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SUPPRESSION OF ALKALI–AGGREGATE REACTION BY CONCRETE SURFACE COATING

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1. INTRODUCTION

One of the causes of concrete deterioration is alkali-aggregate reaction. In this study, concrete specimens containing alkali reactive aggregate were coated with various organic and inorganic coatings to examine suppressing effect of cracking caused by alkali-aggregate reaction (AAR). Some of the specimens were coated prior to AAR acceleration test, and the others were coated after cracking has appeared. In addition, transmission rate of AAR accelerating substances and extension ratio at break for the coating films to discuss relationship between these basic properties of coating films and crack formation.

2. OUTLINE OF THE STUDY

2.1 Objective of the study

The study was conducted to make following points clear. (1) Suppressing effect of coating films on concrete stability, before and after cracking starts. (2) Which properties of coating films affect to suppress cracking? Flow diagram of the study is shown in FIGURE-1. The experiment mainly consists of two parts; the stability test using concrete specimens, and the measurements of coating film perfomances.

2.2 Procedures of the experiment

2.2.1 Performance tests of coating films Thirty two coatings, i.e., heavy duty types, such as epoxy resins and a vinyl ester resin(with glass flake), acrylics and inorganic coatings for architecture, a new material, such as fluoropolymer coating were subjected to tests.

(1) Measurement of transmission rate

1) Water vapor transmission rate

a) JIS-Z-0208 (dish method)

b) Lyssy method (electrical method, using humidity sensor)

2) Water transmission rate

a) JIS-A-6900-5-10

b) Gravimetrical method (using coated specimens)

3) Ion transmission rate

Transmission rate of Na^+ and Cl^- was determined after a month's immersion test using double cells (3%NaCl soln./distilled water) which were divided by a free film.

(2) Extension ratio at break of coating films to over coat surface cracking concrete

Extension ratio at break was determined using Instron type tester with crosshead speed 5mm/min. at 20 C.

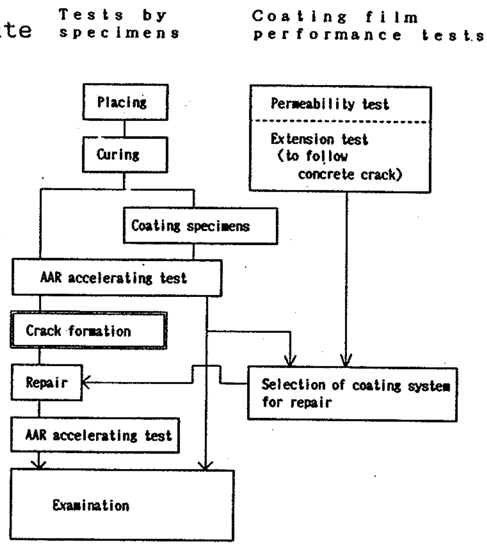

FIGURE-1 The flow diagram of the study

2.2.2 <u>Preperation of concrete specimens and the procedure of AAR acceleration test</u>

(1) Mix proportion of concrete

Mix proportion of concrete is shown in TABLE-1. Specimens were subjected to the test after 28 days' curing in water.

No.1 and No.3 were subjected to the test as uncoated, No.2 as both coated and uncoated. Specimens were cubic, having dimension of 100 mm on each side.

TABLE-1 Mix proportion of concrete

No.	(1)	W kg/m³	C kg/m³	S kg/m³	G kg/m³	(2)	NaCl kg/m³	W/C %	S/A %	Air %	Slump cm	(3)	(4)	(5)
Standard		181	362	686	993	0.025	-	50	40	5.0	8.0	-	-	-
1	T	180	362	687	993	0.025	-	50	40	5.2	11.3	0.1	502	3.27
2	T	176	362	691	993	0.025	8.8(6)	50	40	5.4	13.8	0.7	481	3.09
3	K	180	362	687	993	0.025	-	50	40	5.2	11.3	0.1	459	3.30

(1) Sort of aggregate
T: Judged potentially reactive through ASTM C 289. Rc=183, Sc=639
K: Judged nonreactive through ASTM C 289. Rc=34.3, Sc=39.6
(2) A E Agent (%)
(3) Surface moisture in fine aggregate (%)
(4) Compression strength (kgf/cm²)
(5) Modulus of elasticity (10^5kgf/cm²)
(6) As total $R_2O(Na_2O+0.658K_2O)$=8kg/m³

(2) Coating of specimens

1) Coating before crack appeared

Specimens were treated with disc sander (cc#50 paper) prior to coat after 28 days' curing in water. They were coated all of the surfaces. Targets of dry film thickness were 100 μm as standard, 350 μm as specified. Coatings contained neither primer nor putty inorder to evaluate their properties directly. They were dried for 7 days at 20 °C prior to subject to the test.

2) Repair coating after crack appeared

Target of dry film thickness was specified value of each coating system. Coating films were evaluated as film system (each contains primer, putty, top coat). Pretreatment and coating method were as same as mentioned above.

(3) AAR acceleration test

Specimens were subjected to the wet/dry cycle exposure test. They were placed under the sun periodically being sprayed water.

Spraying period was 30 minutes, four times a day. It was obvious that the wet/dry cycle test accelerated AAR more effectively than immersion or high temperature humidity test.

3. RESULTS AND DISCUSSION

3.1 Performance tests of coatings

Test results were shown in TABLE-2. Vinyl ester, epoxy and polyurethane resins were highly resistant to water or water vapor transmission, on the other hand, inorganic and acrylic coatings were highly transmittable. Inorganic and acrylic coatings were highly transmittable to sodium ions, while vinyl ester, epoxy and polyurethane coatings hardly transmitted sodium ions.

TABLE-2 Test results of coatings

Coating		1) F.T. (μ)	2) M	V V T 3) a	V V T 3) b	4) VT(1)	5) VT(2)	6) Na^+	7) Cl^-	8) E.R.
Epoxy	Epoxy (primer)	-	A				0.017			
		-	B			23.0	0.079			
		-	C			78.0	0.024			
	Epoxy (int.)	100	A	3.4		7.0	0.009	‡	6.96	0.93
		100	B		1.7		0.007			1.2
		100	C	1.4		2.1	0.003	‡	‡	4.1
	Epoxy(top)	100	A	2.7		6.9		‡	0.10	2.2
	Epoxy (flexible)	100	A	5.8		10.0	0.015	‡	1.38	130
		100	C	2.8				‡	‡	25
	Epoxy (high-build)	350	A	1.4		1.7	0.025	‡	‡	1.8
		350	B		2.5			‡		1.5
		350	C	0.2				‡	‡	5.8
Urethane	Ur.(primer)	-	B			12	0.004			
	Ur.(top)	100	B		35			‡		41
		100	A	2.6		21		‡		77
	Ur.(flex.)	100	B		52			‡	1.38	68
In-organic	Water repellent	-	A	81		60	0.10	900	400	
		-	B			20	0.14			
		-	C			69	0.16			
	Inorganic	350	A			4900	1.40	31000	53700	55
		100	C	240					944	55
	P.cement (flexible)	350	B		35	7.0		6.88		94
V.Es.	Glass flake	350	B		0.6	‡		‡		1.5
Others	Acrylic (solvent)	100	A	13.0		10.0	0.048	0.17	2.43	171
		100	B		160			2490		28
		100	C	13.0				20.5	12.6	
	Acrylic(em.)	100	B		1960	1560		21000		8.3
	Acrylic(em.) (flexible)	100	C	200					4330	940
	Polybutadien (flexible)	100	C	29				‡	‡	260
	Vinyl	100	B		34			‡		3.0
	Chld.rubber (flexible)	100	C	2.9				19.3	14.6	250
	Fluoric	100	B		28			‡		44

1) Film thickness
2) Paint maker
3) Water vapor transmission rate ($g/m^2 \cdot 24hrs.$)
   a: Measured through JIS-Z-0208 (20 ℃)
   b: Measured through Dr.Lyssy method (40℃)
4) Water transmission rate ($ml/m^2 \cdot 24hrs.$)
5) Water transmission rate (ℓ/24hrs.)
6) Na^+ transmission rate ($mg/m^2 \cdot 24hrs.$)
7) Cl^- transmission rate ($mg/m^2 \cdot 24hrs.$)
8) Extension ratio at break point (%)

3.2 AAR acceleration test of uncoated or originally coated specimens

All of the No.1 and No.3 specimens in TABLE-1 were subjected to the test as uncoated. Thirty in 86 of No.2 specimens were subjected to the test after being coated, while 56 as uncoated.

3.2.1 Crack formation in uncoated specimens As shown in FIGURE-2, cracking was observed in 90 per cent of No.2 specimens after 12 months, 100 per cent after 24 months. While, No.1 specimens (potentially reactive, but without NaCl) were observed no cracking after 17 months, and 7 in 54 were observed to have been cracked (fine crack; under 0.05mm) after 24 months. The crack was considered to originate in AAR, because white gel was observed and it was remarkably accelerated to appear by addition of NaCl.

3.2.2 Crack formation in specimens which have been coated before crack appeared Crack was observed in 33 per cent of originally coated specimens after 16 months, and in 48 per cent after 23 months. Crack suppressing effect of coatings was obvious.

Relationship between crack formation and water vapor transmission rate or extension ratio is shown in TABLE-3 and FIGURE-2. As shown in FIGURE-2, cracking formation ratio was low in A type, and it formed in early time, no increace was noticed by passage of time.

C type showed low ratio of crack formation too, but it increaced by

TABLE-3 Number of cracked specimens

	Coating properties: Transmission	Coating properties: Extension	Crack	Number of specimens: 11months	Number of specimens: 16months	Number of specimens: 23months
A	Low	Small	Finded	1	1	1
			Non	4	4	4
			(%Finded)	20	20	20
B	Medium	Small	Finded	4	6	8
			Non	7	5	3
			(%Finded)	36	55	73
C	Medium	Large	Finded	0	1	4
			Non	7	6	3
			(%Finded)	0	14	57
D	High	Large	Finded	0	0	1
			Non	1	1	0
			(%Finded)	0	0	100
E	High	Small	Finded	2	2	2
			Non	1	1	1
			(%Finded)	67	67	67

Transmission rate; Low Water vapor transmission rate 0 - 1 $g/m^2 \cdot 24hrs.$
Medium 1 - 100
High 100 <
Extension ratio ; Small 0 - 10 %
Large 20 % <

passage of time.

The reason was considered as follows. As the specimens were coated under well dried condition, if they were coated with nontransmmittible coatings, expansion from AAR was considered to be suppressed.

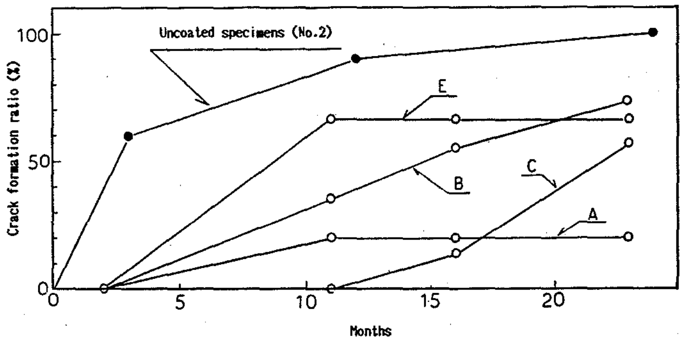

FIGURE-2 Crack formation ratio with time

In case that a specimen is coated with a coating which is comparatively low water vapor transmittible and having high extension ratio, it is considered that the coating may yet suppress cracking of the specimen after it expands to a certain extent, because the coating film will extend following to expantion of the specimen and may keep a certain extent of transmission resistance. On the other hand, in case that a coating film has comparatively high transmission resistance, but poor in extending property, micro-fault might occur in it according to the specimen expands, as a result, transmission resistance of the film might decrease and water transmission into the specimen will occur, resulting in further expantion of the specimen and crack formation on it.

3.2.3 Crack formation in repair coated specimens After 4 months' acceleration test, cracked specimens of No.2 were repaired with 13 types of coating systems shown in FIGURE-3 and subjected to the acceleration test again.

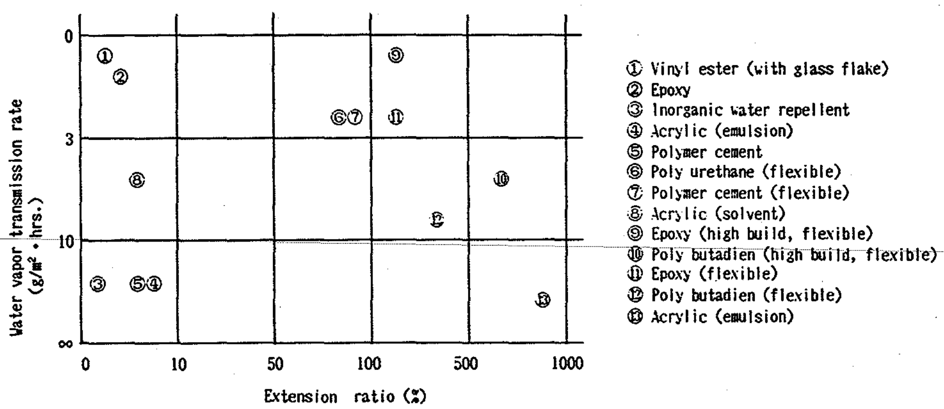

FIGURE-3 Properties of selected repair systems

Each system was coated on two specimens, having small crack and large one. No crack growth was observed on the coating surface after 20 months' acceleration test. Then coating films were removed to examine crack growth under the films, but no growth of crack was observed.

4. CONCLUSION

(1) Cracking due to AAR of concrete which contains alkali reactive aggregate is expected to be suppressed by surface coatings.
(2) As shown in this study, if all of the surface are coated with a coating of low transmission rate towards water, cracking of concrete is considered to be suppressed effectively.
(3) Concrete cracking could not be prevented perfectly by coating concrete surface before crack formation, while crack growth was effectively suppressed by coating after crack formed, because in the former case too large extension ratio of the coating film would be required to cover crack width, on the other hand requirement for extension ratio of the coating film would be much smaller than that of latter case.
(4) In the actual concrete structures which might be inevitable to have uncoated portion from where water can permeate, other coating system might be required. (The authors are conducting an further experiment, in which coated concrete specimens having uncoated portion are exposed under the sun being buried uncoated portion in the earth.)

5. ACKNOWLEDGMENT

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REFERENCE

[1] K.Noda, M.Takeyoshi, T.Taki, K.Katawaki, Proceedings of JCI Vol.9, No.1, p591-596, (1987)