8th ICAAR 1989 KYOTO
8th Internationl Conference
on Alkali-Aggregate Reaction

DEVELOPMENT OF INJECTION MATERIALS AND THE STANDARD FOR REPAIRING DAMAGE TO STRUCTURES CAUSED BY AAR

Masahiro Koike*, Kiyoshi Katawaki and Susumu Moriya**

* 1st Construction Dept., Hanshin Expressway Public Corporation, Suminoe-ku, Osaka 559, Japan
** Public Works Research Institute, Ministry of Construction, Tsukuba, Ibaragi 305, Japan

1. ABSTRACT

In order to establish a guideline for repairing damage to concrete structures caused by Alkali-Aggregate Reaction (AAR), new repairing materials and a standard were desired.

As for repairing materials, this paper dealt with injection materials and these materials were selected through 20 experiments.

Through a series of studies, a repair standard and a quality specification for injection materials have been developed.

2. INTRODUCTION

Because the behaviour of deterioration caused by AAR in concrete structures is different from that of cracks caused by outside sources, a technique for repairing those cracks up to now had been not useful for cracks cuased by AAR.

The purpose of our study was, firstly, to develop by experiment repair materials, the characteristics of which should be taken into account the

Table 1 Test Materials

Classification of Material	Outstanding Properties	Mixed Ratio (weight)
1 Epoxy Resin Group		
(1)Regular (Hard)	tensile strength ≧ 300kgf/㎠	Masteragent(M)
(2)Flexible - 1	elongation ≧ 50% & Thixotropy	/ Hardner(H) = 2 / 1
(3)Flexible - 2	elongation ≧ 100%	
(4)Flexible - 3	elongation ≧ 200%	
2 (5)Polyuretane	elongation ≧ 300%	M / H = 100 / 2
3 Polymer Cement Group		
(6)Acryl	cement slurry injectable to wet section	Powder / Latex / Water = 9/1/2.5
(7)Epoxy		Slurry / Powder / Cement = 8/5/10
4 (8)Slag	colloidal state injectable to wet section	Powder / Nonshrink / Water = 100 / 2 / 70
5 (9)Sealant:Polysulfide	elastomeric sealing compound	M / H = 10 / 1

behaviour of both damages by AAR and of the structure itself. (This paper covers injection materials. A further paper[1] covers coating materials.) And our ultimate objective is to indicate a practical standard for repairing damage by AAR.

This study was a part of the projects which the Ministry of Construction organized entitled "Development of Techniques for Improving Durability of Concrete Structures".[2]

Table 2 Test Items and Methods

	Test Item		Test Method	Test Condition
Basic Physical Test	coefficient of thermal expansion		T M A	
	visco-elasticity		visco-elastic spectromerter	(measurement of Tg)
	tensile strength		JIS K 7113 ASTM C 190	-20,-10,0,20,40,60 ℃
	elongation percentage		JIS K 7113	-20,-10,0,20,40,60 ℃
	Adhesives in shear by tension loading		JIS K 6850	-20,0,20,40,60 ℃
	Water Vaper Transmission Rate		JIS Z 0208	20,40 ℃ ; RH 90 %
	Hardening shrinkage percentage		JIS A 6024	20 ℃
	Adhesion to Mortar		JIS A 6024	-10,0,20,40℃ ; dry & wet
Workable Test	Injectable depth		Reinforcing Concrete Bars (50×80×120cm; 20 bodies)	(except sealant)
	Injectable Crack Width		Checking by drilled-out cores	5,20,35 ℃
	Viscosity		JIS K 6833	
	Pot Life		JIS K 6833	
	Setting Time		JIS A 6024 Code by J C E A	
Durability Test	Water Resistance		JIS K 7114	20℃,30days; Ion exchange water
	Alkali Resistance		JIS K 7114	20℃,30days; Saturated $Ca(OH)_2$
	Salt-Water Resistance		JIS K 7114	20℃,30days; Solution of 3% salt
	Durability of Adhesion	repetition of drying and moistening	JIS A 6024	68℃30cycles (1cyc = Dry & Moist,24HR)
		fatigue by bending	JIS A 6024 JIS K 7188	20℃ 10^6 cycles
		Resistivity to Creep	JIS A 6024 JIS K 7116	bending deflection after 1000Hrs at 20℃
Effect Test	Resistance for progressing of crark		reinforcing concrete bars (25x25x100㎝ ; 12bodies)	R_2O = 2.3% repair(Injection,Coating) accelerated curing time ; 6M(+repair) + 6M

3. DEVELOPMENT OF INJECTION MATERIALS FOR REPAIR

3.1 Outline of Investigation

Experiments were carried out in order to judge whether injection materials retained the physical properties which were desired for repairing cracks due to AAR in use. Using the nine kinds of injection materials composed from organic and inorganic materials shown in Table 1, 1) basic physical tests of the material, 2) workability tests for repair work and 3) durability tests were carried out. As a result of these tests three of the materials were eliminated. Then, 4) a test for ascertaining the effect of the injection method for repair was carried out. These test items and methods are shown in Table 2. The test were mainly conducted according to Japanese Industrial Standards. Some of the conditions or definitions of physical values were, however, defined by ourselves. Discussion will be required regarding items defined in this way.

3.2 Test Results and Selection of Injection Material for Repair

Figure 1 represents elongation percentages at each temperature as one of the results of basic physical tests. Similar elongation factors at temperatures other than 20°C, although desirable, weren't expected because of the materials' thermal sensibility. It should be noticed that polysulfide's elongations at temperatures other than 20°C exceeded the capacity of test machine.

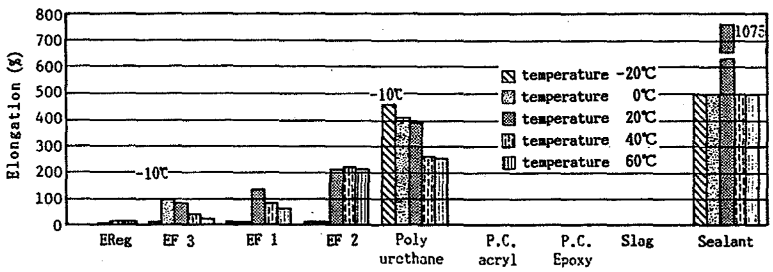

Fig. 1 Result of Elongation

Table 3 Results of Workability Test

Item	Temp (℃)	Epoxy Resin Group (1)Regular	(2) F 1	(3) F 2	(4) F 3	(5) Poly -urethan	Polymer Cement (6)Acryl	(7)Epoxy	(8) Slag	(9) Sealant
Injected Depth (cm)	5	158	83	168	175	143		118		
	20	120	130	158	158	130	95	118	155	
	35	120	108	158	158	130		80		
Injectable Minimum Width of Crack (mm)	5	0.08	0.20	0.04	0.04	0.08		0.15		
	20	0.08	0.10	0.04	0.08	0.08	0.25	0.15	0.04	
	35	0.15	0.10	0.10	0.10	0.04		0.20		
Viscosity (cps)	5	3100	34500	1700	1200	5400	8000	5800	300	1050000
	20	620	25000	550	400	2075	5600	1850	200	890000
	35	185	12000	230	190	800	5000	1050	150	850000
Pot life (min)	5	405	120	300	420	120	>300	>300	>300	240
	20	92	50	56	69	60	>300	>150	>300	240
	35	18	15	15	18	45	180	60	230	120
Settig Time (HR)	5	30	20	45	>48	13	9	12	18	45
	20	10	6	16	23	5	3.5	7.5	6	16
	35	3.5	2.5	6.5	9.5	2	1.5	2.5	1.5	6

Table 3 shows the results of the workability tests. To each concrete bar (50x80x120cm) three kinds of crack width (0.5, 1, 2 mm) were introduced by driving in wedges at each temperature (5, 20, 35°C). After the cracks were repaired by the injection technique using coloured materials, the injected depth and injectable crack width were measured not only visually and ultrasonically from outside the bars, but also by examing drilled-out cores.

Figure 2 and Table 4 represent results of durability tests of adhesion. Photo 1 shows a test for resistivity to creep. On these durability tests of adhesion, held values of adhesive strength and deflection after repetition or long-term loading were evaluated to the strength or deflection at static failure. The injection width at these three tests were 0.5, 2 and 5 mm.

As a result of the durability test, it was found that

1) Epoxy resin flexible type 3 and polyurethane had considerable elongation capacity, but less fatigue strength and less resistivity to creep respectively, and when they failed, the failures were interfacial.
2) Slag in colloidal state had, on the other hand, little elongation and less held ratio of adhesive strength in repeated drying and moistening tests.

These three materials were, therefore, judged to lack durability of adhesion and ruled out as injection materials for reparing cracks due to AAR.

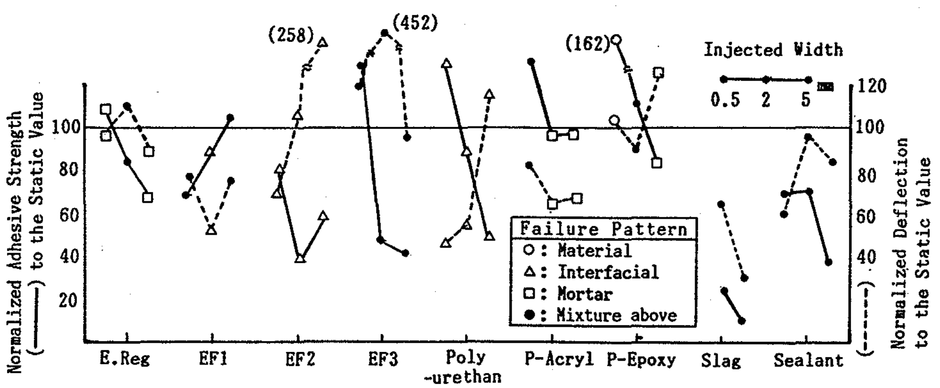

Fig. 2 Results of Repetition Test of Drying and Moisterning

Table 4 Results of Durability Test of Adhesion

(at 20℃)

Test Material	Fatigue Strength (kgf / ㎠)			Bending Deflection (mm)			
	Static	Fatigue	Ratio(%)	Static	Creep	Ratio(%)	Ultimate time(Hr)
(1) E-Regular	71	44	63	0.42	0.29	69	> 1000
(2) E-F-1	67	23	35	1.17	0.41	35	941
(3) E-F-2	86	35	42	0.58	0.33	57	994
(4) E-F-3	60	15	25	0.78	1.24	35	944
(5) Polyurethane	14	8	56	1.97	0.30	16	560
(6) P-Acryl	52	26	44	0.32	0.13	40	480
(7) P-Epoxy	63	31	47	0.37	0.22	61	616
(8) Slag	25	12	47	0.25	0.08	32	768
(9) Polysulfide	32	23	71	6.5	2.6	40	912

3.3 Repair Effect of the Injection Method

Resistance effect against crack progression of the injection method was investigated by using concrete bars (25x25x100cm) with low reinforcement ratio 0.4% (reinforcing bar's strains were measured). The reactive coarse aggregate was bronzite andesite from Teshima Island which is the same as used on the Hanshin Expressway's structures damaged by AAR[3] and the mixture ratio was 50%. The injection material was epoxy resin flexible type 2. Figure 3 is an example of crack maps and shows cracks before and after repair work. As a result of this test, the repair effect of the injection method was shown with a comparison between repaired and unrepaired parts, that is, 1) no change of injected cracks, 2) enlargement or expansion of unrepaired crack widths and 3) new cracks in the unrepaired surface during accelerated curing. The repair effect of both the injection and the coating methods wasn't, however, shown clearly in this experiment.

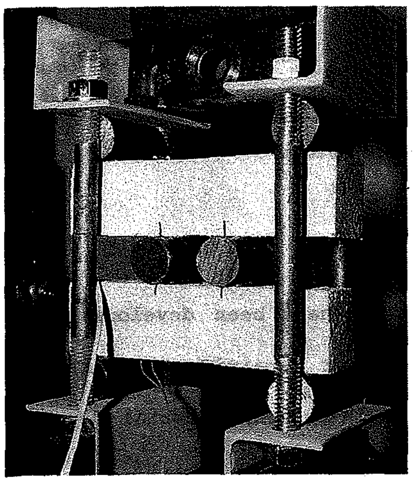

Photo 1 Resistivity to Creep Test

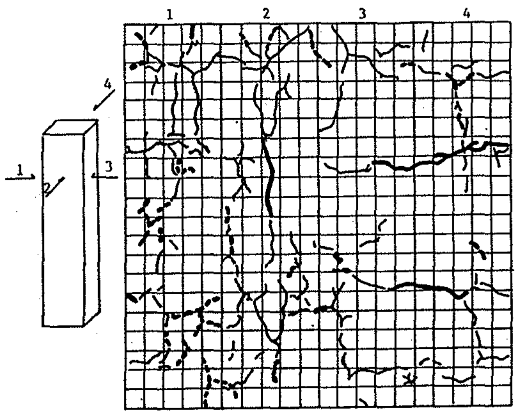

Fig. 3 Crack Map

4. REPAIR DESIGN

The aim of repairing damage to concrete structure caused by AAR, the load carrying capacity of which has not been significantly reduced from the original value,[4] was the rehabilitation of the durability of the concrete structure. Our discussion about how to repair damage due to AAR produced a practical standard for repair in Table 5. By diagnosis damage should be classified into 4 groups, 2 comprising crack behaviour - whether it is progressive or stable, and 2 comprising crack width - 0.2 ~ 5 mm or over 5 mm.

Table 5 Standard for Repair

State of Crack	Crack Width(mm)	Procedure of Crack: Injection	Procedure of Crack: Plug	Coating System
A Progressive	0.2 ~ 5	Epoxy III (EF2)	—	Flexible type
	> 5	—	Sealant	with thick film
B Stable	0.2 ~ 5	Epoxy II (EF1)	—	Flexible type
		Epoxy I (E·Reg)		Hard type
	> 5	—	Sealant	Flexible type
		—	Polymer cement	Hard type

The optimum injection material is determined by a combination of crack width and whether or not it is progressive. Quality specification of injection materials is shown in Table 6. In case of repair work, results of workability test in Table 3 should be especially taken care because of each value in Table 6 is only at 20°C. Tables 5 and 6 should be improved through future repair works and subsequent investigations. Follow-up inspection is, therefore, important.

Table 6 Quality Specification for Injection & Plug Materials (at 20℃)

Item	Injection M.			Plug M.	
	Epoxy I	Epoxy II	Epoxy III	Polymer cement	Sealant
State fo Crack	B		A	B	A, B
Crack Width (mm)	0.2	~	5	> 5	
Viscosity (cps)	1000 >	4(1)	1000 >	10000 >	No recognition of film droop
Pot Life (min)		> 30		> 30	> 240
Setting Time (hr)	16 >		24 >	16 >	24 >
Hard Shrinkage (%)		0.1 >		0.1 >	
Elongation (%)	—	50 ~ 100	100 ~ 150	—	> 800
Adhesive Strength to Mortar (kgf/cm²)		> 60		> 60	Failure at over 10mm of deflection
Rate of Durability on Adhesive Strength (%)(2)		> 60		> 60	

note (1) ; coefficient of thixotropy (value at 2rpm/20rpm)
(2) ; percentage to the setted value

5. CONCLUSION

The conclusions are summarized as follows:

1) Six kinds of desirable injection materials have been developed through experiments with 20 items.
2) A practical standard and a specification for repairing works have been established including test methods for materials.
3) In this repair standard, optimum repair (injection) material depends on crack width or its stability.

6. ACKNOWLEDGEMENT

The authors wish to thank Prof. K. Okada (Chairman of the Committee of Development of Techniques for Improving Durability of Concrete Structures), members of the committee and Mr. Y. Mori (Public Work Research Center) who offered helpful advice and valuable discussion. Thanks are also due to Mr. K. Domon (Sho-Bond Construction) and many colleagues for their assistance.

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