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Mechanical Property Test of Polyvinyl Alcohol (PVA) Fiber Reinforced Concrete

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The traditional PVA-ECC mix proportion is improved based on the orthogonal test to obtain the PVA fiber concrete material with lesser fiber content and conventional aggregate size satisfying structure use requirements and lower construction cost requirements. Moreover, material property test of this material is conducted, and the failure mode of the test piece and the influence factors are analyzed. Then the rupture strength, compressive strength and the respective load-deformation curves are obtained, and a basis for numerical simulation is provided.

1. Introduction

Along with the development of urban construction and building technology, property of the normal concrete cannot satisfy requirements of the human life any more (Georgiou, 2016), and development of the fiber concrete receives much concern thereof (Ayub et al., 2014). Comparing with the normal concrete, fiber concrete has enhanced tensile strength, crack resistance, bending strength and impact resistance for being as a new cement-based mixed material (Brandt et al., 2003; Xiao et al., 2011), while the exorbitant cost restricts its extensive use in projects. In this research, it gives improvement based on the traditional PVA-ECC formula, with purpose of reducing construction cost and satisfying structure use requirements simultaneously by broadening the requirements for fine aggregate size and reducing fiber content. Four-point bending test and uniaxial drawing test are conducted respectively, and the respective test results are analyzed, with the purpose of providing a reference for the popularization and application of fiber concrete.

2. Test Program Design

Mechanical performance and work performance of PVA-ECC material are influenced by many factors (Nematollahi et al., 2015). If this material is expected to be promoted and used, one shall reduce the construction cost at the same time of satisfying use requirements, and fiber content and fine aggregate size are two important influence factors (Zhu et al, 2011). Moreover, it is indicated by a large number of researches that water-binder ratio also has greater influence on the property of ECC (Du, 2013). Thus, water-binder ratio, fiber volume content and the maximum fine aggregate size are deemed as the three influence factors in the test, and three level states are set for each influence factor. The L9(34) orthogonal table in orthogonal design method is used in test design, and levels of the orthogonal test factors are as shown in Table 1

Table 1: Table of Levels of the Test Factors

Level	Factors		
	Water-binder ratio (A)	Fiber volume content (B)	The maximum aggregate size (C)
1	A1(0.29)	B1(1%)	C1(0.09mm)
2	A2(0.34)	B2(1.5%)	C2(0.315mm)
3	A3(0.40)	B3(2%)	C3(0.63mm)

Fiber is represented by adopting the volume method, and other components are represented by adopting the relative mass method. Mix proportion of compression test and bending test is as shown in Table 2.

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Sand-binder ratio is taken as 0.34, and quantity of water reducing agent shall be adjusted according to the different water-binder ratio.

Table 2: Mix Proportion of PVA-AFCC Test

No.	Cement	Fly ash	Sand	Water	PVA fiber(%)	The maximum sand size	Water-binder ratio
YZ1	1	1.20	0.75	0.64	1	0.09	0.29
YZ2	1	1.20	0.75	0.88	1	0.63	0.40
YZ3	1	1.20	0.75	0.75	1	0.315	0.34
YZ4	1	1.20	0.75	0.88	1.5	0.09	0.40
YZ5	1	1.20	0.75	0.75	1.5	0.63	0.34
YZ6	1	1.20	0.75	0.64	1.5	0.315	0.29
YZ7	1	1.20	0.75	0.75	2	0.09	0.34
YZ8	1	1.20	0.75	0.64	2	0.63	0.29
YZ9	1	1.20	0.75	0.88	2	0.315	0.40
YZ10	1	1.20	0.75	0.69	0	0.63	0.23

3. Bending Test

As the aggregate in PVA-FRCC measured in this test is fine sand, no coarse aggregate is added, and there is PVA fiber reinforced, the Test Methods for the performance of Glass Fiber Reinforced Cement (GB/T 15231-2008)is used as test reference standard.

3.1 Test piece production

The 40mm×40mm×160mm prism test piece is adopted in the test, three test pieces are produced for each proportion, and the test model adopts steel cement-glue-sand triple test model. To determine the influence on cement-based material property by mixing fiber or not, a group of cement-glue-sand test piece without fiber is added.

3.2 Test process

Figure 1 is the schematic diagram of bending test. This test is conducted by using the lower space of the WDW-100E testing machine, loading mode is displacement control mode, constant speed displacement is adopted and controlled at 0.05mm/min, and axial spacing of support is adjusted to be 100mm. During test piece assembly, one side of the test piece shall be placed on the support cylinder, so that loading cylinder and support cylinder can contact with the side formed in test piece molding, and it shall be put in the middle.

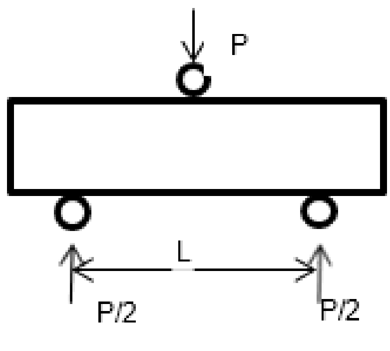

Figure 1: Schematic Diagram of Bending Test

3.3 Test results

3.3.1 Failure mode of test piece

YZ10 test block without fiber shall be in failure once showing crack when reaching the ultimate bending bearing capacity. It shall show only one fissure and the cross section is smooth. The performance is obvious. PVA-AFCC test block with fiber shall show multi cracks. It shall not be in failure after initial crack and can bear the weight continuously. The test piece might still maintain the integrity. One can hear the squeak of fiber cracking during loading process. The cross section is rugged, and one can see the fiber being snapped or pulled out.

3.3.2 Test results data analysis

Three test pieces are produced for each proportion in this test, and test results are given statistics according to arithmetic mean values of the three test pieces satisfying requirements based on the strength evaluation standard. When there is one of the three values exceeds the average value for ±10%, the average value shall be taken as test result. When there are two of the three values exceed the average value for ±10%, rupture strength results of this group shall be invalid. All test data of this paper shall be treated according to this method, without repeat below. The result of the test is presented in Table 3.

Table 3: Statistical Table of Rupture Strength

No.	PVA fiber content (%)	The maximum sand size (mm)	Water-binder ratio	Average value of rupture strength (MPa)	Increment amplitude of rupture strength (%)
YZ1	1	0.09	0.29	7.99	51.3
YZ2	1	0.63	0.40	8.59	38.5
YZ3	1	0.315	0.34	7.60	43.9
YZ4	1.5	0.09	0.40	7.40	40.2
YZ5	1.5	0.63	0.34	9.03	71.0
YZ6	1.5	0.315	0.29	8.03	52.1
YZ7	2	0.09	0.34	9.83	86.2
YZ8	2	0.63	0.29	8.85	67.6
YZ9	2	0.315	0.40	7.28	37.9
YZ10	0	0.63	0.23	5.28	——
average	——	——	——	8.28	54.3

Note: Increment amplitude of rupture strength is the strength increment percentage relative to the strength of test case YZ10 (fiber content 0%).

It is seen from Table 3 that comparing with the YZ10 test block without fiber, the other 8 groups of test blocks all have enhanced rupture strength excepting for YZ5. Average value range of the rupture strength of the test blocks YZ1-YZ9 is 7.28-9.83MPa with total average value 8.28MPa, and increment amplitude is 37.9%-86.2% with average value 54.3%, which indicates that the rupture strength is enhanced somewhat after mixing with fiber. The formula with the maximum appreciation is that of YZ7, with fiber content 2%, the maximum sand size 0.09mm and water-binder ratio 0.34.

Table 4 is the average value of rupture strength and the extreme difference calculation results.

Table 4: Average Value of Rupture Strength and the Extreme Difference Calculation Results

Factor / Average Value	A(fiber content)	B (maximum sand size)	C(water-binder ratio)
K1	7.93	8.41	8.29
K2	7.72	7.64	8.72
K3	8.65	8.72	7.76
R	0.93	1.08	0.96

It is obtained from Table 4 that R of sand size is more than R of water-binder ratio and R of water-binder ratio is more thaan R of fiber content, which indicates that sequence of the factors affecting PVA-FRCC rupture strength is sand size, water-binder ratio and fiber content. When considering rupture strength merely and not considering work property, the optimal level combination shall be fiber content 2%, the maximum sand size 0.09mm and water-binder ratio 0.34, which is identical with the test results.

4. Compression Test

Compression test is conducted by adopting half of the test piece snapped in another compression test, size of the pressure-bearing surface shall be 40×40mm, and special jig shall be used in this compression test.

4.1 Compressive strength test method

Figure 2 shows the schematic diagram of compression test.

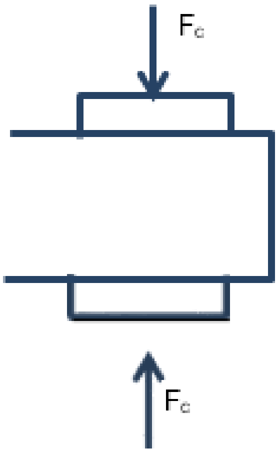

Figure 2: Schematic Diagram of Compression Test

4.2 Loading device and loading process

This test is conducted by adopting the lower compression space of WDW-100E testing machine. Loading method is displacement control mode and constant speed displacement is adopted and controlled at 0.5mm/min. During the test piece is assembled, the test piece shall be wiped firstly. Side of the test piece shall be considered as the pressure-bearing surface, center line of the test jig is required to coincide with centers of the up and down pressure heads. Sand or impurities on surfaces of up and down pressure heads shall be cleaned before test. Test piece shall closely adjoin with the column in the side of jig, and horizontal center of the test piece shall be ensured.

4.3 Test results

4.3.1 Failure mode of test piece

After suffering pressure, the PVA-AFCC test piece still maintains certain integrity. There is no visible crack showing on the surface of test piece utill to the time of realizing peak load. Along with continuous increment of load, axial size of test piece become smaller and lateral size become larger. Ductility is obvious. The test piece shows no crack during failure. Failure mode of the test piece without fiber is similar to that of concrete. It has obvious fragility. The test piece is similar as a rectanggular pyramid after complete fracture, and the cross sections are regular.

4.3.2 Test data analysis

Statistical value of compressive strength of YZ1-YZ10 and the rupture-compression ratio are shown in Table 5. It is seen from the table 5 that average value of the compressive strength of YZ1-YZ9 is 20.62-44.42 MPa with average value 35.90MPa. By comparing with the YZ10 test block without fiber, compressive strength values of the 9 groups of test blocks are all lower with average decreasing amplitude -21.27%, which indicates that compressive strength of material reduces inordinately after mixing with fiber. That with the greatest compressive strength in YZ1-YZ9 is YZ1 with fiber content 1%, the maximum sand size 0.09 and water-binder ratio 0.29, and that with the smallest compressive strength is YZ9 with fiber content 2%, the maximum sand size 0.315 and water-binder ratio 0.40.
It is discovered from research that rupture-compression ratio has some corresponding relation with material toughness, the larger the numerical value of rupture-compression ratio is, the greater the material toughness is, and vice versa. It is seen from the table that rupture-compression ratio of YZ10 is 0.12, that of the other groups in YZ1-YZ9 is 0.17-0.34, and they are all greater than rupture-compression ratio of the test piece without fiber, which indicates that material toughness can be promoted obviously by adding PVA fiber. The

group with the maximum rupture-compression ratio, namely the best toughness, in YZ1-YZ9 is YZ9 with fiber content 2%, the maximum sand size 0.315 and water-binder ratio 0.40, and that with the minimum rupture-compression ratio, namely the worst toughness, is YZ3 with fiber content 1%, the maximum sand size 0.315 and water-binder ratio 0.34.

Table 5: Statistical Table of Compressive Strength and Rupture-compression Ratio of PVA-AFCC

No.	Average value of compressive strength (MPa)	Increment amplitude of compressive strength (%)	Average value of rupture strength (MPa)	Rupture-compression ratio
YZ1	42.74	-6.68	7.99	0.19
YZ2	25.04	-45.33	8.59	0.34
YZ3	44.42	-0.03	7.60	0.17
YZ4	36.48	-20.35	7.40	0.20
YZ5	34.98	-23.62	9.03	0.26
YZ6	40.63	-11.29	8.03	0.20
YZ7	40.73	-11.07	9.83	0.24
YZ8	37.50	-18.12	8.85	0.24
YZ9	20.62	-54.98	7.28	0.35
YZ10	45.80	——	5.28	0.12
average of YZ1-YZ9	35.90	-21.27	8.28	0.23

Table 6: Average Value of Compressive Strength and the Extreme Difference Calculation Results

Factor / Average Value	A(fiber content)	B (the maximum sand size)	C(water-binder ratio)
K1	37.40	39.98	40.29
K2	37.36	35.22	40.04
K3	32.95	32.51	27.38
R	4.45	7.47	12.91

It is known from Table 6 that: the smaller the sand size is, the fewer the gaps in test piece are, the denser the test piece is, the smaller the water-binder ratio is, the lesser the water use is, and the larger the strength value of test piece is. It is obtained from table 6 that R of water-binder ratio >R of sand size >R of fiber content, which indicates that sequence of the factors influencing compressive strength is water-binder ratio, sand size and fiber content. However, PVA-AFCC is not used as the main compression member in practical projects.

Table 7: Average Value of Rupture-compression ratio and the Extreme Difference Calculation Results

Factor / Average Value	A(fiber content)	B (the maximum sand size)	C(water-binder ratio)
K1	0.23	0.21	0.21
K2	0.20	0.24	0.21
K3	0.34	0.29	0.30
R	0.14	0.08	0.09

It is obtained from Table 7 that the R of fiber content >the R of water-binder ratio >the R of sand size, which indicates that sequence of the factors influencing rupture-compression ratio is fiber content, water-binder ratio and sand size. Combination with the maximum toughness is fiber content 2%, the maximum sand size 0.63mm and water-binder ratio 0.40.

When comparing compressive strength with rupture-compression ratio, it can be seen that numerical values of the optimal combination are just on the contrary. Rupture-compression ratio represents the toughness of material. When the inter-atomic binding force of material is greater and the strength is higher, the binding force is smaller, the toughness is better. Simultaneously, it is a great puzzle of the materials sector to obtain materials with great rigidity and good toughness.

5. Conclusion

It can be seen by analyzing the orthogonal test results that sequence of the factors influencing PVA-FRCC rupture strength is sand size, water-binder ratio and fiber content. After adding fiber, compressive strength and rigidity of test piece reduce and with average decrement amplitude 21.27%. Peak growth of compressive strain indicates the growth of toughness. The average increment amplitude is 2.55%, which is about 12 times of normal concrete. It can be seen by analyzing the orthogonal test data that sequence of the factors influencing PVA-AFCC compressive strength is water-binder ratio, sand size and fiber content, and that of the factors influencing rupture-compression ratio is fiber content, water-binder ratio and sands size. Fiber concrete material can improve their ductility by using aggregate with conventional size or by reducing fiber content, which provides reference bases for the application of fiber concrete in projects.

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