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Properties of polymer-modified cement mortar using pre-enveloping method

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Abstract

A new method, pre-enveloping sand with polymer, was adopted to make polymer-modified cement mortar (PCM). In the research, two kinds of latex, i.e., styrene acrylate rubber and styrene butadiene rubber, were used. The experimental results of physical and mechanical tests showed that, at the same level of polymer cement ratio, pre-enveloping method was better than normal method regarding the performance of the resulted composite. Moreover, in the condition of relatively low addition of polymer, the improvement of physical and mechanical properties, especially the resistance to cycling of freezing–thawing, by the pre-enveloping method was more significant. Additionally, it was found that styrene butadiene rubber can improve the fluidity of the mortar, and mortar with styrene acrylate rubber can maintain the same fluidity as the control sample by adding small quantities of a superplasticizer. Styrene acrylate rubber had no water-reducing ability by itself.

Keywords: Pre-enveloping method; Latex; Polymer-modified cement mortar

1. Introduction

Recently, the outstanding performance of polymer-modified cement mortar (PCM) has attracted increasing attention from both scientific and engineering communities. During the hardening of mortar, polymer can form another network in the material, which fills up pores in cement matrix and improves the bonding between aggregates and cement paste [1]. As a result of this microscopical mechanism, PCM possesses low permeability, good freeze–thaw resistance and relatively higher flexural strength and bonding strength to old concrete, which allow this material to be used successfully as concrete repairing materials, concrete bridge and road covering materials and waterproof materials [2–4]. The shortcoming of PCM is the relatively large addition of polymer, generally, the polymer to cement ratio is around 15–20 %. This increases greatly the price of this kind of engineering material and limits its applications.

In normal-strength cement-based materials, it is believed that cracks and large pores that govern the physical and mechanical properties mainly occur in the interfacial zone between aggregates and hardened cement paste [5]. Some techniques were invented in the history of concrete for the purpose of strengthening the interfacial zone, such as Sand Enveloped with Cement (SEC) concrete [6]. Therefore, if polymer is used to improve the microstructure, and physical and mechanical performances of cement mortar, it will be more effective to increase concentration of polymer within interfacial zone than having a uniform distribution of polymer in the whole composite, in consideration of strengthening the weakest part of the materials [7]. A new mixing method, pre-enveloping sand with polymer, was adopted in this research to increase the concentration of polymer in the interfacial zone. The experimental results showed that at the same level of polymer cement ratio, pre-enveloping method was better than the normal method regarding the performance of the resulted composite. Moreover, in the condition of relatively low addition of polymer, the improvement of physical and mechanical properties, especially the resistance to cycling of freezing–thawing, by the pre-enveloping method was more significant.

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2. Methods

2.1. Raw materials

Cement used in the research was 525 Ordinary Portland Cement. Two kinds of latex, styrene acrylate rubber (commercial name: Acronal S-400) and styrene butadiene rubber (commercial name: Styrofan SD 622S), were provided by BASF. In Table 1, the main properties of these two kinds of latex are listed. The average diameter and the fineness modulus of the sand are 0.9 and 2.37 mm, respectively. A defoamer provided by BASF was used together with the latex.

2.2. Specimen preparation

The cement–sand ratio (C/S) and water–cement ratio (W/C) of control mortar were 0.4 and 0.45, respectively. The polymer–cement ratio (P/C) of PCM was calculated using the solid content of the latex. P/C of styrene butadiene rubber was 0%, 3%, 6% and 8%, and P/C of styrene acrylate rubber was 0%, 3%, 5%, 10% and 15%. The W/C of PCM was adjusted to maintain the same fluidity as for the control mortar.

Two mixing methods, normal mixing method and pre-enveloping method, were used and compared in the research. In the normal method, sand and cement were first mixed dry, and then water was added into the mix, then latex, later some additives were added into the mix. In the pre-enveloping method, sand and latex were first mixed to homogeneity, then cement, then water and some additives were added. The fluidity of the fresh mix was tested using flow table. $40 \times 40 \times 160$ mm^3 prisms, $70.7 \times 70.7 \times 70.7$ mm^3 cubes and truncated cones with upper diameter of 70 mm and lower diameter of 80 mm were cast and cured for 1 day at the temperature of 20 °C and relative humidity larger than 90%. Then, the specimens were demoulded and cured in a dry state (20 °C and 60% relative humidity) until testing.

2.3. Test

Measurement of compressive and flexural strength of control samples and PCM was performed according to Chinese standard GB 177-85. The loading rates of flexural and compressive tests were 50 N/s and 5 kN/s, respectively.

Permeability was tested according to Chinese standard JC 474-92 using truncated cones on a model SS-15 Permeability Tester. Six samples were used for every mix. Mixture of grease and fly ash was used to seal the contact aperture between samples and test table. Water was driven into the sample from bottom and the driving pressure increased from 0.1 MPa at a rate of 0.1 MPa/h. When water was found on the surface of three of the six samples, the procedure was stopped and the water pressure was recorded as the permeability pressure.

Water absorption was tested using $70.7 \times 70.7 \times 70.7$ mm^3 cubes. After curing, the cubes were heated to 80 °C. The temperature was maintained at least for 4 h until the weight change was <1 g. Then, the cubes were placed into water of 20 °C for 48 h. At last, the cubes were taken from water and swabbed. Water absorption (m) was calculated as:

$$m = m_1 - m_0$$

where m_1 and m_0 are the specimen weights after and before absorbing water, respectively.

The water absorption ratio (w) was calculated as:

$$w = \frac{m_t}{m_c} \times 100$$

where m_t and m_c are the water absorption of PCM sample and control sample, respectively.

Test of resistance to cycling of freezing and thawing was performed according to Chinese standard GBJ 82-85 using $40 \times 40 \times 160$ mm^3 prisms. Rapid freezing and thawing test was used in the test. After curing process and measurement of original mass, the prisms were divided into two groups, one for cycling of freezing and thawing, and another for control samples. At the end of freezing and thawing cycle, the center temperature of the prisms was controlled to be -17 ± 2 and 8 ± 2 °C, respectively. After 100 cycles of freezing and thawing, the mass and strength of tested and control samples were measured. The strength loss ratio and mass loss ratio were calculated as below.

$$\text{Strength loss ratio} = \frac{f_1}{f_2} \times 100(\%)$$

where f_1 and f_2 are the strength of tested samples after specified number of cycles of freezing and thawing and that of control sample, respectively.

$$\text{Mass loss ratio} = \frac{m_f}{m_0} \times 100\ (\%)$$

Table 1
Properties of SAR and SBR emulsions

Materials	Commercial name	Solid content (wt.%)	pH	Viscosity (MPa s)	Glass transition temperature (°C)
Styrene butadiene rubber (SBR)	Styrofan SD 622S	47	9.5	30	11
Styrene acrylate rubber (SAR)	Acronal S-400	57	7.0–8.3	140–200	– 6

Table 2
W/C of Acronal S-400-modified cement mortars at constant fluidity of 160 mm

P/C (%) (based on latex solid content/cement weight)	W/C	
	Without a superplasticizer	With a superplasticizer
0	0.45	0.45
3	0.52	0.36
5	0.57	0.35
10	0.50	0.28
15	0.47	0.26

where m_f and m_0 are the mass of the tested sample measured after specified number of cycles of freezing and thawing and the original mass, respectively.

3. Results and discussion

3.1. Fluidity

For both normal and pre-enveloping method, water-reducing phenomenon brought by styrene butadiene rubber was observed. Similar observations were made by Tan et al. [8]. In fact, when P/C of PCM increased from 0% to 3%, the fluidity of fresh mixture increased remarkably. It was noted that for the same fluidity, the W/C can be decreased from 0.45 to 0.38 and, for 6% and 8% of P/C, W/C can be decreased to 0.36 and 0.33, respectively.

Styrene acrylate rubber on the other hand did not have water-reducing ability. W/C could be decreased by the addition of a superplasticizer. Table 2 shows results of W/C change for styrene acrylate rubber-modified mortar at constant fluidity.

3.2. Mechanical properties

Tables 3 and 4 show the test results of compressive strength and flexural strength of mortar modified by styrene acrylate rubber and styrene butadiene rubber, which are expressed as the ratio of the strength of PCMs to that of control mortar.

Table 3
The strength ratio of SAR-modified cement mortar

Samples	P/C (%)	Bending strength ratio		Compressive strength ratio	
		7 days	28 days	7 days	28 days
Control	0	1	1	1	1
A-3	3	1.04	1.06	0.99	0.99
B-3	3	1.05	1.10	1.05	1.02
A-5	5	0.86	1.02	0.72	0.74
B-5	5	1.05	1.07	0.93	0.94
A-10	10	0.99	1.15	0.74	0.75
B-10	10	1.01	1.21	0.90	0.98
A-15	15	0.93	1.25	0.62	0.66
B-15	15	0.93	1.24	0.65	0.58

A: Normal method, B: polymer pre-enveloping method.

Table 4
The strength ratio of SBR-modified cement mortar

Samples	P/C (%)	Bending strength ratio		Compressive strength ratio	
		7 days	28 days	7 days	28 days
Control	0	1	1	1	1
A-3	3	1.08	0.91	0.88	0.87
B-3	3	1.10	0.93	0.83	0.87
A-6	6	1.10	1.08	0.81	0.79
B-6	6	1.14	1.09	0.81	0.79
A-8	8	1.28	1.22	0.72	0.71
B-8	8	1.30	1.22	0.76	0.68

It can be found from Table 3 that the addition of styrene acrylate rubber can improve the flexural strength of mortar, especially for the flexural strength at 28 days. The maximum increase of flexural strength was found to be 25%. In general case, the addition of latex will impair the compressive strength using normal mixing and casting methods. The compressive strength decreased with the increase in the amount of latex. But, in this work, by using pre-enveloping method, when the addition of styrene acrylate rubber was 3%, the compressive strength of PCM was higher than that of control mortar. Moreover, in Tables 3 and 4, it is seen that the strength of almost all PCMs prepared using the pre-enveloping method is higher than that of PCMs prepared using normal mixing method. The comparison of compressive strength is visualized in Figs. 1 and 2. In Fig. 1, the advantage of pre-enveloping method over normal method for compressive strength is more remarkable when the P/C ratio is below 10%. When the P/C ratio reaches 15%, the difference between the two methods regarding their effect on the compressive strength disappears. This means that with the increase of the P/C ratio, the advantage of pre-enveloping method decreases. Fig. 2 shows the difference between the two kinds of latex regarding their effect on the compressive strength of PCMs at 28 days. It can be seen from the

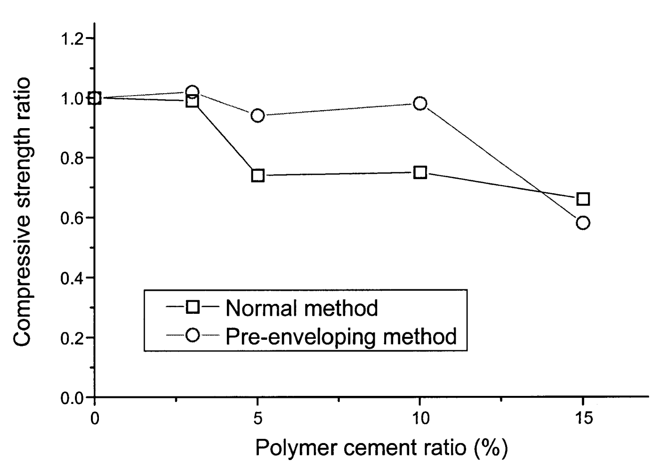

Fig. 1. Compressive strength of SAR-modified PCM prepared with two methods.

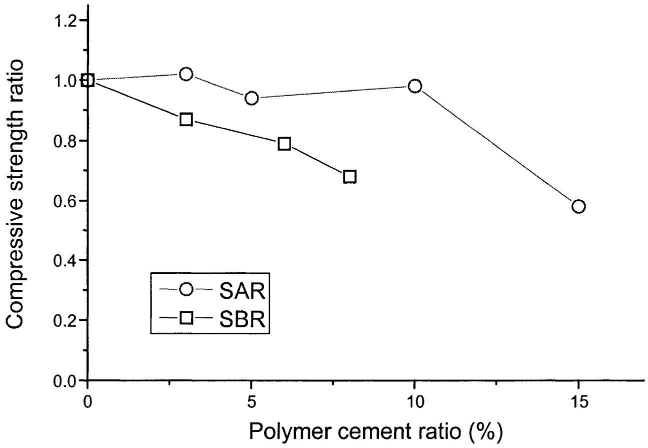

Fig. 2. Comparison of compressive strength of SAR- and SBR-modified PCM prepared with pre-enveloping method.

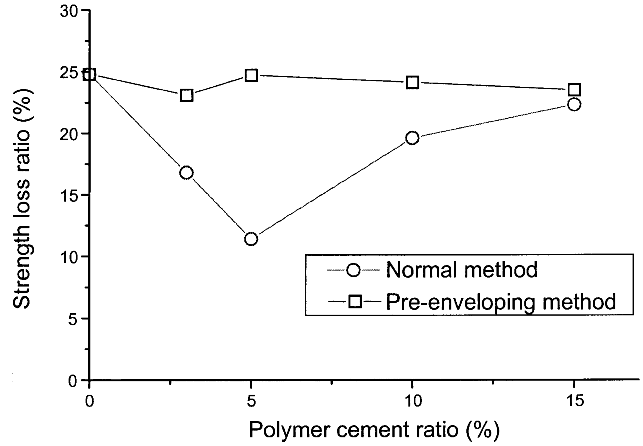

Fig. 4. Strength loss of SAR-modified PCM.

figure that the compressive strength of PCM with styrene acrylate rubber is larger than that of PCM with styrene butadiene rubber.

When PCM is prepared using the pre-enveloping method, the surface of sand particles will be covered by latex at the beginning of mixing, which improves the bond between the sand particles and cement paste. Moreover, the water released by the latex as the result of dehydration and hardening can be consumed by cement, which can reduce the actual water content and lead to denser microstructure. Hence, with this simple pre-enveloping method, satisfactory mechanical properties can be achieved at relatively low dosage of latex.

3.3. Water absorption

Fig. 3 shows the change of water absorption for different P/C ratio. It can be seen in the figure that with increase of addition of polymer the water absorption decreases remarkably when P/C is small. But, when P/C exceeds 10%, the change becomes unnoticeable. Additionally, the mixing method does not influence water absorption.

3.4. Resistance to cycling of freezing and thawing

The strength loss and mass loss ratios of styrene acrylate rubber modified mortar after 100 cycles of freezing and thawing, as functions of P/C ratio, are shown in Figs. 4 and 5. The improvement of the resistance of mortar to freezing and thawing by addition of latex can be easily seen in Fig. 4. The advantage of the pre-enveloping method over normal method regarding improvement of the resistance is obvious, especially for small P/C (3% and 5%). With the increase of P/C, the difference between the two methods diminishes. From Fig. 5, it can be seen that when small quantity of latex is incorporated the mass loss ratio decreases greatly. But, as the addition of latex surpasses 5%, the further decrease of mass loss ratio becomes unnotice-

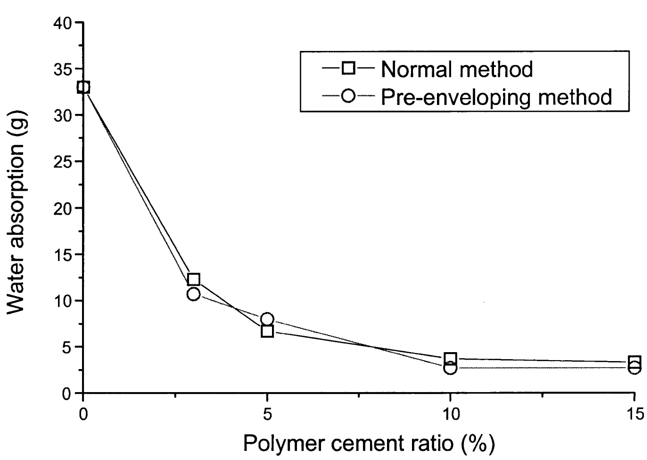

Fig. 3. Water absorption of SAR-modified PCM.

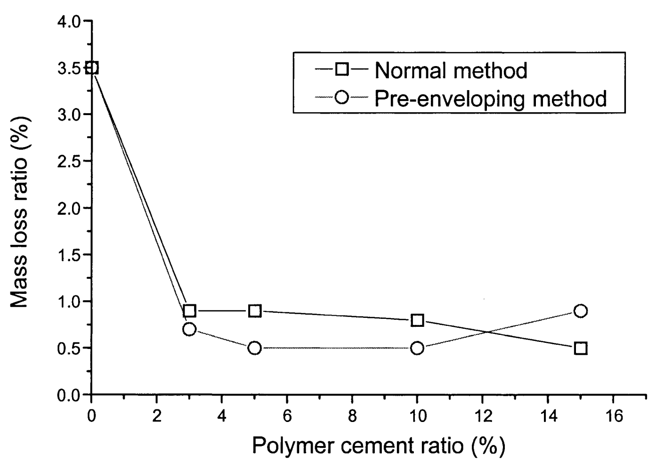

Fig. 5. Mass loss ratio of SAR-modified PCM.

Table 5
Test results of permeability of SAR-modified cement mortar

Samples	Control	A-3	B-3	A-5	B-5	A-10
P/C (%)	0	3	3	5	5	10
Pressure (MPa)	0.2	0.9	1.1	1.1	1.1	> 1.5

able. Moreover, mixing method does not have noticeable effect on the mass loss ratio.

3.5. Permeability

Permeability test was performed on PCM with P/C ratio in the range of 0–10%. Test results are shown in Table 5. It is obvious that when latex is incorporated the permeability pressure increases considerably. But, the methods of mixing did not make any noticeable difference to the permeability of PCM.

4. Conclusions

1. The mechanical properties of PCM prepared with pre-enveloping method were better than those of PCM prepared with normal method, especially for those modified by styrene acrylate rubber.
2. The influence of pre-enveloping method was much more remarkable for relatively low P/C (3–5%).
3. The resistance to cycling of freezing and thawing of PCM prepared with pre-enveloping method was better than that of PCM prepared with normal method, but the water absorption and permeability did not change greatly.
4. Acronal S-400 did not have water-reducing ability by itself, but the water-reducing and bettering of the mechanical properties of PCM with Acronal S-400 can be achieved by adding some additives.

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