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STUDY ON THE EFFECT OF CONCRETE SURFACE COATING FOR PREVENTION OF ALKALI SILICA REACTION

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1. ABSTRACT

Cracking and deterioration of concrete structures caused by the alkali silica reaction are now becoming a matter of social concern, with studies undergoing on the reaction mechanism for this deterioration and repairing measures of deteriorated buildings as well as prevention of such deterioration.

However, no effective acceleration method which can cause cracking by this reaction in reasonably shorter period of time and is not excessively severe to the coatings and yet which can simulate the actual ambient conditions as close as possible has been established.

This report is intended to describe a testing equipment which can simulate actual ambient conditions and effective for acceleration of concrete cracking and the results of studies carried out at the Public Works Research Institute, Ministry of Construction, as the guest researchers on effectiveness of concrete surface coating with this equipment.

2. OUTLINE OF EXPERIMENT

2.1 Concrete Test Pieces

In total, 7 types of concrete samples were prepared using two types of crushed stones which show alkali silica reaction (T.F.) and two types of crushed stones which do not show this reaction (K.C.). Table 1 shows analysis of crushed stones while Table 2 and Table 3 respectively show standard mixing of concrete and types of mixing. The dimension of concrete test pieces was 10 x 10 cm.

Table 1 Results of Chemical Analysis

	Rc (mmol/ℓ)	Sc (mmol/ℓ)
Crushed stone from T	183.0	639.0
Crushed stone from K	34.3	39.6
Crushed stone from F	110.0	236.6
Crushed stone from C	21.1	17.9

Rc: Reduction in alkali concentration
Sc: Silica elusion amount

Table 2 Concrete Standard Mixing

Maximum size of coarse aggregate (mm)	Slump (cm)	Air (%)	A/C (%)	s/a (%)	Unit quantity (kg/cm³)			
					Water (W)	Cement (C)	Coarse aggregate (G)	Fine aggregate (S)
20	8	5	50	40	195	390	905	924

Normally, Portland cement is used.

Table 3 Mixing of Concrete

Concrete No.	Coarse aggregate	Sand	Alkali
A	F/C=80/20	Harmless standard river sand	NaOH
B	F/C=80/20	ditto.	—
C	K	ditto.	—
D	T	ditto.	NaCl
E	T	ditto.	—
F	T/C=50/50	ditto.	NaOH
G	T/C=50/50	ditto.	—

Cement alkali, (NaOH, NaCl), were adjusted to $8kg/cm^3$ on R_2O basis.

2.2 Surface Coating Materials

As the surface coating materials, the following were selected.

(1) Epoxy system materials of high elasticity and high cut-off,

(2) Rubber system materials of high elasticity

These materials which have high cut-off capacity for moisture and harmful ions, with coefficient of extension higher than 200%, can withstand dynamic changes due to generation and growth of fine cracks of concrete, etc.

(3) Silane system penetrants

These penetrants are reasonably priced penetrants and do not form films on concrete surface.

They have features in that they penetrate deep into concrete structures and form water repelling layers by combining with concrete.

(4) Acrylic emersion system materials

Being acqueous emersions, these are low pollutive materials. They are also less expensive and have high elasticity.

Table 4 shows coating specifications of each sample concrete piece.

Coating was made on test pieces with water content of approximately 5%.

Coating had been made after surfaces had been conditioned (CC 50).

After coating all surfaces in the room kept at 20°C, they were dried for ten days for test use.

Table 4 Coating Specification

No.	Type of coating material system	Processing	Film thickness (μ)
①	Silane system	Silane system penerants Silane system penerants	— —
②	High elasticity epoxy system	Epoxy primer Epoxy putty High elasticity epoxy type intermediate coat Elastic polyurethane	— — 170 30
③	High elasticity rubber system	Epoxy primer Epoxy putty High elasticity epoxy type intermediate coat Elastic polyurethane	— — 200 30
④	Acrylic emulsion system	Polymer cement Acrylic emulsion top coat Acrylic emulsion top coat	(2mm) 30 30

2.3 Development of Accelerated Test Equipment

An equipment to satisfy the following requirements was developed:

(1) to be capable of supplying water (or water containing harmful ion)

(2) capable of heating concrete test pieces by radiant heat containing far infra-red ray,

(3) capable to dry with hot air of low humidity, and

(4) capable of repeating drying and wetting by (1) and (2) + (3) above.

These conditions were determined assuming that acceleration of reaction by radiant heat after supplying sufficient water (or water containing harmful ion) into concrete and subsequent rapid evaporation of moisture by hot air of low moisture content from concrete surface should cause moisture migration and concentration of alkali within concrete test pieces and that repeating of these procedures would cause repeated supplies of moisture and alkali around the reactive crushed stones thereby accelerating generation of gels and expansion.

Also, these conditions simulate actual ambient conditions in which actual concrete structures deteriorate by this reaction.

2.4 Test Method

All types of concrete test pieces without surface coating were tested. For surface coating effect test, test pieces of mixing Nos. A, B and D were used. Test was repeated twice or more.

Tests were performed using the following three methods.

2.4.1 Test method using accelerated test equipment In this method, the test equipment as described in 2.4 above was employed. Conditions for repeated tests were water spraying (by tap water) 0.5 hour, heating+drying=2.5 hours, total one cycle 3 hours. Room temperature and water temperature at drying were set at 40°C and 35°C respectively.

2.4.2 Outdoor exposure test by water spraying A test one cycle of which consisted of 0.5 hour of water spraying and 2.5 hours of drying during day time (7:00 to 19:00) was repeated, in other words, 4 cycles a day, which simulates the actual ambient conditions.

2.4.3 High temperature high humidity aging test Test pieces were left in a room kept at 40°C and RH of 100% as the standard test pieces for crackings generated on concrete.

3. RESULTS AND OBSERVATION

3.1 Results on Test Pieces Without Surface Coating

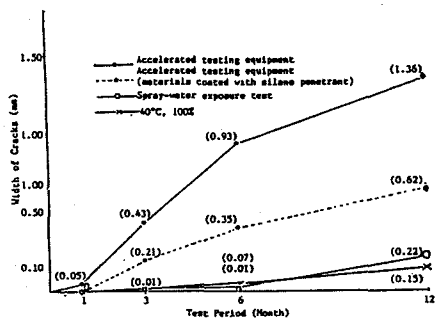
Table 5 shows results after 12-month test period by each of three methods as described in 2.4.1 through 2.4.3 above. As is clear from this Table, on all concretes with increased alkali contents and using harmful crushed stones (mixing Nos. A, D and F), cracking was observed on all three testing methods.

Table 5 Cracking of Uncoated Test Pieces by Different Testing Methods

Type of concrete	Test period / Test items / Type of test	1 month		3 months		6 months		12 months	
		No. of cracks	Max. width of cracks (Av. mm)	No. of cracks	Max. width of cracks (Av. mm)	No. of cracks	Max. width of cracks (Av. mm)	No. of cracks	Max. width of cracks (Av. mm)
A	①	3/3	0.05	3/3	0.43	3/3	0.93	3/3	1.36
	②	0/30	—	7/30	0.01>	24/30	0.01	30/30	0.22
	③	0/3	—	2/3	0.01	3/3	0.07	3/3	0.15
B	①	1/3	0.01>	3/3	0.01	3/3	0.01	3/3	0.02
	②	0/6	—	0/6	—	0/6	—	0/6	—
	③	0/3	—	0/3	—	0/3	—	0/3	—
C	①	0/3	—	0/3	—	0/3	—	0/3	—
	②	0/3	—	0/3	—	0/3	—	0/3	—
	③	0/2	—	0/2	—	0/2	—	0/2	—
D	①	0/3	0.05	3/3	0.30	3/3	0.65	3/3	1.08
	②	0/3	—	2/3	0.01>	2/3	0.01	3/3	0.32
	③	0/3	—	0/3	—	2/3	0.01	2/3	0.08
E	①	3/3	0.01>	3/3	0.01	3/3	0.01	3/3	0.02
	②	0/3	—	0/3	—	0/3	—	0/3	—
	③	0/3	—	0/3	—	0/3	—	0/3	—
F	①	3/3	0.10	3/3	0.37	3/3	0.63	3/3	1.13
	②	0/6	—	6/6	0.07	6/6	0.10	6/6	0.41
	③	0/3	—	3/3	0.10	3/3	0.15	3/3	0.20
G	①	2/3	0.01>	2/3	0.01	2/3	0.01	3/3	0.01
	②	0/5	—	0/5	—	0/5	—	0/5	—
	③	0/3	—	0/3	—	0/3	—	0/3	—

Testing Method:
1 Accelerated testing equipment
2 Spray-water exposure test
3 Curing at 40°C, 100% (RH)

As for test pieces without increased alkali but in which harmful crushed stones were used, crackings were generated only on samples tested on our accelerated testing equipment. In Fig. 1, 2 and 3, growth of cracks by each test method is shown. These figures indicate that growth of crackings on samples tested on the accelerated testing equipment is very rapid. No generation of cracks was observed on all test pieces in which harmless crushed stones were used. From these observations, it is considered that cracks generate due to alkali silica reaction.



Accelerated testing equipment
Accelerated testing equipment (materials coated with silane penetrant)
Spray-water exposure test
40°C, 100%

Fig. 1 Growth of Concrete Cracks (No. A)

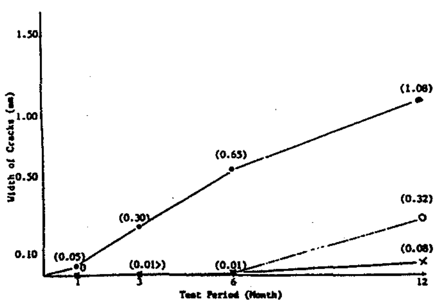


Fig. 2 Growth of Concrete Cracks (No. D)

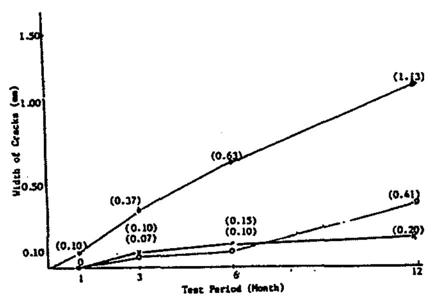


Fig. 3 Growth of Concrete Cracks (No. F)

Studies on effect of increased alkali contents failed to reveal clear indication on difference of influence by NaCl and NaOH as types of crushed stones used were not same.

However, it can be said that NaCl has more significant influence.

Thus, it would be necessary for actual structures to pay careful attention as in case of damage by salt.

3.2 Tests on Effect of Surface Coating

3.2.1 Epoxy system of high elasticity and high cut-off quality On concrete test pieces coated with these coating materials, no cracking was observed after 12-month test (The coating films also remaining in good conditions).

3.2.2 High elasticity rubber system materials Test pieces tested on the accelerated test equipment began to cause cracks under films, after 10-month period. The maximum width of craks was 0.2 mm. Though cracks could be observed through coating films, no defect was observed on film itself. On all other test methods, no cracking nor other change was observed after 12-month test.

3.2.3 Silane system penetrants On test pieces tested on the accelerated test equipment, after three-month tests, cracking was observed on Mixing No. A only. Fig. 2 shows growth of cracks and Photo. 2 indicates status of the sample piece/cracks 6-month after start of the test. On all other test methods, no cracking nor other change was observed after 12-month test.

3.2.4 Acrylic emersion system coating materials On test concrete pieces coated with these coating materials and tested on the accelerated test equipment, blisterings were observed on films with cracks generating as well. Studies of test pieces by removing films revealed cracks on concrete test pieces. The maximum width of cracks was 0.1 mm.

Again, on all other test methods, no cracking nor other change was observed after 12-month test.

4. CONCLUSION

The above clearly proved that the accelerated test equipment developed by us is an effective instrument to accelerate concrete cracking due to alkali silica reaction. It was further confirmed that application of proper coatings on concrete surfaces, cutting off infiltration of external moisture, etc., can prevent or delay cracking of concrete due to this reaction.

It is our film belief that this equipment can be applied to verification test of cracking of concrete which uses crushed stones determined harmful by chemical analysis, verification test using cores taken from actual concrete structures as well as for salt-resistance tests using brine.

REFERENCE

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