EFFECT OF CONCRETE SURFACE COATING ON PREVENTION OF ALKALI SILICA REACTION

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ABSTRACT

Coating of flexible polymer cement mortar (PCM) with silane water repellent and impregnation of aqueous solution of lithium nitrite (aq. $LiNO_2$) has been used to repair concrete structures damaged by alkali silica reaction (ASR) in Japan. In this study, physical properties of flexible PCM were measured at various polymer cement ratios. Two field exposure tests were performed using concrete specimens damaged by ASR. The results of the tests showed that flexible PCM coating prevents ASR, but that epoxy resin coating promotes ASR, and ASR expansion is reduced with an increase in water vapor permeability of flexible PCM. The mixed treatment of aq. $LiNO_2$ and the flexible PCM is more effective for prevention of ASR.

1. INTRODUCTION

Concrete structures damaged by alkali silica reaction (ASR) have poor resistance to carbonation and reinforcement corrosion since rainwater and carbon dioxide easily penetrates into the concrete through cracks caused by ASR. Prevention of water penetration by coating is the most practical method to prevent ASR. Coating materials such as epoxy resin , however, resulted in acceleration of ASR since they had no water vapor permeability and water remaining in the concrete slowly accelerated ASR [1]. Therefore, coating materials for the repair and prevention of ASR are required for water vapor permeability as well as being waterproof. Furthermore, strong adhesion to the concrete and high elongation to accommodate ASR expansion are also required. Flexible polymer cement mortar (PCM) with silane water repellent has these properties and has been used for the repair and prevention of ASR in Japan. On the other hand, it was reported that impregnation of aqueous solution of lithium nitrite (aq. $LiNO_2$) is effective to prevent ASR [2]. In practical repair of concrete structures damaged by ASR, it is generally used as a primer. This paper presents physical properties of flexible PCM with various polymer cement ratios (P/C) and results of the field exposure tests using concrete specimens damaged by ASR and coated with flexible PCM with and without aq. $LiNO_2$ as a primer.

2. EXPERIMENT

2.1. Physical properties of flexible PCM

2.1.1. Materials of flexible PCM

Normal portland cement with specific surface area of 3,300cm² /g was used as a cement. Calcium carbonate with specific surface area of 10,500cm²/g was used as a filler. Polymer latex as shown in Table 1 was used to make the mortar flexible. Main monomer of the polymer latex was 2-ethyl hexyl acrylate.

Table 1 Properties of the flexible polymer latex

Type of polymer latex	Appearance	Total solid (%)	pH (20℃)	Specific gravity (20℃)	Viscosity (mPa·s,20℃)	Tg (℃)
PAE	Milk-white	50	8.5	1.02	<100	-50

2.1.2. Preparation of specimens

Table 2 shows the mix proportions of flexible PCM. The materials of each mix proportion was mixed for one minute by a fast stirrer (1,100 rpm). The amount of mixing water was determined to have a viscosity of about 10,000 mPa·s.

Table 2 Mix proportion of flexible PCM

No	Normal portland cement	Calcium carbonate	Polymer latex	Water	P/C
1	50	50	95	0.0	0.95
2	50	50	85	0.0	0.85
3	50	50	75	0.0	0.75
4	50	50	65	1.5	0.65
5	50	50	55	4.5	0.55
6	50	50	45	10.0	0.45
7	50	50	35	20.0	0.35

Free films of the flexible PCM were used to measure elongation. Asbestos-cement sheets coated with the flexible

PCM were used for measurement of water and water vapor permeability. The flexible PCM was coated on concrete plates for the adhesive strength test. The free film was 1.2mm in thickness and the quantity applied was 2.1 kg/m^2. In the preparation of coated specimens, flexible PCM was applied by brush. Free films and coated specimens were cured at 20℃ and 60% R.H. for 28 days.

2.1.3. Water and water vapor permeability test

Water permeability was determined in accordance with JIS A 6910 (Multi-Layer Wall Coating for Glossy Textured Finishes), using the apparatus shown in Fig. 1. The height of waterhead was measured after 24 hours. Water vapor permeability was determined in accordance with JIS Z 0208 (Testing Method for Determination of the Water Vapor Transmission Rate of Moisture-Proof Packaging Materials), using the apparatus shown in Fig. 2. The specimens were placed in a chamber of 40℃ and 90% R.H., and weighed once every 24 hours.

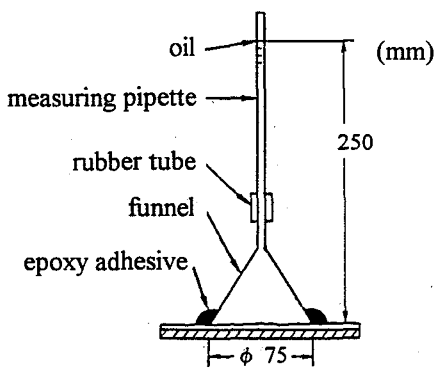


Fig. 1 Specimen for water permeability test

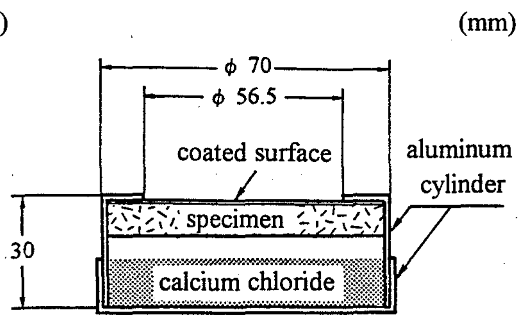


Fig. 2 Specimen for water vapor permeability test

2.1.4. Elongation test

Elongation of free film was determined in accordance with JIS A 6910, using the

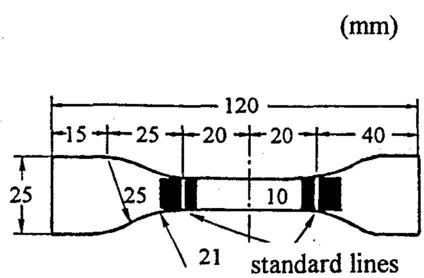


Fig. 3 Specimen for Elongation test.

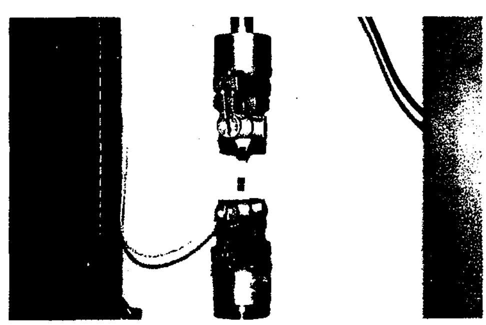


Photo. 1 Elongation test.

specimens shown in Fig. 3. The tensile speed was 5mm/min.. The distance between standard lines was measured as shown in Photo. 1.

2.1.5. Adhesive strength test

A 40mm square was cut into the specimens through to the concrete plate, then an attachment was fixed 24 hours before the test by epoxy resin adhesive as shown in Fig. 4. The adhesive strength test was performed using an hydraulic testing machine.

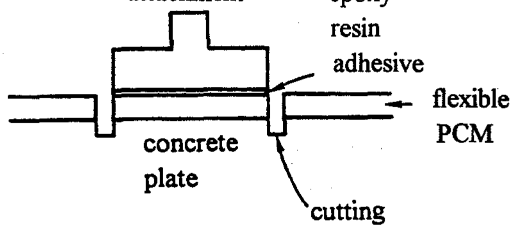


Fig. 4 Adhesive strength test

2.2. Field exposure test I

2.2.1. Mix proportion of concrete

Normal portland cement (alkali content 0.62%) was used. Sand from the River Ibi in Japan was used as the fine aggregate. It was judged innocuous by the ASTM C 289 Standard Method of Test for Potential Reactivity of Aggregates (Chemical Method). Reactive andesite with pessimum effect was used as the coarse aggregate. Distilled water was used as the mixing water. AE water reducing agent was used as the chemical admixture. The unit alkali content of the concrete was adjusted by sodium hydroxide (NaOH), sodium chloride (NaCl) and sodium nitrite ($NaNO_2$) to an equivalent alkali level of 8kg/m³. Table 3 presents the mix proportions of concrete.

Table 3 Mix proportions

W/C (%)	S/a (%)	Air Content (%)	Slump (cm)	Unit content (kg/m³)						
				Water	Cement	Aggregate Fine	Aggregate Coarse Reac.	Aggregate Coarse Non.	AE water reducing a.g.	Total alkali
54.3	43.9	4.0	18	190	350	749	494	472	0.0105	8.0

2.2.2. Procedure for field exposure test I

Concrete specimens measuring 7.5×7.5×40cm were removed from molds after one day and stored in a room at 40℃ and 90% R.H. for approximately one month. When expansion reached a level of approximately 0.05%, the specimens were placed in a room at 20℃ and 85% R.H. until the surface moisture content decreased to 9-11%. They were then coated with either epoxy resin or seven types of flexible PCM shown in Table 2. The specimens were subjected to outdoor exposure in Osaka, Japan. Length and weight changes were measured in accordance with JIS A 1129 (Method of Test for Length Change of Mortar and Concrete). Initial length was measured one day after the surface coating was applied.

2.3. Field exposure test II

Size, mix proportion and curing condition of the concrete specimens were as shown in 2.2. When the surface moisture content of the specimens decreased to 9-11%, five surfaces except on surface (7.5×40cm) of the specimens were treated as shown in table 4. Table 5 shows properties of the aq. $LiNO_2$, and the quantity applied was 570 g/m^2 to control Li/Na molar ratio at 0.6. The flexible PCM shown in No.6 of table 2 (P/C : 0.55) was used. The coating condition was as shown in 2.2. The concrete specimens were cured outdoors in Osaka, Japan, under the apparatus shown in photo. 2 in order to absorb rainwater from the soil part of the apparatus into the untreated upper surface (7.5×40cm) of the specimens. Length and weight changes were measured as in 2.2.

Table 4 Surface treatment of specimens

No	Treatment
1	Untreated
2	aq. $LiNO_2$
3	Flexible PCM
4	aq. $LiNO_2$ & flexible PCM

Photo. 2 Curing apparatus

Table 5 Properties of aq. $LiNO_2$

Appearance	Concentration	Viscosity	Specific gravity	pH
Yellow-transparent	25%	$<$10mPa·s	1.15	10.5

3. RESULTS AND DISCUSSION

3.1. Physical properties of flexible PCM

3.1.1. Water and water vapor permeability

Fig. 5 and 6 shows the relation between P/C and water and water vapor permeability respectively. Water and water vapor permeability of flexible PCM were reduced with an increase in P/C due to its dense structure in which the larger pores were filled by polymers and sealed by continuous polymer films as shown in Photo. 3.

Photo. 3 SEM of flexible PCM (P/C:0.55)

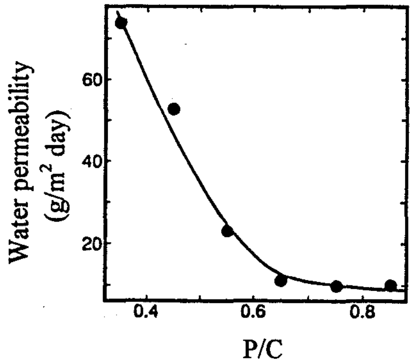


Fig. 5 Relation between P/C and water permeability

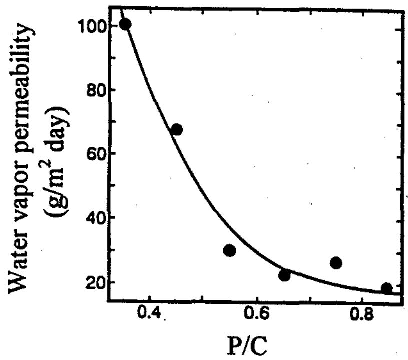


Fig. 6 Relation between P/C and water vapor permeability

3.1.2. Elongation and adhesive strength

Fig. 7 and 8 shows the relation between P/C and elongation and adhesive strength respectively. Elongation of flexible PCM tends to increase with increasing P/C. Especially, elongation markedly increased at P/C levels higher than 0.5. However, adhesive strength had an optimum P/C (0.55). At levels of P/C lower than 0.55, pores among the hydrated and unhydrated cement particles increased with reduction of P/C. On the other hand, at levels of P/C higher than 0.55, unhydrated cement particles existed within polymer films, and adhesive strength depended upon the strength of the polymer film.

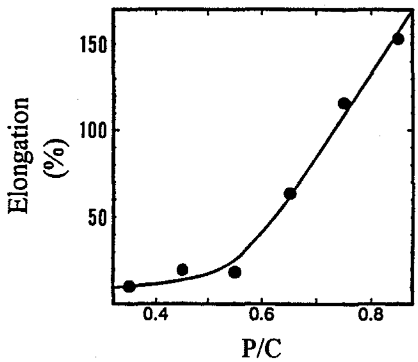


Fig. 7 Relation between P/C and elongation

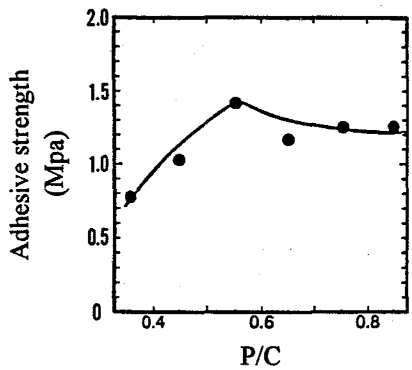


Fig. 8 Relation between P/C and adhesive strength

3.2. Field exposure test I

Fig. 9 shows length change in field exposure test I. The weight of the uncoated specimen showed a tendency to increase when it was raining and to decrease when the weather was fine. Uncoated specimens showed a tendency to expand but, specimens coated with flexible PCM demonstrated an ability to prevent ASR. On the other hand, expansion of the specimens coated with epoxy resin was less than that of the uncoated specimen until about 48 weeks. However, expansion became larger than that of the uncoated specimen after 50 weeks. It is assumed that water remaining in the concrete slowly promoted ASR since epoxy resin has no water vapor permeability [1], [3]. As shown in Fig. 10, there exists an obvious quantitative relation between water vapor permeability and ASR expansion. ASR expansion is reduced with an increase in water vapor permeability.

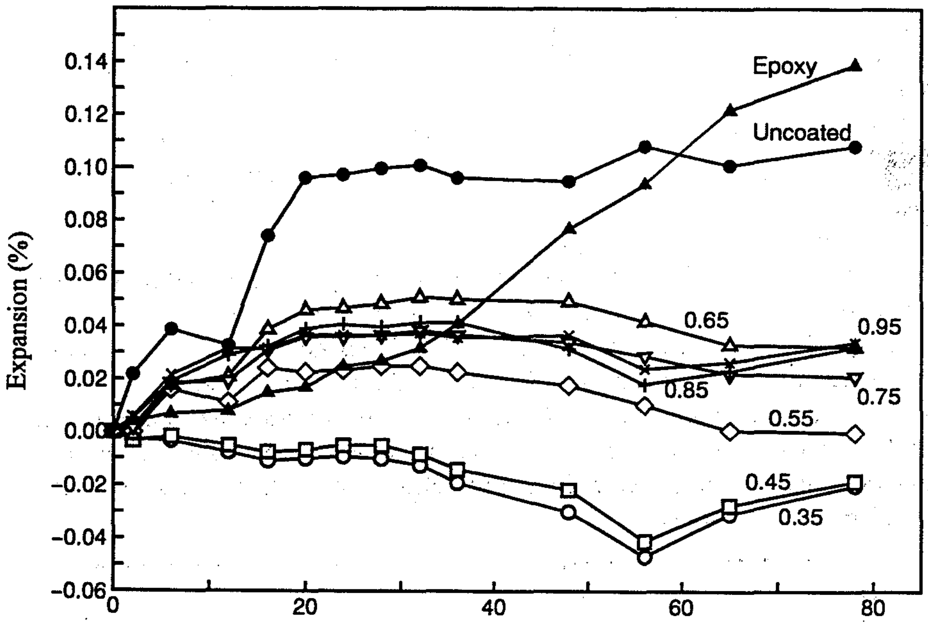
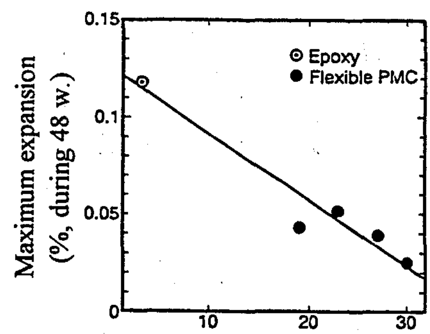


Fig. 9 Length change in field exposure test I

3.3. Field exposure test II

Fig. 11 shows length change in field field exposure test II. Expansion of the untreated specimens was about 0.04% and less than that of test I (about 0.10%). This difference of expansion between test I and II was due to the different curing methods.

Flexible PCM and aq. $LiNO_2$ showed the same level of effect on prevention of ASR. Mixed treatment of aq. $LiNO_2$ and flexible PCM is more effective for prevention of ASR.



Water vapor permeability (g/m^{2}day)

Fig. 10 Relation between water vapor permeability and ASR expansion (48 weeks)

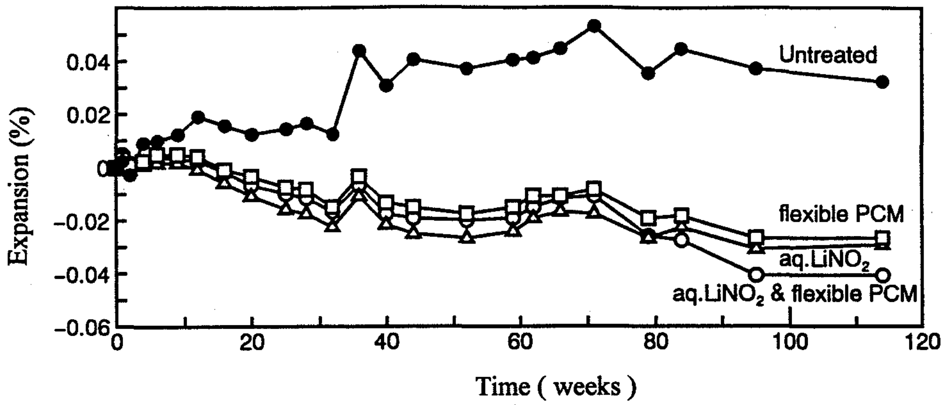


Fig. 11 Length change in field exposure test II

4. CONCLUSION

As a result of the physical property tests of flexible PCM which consist of a polyacrylic latex, portland cement and admixtures, it is found that the water and the water vapor permeability are reduced with an increase in P/C. Also, elongation tends to increase with an increase in P/C. On the other hand, adhesive strength has an optimum P/C. As a result of the two field exposure tests using concrete specimens damaged by ASR and treated with flexible PCM or epoxy resin coating and aq. $LiNO_2$ impregnation, it is found that epoxy resin coating promotes ASR, but that flexible PCM coating and aq. $LiNO_2$ impregnation prevent ASR. ASR expansion of the specimens coated with flexible PCM is reduced with an increase in water vapor permeability of the flexible PCM. The mixed treatment of aq. $LiNO_2$ (Li/Na molar ratio : 0.6) impregnation and flexible PCM coating is more effective for prevention of ASR.

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