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EFFECT OF CONCRETE SURFACE TREATMENT ON EXPANSION DUE TO ALKALI-SILICA REACTION

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Recently a number of examples of premature deterioration caused by alkali-silica reaction and/or chloride corrosion have been reported. This paper deals with concrete surface treatment adopted in maintenance and repair work. The long term performance of reactive specimens with typical treatment is examined. The effect of surface treatment on the expansion of concrete due to alkali-silica reaction and on the rate of reinforcement corrosion is discussed based on the water vapour and water liquid permeabilities.

INTRODUCTION

The deterioration of concrete structures due to alkali-silica reaction (ASR) becomes significant on the conditions that there are sufficient moisture, sufficient alkali and sufficient reactive silica altogether. Therefore, in order to prohibit the severe expansion caused by ASR, it is necessary to prevent at least one of these conditions from being satisfied. When repairing damaged structures, however, it is very difficult to take away even only one factor from existing concrete. Recently the removing of alkali from concrete has been examined, but it has not been proved sufficiently.

Surface treatments can be applied to control the moisture content of concrete. The hydrophobic surface treatment system has interested many researchers from the view points of corrosion (1) and ASR (2). Basically, the required property of hydrophobic treatment consists of difficult absorption and easy dissipation of water. Although there are many systems having various levels of water control, the standard testing method and the quantitative requirement are not clear (3).

OBJECTIVE

In this paper, the basic water control property of various surface treatments was examined experimentally. Using typical Japanese reactive aggregate (4), the relation between water control property and the effect on the expansion due to ASR and the rate of corrosion was discussed.

TABLE 1 - Surface Treatment Systems.

Type	System	Elongation of film(%)	Thickness (mm)	Note
Water-proof	Epoxy	4	0.06	E4/6
			0.24	E4/24
		100	0.06	E100/6
			0.24	E100/24 Top coat
	Urethane	100	0.06	U100/6 = Acrylic urethane (0.03 mm)
			0.24	U100/24
		400	0.06	U400/6
			0.24	U400/24
Hydro-phobic	Silan	-	-	S
	Silan+PCM	70	1.20	S-PCM70 (Acrylic PCM)
	Silan+PCM	150	1.20	S-PCM150 (Acrylic PCM)
	Silan+MMA	30	0.04	S-MMA
	Acrylic	40	0.05	A
	PET sheet	-	0.30	PET : with many fine holes

TABLE 2 - Concrete Mix Proportion.

Type	M.S. (mm)	Slump (cm)	Air (%)	W/C	Unit Weight (kg/m^3) W	C	S	NG*	RG*	AE	Note
Non-reactive	20	9	4	0.50	176	352	783	1028	0	0.035	N-50
	13	8	4	0.70	205	293	847	890	0	0.073	N-70
	13	8	4	0.70	205	293	847	890	0	0.073	N-Cl
Reactive	20	9	4	0.50	176	352	783	514	487	0.035	R-50(Cl)
	13	8	4	0.70	205	293	847	445	431	0.073	R-70(Cl)

*)NG:Non-reactive coarse aggregate, RG:Reactive coarse aggregate

TEST PROCEDURE

Water Control Property

There are many testing methods for water permeability of concrete or plastic film. In the case of surface treated concrete, however, there are many factors such as parent concrete, primer, main coat, top coat and so on. Therefore, the treatment - mortar or concrete system was used as specimen. Figures 1, 2 and 3 show the specimens for water permeability. The systems of surface treatment are listed in Table 1. Surface treatments were applied when the surface moisture content of concrete decreased down to 10 %. Table 2 shows the mix proportion of concrete. In Series 1, N-50 and R-50 were used. In Series 2, in order to accelerate the corrosion process, N-70, N-Cl and R-70 were used. The equivalent alkali content of R-50 and R-70 was $8kg/m^3$, and the chloride content of N-70 and R-70 was $5kg/m^3$.

Series 1 : Alkali-Silica Expansion

In this Series, two exposure conditions were selected. One was outdoor (Kyoto, Japan), and another was wet (40^{O}C, 100%R.H., 12hrs) and dry (20^{O}C, 60%R.H., 12hrs) cyclic repeated condition (4). Using the concrete specimens (Prism : 100x100x400mm) treated with various types of system, expansion and weight change were measured. From the expansion and weight change at the last measurement, Expansion Reduction Effect (Ee) and Water Reduction Effect (Ew (%)) were calculated.

$$Ee = 1-(E-En)/(Er-En) \qquad (1)$$

$$Ew = Wr-W \qquad (2)$$

Series 2 : Combination With Reinforcement Corrosion

When concrete is contaminated with NaCl, there is a possibility that both chloride-induced corrosion and alkali-silica reaction may proceed at the same time. In this Series, the effect of surface treatment on the combination of corrosion and ASR was examined experimentally. Figure 4 shows the specimen of this Series. Specimens were partially immersed in NaCl solution (3.13%). Expansion, weight change, half cell potential, polarization resistance and concrete electric resistance were measured. The polarization resistance and concrete electric resistance were measured using the square wave current method (0.1mA, 0.1Hz).

TEST RESULTS

Series 1 : Alkali-Silica Expansion

Figures 5 and 6 show the expansion. In the outdoor tests, all surface treatment systems except PET showed no significant expansion. Various levels of expansion were seen, however, in the wet and dry exposure tests, particularly, the expansion of E100/24 was larger than that of untreated specimens. On the surface of E100/24, many cracks were generated. On the other hand, S-MMA showed the best protection behaviour.

Figure 7 shows the relationship between expansion and weight change. Large expansions were related to large weight increase due to water absorption. Particularly, when the weight change became larger than around 0.4 %, the expansion increased remarkably. The large weight increase in PET may be caused by water absorption of the surface treatment layer itself. The severe expansion could be controlled by reducing the water absorption.

Figures 8 and 9 show the influence of permeability on Ee and Ew. In the outdoor exposure, the significant tendency was not recognized in these figures, but, although there were large variations, Ee and Ew increased with increase in the ratio of vapour permeability and liquid permeability ((Vapour/Liquid)). The system which showed the minimum Ew is PET; this may be caused by the same reason as mentioned above. Therefore, the ratio of the two permeabilities is a very important parameter to evaluate the effect of surface treatment on expansion due to ASR.

Series 2 : Combination With Reinforcement Corrosion

Figures 10 and 11 show the permeability of various surface treatments. The liquid permeability measured in Series 2 was larger than that of Series 1. The water permeability values of surface treatments were different due to effects of the parent concrete. This phenomenon may be caused by fine pin holes in the treatment layer. The liquid permeability of reactive concrete was much larger than that of non-reactive concrete, but in the vapour phase, there was no significant difference. This may be caused by the water absorption of reactive gel, and, when applying the surface treatment, the difference between reactive and non-reactive concretes was very small. There were no systems that showed very large (Vapour/Liquid). The hydrophobic treatments showed larger water permeability than the waterproof treatments, and (Vapour/Liquid) was close to 1. S-MMA, which showed a good result in Series 1, had a large (Vapour/Liquid). In Series 2, 4 systems were chosen for corrosion specimens, E100/24 as rigid waterproof type, U400/24 as flexible waterproof type, S-MMA as hydrophobic type and S-PCM70 as flexible hydrophobic type.

Assuming a critical humidity to prohibit ASR expansion and corrosion, the ideal surface treatment allow water to dissipate under site exposure conditions as much as that from untreated reactive concrete under critical humidity (4). In practice, to develop better hydrophobic treatments, it was considered that not only large values of (Vapour)/(Liquid) were required but also appropriate values of permeability.

Table 3 shows the weight change after 6 months' immersion.

TABLE 3 - Weight Change (%).

	E100/24	U400/24	S-MMA	S-PCM70	Plain
Non-reactive without Cl	0.11	-0.05	0.03	0.04	1.84
Non-reactive with Cl	-0.02	-0.04	0.02	-0.02	1.23
Reactive with Cl	-0.01	-0.05	0.05	0.03	1.84

TABLE 4 - Half Cell Potential (-mV vs Ag/AgCl).

	E100/24	U400/24	S-MMA	S-PCM70	Plain
Non-reactive without Cl	39	80	104	263	94
Non-reactive with Cl	281	281	247	49	466
Reactive with Cl	262	268	283	247	389

TABLE 5 - Polarization Resistance (ohm).

	E100/24	U400/24	S-MMA	S-PCM70	Plain
Non-reactive without Cl	725	1075	632	259	474
Non-reactive with Cl	144	171	180	576	39
Reactive with Cl	238	189	193	157	105

The weight change of hydrophobic systems show the tendency of larger weight gain than that of waterproof types. However, except for the plain specimens, weight changes are very small. The effect of surface treatment is clear. The expansion was very small due to the constraint by reinforcing steel and no acceleration took place at raised temperature. The electric resistance of surface treated concrete was larger than that of untreated specimens due to lower water absorption. Tables 4 and 5 show half cell potential and polarization resistance values. In the case of concrete contaminated with Cl, the half cell potential and the polarization resistance of treated specimens were more noble and larger than those of untreated specimens respectively. However, there were some side effects of hydrophobic systems in the sound concrete from viewpoints of half cell potential and polarization resistance.

CONCLUSION

The ratio of water vapour permeability and water liquid permeability is a very important index to evaluate the water control property of hydrophobic surface treatment. Although the effect of surface treatment is dependent on the exposure condition, the hydrophobic treatment may have side effects under some conditions.

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SYMBOLS USED

E = expansion of the specimen.

En = expansion of the non-reactive specimen without treatment under the same exposure condition.

Er = expansion of the untreated reactive specimen under the same exposure condition.

W = weight change of the specimen (%).

Wr = weight change of untreated reactive specimen under the same exposure condition (%).

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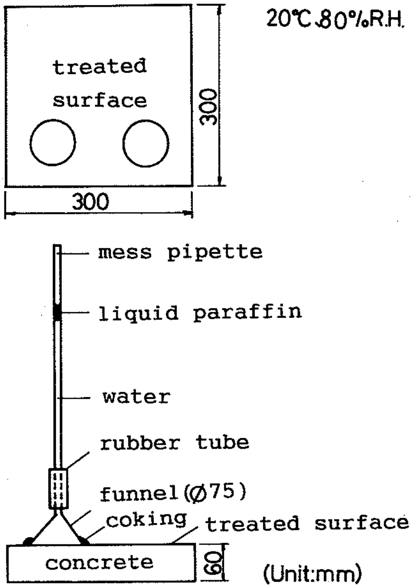

Figure 1 Water liquid permeability:Series 1 and 2

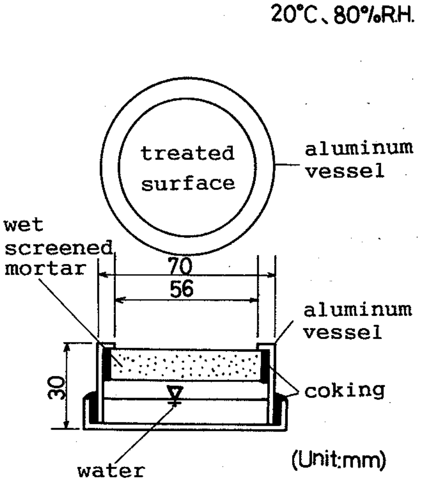

Figure 2 Water vapour permeability -Mortar:Series 1

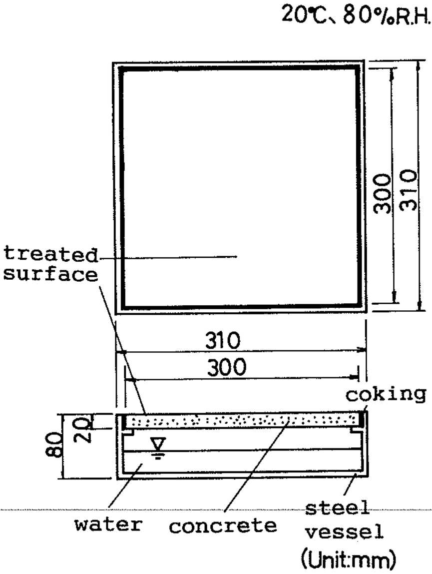

Figure 3 Water vapour permeability -Concrete:Series 2

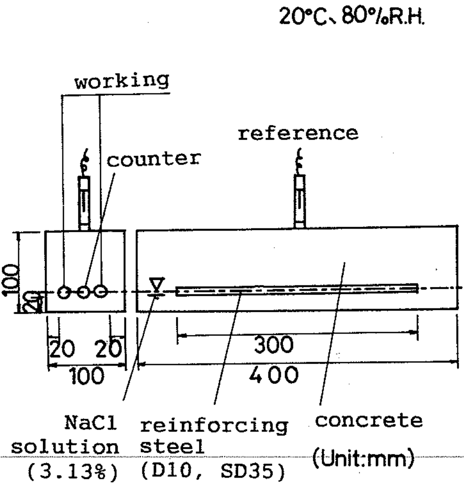

Figure 4 Specimen for Series 2

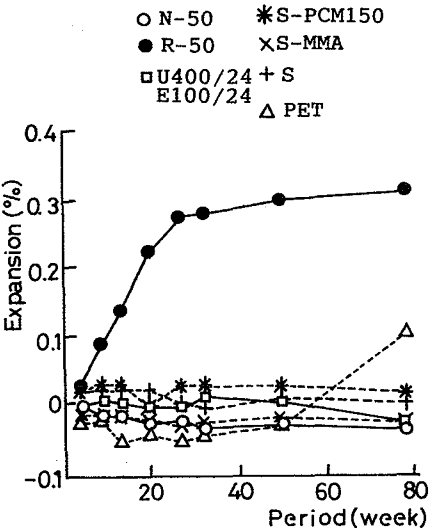

Figure 5 Expansion : Outdoor

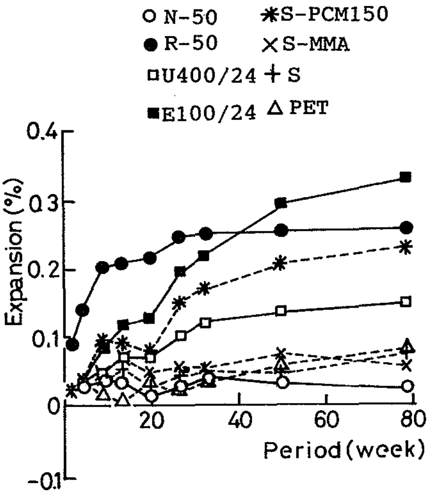

Figure 6 Expansion : Wet and dry

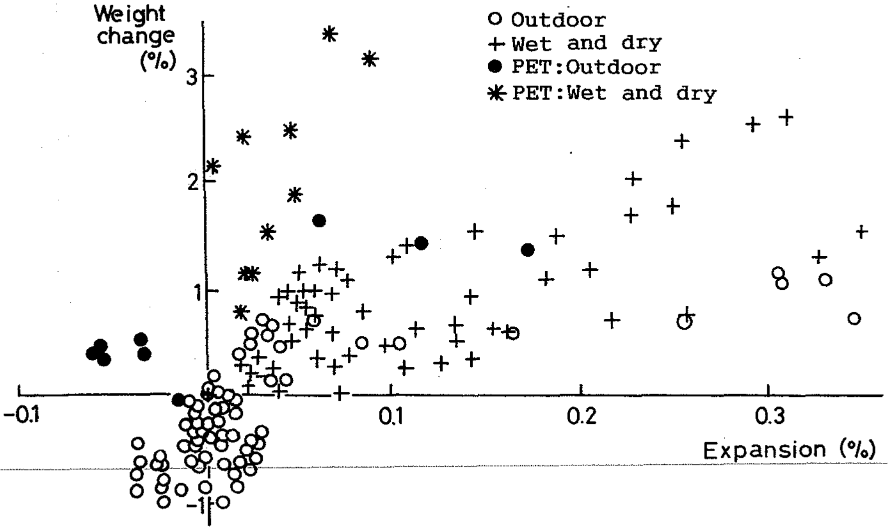

Figure 7 Relationship between expansion and weight change

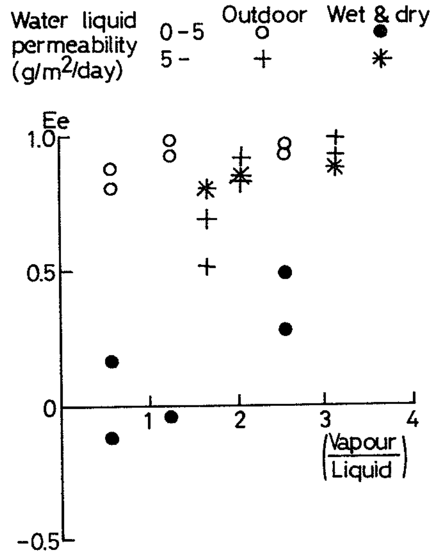

Figure 8 Relationship between permeabilities and Ee

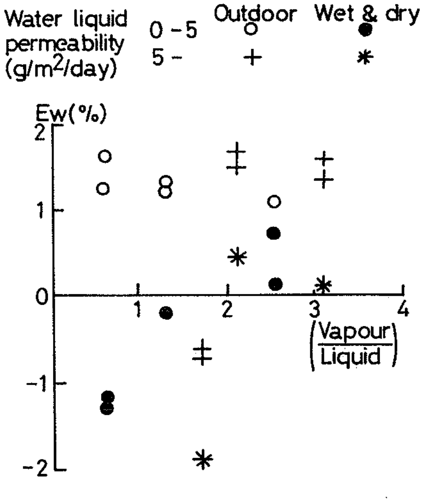

Figure 9 Relationship between permeabilities and Ew

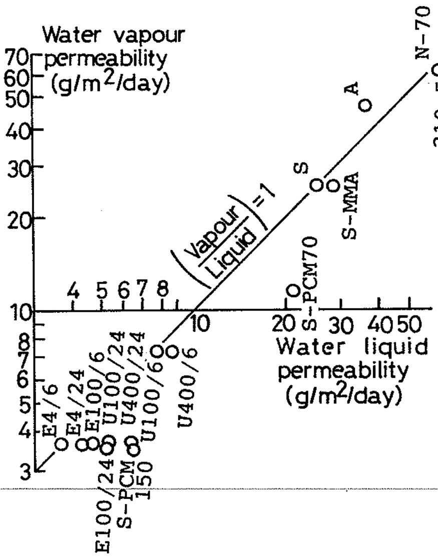

Figure 10 Relationship between permeabilities : Non-reactive

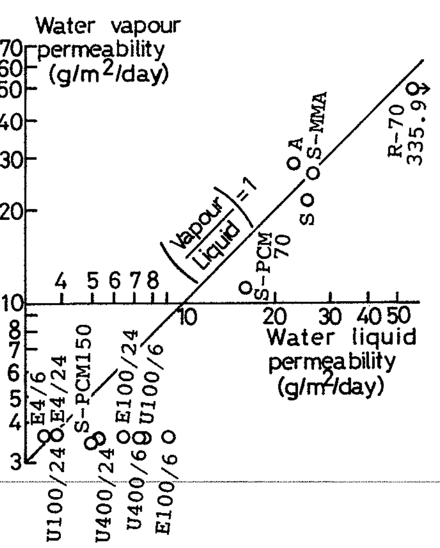

Figure 11 Relationship between permeabilities : Reactive