of concrete, but also enhance the bond between BF and concrete mortar, internal compaction, increase the bite force between the matrix, BF and NS make the concrete performance has been greatly improved.


(a)Single Basalt fiber

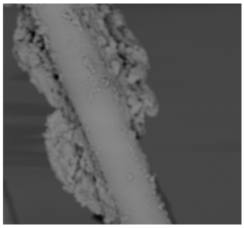

(b)Basalt fiber mixed with Nano-SiO_2

Figure 5. Surface micromorphology of Basalt fiber

5 Conclusion

1) The compressive strength improvement effect of single SiO_2 on concrete is stronger than that of single basalt fiber; the tensile strength of concrete is stronger than that of single SiO_2.

2) The improvement effect of single mixing SiO_2 or basalt fiber on concrete performance is not as good as mixing, but when the BF dosage exceeds 0.24% and the NS dosage exceeds 1.5%, the improvement effect of the compressive strength of concrete is not obvious.

3) The strength of concrete increases with the increase of SiO_2 and basalt fiber. When the incorporation of SiO_2 is 1.0% and the volume rate of basalt fiber is 0.24%, the splitting tensile strength reaches 3.42MPa, and the strength improvement rate is 23.91%. When the SiO_2 mixture is 1.0% and the volume rate of basalt fiber is 0.16%, the splitting tensile strength reaches 48.33MPa and the strength improvement rate is 16.29%.

4) From the microscopic experimental results, it can be seen that NS can play a filling role, and react with hydration products to form a more stable gel structure, to enhance the integrity of concrete gel, and also enhance the bonding force between BF and cement gel, so as to improve the toughness of concrete.

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