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Mechanical Properties Optimization of Fiber Reinforced Foam Concrete

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Abstract. 3 factors including fiber kind, fiber content and fiber mix-ability are selected to optimizing mechanical properties of foam concrete. By orthogonal experiment design, compression and flexural stress and strain of specimens from different fiber added ways were test. Range analysis and factor levels analysis show the best fiber added way. Test shows that fiber content is the most important factor to flexural stress. Next one is fiber kind and the third is fiber mix-ability. Fiber kind is the most important factor to stress curves. Fiber is not good for compression strength but good for flexural strength.

1 Introduction

Foam concrete is insulation material due to lots of enclosure pores in it. It is used in constructions widely. While it is also limited by its friability and low strength. Fiber was added into foam concrete to enhance its ductility and strength. Fiber added ways have different effects on mechanical property.

Fiber added ways include fiber kinds, fiber content and fiber mix-ability. Park's indicates that carbon fiber reinforced concrete is more strong than glass fiber one [1]. Mohammed Imtiaz Khan indicates that basalt fiber is better than polypropylene fiber to concrete [2]. Han Po indicates that polyvinyl alcohol (PVA) fiber concrete has more flexural property than polypropylene (PP) fiber [3].

Fiber content has an effect on concrete mechanical strength. Cai Na indicates that concrete with 1.2%-1.6% PP fiber has lower compression strength than concrete without fiber [4]. Zhang Xi indicates that 20% fiber content is a critical value. More than 20%, concrete strength begin reducing gradually [5]. Zhao Xing indicates that foam concrete compression and flexural strength increase by fiber content increasing [6].

Fiber mix-ability has an effect on foam concrete mechanical properties. Li .V .C indicates that fiber can be separated into concrete by friction among concrete slurry [7].

In order to enhance foam concrete mechanical property, by means of orthogonal test, fiber kinds, content and mix-ability are studied. The best fiber added way is selected. It can provide a reference to construction.

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2 Experimental Design

2.1 Raw Materials

Quick solidification aluminate sulfate cement. Low-calcium fly ash. Silica fume. Expanding agent. Silica sand. Poly carboxylic acid water reducing agent. FP-180 animal protein foaming agent. Tap water. Fiber properties are shown in table 1.

Table 1 Fiber Prpperties

Number	Properties	Mark
1	L=12mm,d=0.039mm,ρ=1.2g/m^3	IPVA
2	L=12mm,d=0.039mm,ρ=1.2g/m^3	LPVA
3	L=12mm,d=0.059mm,ρ=0.91g/m^3	PP

2.2 Orthogonal Test

3 kinds of fiber are listed above, 3 kinds of fiber contents include 0%, 1.0% and 1.5%, 3 kinds of fiber mix-ability are shown as follow: ① fiber added during mortar mixing, ② fiber added during cement and sand mixing. ③ fiber added during foam concrete mixing. Factors and levels of orthogonal test are shown in table 2.

Table 2 Factors And Levels

Factor	ID	level		
		1	2	3
Fiber kinds	A	IPVA	LPVA	PP
Fiber contents	B	0%	1.0%	1.5%
Mix-ability	C	Raw materials	Mortar	Foam concrete

Remark: fiber contents indicate percent of mortar volume.

According to orthogonal design schedule [8], 9 fiber added ways are selected as shown as table 3.

Table 3 Fiber Added Ways

Number	Fiber added way
1	IPVA-1.0%-mortar
2	IPVA-1.5%-foam concrete
3	LPVA-1.0%-foam concrete
4	LPVA-1.5%-raw materials
5	PP-1.0%-raw materials
6	PP-1.5%-mortar
7	IPVA-0%-raw materials
8	LPVA-0%-mortar
9	PP-0%-foam concrete

In table 3, IPVA-1.0%-mortar means that 1.0% import PVA fiber are added during mortar mixing. The rest can be done in the same manner.

2.3 Mix Proportion

Foam concrete density is 500 kg/m^3. Mix proportion of fiber foam concrete is as shown as table 4.

Table 4 Foam Concrete Mix Proportion / Kg/M3

cement	Fly ash	water	sand	foam
319	80	92	60	30±5

2.4 Specimen Preparation

Prepare foam with foam machine. Put cement, sand, Low-calcium fly ash, silica fume and expanding agent into concrete mixing machine and mix 30s. Put water into machine and mix 30s. Put foam into machine according to 3 kinds of fiber mix-ability. Pour foam concrete slurry into moulds. Smoothing. Lay aside 24h. Remove moulds. Put specimens into standard curing room and lay aside 7d.

2.5 Test Method

Compression and flexural experiments are finished on TONINORM2000 machine. Compression specimen is cubic with size 100mm×100mm×100mm. Loading rate is (2±0.5) kN/s. Piston displacement regards as compressive deformation. Flexural specimen is cuboid with size 100mm×100mm×400mm. Loading rate is (0.20±0.05) kN/s. Deflection is detected with LVDT. Bending test diagram is as shown in figure 1.

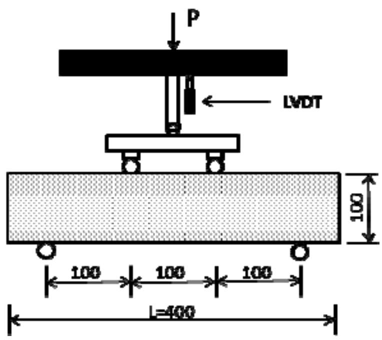


Fig.1 Bending test diagram

3 Results and Analysis

3.1 Range Analysis

Compression and flexural strength of foam concrete with different fiber added ways are listed on table 5.

Table 5 Compression And Flexural Strength Of Foam Concrete With Different Fiber Added Ways / Mpa

A	B	C	Compression	Flexural
1(IPVA)	1(0%)	1(raw materials)	0.58	0.37
1(IPVA)	2(1.0%)	2(mortar)	0.56	0.97
1(IPVA)	3(1.5%)	3(foam concrete)	0.63	0.93
2(LPVA)	1(0%)	2(mortar)	0.58	0.37
2(LPVA)	2(1.0%)	3(foam concrete)	0.50	0.71
2(LPVA)	3(1.5%)	1(raw materials)	0.48	0.62
3(PP)	1(0%)	3(foam concrete)	0.58	0.37
3(PP)	2(1.0%)	1(raw materials)	0.55	0.85
3(PP)	3(1.5%)	2(mortar)	0.52	0.55

Range analysis results are list into table 6.

Table 6 Range Analysis Results

Item	Compression strength / MPa			Flexural strength / MPa		
	A	B	C	A	B	C
K1	1.77	1.74	1.61	2.26	1.11	1.83
K2	1.56	1.61	1.66	1.70	2.53	1.88
K3	1.65	1.63	1.71	1.76	2.09	2.01
K1’	0.59	0.58	0.54	0.75	0.37	0.61
K2’	0.52	0.54	0.55	0.57	0.84	0.63
K3’	0.55	0.54	0.57	0.59	0.70	0.67
Max	A1	B1	C3	A1	B2	C3
Rj	0.070	0.046	0.035	0.17	0.47	0.06
/	A>B>C			B>A>C		

For compression strength, for A factor, K1’>K3’>K2’, A1 is the best level. For B factor, B1 (0% fiber content) is the best level. It means that fiber has no effect on compression strength. For C factor, C3 is the best level. A1B1C3 is the best fiber added way to compression.

For flexural strength, for A factor, A1 is also the best level. For B factor, B2 is the best level. For C factor, C3 is the best level. A1B2C3 is the best fiber added way for flexural. Adding 1.0% IPVA fiber into mortar is the best way to enhance flexural property. $R_B>R_A>R_C$, it shows that fiber content is the most important factor to flexural property. The second is fiber kinds and the third is fiber mix-ability.

Actually, optimal combination selected is smart. For main factor, the best level is needed. The most proper production mode has to be considered other reality factors such as productivity, costing, labor condition and so on.

3.2 Factor and Level Analysis

Experiment indexes VS factor levels are as shown in figure 2.

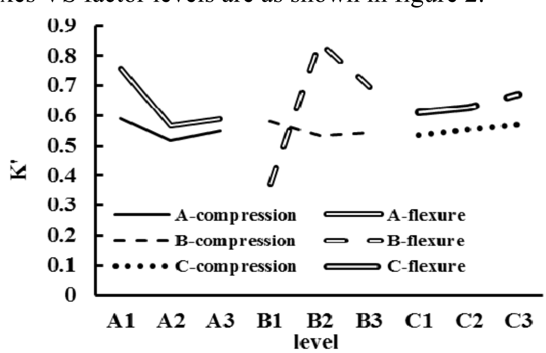


Fig.2 Experiment indexes VS factor levels

In figure 2, for compression strength, for fiber kinds, IPVA fiber is better than PP fiber. For fiber contents, no fiber is the best. For fiber mix-ability, adding fiber into foam concrete is the best way. The second is adding into mortar and the third is adding into raw materials.

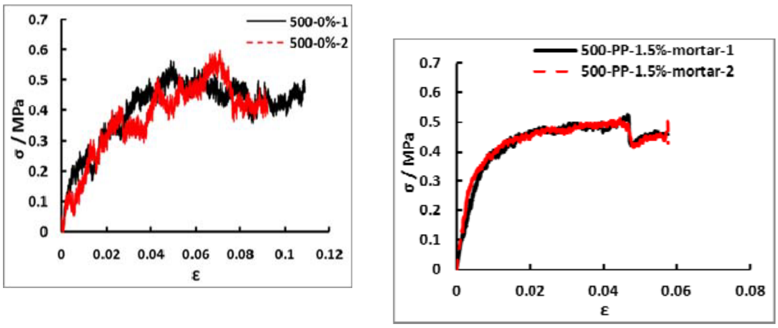
For flexural strength, for fiber kinds, IPVA fiber is better than PP fiber and the last one is LPVA fiber. For fiber contents, 1.0% is better than 1.5%. For fiber mix-ability, adding fiber into foam concrete is the best way. The second is adding into mortar and the third is adding into raw materials.

3.3 Stress Curve Analysis

For different fiber added ways, foam concrete mechanical properties are different.

3.4 Results Analysis

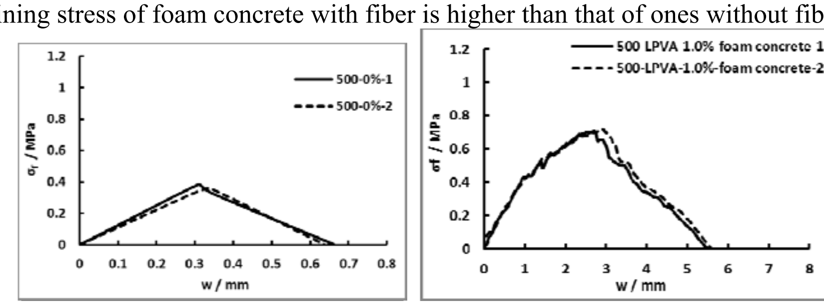
Figure 3 shows relationships of compression stress and strain for concretes with or without fiber. Figure 4 shows relationships of flexural stress and strain for concretes with or without fiber.



a) No fiber b) Fiber concrete

Fig.3 Compression stress VS strain for concrete with or without fiber

From figure 3, compression curve shapes have no difference between concretes with or without fiber. But for peak value, foam concrete with fiber is lower than ones without fiber. Remaining stress of foam concrete with fiber is higher than that of ones without fiber.

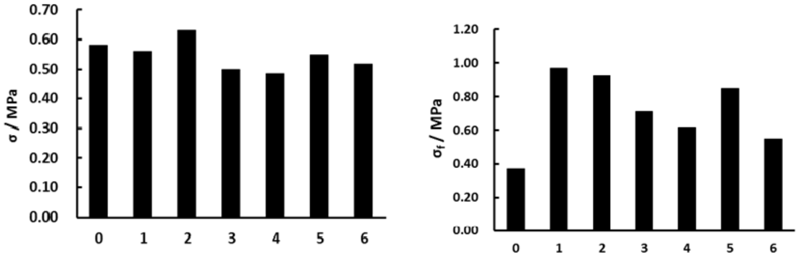


a) No fiber b) Fiber in concrete

Fig.4 Flexural stress VS deflection for concretes with or without fiber

For foam concrete without fiber, stress and deflection curves present brittle failure properties. For foam concrete with fiber, curve drops slowly after peak value. Deflection is also more than that of concrete without fiber. It shows that foam concrete with fiber has better ductility than ones without fiber. Fiber can enhance foam concrete flexural property.

Plot peak values on figure 5, number 0 is concrete without fiber. Number 1-6 are fiber foam concretes from different fiber added ways.



a) Compression strength b) Flexural strength

Fig.5 Strength comparison

From pic.5-a), comparing with number 0 fiber added way, number 2 enhances concrete compression strength. Number 1, 3-6 fiber added way make compression strength reducing.

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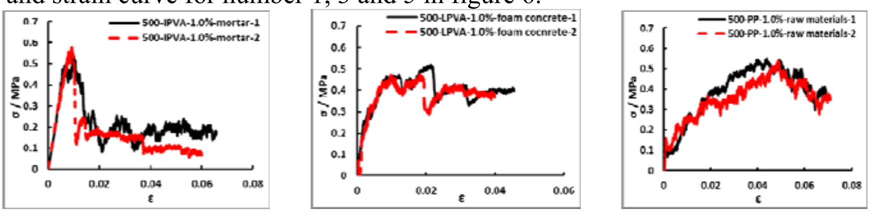
Number 4 is the least. From pic.5-b), 6 kinds of fiber added ways all can enhance concrete flexural strength, especially number 1 and 2.

From Pic 3-Pic 5, fiber can enhance flexural property of foam concrete but can't enhance compression strength. Test results is agreed to theory analysis results mentioned above.

3.5 Compression Property Analysis

For compression property, in order to find the best fiber added way, plot compression stress and strain curve for number 1, 3 and 5 in figure 6.



a) IPVA b) LPVA c)PP

Fig. 6 Compression stress VS strain

Fiber kind makes the most important effect on curve shapes. This test result is agreed to theory analysis results that fiber kind is the most important factor for compression strength.

For 6 kinds of foam concretes, plot compression strength on figure 7.

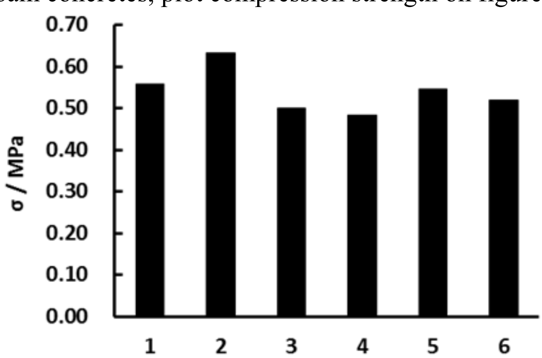


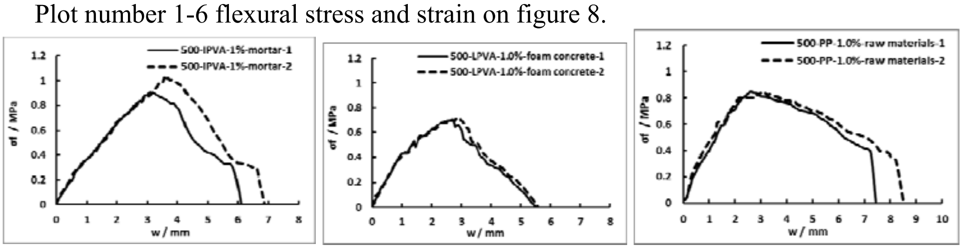
Fig.7 Compression strength comparing for 6 kinds fiber foam concretes

For compression strength, number 2 fiber added way, adding 1.5% IPVA fiber into foam concrete, is the best way. Number 1 added way is the second good one. And then is number 5, number 6, number 3 and number4 successively.

Concrete with IPVA fiber has the largest compression strength. And then is concrete with PP fiber. The last is concrete with LPVA fiber. Test result is agreed to theory analysis results mentioned above.

3.6 Flexural Property Analysis

Plot number 1-6 flexural stress and strain on figure 8.



a) IPVA b) LPVA c) PP

Fig. 8 Flexural stress VS deflection

From pic.8-c, flexural stress increases rapidly with deflection increasing. Stress drop slowly after peak value. This means that concrete with PP fiber has better ductility than that with PVA fiber. While flexural strength of concrete with PP fiber is lower than that with PVA fiber.

Plot 6 kinds of concretes with different fiber added ways on figure 9.

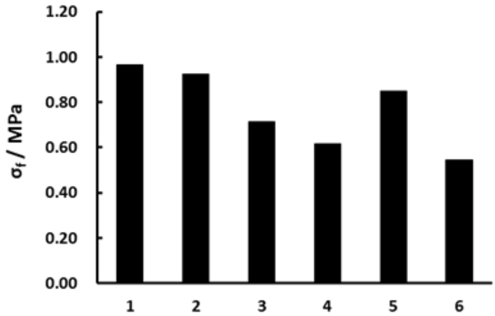


Fig.9 Flexure strength

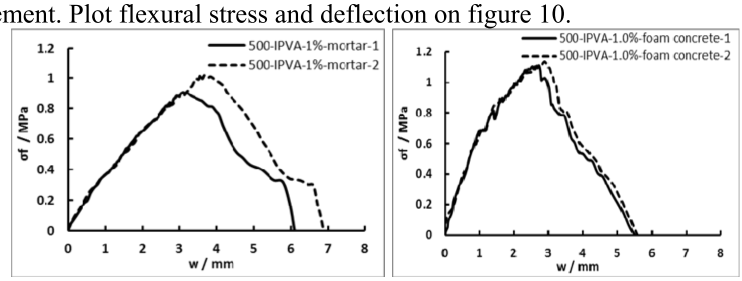
For flexural strength, number 1 fiber added way-adding 1.0% IPVA fiber into mortar-is the best fiber added way. The second is number 2 way. The last is number 4 way.

For compression and flexure strength, number 1 and 2 ways are better than other ways. Comparing number 1 and 2, the former strength is lower but not so much difference from later. Number 1 remaining strength is larger than number 2. Number 1 flexural strength is larger than number 2. Number 1 fiber added way-putting 1.0% IPVA fiber into mortar-is the best fiber added way.

3.7 Experimental Best Fiber Added Way VS Theory Best One

The best fiber added way from experimental data analysis is $A_1B_2C_3$ (IPVA-1.0%-mortar), named as experimental optimal combination. The best fiber added way from former range analysis is $A_1B_2C_3$ (IPVA-1.0%-foam concrete), named as theory optimal combination. So theory optimal combination is different with orthogonal experiment. This is because optimization results can response full group information.

In order to find the best fiber added way from full group information, test about $A_1B_2C_3$ was supplement. Plot flexural stress and deflection on figure 10.



a) Experiment optimal group b) Theory optimal group

Fig.10 Experiment optimal group VS Theory optimal group

There is no significant difference between experiment optimal group and theory optimal group. Comparing these two groups, only fiber mix-ability is different. From former theory analysis, range analysis results show that fiber mix-ability is the insignificant factors comparing fiber kinds and contents. So experiment analysis results is agreed to theory analysis results mentioned above.

4 Conclusions

Based on orthogonal experimental design method, 9 kinds of fiber added ways are selected with 3 factors such as fiber kind, content and mix-ability. By means of range analysis, factor and level analysis and experimental curve and peak value analysis, results can be concluded as follow:

1. For compression stress, fiber kind is the most important factor. The second is fiber content. The third is fiber mix-ability.
2. Fiber is bad for compression strength but good for flexural strength. Number 2 fiber added way (IPVA-1.0%-mortar) can enhance compression strength a little. Other fiber added way is bad for compression strength. All of fiber added ways can enhance foam concrete flexural strength.
3. Stress curve shapes are influenced by fiber kind obviously. Failure modes of fiber foam concretes are all not brittle failure. Fiber can enhance flexural strength and ductility of foam concrete.
4. The best fiber added way is adding 1.0% IPVA fiber into foam concrete.

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