Study on the Hydraulic Performance of Concrete Reinforced by $CaCO_3$ Modified Polypropylene Fiber

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Abstract: In this paper, the concrete were reinforced by $CaCO_3$ modified PP fiber. The freeze-thaw resistance, anti-permeability and anti-erosion performances of the concrete were studied. The results indicated that $CaCO_3$, modified PP fiber played a significant role on reinforcement of concrete due to improvement of its density and hydrophilic property. Moreover, freeze-thaw resistance, anti-permeability and anti-erosion performances were greatly improved. Impermeability level of the modified concrete was beyond W8, and anti-erosion performance was improved by 33%~87%.

Keywords: $CaCO_3$, PP, concrete, reinforcement, hydraulic property

1. Introduction

In recent years, water conservancy and road construction have entered a new period. Since the concrete would be applied in the harsh environment. The freeze-thaw cycle[1], anti-permeability and anti-erosion performances are important both for of engineering design and real applications. According to the structural characteristics, durability and the requirements for different projects, improving the freeze-thaw resistance, anti-permeability and anti-erosion performances of concrete have been more and more concerning points in engineering field.

The shortcomings of concrete limit its further applications in engineering. The ease of plastic shrinkage cracking, low tensile strength and low toughness, which lead to decrease in durability and security. Reinforced concrete is the most commonly used construction material worldwide. The need for high compressive strength concrete and increased service life of reinforced concrete structures led to the development of high performance concrete[2]. Synthetic fibers have become more attractive in recent years as reinforcements for cementitious materials. They can provide effective, relatively inexpensive reinforcement for concret[3]. P. N. Balaguru and S. P. Shah present a summary of the physical properties of various synthetic fibers [4]. If the fibers were further optimized, the same fiber-reinforced concrete property improvement could be achieved at a lower expense or greater improvements could be obtained without increasing the reinforcement cost[5].

Zhihong Zheng and Dorel Feldman investigated the behavior of concrete reinforced with various of fibers[3]. Among them, PP fibers could effectively increase the impact resistance of concrete [6,7,8].However, PP shows poor adhesion with cementitious matrix due to its hydrophobic and smooth surfaces [9,10]. Due to this reason, various researches have been implemented to modify the surface structure of polypropylene fibers in order to improve their performance in composite applications [11]. Some surface processing attempts of polypropylene such as wet chemical treatment [12], PP/$CaCO_3$ composites have been extensively paid more attention [13,14], and PP fiber modified by $CaCO_3$ made up the shortcomings of traditional concrete [15]. The durability of concrete will be improved by optimized content and type of the filling fiber. This research plays a significant role on improvement of anti-permeability and frost-resistance performances and engineering efficiency.

2. Experimental

2.1 materials

In this study, $CaCO_3$ modified PP fibers and ordinary PP fibers were prepared in our lab. It should be point out that the content of $CaCO_3$ is 6 wt%. The characteristics of two types of the fiber are shown in Table 1.

Ordinary Portland cements (P.O.42.5), river sand, and 5-20mm gravel were also used for preparation of the concretes.

Table 1 the characteristics of two types of fibers

types	Tensile strength (MPa)	Elongation at break (%)	Elastic modulus (GPa)	Melting point (℃)
Modified PP fiber	448	22	6	165
Ordinary PP fiber	407	25	6	165

Mix proportions of the concretes of hydraulic characteristics in study are presented in Table 2.

Table 2 Mix proportions of the concretes

Water-cement ratio (w/c)	The amount of concrete per cubic (kg/m^3)				
	cement	sand	gravel	water	fiber
0.45	250	695	620	113	0
0.45	250	695	620	113	0.3
0.45	250	695	620	113	0.6

0.45	250	695	620	113	0.9
0.45	250	695	620	113	1.2

2.2 Test of freeze-thaw cycle performance of the concretes

According to Chinese standard GBJ82-85, freeze-thaw test was performed by Quick Freeze Large Specimens Method. The specimen samples were 100×100×400 mm Prism. Before the freeze-thaw test, the specimens were all immersed in water. Freeze-thaw tests of the samples were carried out in saturated water, at the temperature between -17±2℃ and 8±2℃. It is noted that the freeze-thaw conversion time was less than 10 min and the melting time was not less than 1/4 of the whole test.

2.3 Test of anti-permeability performance

According to Hydraulic Concrete Norms, test of anti-permeability performance was performed by Stepby Pressure Method. The maximum pressure was up to 0.9Mpa and 2.1MPa respectively, and then held for 8 hours. After that the specimens were taken out and split along the axis of samples, and then the water level was measured.

2.4 Test of anti-erosion performance

Test of anti-erosion performance was performed according to ASTM C1138-89, which simulates the course of high-speed coarse flow wash to damage the samples surface. The surfaces of specimens were abraded for 72 hours by water and seventy various sizes of steel balls which were driven by impellers at the speed of 1400r/min. Anti-erosion strength was calculated by weight loss of the specimens. Dimension of the specimens wereф285×100mm.

3. Results and discussion

3.1 Freeze-thaw cycle performance

In this study, freeze-thaw cycle tests were carried out 200 times for each sample. Compressive and flexural strengths of the specimen reinforced by two types of fiber were shown in Fig 1 and Fig 2, respectively. From the charts both compressive and flexural strengths increased with the increasing content of PP fiber, and the value of compressive and flexural strengths of the concrete reinforced by $CaCO_3$ modified PP fiber were greatly up to 41.43MPa and 4.72MPa, increased by 79.7% and 177.6% compared to plain concrete respectively, whereas that of the concrete reinforced by ordinary PP fiber were 39.42MPa and 4.54MPa, increased by 71.06% and 167.6% respectively. Therefore modified PP fiber reinforced concrete was obviously better than that of ordinary PP fiber reinforced concretes.

$CaCO_3$ modified PP fiber reinforced concrete has better freeze-thaw resistance property than ordinary PP fiber reinforced concrete. Because modified PP fiber would be more evenly dispersed in the concrete, because

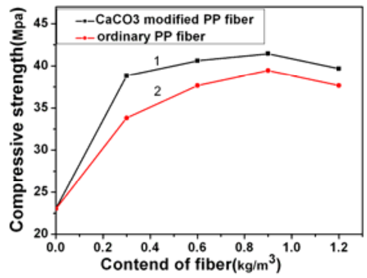

Fig 1 Compressive strength of concrete reinforced by PP fiber 1. CaCO3 modified PP fiber, 2. Ordinary PP fiber

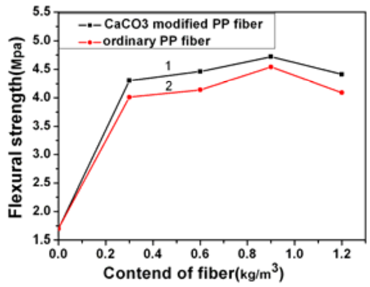

Fig 2 Flexural strength of concrete reinforced by PP fiber 1. CaCO3 modified PP fiber, 2. Ordinary PP fiber

strong cohesion force between fiber and matrix would certainly reduce the cracks generated in the freeze thaw cycle test and more phase transition pressure of internal water in the concrete would be afforded.

3.2 Anti- permeability performance

Results of anti-permeability performance test were shown in table 3 and table 4.

It can be seen from the table 3 and table 4 that the impermeability level of all the samples were all beyond W8, much higher than the designed requirements. The water height of the concrete reinforced by $CaCO_3$ modified PP fiber was only 2.3cm compared to plain concretes 4.6cm with content of modified PP fiber of 0.9kg/m^3 at water pressure of 0.9MPa, and that of the concrete reinforced ordinary PP fiber was 2.6cm. Therefore the anti-permeability performance of modified PP fiber reinforced concretes was highly improved. According to the former literature [16], $CaCO_3$ modified PP fibers were homogeneous distributed to the three-dimensional in the concretes and had a strong adhesive force with the matrix, which can make PP fiber fully play a role of reinforcement, in favor of overcoming the damage and preventing temperature cracks resulting from thermal stress of the concrete. Meanwhile PP fiber has strong tensile strength that it can effectively control the load cracks and improve the tensile strength of concrete matrix. Modified concretes can adapt to a certain scale and scope of the deformation and reduce visible cracks, which will prevent internal early-staged micro-cracks and invisible cracks caused by shrinkage from occurring and expanding.

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Table 3 Anti-permeability performance of modified PP fiber reinforced concrete

Content of fiber (kg/m³)	Water height (cm)	
	Water pressure 0.9MPa	Water pressure 2.1MPa
0.0	4.6	6.9
0.3	3.6	4.9
0.6	3.1	3.5
0.9	2.3	5.8
1.2	3.3	5.0

Table 4 Anti-permeability performance of ordinary PP fiber reinforced concrete

Content of fiber (kg/m³)	Water height (cm)	
	Water pressure 0.9MPa	Water pressure 2.1MPa
0.0	4.6	6.9
0.3	3.8	5.1
0.6	3.4	3.8
0.9	2.6	6.0
1.2	3.9	5.4

3.3 Anti-erosion performance

Results of anti-erosion performance of fiber reinforced concretes were presented in Fig 3.

Anti-erosion strength of the concretes increased with increasing content of $CaCO_3$ modified PP fiber. Anti-erosion strength of reinforced concretes with modified fiber content of 0.3kg, 0.6kg, 0.9kg and1.2kg per cube increased by 33%，49% ， 87% and 57%, respectively. It can be seen from Fig 3 that anti-erosion performance of modified PP fiber reinforced concretes was obviously better than that of ordinary PP fiber reinforced concretes.

Adding $CaCO_3$ modified PP fiber into concretes improved the integrity and impact resistance, so that $CaCO_3$ modified polypropylene fiber reinforced concretes can stand against cutting breaking of suspended load and impact failure of traction load. $CaCO_3$ modified PP fiber evenly dispersed in the concretes so that internal cracks can not expand and cross-connectivity, thus concretes can maintain to integrity to prevent overall breaking from washing. When high-speed coarse flow continuous washed concrete surface, interaction of molecules in the concrete was not less erosive force,

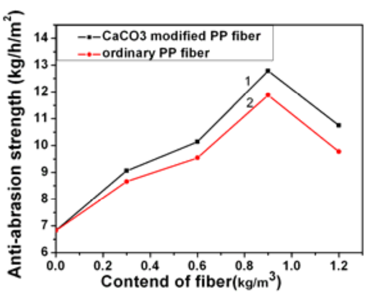

Fig 3 Anti-abrasion strength of concrete reinforced by PP fiber 1. CaCO3 modified PP fiber, 2. Ordinary PP fiber

resulting that most of molecules in the concrete surface can not be washed away. Therefore, $CaCO_3$ modified PP fiber optimized the structure of concrete matrix and improved anti-erosion performance.

4. Conclusions

(1) Frost resistance of concrete could be greatly improved by adding modified PP fiber. After 200 times freeze-thaw cycle tests, compressive and flexural strengths of the concrete reinforced by $CaCO_3$ modified PP fiber were greatly up to 41.43MPa and 4.72MPa, increased by 79.7% and 177.6% compared to plain concrete respectively.

(2) The anti-permeability performance of modified PP fiber reinforced concretes was highly improved. The impermeability level of the reinforced concretes were all beyond W8.

(3) Anti-erosion strength of the concretes increased with increase of content of CaCO3 modified PP fiber. Comparing with ordinary PP fiber reinforced concretes, anti-erosion strength of reinforced concretes with modified fiber content of 0.3kg, 0.6kg,0.9kg and 1.2kg per cube increased by 33%，49% ， 87% and 57%, respectively.

References

[1] Liu Weidong , Su Wenti , Wang Yimin, “Research on damage model of fiber concrete under action of freeze-thaw cycle,” Journal of Building Structures,China, vol.29(1), pp.124-128,2008.

[2] K.K. Sideris, P. Manita, E. Chaniotakis, “Performance of thermally damaged fiber reinforced concretes,” Construction and Building Materials, vol.23, pp.1232–1239,2009.

[3] Zhihong Zheng, Dorel Feldman, “Synthetic fiber reinforced concrete,” Prog. Polym. Sci., Vol. 20, pp.185-210, 1995.

[4] P. N. Balaguru , S. P. Shah, “Fibre-Reinforced Cement Composites,” McGraw-Hill,p110,1992.

[5] V. C. Li, Y. Wang and S. Backer, “Fiber-Reinforced Cementitious Materials,” Materials Research Society Symposium Proceeding(S. Mindess and J. Skalny Eds.), Vol. 211,1991.

[6] S. Hasaba, M. Kawarmura, T. Koizumi and K. Takemoto, “Fiber Reinforced Concrete–International Symposium(G. C. Hoff Ed.)”,American Concrete Institute, pp187-196,1984.

[7] A. Bentur, S. Mindess and J. Skalny, “ Fiber Reinforced Cements and Concretes: Recent Developments(R. N. Swamy and B. Barr Eds.),” Elsevier Applied Science, London, 1989.

[8] S. Mindess and G. Vondran, Cem. Concr. Res.,vol.18,pp.109-115,1988.

[9] Lee, S.D., Sarmadi, M., Denes, E., Shohet, J.L., “Surface modification of polypropylene under argon and oxygen-rf-plasma conditions,” Plasmas and Polymers, vol.2, pp.177–198,1997.

[10] Singh, S., Shukla, A., Brown, R., “Pullout behavior of polypropylene fibers from cementitious matrix,” Cement and Concrete Research, vol.34, pp.1919–1925,2004.

[11] Burak Felekoglu, Kamile Tosun, Bulent Baradan, “A comparative study on the flexural performance of plasma treated polypropylene fiber reinforced cementitious composites,” Journal of Materials Processing Technology, vol.209, pp.5133–5144,2009.

[12] R.Morent, N.De Geyter, J.Verschuren, K.De Clerck, P.Kiekens, C.Leys, “Non-thermal plasma treatment of textiles,” Surface &

Coatings Technology, vol. 202, pp. 3427–3449,2008.

[13] Zhen J, Ding YF, Du JQ, "A study of property of PP/nano-$CaCO_3$ composites," Plast Proc Appl, vol. 23 (1), pp.5–8, 2001.

[14] Attila Kiss, Erika Fekete, Bela Pukanszky, "Aggregation of $CaCO_3$ particles in PP composites:Effect of surface coating," Composites Science and Technology, vol. 67, pp.1574–1583, 2007.

[15] Jiang Xuejie, Wang Shuxiang, "Test and Mechanism analysis on anti-freeze and melt of fiber concrete," Architecture Technology, China, vol.37(2),pp.135,2006.

[16] G. A. Khoury , B. Willoughby, "Polypropylene fibres in heated concrete. Part 1: Molecular structure and materials behaviour," Magazine of Concrete Research, vol.60(2), pp.125-136, 2008.

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