Send Orders for Reprints to reprints@benthamscience.ae

Open Access

Frost Resistance Test Research on Hybrid Fiber Concrete Based on Range Analysis

Liu Faming[1,*], Zhao Lisha[2] and Ma Jie[1]

[1]*School of Resources and Civil Engineering, Suzhou University, Suzhou, Anhui, 234000, P.R. China;* [2]*School of Mathematics and Statistics, Suzhou, Anhui, 234000, P.R. China*

Abstract: The research of single doped fiber concrete is relatively mature. But the research about different varieties and different geometry shape of hybrid fiber concrete was very poor. Across the research in theory, hybrid fiber concrete can improve the balance of fiber three-dimensional distribution and coordinating role of aggregate and fiber, improve the efficiency of toughening crack resistance. In this paper, through the orthogonal experiment design method for hybrid fiber reinforced concrete, the mass and compressive strength loss rate after 50 times, 75 times, 100 times freeze-thaw cycle had been studied. Use range analysis quantified the influence level of various factors on the mechanical properties. It was analyzed the hybrid fiber influence on improving the efficiency of toughening crack resistance and frost resistance. It is concluded that adding the fiber can enhance the performance of concrete frost resistance. Long steel fiber have great influence on compressive strength loss rate of hybrid fiber concrete, such as the compressive strength loss rate was reached 65.47% after 75 times freeze-thaw cycle. Short steel fiber have certain influence on mass loss of concrete which were after less freeze-thaw cycles. The influence of polypropylene fiber on concrete frost resistance increases significantly, the effect can reach 36.78% after 50 times of freeze-thaw cycle. The optimal combination of the hybrid fiber concrete ultimately determined was $A_2B_2C_3$ (simultaneously mixed with 50kg/m^3 short steel fiber and long steel fiber as well as 0.9kg/m^3 polypropylene fiber). The addition of steel fiber and polypropylene fiber are both beneficial to increase the internal air content of concrete, strengthening the frost resistance of concrete. However, with the increase of dosage, the internal porosity of concrete is gradually increasing, the density is reduced, and, as a result, the corresponding increase of the compressive strength loss rate is also improved.

Keywords: Compressive strength loss rate, hybrid fiber concrete, mass loss, range analysis.

1. INTRODUCTION

In order to overcome the natural defects of low tensile strength, large brittleness and easy cracking of concrete, the addition of fiber can help the development of crack, reduce plastic shrinkage, enhance tensile strength, and improve the durability of concrete. Compared with the relatively mature single fiber concrete, the hybrid fiber concrete with different varieties and different geometry shape can improve the balance of fiber three-dimensional distribution and coordinating role of aggregate and fiber, thereby improving the efficiency of enhancement. Research on the properties of concrete freeze-thaw damage is ongoing. A lot of valuable results have been achieved on the failure mechanism, porosity, mechanical properties and so on. But these research works are mainly based on one aspect of the qualitative researches, whereas the research on the comprehensive influence of multi factors is determined by a variety of factors. In this paper, the range analysis method is used to study the frost resistance of hybrid fiber reinforced concrete to improve the crack resistance of concrete. Freeze-thaw cycle times were used to analyze hybrid fiber concrete frost resistance.

*Address correspondence to this author at the School of Resources and Civil Engineering, Suzhou University, Anhui, 234000, P.R. China;
Tel: 15005578576; E-mail: 94502161@qq.com

2. HYBRID FIBER RESISTANCE MECHANISM

Concrete strength, deformation and failure performance are associated with the extension of crack [1]. In the process of concrete structure formation, the fiber prevents the generation of micro cracks, which reduces the cracks source number and reduces the width of crack, and alleviates the crack tip stress concentration degree. This is called the crack resistance of fiber effect, which is the root cause of concrete reinforcement [2-4]. Factors affecting the frost resistance of concrete mainly has two aspects: one includes the time, temperature, humidity and freeze-thaw cycle factors; the other hand includes the limit tensile strain of concrete, air content, fiber content, toughness and so on.

The capillary filtration produces plastic shrinkage stress with cement hydration, and micro cracks were formed, further developed and expanded, eventually leading to the hardened mortar cracking damage. So, the key to improve the performance of concrete frost resistance is to reduce the shrinkage stress. Hybrid fiber inside the mortar can transfer stress, which can reduce the plastic shrinkage and cracking of the cement mortar. This is because on one hand, hybrid fiber in the concrete enhances three-dimensional random distribution and adhere with each other. This can effectively inhibit the generation of cracks of concrete before hardening. On the other hand, hybrid fiber can be used to

Table 1. Each factor and different level of numerical Unit: kg/m^3.

Level numerical	Factor		
	A	B	C
1	0	0	0
2	50	50	0
3	80	80	0.9

Note: A, B, C three factors are for 0 which are ordinary concrete specimen, as the benchmark of hybrid fiber concrete freeze-thaw test.

Table 2. Hybrid fiber concrete freeze-thaw test table of orthogonal proportion Units: kg.

Specimen number	Water	Cement	Sand	Gravel	A	B	C
DR-1	200	400	675	1200	0	0	0
DR-2					0	50	0
DR-3					50	0	0
DR-4					0	80	0.9
DR-5					80	0	0.9
DR-6					50	50	0.9
DR-7					50	80	0.9
DR-8					80	50	0.9
DR-9					80	80	0.9

squeeze the capillary inside the mortar, and mortar water area will be greatly reduced, so that Capillary tension is formed by losing water from Capillary. Hybrid fiber uniform distribution can effectively restrain the cracks caused by tensile stress. By improving the compactness of cement, water infiltration is reduced from the external environment to the internal porosity of concrete. To reduce the effective freezing of free water, this can accordingly improve the frost resistance of concrete.

Disordered fibers are interwoven to form dense mesh, which hinders the overflowing of the internal air during the forming process and increases the entrained air content of concrete. These mutually connected pores make the hydrostatic pressure of wool stoma decreased at the beginning of the cold concrete, which causes pressure relief effect. The increased bubbles can prevent or restrain the forming of tiny ice in cement paste. The hydrostatic pressure and seepage pressure of concrete is relieved under the condition of low temperature.

3. EXPERIMENTAL RESEARCH

3.1. Orthogonal Freeze-Thaw Test Design

According to Shang and Song's [5] experiment on the concrete's biaxial compression test of concrete after freeze-thaw cycle under different water-cement ratios. The result shows that when the water-cement ratio is 0.5, the concrete's uniaxial and biaxial compressive strength tends to be steady after freeze-thaw, and there will be no drop phenomenon. This experiment also adopts water-cement ratio as 0.5, uses 400 kg/m^3 of cement, and sets sand ratio 36%. Fiber used in this experiment are of two kinds: one steel fiber and another polypropylene fiber. In the mix proportion design of orthogonal test, factor A represents the 15mm short steel fiber, factor B represents the 25mm long steel fiber, and factor C represents the 2-30mm long polypropylene fiber. In order to facilitate analysis, the mixing amount of polypropylene fiber was set as 0.9kg/m^3. Defined specific factors level values are shown in Table **1**. The orthogonal proportion of hybrid fiber concrete freeze-thaw test are shown in Table **2**.

3.2. Hybrid Fiber Concrete Frost Resistance Test

This series of tests included slow freezing methods which are based on 《Standards for test method of mechanical properties of ordinary concrete》 (GB_T50081-2002). This series of methods measured the mass loss and compressive strength loss of the specimens, in order to assess the extent of the concrete internal and surface damage. Hereby, this paper evaluates and researches hybrid fiber concrete freeze-thaw resist performance.

3.2.1. Mass Loss Test

3.2.1.1. Experimental Data and Analysis

Mass loss is an important indicator to evaluate the degree of freeze-thaw by slow freezing method. From every group, hybrid fiber concrete specimens were removed from the water and dried to the best. At the same time, take out the contrast specimens which were maintained in curing room and get quality of freeze-thaw test block after being weighed on electronic balance. All of the specimens mass loss rates are calculated as shown in Table **3**.

Table 3. Specimens mass loss under different freeze-thaw cycle times Unit: %.

Specimen number	Freeze-thaw cycle times		
	50 times	75 times	100 times
DR-1	3.44	4.27	4.97
DR-2	2.97	3.83	4.24
DR-3	2.42	3.07	3.42
DR-4	2.06	2.54	2.79
DR-5	1.11	1.93	2.24
DR-6	2.15	2.66	3.02
DR-7	1.04	2.08	2.34
DR-8	2.03	2.76	3.16
DR-9	3.17	3.54	3.94

Table 4. Mass loss of hybrid fiber concrete after different freeze-thaw cycle times range data.

Freeze-thaw cycle times	Range	Factor		
		A	B	C
After 50 freeze-thaw cycle times	R1	2.94	2.18	2.54
	R2	1,77	2.84	2.73
	R3	2.08	3.09	1.52
	Range R	1.17	0.91	1.21
	Primary and secondary relationship	C>A>B		
After 75 freeze-thaw cycle times	R1	3.72	2.96	3.23
	R2	2.38	2.84	3.30
	R3	2.79	3.09	2.36
	Range R	1.34	0.25	0.94
	Primary and secondary relationship	A>C>B		
After 100 freeze-thaw cycle times	R1	4.21	3.37	3.72
	R2	2.68	3.21	3.12
	R3	3.15	3.46	2.67
	Range R	1.53	0.25	1.05
	Primary and secondary relationship	A>C>B		

As shown from the data in Table **3**, the average value of the mass loss rate of DR-5 (simultaneously mixed with 50kg/m^3 short steel fiber and long steel fiber as well as 0.9kg/m^3 polypropylene fiber) is the least among all specimens, and DR-1 (ordinary concrete) is the most, which is bigger than other specimens mixed with fiber. It is thus clear that the addition of hybrid fiber can control the mass loss rate of the freeze-thaw cycle. Especially, the addition of polypropylene fiber makes internal friction resistance increased and the concrete unlikely to burst, and reduces mass loss and mass loss rate [6-8]. In addition, steel fiber can also make the mass loss rate of concrete after freeze-thaw cycle steadily declining.

3.2.1.2. Range Analysis

The range data analysis on the mass loss rate of hybrid fiber concrete after different freeze-thaw cycles is shown in Table **4**.

After 50 freeze-thaw cycle times, the primary and secondary relationship among three factors is C>A>B. The optimal combination for mixture ratio is $A_2B_1C_3$, namely mixed 50 kg/m^3 short fiber and 0.9 kg/m^3 polypropylene fiber. But after 75 freeze-thaw times, primary and secondary relationship among three factors becomes A>C>B. The optimal combination for mixture ratio is $A_2B_2C_3$, namely mixed 50 kg/m^3 short fiber, 50 kg/m^3 long steel fiber and 0.9 kg/m^3 polypropylene fiber.

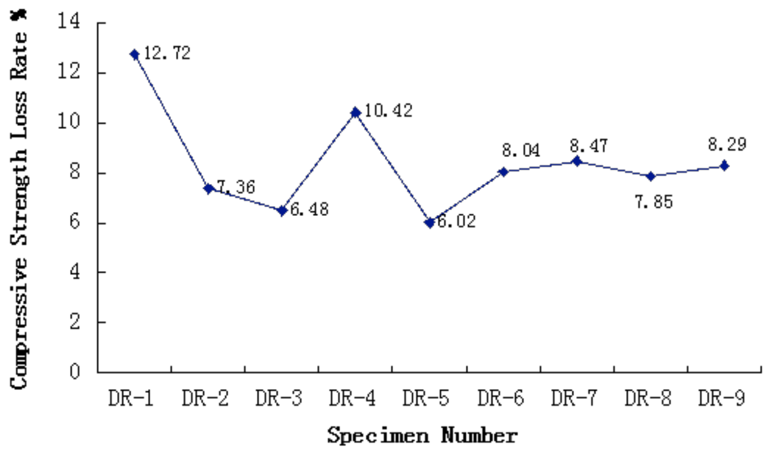

Fig. (1). Compressive strength loss rate of the specimens after 50 freeze-thaw cycle times.

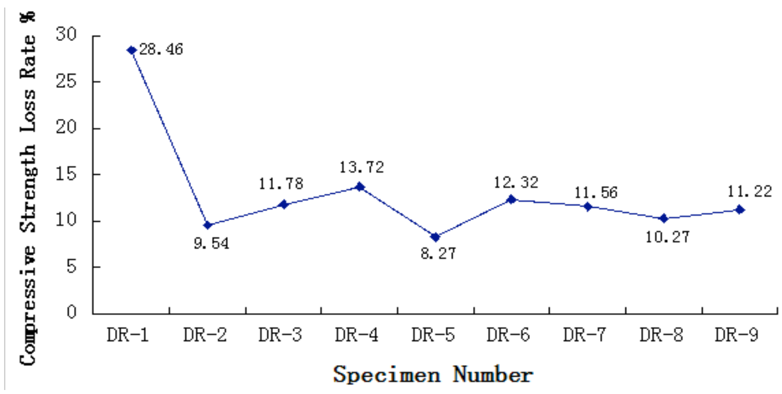

Fig. (2). Compressive strength loss rate of the specimens after 75 freeze-thaw cycle times.

In general, the mass loss of fiber concrete is less than concrete without fiber, and the mass loss in hybrid fiber concrete is less the concrete mixed with single fiber. This is because the quality of concrete block loss is mainly due to the dropping of surface particles and tiny sand grains. Whereas hybrid fiber, with small-diameter monofilament and small elasticity modulus and great deformation capacity, can relieve and prevent the loss situation, small particles, likely to leave off the concrete substrate because of freeze-thaw action, become slow in dropping when they are connected and bounded by hybrid fiber, which is macroscopically reflected by the diminution of the mass loss [9, 10].

3.2.2. Compressive Strength Loss Experiment

3.2.2.1. Experimental Data and Analysis

The determination of the compressive strength loss rate is the key data of freeze-thaw experiment which can reflect the change in mechanical properties of the concrete after freeze-thaw cycle. Meeting the freeze-thaw cycles by slow freezing method, the hybrid fiber concrete specimens were removed from the water and dried. At the same time, take out the contrast specimens, which were maintained in curing room and carry out the compression test. According to the test data from the compressive strength respectively after 50, 75 and 100 times freeze-thaw, the compressive strength loss rates are to be calculated. The compressive strength loss rate of concrete after different freeze-thaw times respectively are shown in Figs. (**1**-**3**).

After 50 freeze-thaw cycle times, all specimens were not broken, and the greatest loss is ordinary concrete, which the compressive strength loss rate reached 12.72%. The smallest compressive strength loss rate of specimens was DR-5 (mixed with 50kg/m^3 short steel fiber and long steel fiber as well as 0.9kg/m^3 polypropylene fiber), which was only 6.02%. When freeze-thaw cycle reaches 75 times, the compressive strength loss rate of ordinary concrete is 28.46%, which was higher than 25%, the standard rate, and the concrete began to break. But the compressive strength loss rate of DR-5 is still the smallest. The worst fiber concrete is DR-4 (single mixed 50 kg/m^3 short steel fiber), its compressive strength loss rate is 13.72%. After 100 freeze-thaw cycle times, the optimal and the worst specimens are respectively DR-5 and DR-4.

3.2.2.2. Range Analysis

The range data analysis of compressive strength loss rate of hybrid fiber concrete after different freeze-thaw cycle times is shown in Table **5**.

After 50,75,100 freeze-thaw cycle times, the primary and secondary relationship among three factors is B>C>A. The optimal mixture ratios are respectively $A_1B_3C_3$, $A_2B_2C_3$ and $A_2B_2C_3$. After 100 freeze-thaw cycle times, factor B's effect upon the compressive strength loss rate of hybrid fiber concrete is greater than other two factors. After 75, 100 freeze-thaw cycle times, $A_2B_2C_3$ (mixed with 50kg/m^3 short steel fiber and long steel fiber as well as 0.9kg/m^3 polypropylene

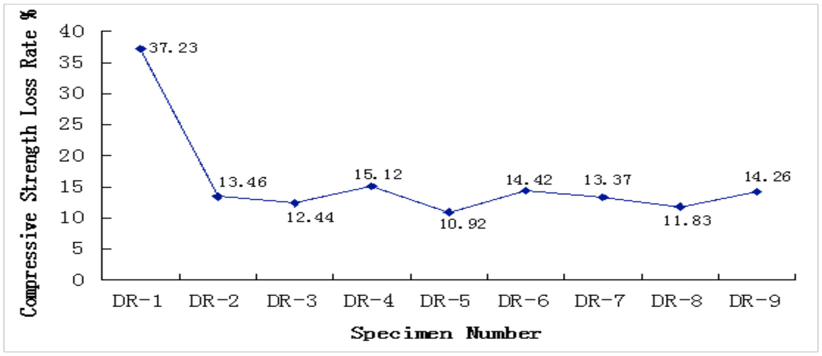

Fig. (3). Compressive strength loss rate of the specimens after 100 freeze-thaw cycle times.

Table 5. Compressive strength loss rate of hybrid fiber concrete after different freeze-thaw cycle times range data.

Freeze-thaw cycle times	Range	Factor		
		A	B	C
After 50 freeze-thaw cycle times	R1	6.69	10.54	9.54
	R2	8.16	9.36	8.69
	R3	8.20	7.60	6.99
	Range R	1.51	2.94	2.55
	Primary and secondary relationship	B>C>A		
After 75 freeze-thaw cycle times	R1	11.02	12.64	11.30
	R2	10.66	9.36	11.49
	R3	11.44	11.77	10.54
	Range R	0.78	3.28	0.95
	Primary and secondary relationship	B>C>A		
After 100 freeze-thaw cycle times	R1	12.95	14.25	13.13
	R2	13.49	12.07	14.28
	R3	13.15	13.71	12.24
	Range R	0.54	2.18	2.04
	Primary and secondary relationship	B>C>A		

fiber) is optimal mixture ratio. Long steel fiber has a greater influence upon the compressive strength loss rate of hybrid fiber concrete than short steel fiber as well as polypropylene fiber. The addition of steel fiber is beneficial to improve the anti-frost property of the concrete [11, 12].

With polypropylene fiber added into the concrete, its compressive strength loss rate decreased significantly to a greater extent. As can be seen from Fig. (**2**), mixed with 50 kg/m3short steel fiber, its strength loss rate fell by 18.08% than concrete without fiber; mixed with 50kg/m^3 short steel fiber and 80kg/m3 long steel fiber, the loss rate fell by 36.79%. It shows that the addition of steel fiber into the concrete generally plays a great role in decreasing its compressive strength loss rate.

CONCLUSION

(1) Although under 50 freeze-thaw cycle times, short steel fiber A slightly enhances the frost resistance of the concrete, yet with the increased freeze-thaw cycles [13, 14], its influence upon the compressive strength loss rate of hybrid fiber concrete greatly reduces. However, its influence upon the mass loss rate of the concrete after freeze-thaw cycle increases greatly, up to 54.06% after 100 freeze-thaw cycle times.

(2) After freeze-thaw cycle of the concrete, long steel fiber B has more effects on the frost resistance of the concrete, especially in reducing the compressive strength loss rate of concrete which reaches 65.47% after 75 freeze-thaw cycle times. However, it has less and less effects upon the mass loss rate after freeze-thaw cycle.

(3) Under 50 freeze-thaw cycle times of concrete, polypropylene fiber C’ effect on the frost resistance of concrete is significantly enhanced, reaching 36.78% after 50 freeze-thaw cycle times. With the freeze-thaw cycles increased, polypropylene fiber’s influence upon the com-

pressive strength loss rate and the mass loss rate of hybrid fiber concrete starts to level off in a downward trend.

(4) Due to the superior bond ability between steel fiber and cement paste, the plasticity and the strength of extension of the concrete are increased, reducing the cracks of the concrete due to its inside contraction, improving its compactness to some extent, reducing its compressive strength loss and improving its frost resistance accordingly.

(5) By comprehensively analyzing the test data, the range and the influence of various factors, it is concluded that the optimal combination of the hybrid fiber concrete is $A_2B_2C_3$ (mixed with 50kg/m^3 short steel fiber and long steel fiber as well as 0.9kg/m^3 polypropylene fiber). The addition of steel fiber and polypropylene fiber is beneficial to increase internal air content of concrete, enhancing the frost resistance of the concrete. With the mixing amount increase, the internal porosity of concrete becomes bigger and its density is reduced, which increases the compressive strength loss rate accordingly.

(6) To a certain extent, hybrid fiber can increase the water retention of cement paste, make the hydration of cement completely reacting, relieve the shrinkage and crack phenomenon in the early stage of cement paste drying, reduce the minor cracks and internal porosity of slurry after being hardened, and increase its density [15], so that the compressive strength loss rate and the mass loss rate of concrete are decreased after freeze-thaw cycle and the frost resistance of the concrete is improved, which is worth promotion and application in the cold region.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This work was financially supported by Suzhou institute of field talented youth fund projects (2013XQRL02). Master research fund start-up project of Suzhou University, Anhui, China (Approval number, 2009YSS04). Construction project in Anhui province (2013YF-19). Anhui province outstanding young talent fund key projects (2013SQRW077ZD). Coal Mine Exploration Engineering Center of Anhui Province (2012YKF14).

ABOUT THE AUTHORS

First Author Liu Faming, lecturer of Suzhou University, M.E. The author's major is Durability and Engineering Structure. Four papers were received by EI and 1 patent had been published.

Second Author Zhao Lisha, lecturer of Suzhou University, M.E. The author's major is mathematical statistics. Four papers were received by national magazines and 3 patents had been published.

Third Author Ma Jie, lecturer of Suzhou University, M.E. The author's major is Durability and Engineering Structure. One paper was received by EI and published.

REFERENCES

[1] X. J. Jiang, and S. X. Wang, "Freeze-thaw resistance experiment of fiber concrete and mechanism analysis", *Architecture Technology*, vol. 7, no. 2, pp. 135-137, 2006.

[2] W. Sun, "Research for steel fiber enhance, toughening and crack resistance effect on high-strength concrete", *Journal of Southeast University*, vol. 21, no. 1, pp. 50-57, 1991.

[3] K. Zielinski, and P. Szewski, "The impact of basaltic fiber on selected physical and mechanical properties of cement mortar", *Concrete Precasting Plant and Technology*, vol. 1, pp. 28-33, 2005.

[4] L. Chen, R. G. Liu, and J. Y. Liu, "The performance of polypropylene fiber concrete and application at home and abroad, *Journal of Qingdao Technological University*, vol. 28, no. 2, pp.27-30, 2007.

[5] H. S. Shang, and Y. P. Song, "The biaxial compressive test research for different water cement ratio of concrete after freeze-thaw cycle", *Journal of Dalian University of Technology (Social Sciences)*, vol. 47, no. 6, pp. 862-866, 2007.

[6] C. Taejun, "Prediction of cyclic freeze-thaw damage in concrete structures based on response surface method", *Construction and Building Materials*, vol. 21, no. 12, pp. 2031-2040, 2007.

[7] G. X. Huang, J. Zhao, D. Y. Gao, "Polypropylene fiber concrete after freeze-thaw mechanics performance test research", *Yellow River*, vol. 5, no. 31, pp. 105-108, 2009.

[8] C. J. Jiao, W. Sun, and Y. S. Zhang, "Polypropylene - steel fiber high-strength concrete bending property test research", *Architecture Technology*, vol. 35, no. 1, pp. 48-50, 2004.

[9] D. Y. Chen, and K. F. Tan, "Polypropylene fiber influence strength and durability of concrete", *Concrete*, vol. 168, no. 11, pp. 61-62, 2003.

[10] Y. Li, and W. Zhao, "*The Durability and Toughening, Crack Resistance of Hybrid Fiber Concrete*". Science Press, China 2012.

[11] J. Y. Sun, Hybrid polypropylene fiber concrete performance research", *Concrete*, vol. 168, no. 11, pp. 16-20, 2003.

[12] X. P. Xie, G. J. Yang, and Q. Y. Guan, "Experimental research of steel fiber on freeze-resistant performance of concrete", *Concrete*, vol 8, pp. 73-75, 2008.

[13] T. Zhang, "Experimental study on basic mechanical properties and durability of hybrid fiber reinforced concrete", PhD thesis, Liaoning University of Technology, 2014, pp. 47-50.

[14] X. K. Liu, "*Research on the Flexural Toughness of Hybrid Fiber Reinforced Concrete",* PhD thesis, Hubei University of Technology, 2014, pp. 3-7.

[15] D. T. Xia, L. H. Xu, and Y. Yan, "Experimental study on hybrid fiber reinforced high-performance concrete strength", *Journal of Shenyang Jianzhu University*, vol. 27, pp. 77-81, 2007.

Received: May 26, 2015 Revised: July 14, 2015 Accepted: August 10, 2015