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Effect of polymer coating on the properties of surface layer concrete

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Abstract

Polymer coating is progressively being used in fields of concrete curing and concrete surface strengthening. However, only very few researches have been reported to investigate the effect of polymer coating on the properties of surface layer concrete. The effects of polymer coating on shrinkage, mechanical property, carbonation, capillary absorption and chloride ion diffusion of surface layer concrete were studied in the present investigation. The experimental results showed that polymer coating could obviously reduce the mortar shrinkage of the concrete surface, and the thicker the polymer coating, the greater shrinkage reducing ratio at early ages. It has been found that the polymer coating enhanced the mortar early age strength of the concrete surface. Meanwhile, the carbonation resistance of surface layer concrete, as well as the mortar infiltration resistance on the surface of concrete was improved by polymer coating. The results also demonstrated that the capillary absorption ratio of mortar in the surface layer of concrete cured under the polymer coating condition could be reduced by 87% and 78%, respectively compared with dry and standard curing conditions. In the same way, polymer coating had an improvement effect on chloride ion diffusion resistance of surface layer concrete.

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Keywords: Polymer coating; Shrinkage; Carbonation; Capillary absorption; Chloride ion diffusion

1. Introduction

Concrete is being used widely in construction area as an important structural material. A mass of diseases of concrete structural such as cracking, carbonation and steel corrosion are caused by deterioration of surface layer concrete. Therefore many researchers have paid their attention on the

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improvement of the properties of the surface layer concrete.

The surface layer concrete refers to the mortar or concrete within 30mm from the surface of concrete [1], and it is usually thinner than the protection layer of reinforced concrete. The penetration and carbonation resistances and mechanical properties of concrete are affected by surface layer concrete to some degree. A poor property of the surface layer concrete will lead to cracks on concrete surface. Then a friable structure and a poor quality of the concrete will be resulted [2]. As a kind of macromolecule material, the latex of polymer coating is being used in some concrete projects such as dam, water tunnel and bridge concrete surface treatment. It can significantly improve the properties of mortar and concrete through the forming of film when losing water within the cement hydrate networks during the concrete hardening process. The hydrate holes can also be filled during this process. In recent years, the studies of polymer coating mostly focus on the improvement of the overall properties of concrete, and there is rare investigations been carried out to discuss concrete properties of volume deformation, media-infiltration resistance and carbonation of surface layer concrete coated with polymer.

In this study, a modified styrene-acrylic emulsion polymer was used in concrete coating experiments. Firstly, effects of coating age and coating thickness of polymer on shrinkage and strength developments of surface layer mortar were investigated; secondly, properties of surface layer mortar coated with polymer compared with other different curing methods were investigated; thirdly, the promotion of carbonation, capillary absorption and chloride ion diffusion resistance of surface layer concrete on polymer coating was investigated.

2. Experimental

The polymer coating material used in this study was a modified styrene-acrylic emulsion with a bulk density of 950kg/m^3 . The cement used in this study was type P. II 52.5 cement with a chemical composition of 64.11% CaO, 20.60% SiO₂, 5.03% Al₂O₃, 4.38% Fe₂O₃, 1.46% MgO, 1.72% SO₃ and a Na₂O equivalent of 0.36%. The sand fineness modulus was 2.6, and the density of sand was 2650kg/m^3 . The size of limestone gravel used in this study was between 5mm and 25mm. Shrinkage reducing agent (SRA) was also used in this study. SRA is a kind of alcohol category of small molecule which is used to coat on the surface of concrete.

2.1. Shrinkage

Mortar specimen was used in this experiment to test the concrete shrinkage because there was less aggregate existent on the surface layer of concrete after specimen was casting. The size of shrinkage specimen used in this study was $25\text{mm}\times 25\text{mm}\times 280\text{mm}$ (in order to simulate the shrinkage of mortar in surface layer concrete, the thickness of specimen was less than 30mm). The water-cement ratio (W/C) of mortar used in this experiment was 0.5. All specimens were cured under a standard condition for $24\pm 2\text{h}$. Then specimen was demoulded and the initial length (L_0) was recorded. Three-quarters of the specimens were moved to a drying condition ($T=20\pm 3^\circ\text{C}$; $\text{RH}=50\pm 4\%$), two-thirds of these specimens were coated with polymer and SRA respectively and the remaining one-third of the specimens without any treatment were control samples. The length of the mortar specimens (L_i) at each corresponding curing age were recorded (specimens cured under a standard condition were transferred to a dry curing room at 7d). The shrinkage ratio (ε_i) and shrinkage reducing ratio (ω_i) were calculated by Eq. (1) and Eq. (2) respectively:

$$\varepsilon_i = (L_0 - L_i) / L_0 \quad \text{Eq. (1)}$$

$$\omega_i = (\varepsilon_0 - \varepsilon_i) / \varepsilon_0 \times 100\% \quad \text{Eq. (2)}$$

Where:

L : the effective length of the specimen;
 ε_0 : the shrinkage of control specimen;
 ε_i : the shrinkage of polymer (or SRA) coating curing specimen.

2.2. Mechanical properties

Mortar specimen was used in this experiment to test the surface layer concrete mechanical properties. The size of the specimen was 40mm×40 mm×160mm. All specimens were cured under a standard condition for 24±2h before demoulded. One fifth of the specimens were kept in the standard curing condition and others were moved to a dry curing room. Those specimens under the dry curing condition were divided into four parts. Quarter of the specimens was mold curing, half parts of the specimens were coated with polymer and SRA respectively and the remaining quarter of specimens without any treatment. The flexural strength and compressive strength measurements of specimens were conducted according to Chinese National Standard GB/T17671–1999 at 7d and 28d respectively.

2.3. Carbonation

Concrete specimen was used in this experiment to test the carbonation. The size of the specimen used in this study was 100mm×100mm×100mm. The concrete mix proportion was cement: fine aggregate: coarse aggregate: water=1: 2.28: 3.72: 0.5. All specimens were cured for 28 days before tested. One-third of the specimens were cured under a standard condition, while other polymer coating and film covering specimens were cured under a drying condition. Paraffin was evenly coated onto four circled faces of the cube before the specimens were put into a carbonation chamber with the CO₂ concentration of 20±1% (T=20±1°C, RH=70±2%). Then the carbonation depth was recorded at each corresponding carbonation age.

2.4. Capillary absorption

Mortar specimen was used in this experiment to test the surface layer concrete capillary absorption. The specimen size was Φ100mm×50mm. All specimens were cured under a standard curing condition for 24±2h. The specimens were divided into three parts (standard curing, dry curing and polymer coating curing). In this experiment, every mortar specimen needed to be special treatment. Firstly, the side of specimen was sealed up completely with epoxy and then the polymer was coated on the testing surface of specimen. Secondly, the specimens were put into an oven at 50°C to obtain a consistent weight after cured for 28 days and then the initial weight was recorded. Keeping the testing surface of specimen immersing into water for 0, 10min, 20min, 30min, 40min, 50min, 60min, 90min and 120min, and then the specimen weight change (ΔM) was recorded. The capillary absorption (I) of mortar was calculated by Eq. (3):

$$I = \Delta M / A \cdot D \quad \text{Eq.(3)}$$

Where:

A : testing surface area;

D : water density.

The capillary absorption ratio was obtained by analyzing the relativity using linear regression method. The schematic diagram of capillary absorption is shown in Fig.1.

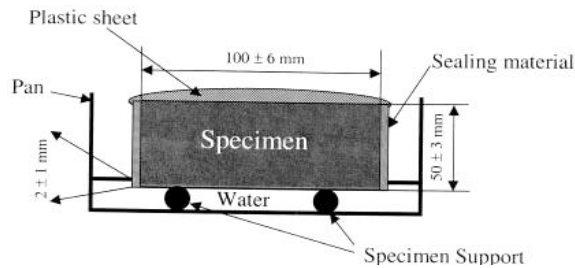


Fig. 1. Schematic diagram of capillary absorption

2.5. Chloride ion diffusion

Concrete specimen was used in this experiment to test the chloride ion diffusion. The concrete mix proportion was the same as concrete carbonation experiment. The chloride ion diffusion of surface layer concrete was tested following rapid chloride mitigation (RCM) method. All concrete disks used in the experiment were cast in 100 mm-diameter cylindrical moulds which were approximately 300 mm in length. After allowing 24 hours for the cylinder to set, the specimens were demoulded. The finishing surfaces of specimen were coated with polymer compared with control sample without polymer coating. While other surfaces of specimen were sealed with film. The specimens were placed in an automatically controlled curing room at $20 \pm 2^\circ\text{C}$ and 60 percent relative humidity. The specimens were cured under these conditions for 28 days. The specimens were then cut to a $50\text{mm} \pm 2\text{mm}$ thick sample using a rock saw with a diamond blade and then kept water-saturated in vacuum condition.

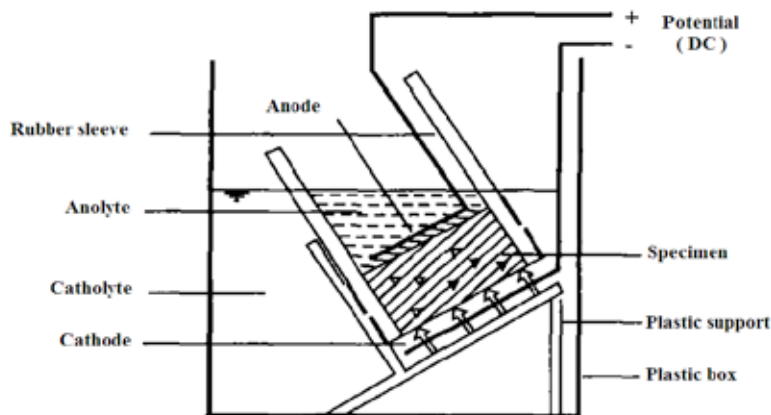


Fig. 2. Experimental setup of RCM test

The voltage in this experiment was 30V and the temperature was $20 \pm 5^\circ\text{C}$. At the end of the assigned test duration, the concrete samples were split in half. To detect the chloride penetration depth, the sample was first sprayed with an aqueous fluoresceine solution (1 g/l in 70% ethyl alcohol). After the surface had slightly dried for a couple of seconds, an aqueous silver nitrate solution (0.1 M) was immediately applied. The penetration depth of chloride revealed by the color change was measured along the diameter at an interval of 1 cm and the rapid migration coefficient was calculated. The experimental setup of RCM test

is shown in Fig.2.

3. Results and discussion

3.1. Shrinkage of the surface layer concrete coated with polymer

Mortar shrinkage on the surface of concrete coated with polymer at different coating time

At 0 hour, 48 hours and 144 hours after demould, the polymer of 70 μm in thickness was coated on the surface of mortar specimen which was used to simulate the concrete surface layer. Fig.3 shows the shrinkage ratio of mortar coated with polymer at different time. Polymer coating could significantly reduce the shrinkage of mortar, while the shrinkage reducing ratio was different at various coating time. When polymer was coated at 48 hours, the shrinkage reducing effect was obvious and the shrinkage reducing ratio remained at a mean value of 20% at 90d. The shrinkage reducing effect was weakened as the coating time was delayed. The shrinkage reducing ratio was reduced to 12% at 90d when polymer was coated at 144 hours.

The shrinkage of mortar under a drying condition was caused by moisture dissipation and rising of capillary negative pressure [3]. When the polymer was coated on the surface of mortar, the shrinkage reducing components of polymer could infiltrate into the capillary in the surface layer of mortar to reduce the surface tensile force of solution in capillary and reduce the negative pressure caused by moisture dissipation, and then the shrinkage of mortar was reduced. Otherwise, polymer coating could form a dense film to seal open capillaries and reduce the moisture dissipation, and then the shrinkage of mortar was reduced. If the polymer was coated at a later time, the almost fully developed capillary structure and the low residual moisture in capillary caused the remaining shrinkage of mortar becoming small; therefore, the shrinkage reducing effect of polymer was insignificant.

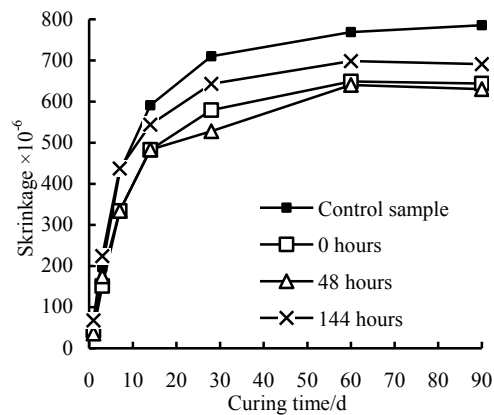


Fig. 3. Shrinkage ratio of mortar coated with polymer at various coating time

Mortar shrinkage on the surface of concrete coated with polymer of different thicknesses

Polymer coatings of 70 μm , 140 μm and 210 μm thick were coated on the surface of mortars (simulation of concrete surface layer) under a drying condition. The effects of coating thickness of polymer on reducing drying shrinkage were contrasted. Fig.4 shows the shrinkage ratio of mortar. A thicker polymer coating could obtain a better shrinkage reducing effect. The shrinkage reducing ratio of polymer of 70 μm

in thickness was 15% at 90d, while the shrinkage reducing ratio increased to 30% when the thickness of polymer was 210 μm .

A thicker polymer coating contained more shrinkage reducing components, in the same way, the surface tensile force of solution in capillary was reduced effectively and the shrinkage of mortar was reduced obviously. In another way, a thicker polymer coating could form a more compact film on the surface of mortar to seal open capillaries and avoid the moisture dissipation and then control the drying shrinkage of mortar.

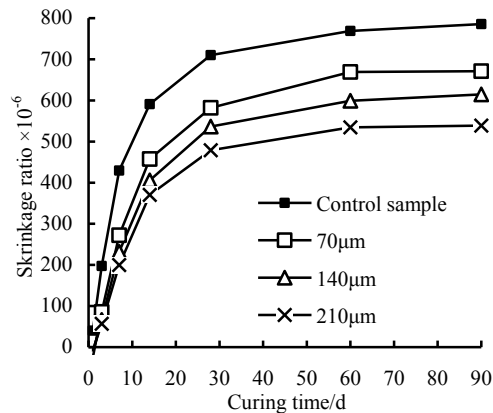


Fig. 4. Shrinkage ratio of mortar coated with different thicknesses of polymer

Mortar shrinkage on the surface of concrete under different curing methods

Fig.5 shows the shrinkage ratio of mortar under different curing methods. Specimen cured under the drying condition exhibited the highest shrinkage ratio. Standard curing for 7 days before dry curing provided a lower shrinkage during the whole curing process. Coating with polymer of 70 μm in thickness (Polymer-C) could also provide a low shrinkage and the shrinkage ratio developed steadily during the experimental period. The shrinkage ratio of mortar coated with SRA (SRA-C) was the lowest before 28d, while the value grew sharply after 28d.

The fast evaporation of the capillary moisture under the drying condition caused a negative pressure; therefore, the drying shrinkage of mortar occurs easily [4]. The increased degree of hydration in cement and the decreased amount of capillaries led to the enhanced ability of shrinkage resistance when the specimen was cured under a standard condition at early age. Meanwhile, the shrinkage ratio of specimen remained low even the specimen was removed from a standard condition to a drying condition at later age. When shrinkage reducing agents were coated on the surface of mortar, the SRA molecule infiltrated into the capillaries on the surface of mortar to reduce the surface tensile force of solution in capillaries, and then the drying shrinkage of mortar was reduced [5]. SRA molecule volatilized and the effects of SRA on restraining shrinkage of mortar became weak with the increasing of curing age. When polymer was coated on the surface of mortar, the shrinkage reducing component infiltrated into the capillaries to play a role in restraining drying shrinkage and the film of polymer on the surface of mortar could reduce the moisture and shrinkage reducing component dissipation. Thus the shrinkage ratio of mortar was low throughout the whole testing process.

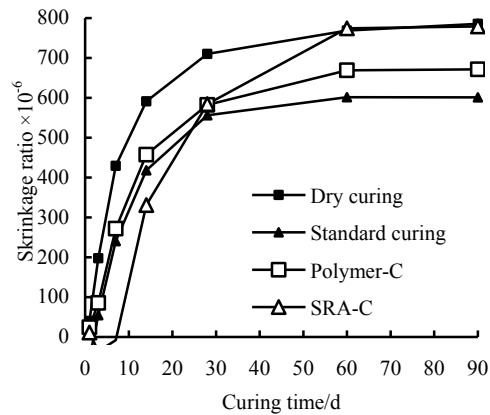


Fig. 5. Shrinkage ratio of mortar under different curing methods

3.2. Mechanical properties of the surface layer concrete coated with polymer

The polymer coating of 70 μ m in thickness was coated on the surface of mortar which was used to simulate the concrete surface layer and then the flexural strength and compressive strength of mortar were tested and compared with the mechanical properties of mortars cured under standard, dry, mold and SRA-C curing conditions. Table 1 shows the flexural and compressive strength of mortars cured under these conditions. W/C of mortar in this study was 0.6 in order to simulate the current W/C of mortar at concrete surface layer. The flexural and compressive strength of mortar coated with polymer increased obviously when compared with those cured under a standard condition, the flexural and compressive strength were enhanced by 9% and 22% respectively at 7d. There strength development of mortars cured under conditions of drying, molding and SRA-C was normal at early age. On the contrary, the flexural and compressive strength of mortars cured under these four conditions were all lower when compared with the strength of mortar cured under a standard condition at later age.

Table 1. Flexural and compressive strength of mortar coated with polymer

Sample NO.		Standard curing	Dry curing	Mold curing	Polymer-C	SRA-C
Flexural strength	(7d) MPa /%	5.90/100.00	5.93/100.51	6.09/103.22	6.43/108.98	5.85/99.15
	(28d) MPa /%	7.98/100.00	6.84/85.71	7.76/97.24	7.77/97.37	7.31/91.60
Compressive strength	(7d) MPa /%	23.11/100.00	27.06/117.09	28.29/122.41	28.23/122.15	28.71/124.23
	(28d) MPa /%	38.43/100.00	30.68/79.83	34.05/88.60	33.20/86.39	32.95/85.74

Standard curing could control the moisture dissipation and reduce the shrinkage of capillary effectively compared with other surface curing methods. The early shrinkage made the mortar structure denser than those cured under a standard condition. Therefore, the strength and compressive strength were higher when compared with mortar cured under a standard station at early age. While, the cubic deformation of mortar could create many micro-cracks and other defects, the hydration of mortars cured under those four curing conditions were inadequate and the micro-cracks could not be filled immediately. All these made the mortars cured under drying, molding, Polymer-C and SRA-C conditions got more easily damaged.

3.3. Carbonation of the surface layer concrete coated with polymer

The carbonation depths of concrete cured under various conditions are shown in table 2. The carbonation depth of concrete coated with polymer of 70 μm in thickness was lower at early age (3d) than carbonation depths of concrete under other two curing conditions. However, the carbonation process of concrete coated with polymer speeded up at later ages. Besides, the development of carbonation was slow when the carbonation depth of concrete was lower than 10mm, and then the development of carbonation became fast after the carbonation depth broke 10mm. Polymer coating could form a dense film on the surface of concrete, while the ability of this film of blocking carbon dioxide was weaker than plastic film. Plastic film could seal the concrete surface effectively and controlled the carbonation speed of concrete excellently. When concrete was cured under a standard condition, the humidity and temperature were appropriate, therefore, a better surface structure and a smaller carbonation depth of concrete were obtained.

Table 2. Carbonation of concrete coated with polymer

Sample NO.		Standard curing	Film curing	Polymer-C
Carbonation depth /mm	3d	7.7	7.9	6.7
	7d	9.6	10.6	10.6
	14d	10.5	11.4	12.1
	28d	12.6	12.3	14.2

3.4. Capillary absorption of the surface layer concrete coated with polymer

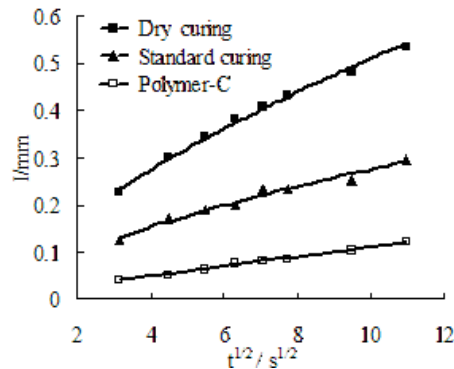


Fig. 6. Capillary absorption of mortar coated with polymer

The 70 μm -thick polymer was coated on the surface mortar specimen (50mm-thick, W/C=0.6, simulation of concrete surface layer), and then the capillary absorption of specimen was tested. The results were compared with those of other specimens cured under standard and drying conditions. Fig.6 shows the capillary absorption curves of mortar. The capillary absorption value of mortar cured under the drying condition was higher than those of other two groups cured under standard and Polymer-C conditions. The capillary absorption value of mortar coated with polymer was the smallest. While, the phenomenon of surface water-absorbent also existed even the surface of mortar coated with polymer was

sealed by polymer coating film.

Table 3. Regression relationship between the capillary absorption of mortar and square root of time

Sample NO.	Standard curing	Dry curing	Polymer-C
Equation		$I=at^{b/2}$	
a/mm/s ^{1/2}	0.0623	0.1075	0.0140
b	1.2906	1.3538	1.7836
R ²	0.9754	0.9943	0.9983

Table 3 shows the regression relationship between the capillary absorption of mortar and square root of time. The regression relationship met the following equation,

$$I=at^{b/2}$$

Where:

I: the capillary absorption value of mortar (mm);

a: the capillary absorption ratio at different time (mm/s^{1/2});

b: the impact factor and all the correlation coefficients were above 0.97.

The capillary absorption ratio of mortar coated with polymer was 0.014 mm/s^{1/2}, decreasing by 87% and 78% when compared with drying and standard conditions respectively. The polymer film sealed most of the open capillaries on the surface of mortar and blocked the water intrusion. Therefore, the capillary absorption ratio of mortar coated with polymer was reduced and the infiltration resistance of surface mortar was enhanced. However, the proliferation and precipitation of water vapor in capillary [6] also led to the capillarity even the polymer was coated onto the surface of mortar, and then the migration of condensation water would cause the capillary absorption.

3.5. Chloride ion diffusion coefficient of the surface layer concrete coated with polymer

Table 4 shows the chloride ion diffusion coefficient of concrete coated with polymer of 70µm in thickness.

Table 4. Chloride ion diffusion coefficient of concrete coated with polymer

Sample NO.	Diffusion depth /mm	$D_{RCM}/10^{-12} \text{ m}^2/\text{s}$
Control	18.50	7.799
Polymer-C	13.25	5.944

Comparing with control sample, the chloride ion diffusion depth of surface layer concrete coated with polymer decreased from 18.5mm to 13.25mm and the D_{RCM} value decreased from $7.799 \times 10^{-12} \text{ m}^2/\text{s}$ to $5.944 \times 10^{-12} \text{ m}^2/\text{s}$. Chloride ion infiltrated into surface layer concrete through micro-cracks and capillarity of capillaries [7]. Polymer coating sealed most capillaries and filled many micro-cracks on the surface of concrete. Therefore, the surface concrete density was increased and the harmful media infiltration resistance of surface layer concrete was enhanced.

4. Conclusions

Based on the information provided in this paper, the following conclusions can be drawn:

1. Polymer coating reduces the mortar shrinkage on the surface of concrete effectively. Coating with thicker polymer at earlier time gets a higher shrinkage reducing ratio. The early flexural strength and compressive strength of surface layer mortar coated with polymer are both enhanced. The mortar flexural and compressive strength on the surface of concrete cured under the polymer coating condition can be increased by 9% and 22% respectively at 7d when compared with strength of mortar cured under the standard condition.
2. The carbonation depth of surface layer concrete coated with polymer is low at early age. However, the value increases rapidly with the increasing of carbonation time.
3. The capillary absorption value of surface layer mortar coated with polymer will decrease and the infiltration resistance of mortar is enhanced significantly. The capillary absorption ratio of surface layer mortar coated with polymer is decreased by 87% and 78% when compared with mortars cured under drying and standard conditions respectively.
4. The chloride ion diffusion coefficient of surface concrete coated with polymer decreases from $7.799 \times 10^{-12} \text{ m}^2/\text{s}$ to $5.944 \times 10^{-12} \text{ m}^2/\text{s}$ and the chloride ion diffusion resistance will be enhanced effectively.

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