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Research Article

Study on Micro-Structure and Durability of Fiber Concrete

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Abstract: In this study, we compare micro-structure characteristics of alkali-resistant glass fiber reinforced concrete, polypropylene fiber reinforced concrete, basalt fiber reinforced concrete and common concrete. Moreover, they were tested and analyzed micro-structure characteristics of fiber reinforced concretes by mercury injection, mainly analyzed the size of pore distribution, studied the influence on improving pore structure. In addition, the internal structure of fiber reinforced concrete was researched by scanning electron microscope analysis. Then the influence of fiber on the internal structure was described. Durability of the fiber reinforced concrete was tested. Durability mainly contains the frost-resistance and permeability. The permeability experiment has water-penetration and chloride penetration test study then characterize the permeability of fiber reinforced concrete through the seepage height and chloride ions diffusion coefficient. Through the result of freeze-thaw cycle 100 times we can analyze the frost resistance of fiber reinforced concrete. Finally, some fiber concrete durability is analyzed and compared.

Keywords: Alkali-resistant glass fiber, basalt fiber, durability, pore structure, polypropylene fiber

INTRODUCTION

Reinforced concrete structure will gradually deteriorate during its use due to variety of the negative factors' corrosion; its application and scope are limited. Fiber reinforced concrete has become a new way to search to improve the mechanical properties and durability of concrete in recent years (Purnell *et al.*, 2010; Yuwaraj and Santosh, 2011). Fiber reinforced concrete, a new type of concrete materials, is invited by foreign scholars in the late 1960. It has advantages of preventing or reducing cracks, improving the long term mechanical property of concrete structures, improving the durability and deformation capacity of concrete structure and so on. Fiber on properties of concrete improvements includes the following 2 main sides: one is to improve the internal structure of concrete through the physical action in the process of setting and hardening of concrete; the second is mechanical function of fiber to be achieved when fiber concrete structure is under the load. It does not change the properties of the material itself to put fibers in concrete. The durability of concrete will not be damaged when fiber mixed well, dispersed evenly and vibrating compacting (Michael and Hempel, 2008). The durability of concrete is improved due to the fiber improving the internal structure of concrete (Peled *et al.*, 2008; Shang-Lin *et al.*, 2009).

With the development of theory and technology of fiber concrete application, especially engineering increasingly demands high on mechanical properties and durability of concrete, the prospects of development of fiber reinforced concrete is well expected (Bames *et al.*, 2008; Malbotra and Mehta, 2006). Currently the internal structure of concrete is mainly divided into macroscopic and microscopic structure of concrete study microscopic structure of concrete can have an important impact on the macroscopic properties of concrete (Roy and Idorn, 1982; Chakraborty *et al.*, 2009). However, study on the pore structure of fiber concrete currently is studied so little that macroscopic behavior change cannot be explained from micro-level (Vipulanandan and Liu, 2008). Pore structure characteristics, micro-structure and durability of polypropylene fiber concrete, alkali-resistant glass fiber and basalt fiber are analyzed and studied in this study.

In this study, we compare micro-structure characteristics of alkali-resistant glass fiber reinforced concrete, polypropylene fiber reinforced concrete, basalt fiber reinforced concrete and common concrete. Moreover, they were tested and analyzed micro-structure characteristics of fiber reinforced concretes by mercury injection, mainly analyzed the size of pore distribution, studied the influence on improving pore structure. In addition, the internal structure of fiber reinforced concrete was researched by scanning electron microscope analysis. Through the result of freeze-thaw cycle 100 times, we can analyze the frost resistance of fiber reinforced concrete.

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Table 1: Physical properties and mechanical properties of cement

Cementgrade	Water consumption (%)	Setting time (h: min)		Fineness (%)	Flexural strength (MPa)			Compressive strength (MPa)		
		Initial	Final		3d	7d	28d	3d	7d	28d
42.5R	27.2	2: 58	6: 43	1.20	5.65	7.29	7.87	28.56	43.5	50.14

Table 2: Performance index of fibers

Fiber varieties	Density (cm^3)	Length (cm)	Diameter (μm)	Elastic modulus (GPa)
Polypropylene fiber	0.91	12	15	3.5
Alkali-resistant glass fiber	2.50	12	15	80
Basalt fiber	2.70	12	15	100
Basalt fiber	2.70	12	15	100

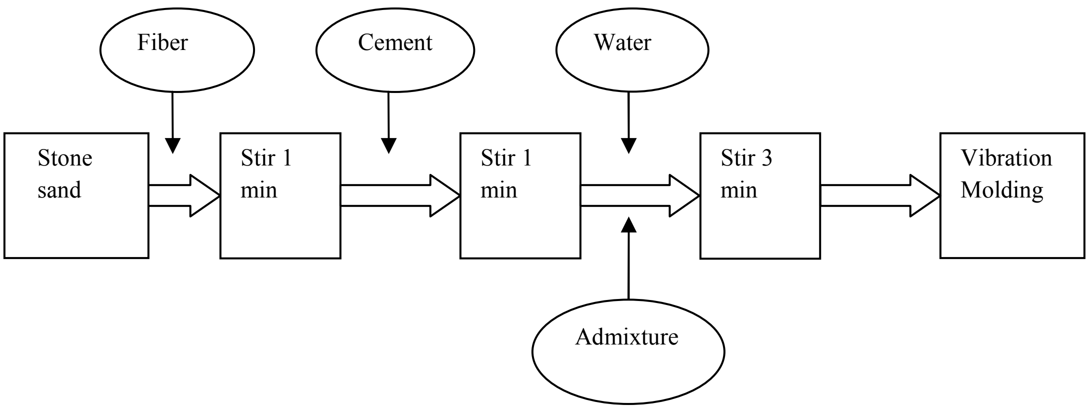

Fig. 1: Forming process of the first-admixing method

RAW MATERIALS AND EXPERIMENTAL SCHEME

Properties of raw material:

Cement: Among concrete structure materials, cement is the main cementing material and price is relatively high. Its quality directly affects the mechanical properties of concrete. Strength grade of fiber concrete studied in this study are C40, Hua'ri 42.5 ordinary Portland cement, produced by Dalian Onoda cement limited, testing learned that cement stability in accordance with the regulatory requirements, measuring its physical and mechanical properties of indicators shown in Table 1.

Fiber: Polypropylene fiber is a hydrocarbon polymer composites, it has good chemical stability study does not react with general chemical, surface with a certain degree of hydrophobic; Alkali-resistant glass fiber containing zirconium oxide is a special glass fiber study has high strength, high modulus, low tensile, does not burn, high temperature resistant and other advantages. It improves and overcomes the disadvantages of low tensile strength of cement concrete, allowing small deformation, poor impact resistance; Basalt fiber is a new type of artificial inorganic fiber, with a high elastic modulus. Its performance and structure are similar to glass-fiber, but are better than glass fiber in high temperature resistance, corrosion resistance and moisture resistance. It does not produce toxic substances in the air and water and has good fire-retardant properties, mechanical properties. The 3 kinds of fibers performance indicators as are seen in Table 2.

Experimental schemes: To make the fibers disperse more evenly and achieve good crack resistance effect, we use the mixing method first when adding fiber, as shown in Fig. 1.

Through test, the best content of alkali-resistant glass fiber is in between 1.50 and 1.90 kg/m^3, then alkali-resistant glass fiber concrete has relative high splitting strength and compressive strength. Using standard curing molding after covering surface, prevent the evaporation of moisture, then numbering, stripping, stripping of cement mortar at a temperature of 20±3° water conservation to the testing period, the pH value of the water is less than 7. the pH value of the water is larger or equal to 7; heat curing use constant temperature water bath, specimen cured 7days in standard condition, put in 60°C constant temperature water to the age requirement of the test, then remove the test piece for the performance test.

RESULTS AND DISCUSSION

Study on pore structure characteristics of alkali-resistant glass fiber reinforced concrete: This study is mainly using mercury method Pore structure is an

Table 3: Pore structure characteristic parameters

Specimen type	Specimen number	Total porosity (%)	The most probable aperture (nm)	Total pore volume (mL/g)
Ordinary concrete	O	8.0925	21.08	0.0387
Polypropylene fiber concrete	PP	13.6893	32.38	0.0658
Alkali-resistant glass fiber	GR	12.5717	26.28	0.0607
Basalt fiber	BF	12.9897	32.37	0.0640

Table 4: Pore size distribution of concrete

	Pore size distribution (%)					
Specimen number	<20 (nm)	20-100 (nm)	100-200 (nm)	>200 (nm)	Harmless holes	Harmless holes
O	23.9	37.2	30.2	8.7	61.1	38.9
PP	26.7	53.2	2.0	18.1	79.9	20.1
GR	32.6	60.2	1.2	6.0	92.8	7.2
BF	30.8	60.0	1.8	7.4	90.8	9.2

important index of micro-structure of concrete study has a great impact on concrete impermeability, frost resistance, strength. Research on pore structure of concrete is important to concrete macroeconomic change. Mercury porosimetry method is based mainly on the functional relationship between the pressure and the amount of mercury pressed in cellular system, to calculate whole diameters and volumes of different sizes hole. Mercury adopts 9,500, produced by United States Michael Company.

The most commonly used indicators is the most probable aperture when the pore structure described Its physical meaning is that it cannot form a connecting passageway less than the aperture in cement paste, as appears likely the largest aperture value. What are shown in Table 3 are characteristic parameters of pore structure of common concrete and fiber concrete based on mercury injection test. It can be concluded that, the most probable aperture of ordinary concrete, concrete with polypropylene fiber, basalt fiber concrete and alkali-resistant glass fiber reinforced concrete are respectively, 21.08, 32.38 study 32.37 nm. The most probable aperture ratio of fiber concrete is larger than that of ordinary concrete, but the most probable pore size of fiber reinforced concrete is distributed within the scope of friendly holes, it does little harmful effect on the mechanical properties of concrete. The most probable aperture of alkali-resistant glass fiber is smaller than the other 2 types of fibers.

Figures in Table 4 are the pore size distribution of fiber reinforced concrete and ordinary concrete based on mercury injection test data processed. By comparing the average pore size distribution of concrete and reinforced concrete, it can be concluded that mixing of fiber improves the characteristics of pore structure of concrete greatly.

From above analysis it can be concluded that, harmless aperture distribution rate of alkali glass fiber concrete is highest, it can reach 92.8%, the second is basalt fiber concrete, its harmless aperture distribution rate is 90.8%, harmless aperture distribution rate of polypropylene fiber concrete is lower, 79.9%.The harmless hole distribution rates of these 3 species fiber concrete are higher than that of general concrete. This is because mixed fiber improves features of pore structure of concrete; alkali glass fiber improves pore structure of concrete best.

Microscopic structure analysis of fiber reinforced concrete: Concrete is a multiphase porous non-homogeneous complex system at all scales and its composition changes over time and under the influence of the environment. Scholars at home and abroad study performance and internal structure of concrete mainly on macro level, but less on micro-level study. Microstructure can have equally important influence on macro properties of concrete.

Characteristics of concrete structures: Micro-structure of concrete is inhomogeneous and dynamic, when the same grade aggregates are used to form concrete strength is mainly dominated by micro-structure of hydrated cement paste. Because the hydration process of cement is a dynamic process, we have the dynamic analysis of the internal structure of concrete in different ages. Hydration reaction of concrete will proceed fully as the age growth, hydrated cement paste mainly include hydrated calcium hydroxide, acid calcium gel hydrates, etc. Also there are some not completely hydration cement particles.

Figure 2 and 3 are the internal structural characteristics of alkali-resistant glass fiber reinforced

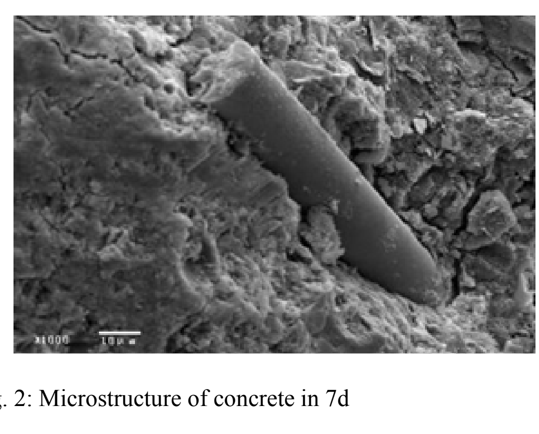

Fig. 2: Microstructure of concrete in 7d

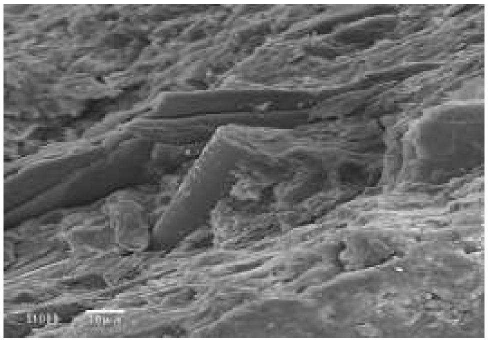

Fig. 3: Microstructure of concrete in 28d

Fig. 4: Instrument concrete intelligent vacuum full of water

Fig. 5: Concrete chlorine ion penetration water resistance measuring instrument

concrete of 7 and 28 days age. You can see in Fig. 2 that fiber and cement slurry bond badly in 7^{th} day, more cracks around, hydration is not obvious; In Fig. 3, alkali-resistant glass fiber around 28 days of age is surrounded by hydration compounds study bond well with cement slurry, cracks in the structure are reduced, the structure is more compact. The bonding between fiber and cement slurry is getting better and better as the age is growing.

Research on durability of fiber concrete: Durability of concrete is 1 of the focus topics to civil engineering at home and abroad currently. Durability is a comprehensive concept; it contains many things, such as impermeability, frost resistance, carbonization resistance, erosion resistance and so on. These properties determine the degree of durability of concrete study affect its service life. Study on durability of concrete in this study is mainly on a micro level of material; impermeability and frost resistance of fiber reinforced concrete are further studied.

Impermeability of fiber concrete: Permeability is 1 of the basic characteristics of porous material, permeability of concrete structure refers to the degree of difficulty of diffusion, permeate or migration of gas, liquid or plasma when they are under pressure, chemical potential and electric field effect, It reflects material pore size, quantity, distribution and connectivity status. Impermeability index is an important indicator to evaluate the durability of concrete study affects the service life of the structure.

(100x100x50 mm) samples are standard cured 28 days, then remove surface laitance, upper and lower surface should be flat, take 3 at random, measure their thickness of spacemen center with micrometer. Five Cm thick concrete will be put vertically in the vacuum chamber of NEL type concrete fast vacuum salt solution device, sealed vacuum chamber and start the vacuum pump and the road switches, in the vacuum dial after show value is less than 0.05 MPa pressure to keep 6 h, disconnect the gas path. Take average of chloride diffusion coefficient value of 3 parallel spacemen as that of this grade concrete; if deviation between the measure value and the mean value of 3 parallel spacemen is more than 15%, a new test need to be taken again.

Experimental chloride ion diffusion coefficient measured values are shown in Table 5.

From Table 5, chloride ion diffusion coefficients from highest to lowest are: polypropylene fiber concrete, basalt fiber concrete, common concrete and alkali-resistant glass fiber reinforced concrete. As can be seen, measured result of chloride ion permeability in the test matches with result of bonding of fiber and cement slurry in micro-structural characteristics of concrete in electron microscope test. In electron microscopy experiments, alkali-resistant glass fiber and cement paste bond best, which improves the characteristics of pore structure of concrete, concrete internal structure is more compact, little pore, coefficient of chloride ion diffusion and permeability is the smallest; Polypropylene fiber concrete is the bonding of organic materials and inorganic materials, which bonds not well between the 2, coefficient of chloride ion diffusion is largest, thus it increases the porosity rate of harmful of holes of structure.

Frost resistance property of fiber concrete: Moist or water-saturated concrete cracks and trips after frozen

Table 5: Chloride ion diffusion coefficient of concrete

Concrete specimen number	O	PP	GR	BF
Chloride ion diffusion coefficient (10-8 cm^2/s)	2.039	3.365	2.426	2.903

Table 6: Result of resistance to freezing and thawing test

	Times of freeze-thaw							
	Relative dynamic modulus of elasticity (%)				Mass loss rate (%)			
Spacemen number	25	50	75	100	25	50	75	100
O	83.8	75.9	67.0	52.6	0	0	0	0.1
PP	85.4	78.2	69.5	54.3	0	0	0	0
GR	93.6	92.2	91.0	89.5	0	0	0	0
BF	95.4	94.4	93.0	90.5	0	0	0	0

in cold environments, it seriously threats the durability of concrete study brings down the strength of concrete. Under the repeated freeze-thaw cycles, even if very good quality of concrete also tends to lower the strength and may even damage occurred.

When testing frost resistance of fiber reinforced concrete, we use (100x100x400 mm) of Prism specimens, each group has 3 specimens. Making specimens should follow GB/T50081 specification requirements. Barring special circumstances, the specimen should be carried out freezing and thawing test at the time of 28 days.

Freeze-thaw cycle reaches 1 of the following 3 things you can stop testing:

- Reach to the times of freeze-thaw cycles that specification requires.
- Relative dynamic modulus of elasticity of spacemen is less than 60%.
- The mass loss rate of specimen is over 5%.

Test result calculation and determination shall meet the following requirements:

- Relative dynamic modulus of elasticity should be calculated in accordance with Equation:

$$p = f_n^2 / f_o^2 \times 100 \quad (1)$$

Take average of 3 spacemen test results as measured value. When the deviation between the maximum or minimum value and the middle value is more than 15%, reject that value and take the average of remaining 2 values as the test value; when the deviation between maximum value and the minimum value is more than 15% of middle value, we take middle value as the final test value.

- Mass loss rate should be calculated by Eq. (2):

$$\Delta W_n = (W_o - W_n) / W_o \times 100 \quad (2)$$

Similarly, we also choose the average value of 3 spacemen test results as the measured value of mass loss rate. Concrete freeze-thaw test results are shown in Table 6.

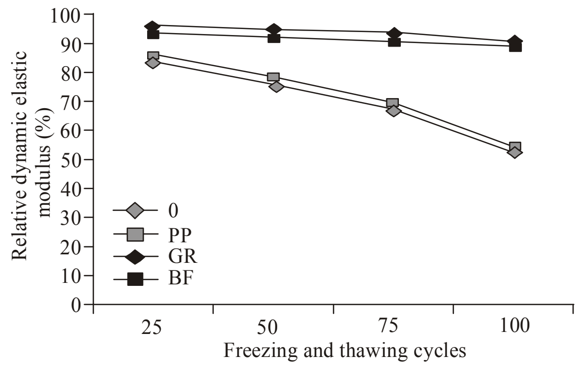

Fig. 6: Effect of fiber on relative dynamic elastic modulus

From the concrete freeze-thaw test results data in Table 6 it can be concluded that, after 100 times freeze-thaw cycles, mass loss of 4 group concrete is not obvious, fiber reinforced concrete without loss of mass. General concrete mass loss rate is only 0.1%. The concrete mass loss is mainly caused by the specimen surface stripping of concrete in freeze-thaw cycle and fiber can improve surface anti-stripping ability. But the relative dynamic elastic modulus changes widely after the same number of freeze-thaw cycles. You can see from Fig. 6, the relative dynamic elastic modulus of ordinary concrete declines largest, its frost resistance is worst; Followed by polypropylene fiber concrete, but its relative dynamic elastic modulus of elasticity is slightly higher than that of ordinary concrete; Last is the basalt fiber concrete and alkali-resistant glass fiber reinforced concrete, relative dynamic modulus change is unlikely, which indicates a good freeze-thaw resistance. By the analysis we may conclude that, after fiber is added, frost resistance of concrete performance improves at a certain degree. This is because the fibers in concrete are distributed by 3 dimensional, which plays a supporting role and inhibiting the formation of cracks and connected holes effectively, improve the internal structure of concrete. Improvement of impermeability makes water around the concrete structures penetrate into the concrete pores hardly, preventing moisture inside the concrete freezes expansion, thus improves frost resistance of the concrete.

CONCLUSION

Based on the analysis of test results we can make the following conclusion:

- Fiber in concrete can reduce formation and development of harmful hole and more harmful hole inside the concrete at a certain degree, whole structure is refined. The most probable of C 40 fiber concrete is distributed within the scope of friendly holes, alkali-resistant glass fiber works for improving pore structure most obvious.
- The interface area is weak in the concrete, concrete damage often occurs in the interface area. The internal structure of concrete of different age is different. With the increase of age, hydration reaction of concrete becomes more and fuller, structure more and denser study bonding of fiber and cement slurry stronger, alkali-resistant glass fiber and cement slurry bond best.
- Compared with ordinary concrete, compressive strength of polypropylene fiber concrete falls. The compressive strength of basalt fiber and alkali-resistant glass fiber reinforced concrete has been significantly improved than ordinary concrete. The improvement effect of basaltic fiber reinforced is more obvious; Cleavage strength of fiber reinforced concrete improves obviously, basalt fibers works best for toughening of concrete.

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