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SURFACE TREATMENT FOR CONCRETE STRUCTURES DAMAGED BY ALKALI-AGGREGATE EXPANSION

Manabu FUJII*, Kazuo KOBAYASHI*, Toyoaki MIYAGAWA*, Makoto HISADA*

* Dept. of Civil Engineering, Kyoto University,
Sakyo-ku, Kyoto 606, Japan

1. INTRODUCTION

In general, the damage due to AAR occurs under the all existence of (1) critical amount of reactive silica in aggregates, (2) sufficient amount of alkali in concrete, (3) sufficient amount of water in concrete[1]. In order to prevent the severe damage by alkali-aggregate expansion, it is essential to make at least one of these three conditions exclusive. When a repair system is applied to the damaged structures, control of water in concrete is the most available under prevalent technique.

Some papers show that the surface treatment is effective for controlling of water in concrete[2]. There are few reports taking account of the actual environmental conditions in Japan, and testing the long term effect of the repair method.

This paper deals with the repair of concrete structures damaged by alkali-aggregate expansion in consideration of properties of concrete surface treatment under various exposures based on actual environmental conditions in Japan.

2. OUTLINE OF EXPERIMENT

It is generally recognized that the environmental condition such as temperature, and humidity affect largely the expansion due to AAR. Thus when discussing the method of repair, care must be taken with respsct to the environmental condition in which repair is applied. In this investigation, the severe exposure condition was chosen from a view point of alkali-aggregate expansion. The test program is composed of the following three series.

Series 1 The effect of various repair systems which can control the water content in concrete was experimentally investigated under two exposure conditions which simulated the actual environment in Japan.

Series 2 The effect of two important factors, treated surface area/total surface area ratio (treating ratio) and surface area/volume ratio (S/V), was experimentally investigated. This series was conducted by using specimens impregnated with silan and covered with PCM (Polymer cement mortar), which has been appreciated as one of the effective methods for controlling alkali-aggregate expansion.

Series 3 The initial surface moisture content of concrete was chosen as an experimental factor. In this series, various treatment methods were tested similarly to series 1.

2.1 Exposure Conditions

Test concrete specimens were placed under the following two exposure conditions.

1) Out door : Test specimens were placed at Kyoto University under natural environmental conditions such as sunlight, wind, rain etc..

2) Wetting-drying : Wetting (40°C, 100%R.H., 12hrs) and drying (20°C, 60%R.H., 12hrs) were cyclicly repeated. This is thought to be the most severe exposure condition expected in Japan.

2.2 Test Measurement

2.2.1 Method of Repair

Nine repair systems were selected.

1) Epoxy (Waterproofing-non crack bridging type)

2) Urethane (Waterproofing-crack bridging type)

3) Methyl-metacrylate (MMA : Waterproofing-impregnation type)

4) Sheet (S70, S35 : Water repellent-sheet sticking type)

5) Sodium silicate (Water repellent-impregnation type)

6) Silan (Water repellent-impregnation type)

7) Silan + PCM (SPC : One type of modified silan systems)

8) Silan + MMA (SMM : One type of modified silan systems)

2.2.2 Surface Area/Volume Ratio (S/V)

Concrete structures have variable size and form. The effect of surface treatment, especially, accompanied by silan impregnation, is probably influenced by S/V of concrete structures because of the evaporation properties of water in concrete. From this point of view, the specimens which have three different ratios of S/V, 0.25(20x20x40cm prism), 0.32(15x15x40cm prism), and 0.45(10x10x40cm prism) were examined in series 2.

2.2.3 Treating Ratio

There may be the case that some concrete structures, like bridge piers, cannot be repaired as they stand partially under the ground or the sea. From this view point, the effect of surface treatment for the specimens which have four different treating ratios, 1(=100%), 13/18(=72.2%), 1/2(=50%), and 0(=0%) were examined in series 2.

2.2.4 Repair Applying Time

In general, the surface treatment repair method can be applied for newly constructed concrete structures as preventative maintenance. Considering such a case, the specimens were cured only for 2 weeks in the waterproof vinyl bags at 20°C. After bag curing, the specimens to be treated were placed in the room at 20°C, 80%R.H. until the surface moisture rate decreased to approximately 10%. When the moisture content became not more than 10%, the repair systems were applied. In order to investigate the effect of surface moisture content of concrete, some specimens in series 3 were repaired immediately after the content decreased to 8%.

2.2.5 Mix Proportion For the mix of reactive concrete, non-reactive fine aggregate was used, and the ratio of reactive and non-reactive coarse aggregate was set to be the pessimum of 0.50. The equivalent alkali contnt was adjusted to be 8 kg/m^3 by the addition of NaCl. In addition, for comparison, non-reactive concrete specimens were made of non-reactive fine and coarse aggregates. Their mix proportions are shown in Table 1.

Table 1 - Mix Proportion of Concrete

Series	Concrete	G_{MAX} (mm)	Slump (cm)	Air content (%)	Water cement ratio	Unit weight (kg/m^2)					
						Water	Cement	Sand	Gravel	Air entraing agent	NaCl
1	Reactive	20	7±1	4±1	0.5	176	352	754	961	0.106	10.4
	Non-reactive	20	7±1	4±1	0.5	176	352	754	1010	0.088	—
2,3	Reactive	20	7±1	4±1	0.5	176	352	783	961	0.0352	10.4
	Non-Reactive	20	7±1	4±1	0.5	176	352	783	1010	0.0352	—

3. RESULTS AND DISCUSSION

3.1 Series 1

The appearance of specimens are listed in Table 2. Silan kept relatively good appearance, but deterioration such as blisters was observed on the surfaces of Epoxy and Urethane treated specimens. In particular, expansive cracks occured on the Epoxy coating surface under both exposure conditions. Hence, Epoxy coating was found to be inferior to Urethane with regard to the crack bridging. MMA and Silicate had cracks and gel under both conditions.

Table 2 - Appearance of Specimens (Series 1)

	Non-reactive	Reactive	Epoxy	Urethane	MMA	Silicate	Silan
Outdoor (162 weeks)	Good	Many wide cracks	Blisters, Cracks, Gel	Blisters Concrete cracks	Many wide cracks	Many wide cracks	Good
Drying-wetting (110 weeks)	Good	Many wide cracks	Blisters, Cracks, Gel	Blisters Cracks, Gel	Many wide cracks, Gel	Many wide cracks	Wide cracks

The expansion-exposure time curves are shown in Figs. 1 and 2 using the average value of two specimens. Final expansions are almost equal for the untreated specimens under two types of exposure conditions. However, it can be seen that the expansion rate in drying-wetting conditions is nearly twice as fast as that in outdoor condition.

In outdoor conditions, Urethane and Silan were effective for reducing AAR expansion. Epoxy and MMA expanded rapidly after 60 weeks exposure, as their impermeability was reduced by cracking of coatings. Therefore, these two repairing systems cannot be expected to have the long term effect of reducing alkali-aggregate expansion. Urethane treated specimen, though it has restrained the expansion, has cracks on the concrete surfaces rather than on the coating.

As Silicate repair allowed significant expansion after 25 weeks exposure similar to that of untreated reactive specimens, its controlling effect against AAR expansion was much smaller than Silan.

In drying-wetting conditions, all the specimens made of reactive aggregate have expanded and almost reached their own saturated states. Silan shows considerably smaller expansion in comparison with other systems. Expansions of Epoxy and Urethane systems are found to be almost equal. It should be noted that these two systems are finally inferior to the untreated. Thus, the waterproofing repairing systems such as epoxy coating, Urethane coating and MMA impregnation may be considered to have much effect on controlling expansion, only when they are applied on sufficiently dried concrete.

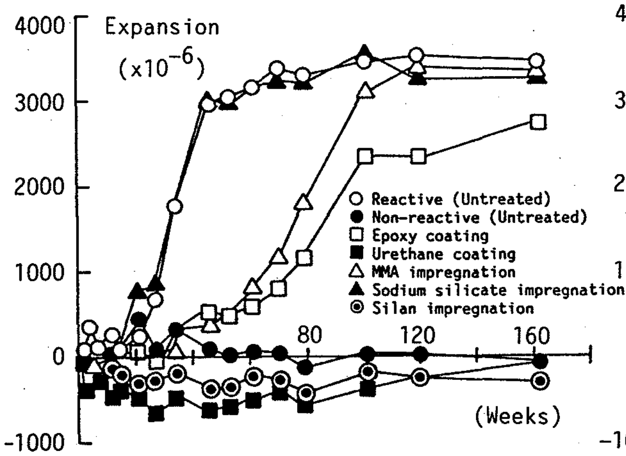

Fig. 1 – Expansion (Series 1 : Outdoor Condition)

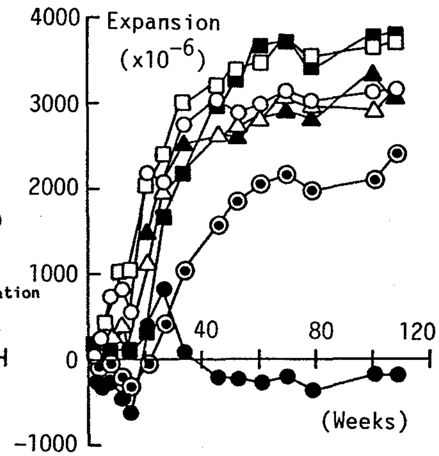

Fig. 2 – Expansion (Series 1 : Drying-wetting Condition)

3.2 Series 2

3.2.1 Effect of S/V At 110 weeks exposure, many cracks can be seen on the surface of untreated specimens. On the other hand, gel can be observed on treated specimens except S/V = 0.45, can be seen gel while there are no cracks. And then, using (1) the expansion reducing effect (Ee) was calculated as an index to evaluate the effect of repair against the expansion due to AAR. Calculated values of Ee are shown in Fig.3. When Ee is much smaller than 1, the expansion reducing effect is very large.

$$Ee = Er / Err \qquad (1)$$

where, Er : expansion due to AAR (= E − Enn)
E : expansion of specimen
Enn : expansion of non-reactive specimen under the same exposure condition
Err : expansion of untreated reactive specimen under thesame exposure condition

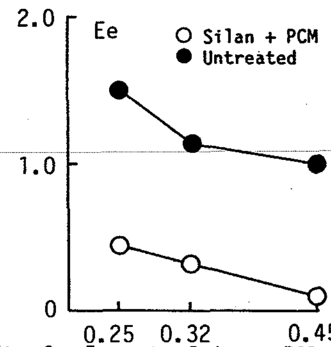

Fig. 3 – Expansion Reducing Effect (Series 2 : Outdoor Condition)

Comparing the treated and untreated specimens, the expansion increases with reducing S/V. From these results, it may be considered that the concrete structures of large S/V can be well protected against alkali-aggregate expansion by surface treatment.

3.2.2 Effect of Treating Ratio : At 49 weeks exposure, expansive cracks initiated at untreated area. But there are no cracks on PCM. From these observations, it has been recognized that cracking can take place on treated areas of concrete surfaces, and that PCM coating is superior in the crack bridging ability.

Ee - treating ratio relationship is shown in Fig.4. It is clearly indicated in Fig.4 that the high treating ratio reduces expansion.

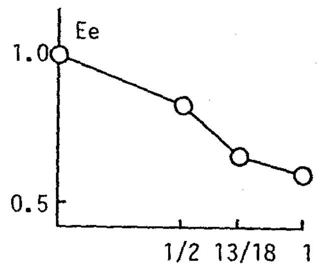

Fig. 4 - Expansion Reducing Effect (Series 2 : Drying-wetting Condition)

3.3 Series 3

3.3.1 Effect of Surface Moisture Content The appearance of specimens at 32 weeks' exposure are listed in Table 3, and the expansion-exposure time curve of each specimen is shown in Fig.5. Much expansion could not be seen in outdoor conditions, except for reactive non-treatment. On the other hand, in drying-wetting conditions, SPC(10%) expanded larger than SPC (8%).

Table 3 - Appearance of Specimens (Series 3, 32 Weeks Exposure)

	Non-reactive	Reactive	Epoxy	Urethane	S70	S35	Silan	SPC	SMM
Outdoor	Good	Wide cracks	Good	Good	Good	Good	Good	Good	Good
Drying-wetting	Good	Wide cracks, Gel	Blisters Wide cracks, Gel	Blisters, Concrete cracks, Gel	Good	Good	Good	Good	Good

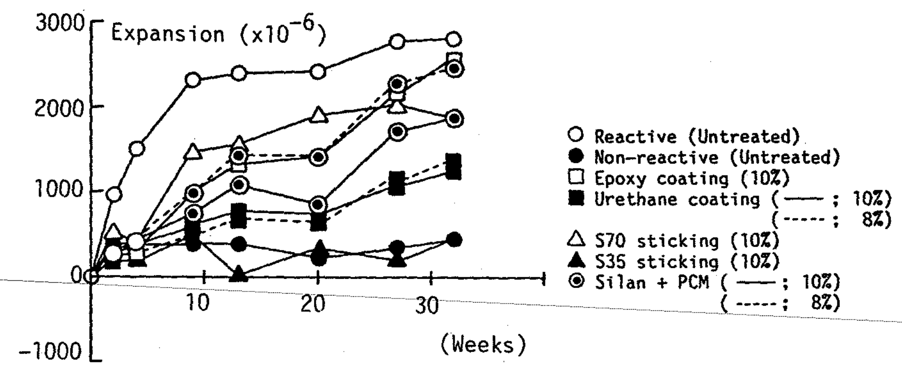

Fig. 5 - Expansion (Series 3 : Drying-wetting Condition)

However, the expansions of Urethane (10%) and Urethane (8%) are almost the same. Therefore, it may be too early to conclude about the effect of surface moisture content. While S35 expanded little in both exposure conditions, S70 expanded largely in drying-wetting condition. It may be considered that, in severe condition such as drying-wetting, the amount of water penetration is larger than the amount of water evaporation through the sheet of S70.

3.3.2 Effect of Silan Systems

The expansions for three types of silan system are shown in Fig.6. In drying-wetting condition, the expansion of SPC is larger than the other two systems. The result of this test implies that, as well as series 2, the drying-wetting condition is severe for PCM coating. There is no considerable difference between silan and SMM treatments at 32 weeks.

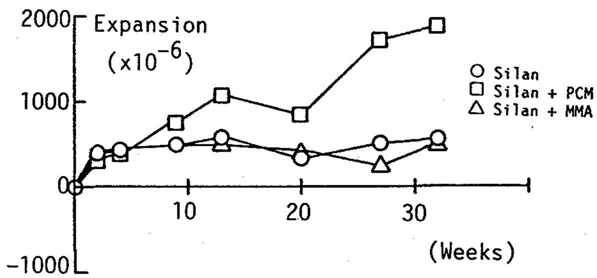

Fig. 6 - Expansion (Series 3 : Effect of Silan Systems, Drying-wetting Condition)

4. CONCLUSION

The main conclusions obtained from this investigation are summerized as follows:

(1) From the expanding process of the untreated reactive specimen, drying-wetting condition used in the tests accelerates the AAR expansion. And its rate of expansion is about twice as fast as the rate of outdoor condition (From series 1).

(2) When the repair for alkali-aggregate expansion is treated, silan monomer (Water repellent-impregnation type) acts better than ohter surface treatment systems used in this test (From series 1).

(3) Surface area/volume ratio (S/V) of concrete structures is one of the important factors affecting alkali-aggregate expansion. In this experiment, the effectiveness of repair can be attained when S/V becomes large (From series 2).

(4) Treating ratio of repair is also one of the important factors governing the effect. (From series 2).

(5) Water repellent sheet can cotrol the alkali-aggregate expansion. It may be possible to controll the expansion when the water passing ability of the sheet is 3500 ml/m^2/day (From series 3).

REFERENCES

[1] Hobbs, D.W., Alkali-Silica Reaction in Concrete, p.10, Thomas Telford Ltd, London, 1988.

[2] Okada, K., Kobayashi, K., Miyagawa, T., and Sugashima, A., REPAIR OF CONCRETE STRUCTURES DAMAGED BY ALKALI-AGGREGATE EXPANSION, Transactions of the Japan Concrete Institute, pp.219-226, Vol.9, 1987.