MECHANICAL AND CHLORIDE PERMEABILITY PROPERTIES OF COARSE FIBRE REINFORCED CONCRETE

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Abstract

Synthetic fibers have been widely studied as reinforcing materials to increase the mechanical and durability properties of concrete. According to its diameter, fibers can be categorized as micro and macro (or coarse) fibers. As most research focuses on the mechanical properties of fiber reinforced concrete, its chloride permeability properties have been rarely studied. In this investigation, the compressive strength, flexural strength and chloride permeability of concrete with steel fibers (SF) and two types of coarse synthetic fibers, polypropylene (PP) fibers and polyvinyl alcohol (PVA) fibers were studied. It was found that steel fibers are able to improve both the compressive strength and the flexural strength of concrete. Addition of PP and PVA fibers could improve the flexible strength of concrete, with little effect on the compressive strength. Furthermore, test results show that addition of PP fibers slightly increases the chloride permeability of concrete while PVA fibers slightly reduce the chloride permeability.
Keywords: Coarse fibers; Mechanical properties; Chloride permeability; Flexural strength

1. INTRODUCTION

Concrete is the most widely used building material in the world. As concrete is strong in compression and weak is tension, various types of fibers have been added in concrete to improve its ductility properties. Studies have reported that proper addition of fibers are able to enhance the tensile strength, flexural strength, fatigue life, ductility and post-cracking performance of concrete.[1-5] Polyvinyl alcohol (PVA) is a low cost high performance fiber with hydrophilic characteristics which improves the bond between fiber and cementitious matrix. According to the geometrical structure, synthetic fibers can be divided into micro fibers and Macro (coarse) fibers. Compared with micro fibers, macro fibers have been found to enhance the post-cracking response of concrete, improve energy absorption capacity, and reduce the risk of cracking. As most research focuses on the mechanical properties of fiber reinforced concrete, [6-10] the effect of coarse fibers on the chloride permeability of concrete has been rarely studied.

In this investigation, concrete specimens with three types of coarse fibers (SF, PP and PVA) were prepared to study their effects on mechanical and chloride permeability properties of concrete. Compressive strength test and flexibility test (according to ASTM C1609 [11]) were performed. Chloride permeability tests were performed using rapid chloride migration test (RCM test, NT Build 492 [12]) and electrical resistivity test (AASHTO T 358 [13]).

2. EXPERIMENTAL

2.1 Materials

Thirteen mixes were prepared in this investigation including specimens that contained only ordinary Portland cement (OPC) and specimens with steel, PP and PVA fibers, as shown in Fig.1. The physical and mechanical properties of the coarse fibers are listed in Table 1.

(a) steel fiber (b) PP fiber (c) PVA fiber

Figure 1: Appearance of different coarse fibers

Table1: Physical and mechanical properties of different coarse fibers

Coarse fibers	Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Length (mm)	Diameter (μm)
SF	7.8	1000.0	154.0	50.0	620.0
PP	0.9	530.0	7.1	50.0	910.0
PVA	1.3	254.0	15.9	30.0	646.4

The volume content ranges from 0.6% to 1.5% for steel fibers, 0.9% to 1.8% for PP fibers, and 0.6% to 1.5% for PVA fibers. P·O42.5 cement was used for all the mixes and the *w/cm* was 0.4. Additionally, 15% Class I fly ash, 40% Class S slag powder and 1% water reducer were added. Limestone with size ranging from 5 to 20 mm was used as coarse aggregate. River sand from the local Songhua River was used as fine aggregate. Details of the mixture designs are listed in Table 2.

Table 2: Mix properties of concrete.

Mix	Cement (kg/m^3)	Fly Ash (kg/m^3)	Slag (kg/m^3)	Fine agg (kg/m^3)	Coarse agg (kg/m^3)	Fibers		
						Type	Mass (kg/m^3)	Volume Content (%)
OPC	194.0	64.7	172.5	830.8	1015.4	-	-	-
SF6	194.0	64.7	172.5	830.8	1015.4	SF	46.8	0.6

SF9	194.0	64.7	172.5	830.8	1015.4	SF	70.2	0.9
SF12	194.0	64.7	172.5	830.8	1015.4	SF	93.6	1.2
SF15	194.0	64.7	172.5	830.8	1015.4	SF	117.0	1.5
PP9	194.0	64.7	172.5	830.8	1015.4	PP	8.2	0.9
PP12	194.0	64.7	172.5	830.8	1015.4	PP	10.9	1.2
PP15	194.0	64.7	172.5	830.8	1015.4	PP	13.7	1.5
PP18	194.0	64.7	172.5	830.8	1015.4	PP	16.4	1.8
PVA6	194.0	64.7	172.5	830.8	1015.4	PVA	7.8	0.6
PVA9	194.0	64.7	172.5	830.8	1015.4	PVA	11.7	0.9
PVA12	194.0	64.7	172.5	830.8	1015.4	PVA	15.6	1.2
PVA15	194.0	64.7	172.5	830.8	1015.4	PVA	19.5	1.5

2.2 Experimental Methods

In this investigation, prism (10 cm×10 cm×40cm) and cylinder (Φ10 cm×20 cm) specimens were prepared. Each mixture included 3 prism specimens and 12 cylinder specimens. The flexural test was performed on the prism specimens at 28 days age. Compressive test was perform on the cylinder specimens at 7, 14, and 28 days age and electrical resistivity measurements were performed on the cylinders specimens until 28 days age. The RCM test was performed at 28 days age using cylinder specimens.

As the large amount of mineral admixtures added in the concrete reduces the hydration rate, an elevated temperature curing regime was used to accelerate the curing rate of specimens. The specimens were demoulded 48 hours after casting and then immersed in 40°C saturated lime water for curing until the age of 28 days. A maturity method according to ASTM C1074 [14] was employed to calculate the equivalent age of specimens cured at 20°C. The calculated equivalent age is listed in Table 3. It is noted that the concrete age presented in this paper is the actual age but not the equivalent age.

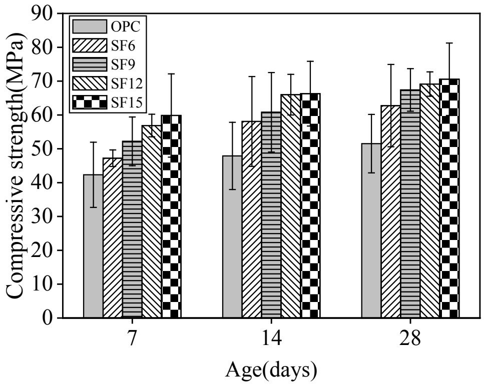
Table 3: Equivalent Age

Curing age at 40°C	Equivalent age at 20°C
7d	49d
14d	99d
28d	197d

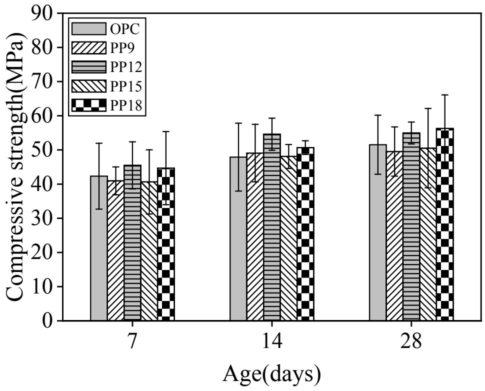
3. RESULTS AND DISCUSSION

3.1 Compressive strength

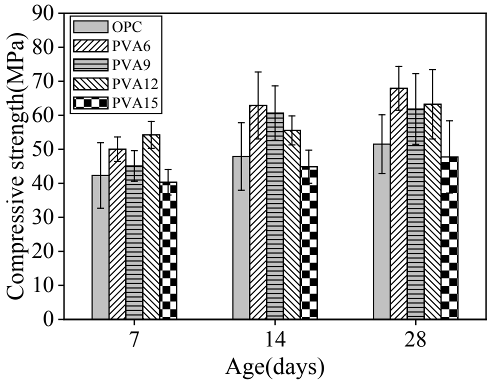
The evolution of compressive strength for various groups are presented in Fig.2. In each plot, the results of OPC specimens were included for comparison. In Fig. 2(a), it shows that addition of steel fibers can significantly increase the compressive strength of concrete, and specimens with 1.5% volume of steel fibers shows the highest compressive strength at 28 days age, which is in agreement with the results from previous researches (P.S. Song 2004). Fig. 2(b) shows that the effect of PP fibers on the compressive strength is almost negligible. Fig. 2(c) shows that addition of PVA fibers could significantly increase the compressive strength of concrete, but this effect decreases with increasing the volume percentage of PVA fibers and becomes detrimental when the percentage reaches 1.5%.



(a) Steel fibers



(b) PP fibers



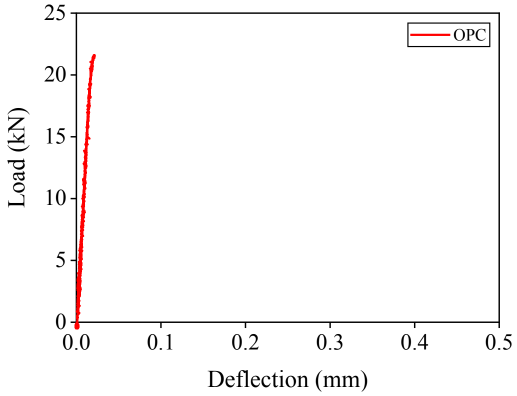
(c) PVA fibers

Figure 2: Compressive strength evolution of concrete

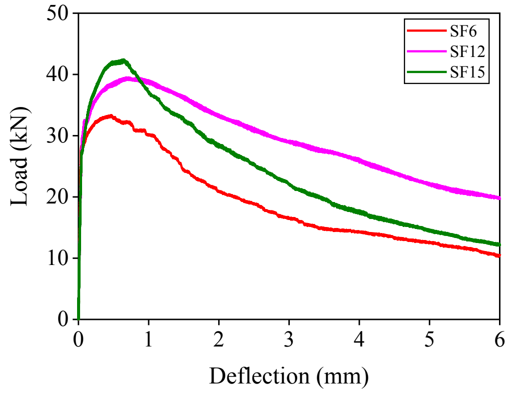
3.2 Flexural strength

The load deflection curves for all the mixtures at the age 28 days are shown in Fig. 3. It shows in Fig. 3(a) that for OPC specimens, they completely crack when deflection reaches about 0.05mm. For specimens with steel fibers, the peak load reaches at the deflection between 0.5 and 1mm. The residue strength of steel fiber reinforced concrete (SFRC) keeps relatively high and decreases as deflection increases. The load deflection curves for the PP and PVA fibers specimens are similar, as shown in Fig.3 (c) and (d). At the same volume percentage, the residual strength of PP fiber reinforced concrete is slightly higher than that of PVA fiber reinforced concrete, which is possibly attributed to the longer length and corrugated surface of PP fibers compared to PVA fibers, despite the hydrophilic characteristics of PVA fibers which could possible increase the bond between fibers and cementitious matrix.

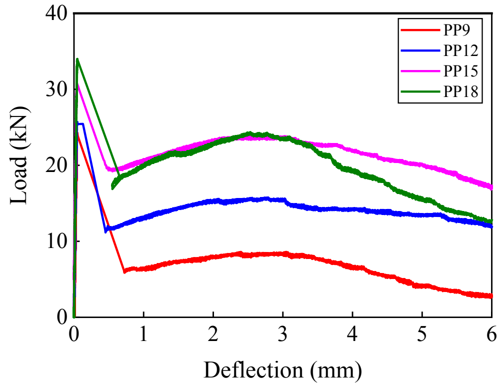
Fig. 4 shows the flexural strength and toughness of the tested specimens. Fig. 4 (a) shows that steel fibers could significantly increase the flexural strength of concrete. At the same volume percentage, the flexural strength of PP and PVA fiber reinforced concrete are similar. However, the results also show that, at the volume percentage of 1.8%, the flexural strength of PVA fiber reinforced concrete is equivalent to that of 1.2% SFRC. Fig.4 (b) shows that in general the toughness value increases with increasing the volume percentage of fibers. At the same volume percentage, the PP and PVA fiber reinforced concrete shows similar values of toughness.



(a) OPC



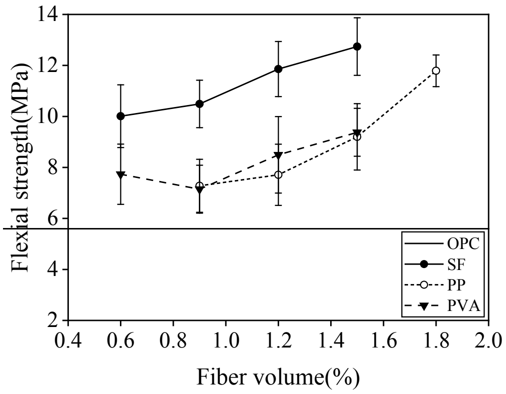
(b) Steel fibers



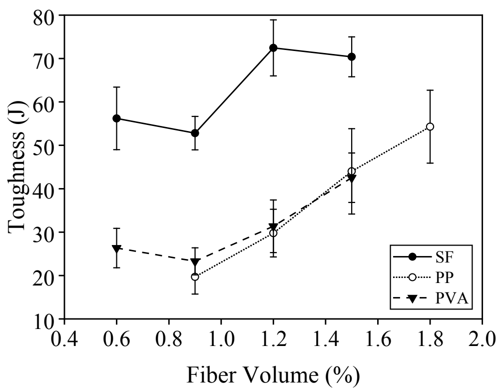
(c) PP fibers

(d) PVA fibers

Figure 3: Load-deformation curves of different fiber concrete



(a)

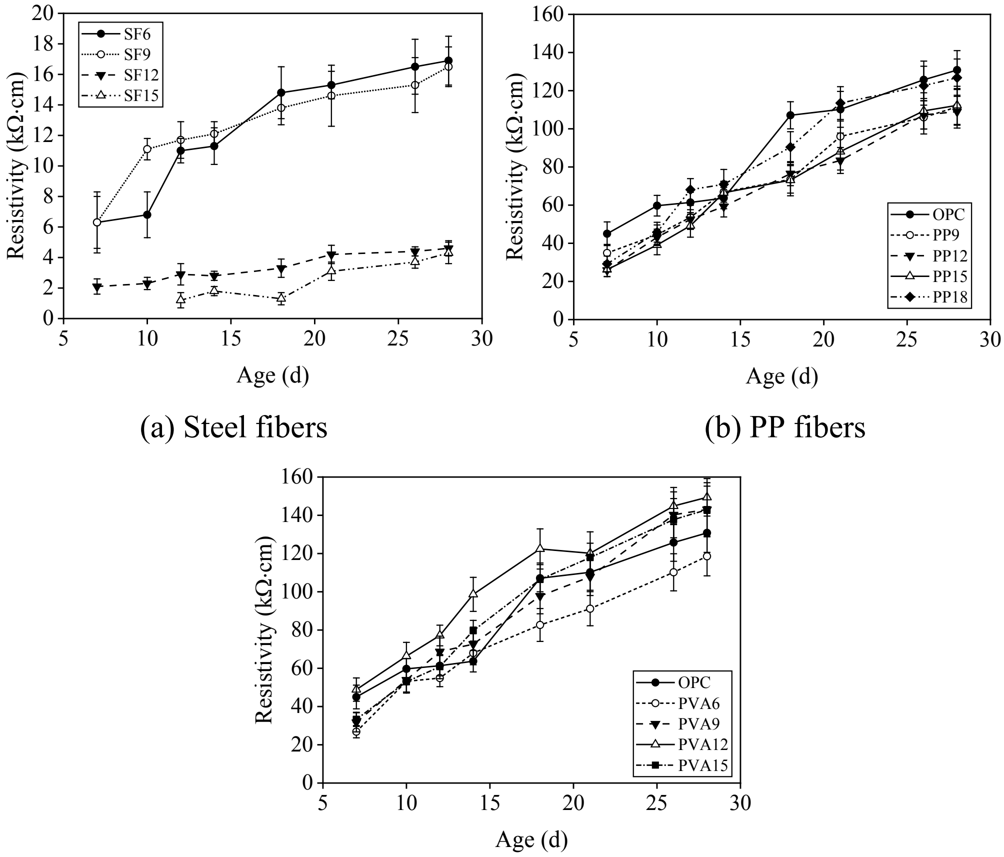


(b)

Figure 4: Flexural strength (a) and toughness (b) at 28 days age.

3.3 Electrical resistivity and chloride migration coefficients

Fig. 5 shows the evolution of electrical resistivity on concrete with different fibers contents. The resistivity vs. content for the different series indicates that the resistivity evolution is significantly different on specimens with different fibers and contents. As can be seen in the figure, the resistivity of all specimens rises with curing age. The 28-day resistivity variation trend of all mixes in Fig. 6 show that the resistivity of SFRC is lower than that of concrete with PP fibers, both are lower than that of OPC and the resistivity of SFRC decreases with the increase of content. Unlike these two kinds of concrete, the resistivity of PVA fibers reinforced concrete rises with increasing content, and is generally higher than that of OPC. This substantial reduction in the resistivity is attributed to the electrical conductivity steel fibers and the hydration products of binding materials cannot completely make up the increased porosity which caused by fibers addition. However, the good affinity and binding property of PVA increase porosity, so resistivity rises along with increase of content.



(a) Steel fibers (b) PP fibers

(c) PVA fibers

Figure 5: Resistivity evolution of different fiber concrete

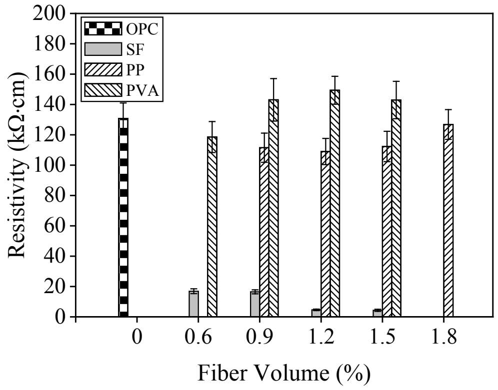


Figure 6：28 days resistivity of different fiber concrete

The 28-day chloride migration coefficients (D_{nssm}) of all mixes are presented in Fig. 7. It shows that D_{nssm} of SFRC is larger than that of OPC test group, and the specimens with 0.9% content are 159.14% higher than OPC test group. But D_{nssm} of the concrete with PP and PVA are similar to that of OPC test group. Compared with the OPC test group, the specimens with 0.9% PP content only increased by $0.2515\times10^{-12}m^2/s$, and the specimens with 0.6% PVA content decreased by $0.074\times10^{-12}m^2/s$.This is attributed to the increase of the weak layer between steel fiber and concrete matrix, which leads to the deterioration of pore structure and the decrease of concrete compactness, thus reducing the chloride penetration resistance. The hydration product of the binding material makes up for the influence of pore structure deterioration to some extent, so D_{nssm} of PP fibers reinforced concrete changes little. The affinity and binding property of PVA fibers make up for the deterioration of pore structure, and even improve the pore structure of concrete, so the chloride resistance permeability is enhanced.

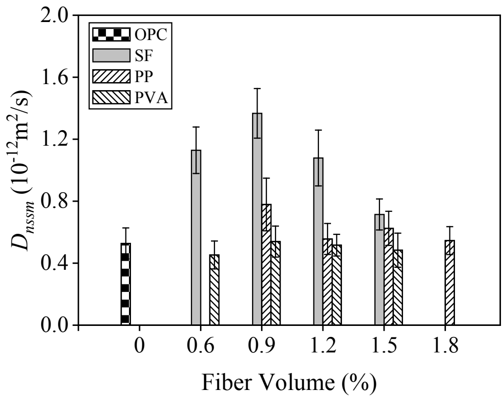


Figure 7: chloride migration coefficients of different fiber concrete

4. CONCLUSIONS

- The compressive strength of concrete is affected by the addition of coarse fibers and the order of improvement effect on compressive strength is steel fibers > PVA fibers > PP fibers.

- The addition of coarse fibers will improve the bending performance of concrete. The flexural strength, remained strength and toughness improve with the increase of fiber content.
- The addition of SF will greatly reduce the resistivity of concrete, while PP fibers and PVA fibers have little effect on it.
- D_{nssm} will increase as the addition of coarse fibers. SFRC has the worst impermeability, while there is no significant difference in impermeability between PP fibers concrete and PVA fibers concrete.

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