AN EXPERIMENTAL STUDY ON AAR-INHIBITING EFFECTS OF VARIOUS REPAIR METHODS

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ABSTRACT

In these experiments, specimens of concrete damaged by alkali-aggregate reaction have been repaired with nine different kinds of crack injecting/filling materials and eleven different surface coating materials under environmental conditions for bridge piers. Five-year outdoor exposure tests have been conducted to the repaired concrete specimens so as to examine the inhibiting effect. As a result, neither cracks nor blisters have been observed on the specimens coated with flexible epoxy resin base materials (500 μm) which have been repaired with the method combining crack injecting/filling with surface-coating. In respect of the specimens only repaired with surface coating materials, those coated with fabric-layered flexible epoxy resin base materials (500 μm) or fabric-layered flexible rubber base materials (1200 μm) have achieved favorable results.

In addition, the specimens re-damaged through the aforementioned tests have been repaired again under the outdoor exposure condition using ten different repair methods that have been developed up to the time of re-repair and are expected to demonstrate excellent inhibiting effects for the purpose of evaluating those ten methods. The re-repaired specimens have been examined to check for cracks after 1-year outdoor exposure period. Cracks have been observed on the specimens coated with the combination of cement base injecting material added with modified zeolite and aqueous silane coating material and the combination of epoxy resin base injecting materials and flexible epoxy resin coating materials (200 μm) or flexible urethane resin coating materials (200 μm).
KEYWORDS :Repair method, crack injecting, surface coating, exposure test, re-repair

INTRODUCTION

Recently, early deterioration of concrete is considered to be one of serious social problems. One of possible causes of the problem is AAR. AAR is said to be a phenomenon where reactive silica contained in aggregate reacts with alkali contained in concrete to form a substance that absorbs water and expands to cause concrete to crack. In order to secure durability of concrete structures for an extended period of time, AAR has to be inhibited. AAR-damaged concrete structures are generally repaired by combining the crack injecting/filling method and the concrete surface coating method. However, at the present, it cannot be said that a technique that completely inhibits AAR under any environment has been established.

The purpose of this study is to select appropriate AAR-inhibiting techniques to be used to repair AAR-damaged concrete structures and repair materials in accordance with the techniques.

This experiment has been carried out, as a part of this study, under environmental conditions for bridge piers. AAR-cracked RC specimens have been repaired using nine different kinds of crack injecting/filling materials and eleven different surface coating materials. Five-year exposure tests have been carried out to the repaired specimens. Upon completion of the test, the RC specimens have been checked for cracks. This paper reports the test results. Additionally, the specimens only repaired by surface coating that have been damaged again through the above-stated five-year outdoor exposure tests [1] have been re-repaired while held remained in the exposure state for the purpose of conducting the following examinations. This paper also reports the results of research for cracking on the specimens after the one-year exposure test [2].

(1) To evaluate and examine repair techniques that have been developed in Japan up to the time of re-repair and are expected to demonstrate outstanding inhibiting effects.

(2) To examine the surface treating method using the existing concrete surface coating materials.

INHIBITING EFFECTS OF VARIOUS KINDS OF REPAIR TECHNIQUES

Overall processes of this test are shown in Fig. 1.

Concrete specimens

Three coarse aggregates such as T-origin (andesite : Hazardous to chemical processes), H-origin (andesite : Hazardous to chemical processes) and Y-origin (chert : Hazardous to chemical processes) ones were used. T-origin and H-origin coarse aggregates were respectively mixed, in consideration of pesimum, with non-reactive S-origin coarse aggregate (rigid sandstone : Non-hazardous to chemical processes) at the rate of 1:1 and 4:1. Y-origin coarse aggregate was used with no additional procedure. Non-hazardous aggregates, according to chemical methods, were used as fine aggregates.

Ordinary portland cement containing 0.72 % of alkali by Na_2O equivalent conversion was used. Na_2O-converted amount of alkali was adjusted to 8 kg/m^3 by adding NaOH aqueous solution.

Fig. 2 indicates the configuration of RC specimens and the arrangement of reinforcement. Dimensions of the specimens were 250 x 250 x 1000 in millimeters. The specimens were subjected to moist-air curing for one day, then were subjected to air curing for 27 days. The compressive strength applied to the specimens of 28-age was 350 kgf/cm^2 (34.3 N/mm^2). The specimens were submitted to the test after accelerated-curing under an environment of 40°C and 95 %RH or more. Width of any and all cracks on the RC specimens prepared in the aforementioned procedure was 0.2 mm or more.

Repair methods

The above-stated specimens were repaired by using repair materials given in Table 1 in combination. On the assumption that the specimens represented bridge piers, they were repaired on the portion up to 65 cm below the top surface of the specimens. The portion of the specimens that were buried under the ground were not repaired but just held in the exposed state.

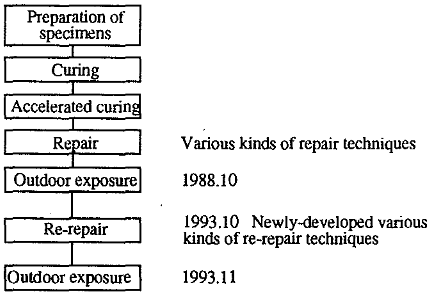

Fig. 1 Overall process of this test

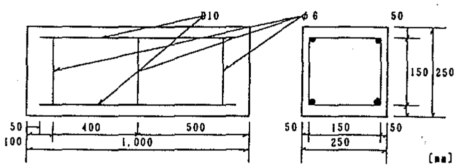

Fig. 2 Configuration of RC specimens and the arrangement of reinforcement

Table 1 Combination of repair methods and repair materials

Origin of coarse aggregates	T-origin			H-origin			Y-origin		
Lithology	Andesite			Andesite			Chert		
Combination of repair techniques	I	C	I+C	I	C	I+C	I	C	I+C
Repair materials									
[1] Crack injecting/filling materials									
1) Rigid epoxy resin	○		○			○			○
2) Flexible-1 epoxy resin	○		○			○			○
3) Flexible-2 epoxy resin	○		○			○			○
4) Flexible-3 epoxy resin	○		○			○			○
5) Polyurethane	○		○			○			○
6) Acrylic polymer cement base	○		○			○			○
7) Epoxy polymer cement base	○					○			○
8) Super-fine grain cement base	○		○			○			○
9) Polysulfide base sealant	○					○			○
[2] Surface coating materials									
1) Flexible epoxy resin base (200)		○			○			○	
2) Flexible urethane resin base (200)					○				
3) Flexible thick film epoxy resin base (500)		○	○		○	○		○	○
4) Flexible rubber base (500)		○			○			○	
5) Fabric-filled soft epoxy resin base (1200)		○			○			○	
6) Fabric-filled flexible rubber base (1200)		○			○			○	
7) Epoxy resin base glass flake (500)		○			○			○	
8) Flexible polymer cement base(500)		○			○			○	
9) Flexible resin fluoride base (200)					○			○	
10) Concrete primer penetrating material base (30)		○							
11) Acrylic resin base (100)		○			○			○	
Unrepaired	○	○	○	○	○	○	○	○	○

* *Symbols in the left table represent the following :*
I : Injection C : Surface coating
I+C : Combination of injection and surface coating
* *Numeric values following the surface coating materials represent thickness of film (in μm).*

Outdoor exposure test

Outdoor exposure test was conducted on the specimens repaired with the various kinds of repair techniques shown in Table 1 and unrepaired specimens. In the outdoor exposure test, the specimens were left exposed, with the unrepaired portions buried under the ground, on the premises of Public Works Research Institute of Ministry of Construction (in Tsukuba City, Ibaraki Prefecture) in five years from October 1988 to October 1993.

Examination works were carried out over time to check the repaired specimens for cracks and the appearance of concrete. The appearance of the surface coating materials were also observed. Cracks on the entire top surface and the side faces down to 65 cm below the top surface were examined. The crack width was measured with a crack scale and the largest crack width on the respective planes of the specimens was obtained. The unrepaired specimens were also checked for cracks. The appearance of the surface coating materials was visually checked and evaluated with respect to absence/presence of blisters and peeling/scaling.

Results and examinations of the repair tests

Effect in accordance with origins of coarse aggregates

Fig. 3 represents changes of crack width with time in the case where outdoor exposure test is conducted on three different kinds of unrepaired specimens with reactive aggregates (coarse aggregates) produced in three different areas. In addition, Fig. 3 gives changes of crack width with time in the case where pieces of concrete that are mixed according to the mixture patterns shown in Table 1 are submitted to accelerated curing in an environmental testing laboratory that is adjusted to 40°C in temperature and 95 % or more in relative humidity.

In Fig. 3, the mean value of the maximum crack widths on the respective planes of the specimens is used as the crack width. With respect to the changes of the crack width with time on three different coarse aggregates shown in Fig. 3, comparison is made between the exposure test result and the accelerated curing result. This proves that there is no noticeable difference between them. It is also determined through this test that there is only a small difference of reactivity with origins of aggregates.

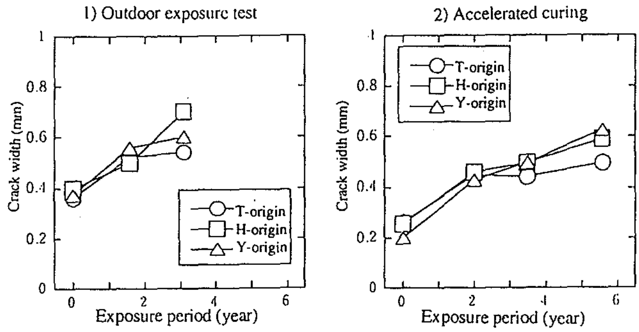

Fig. 3 Change with time of crack width on unrepaired specimens

Effects of crack injecting/filling materials

Table 2 gives, considering that reactivity of aggregates does not substantially depend of their origins, the results of the exposure test on the specimens repaired only with the nine different crack injecting/filling materials while briefly arranging them in terms of classifications of cracks observed, a mean value of the maximum crack widths on all the respective planes of the specimens and the incidence of cracks without discriminating the origins of aggregates.

The results given in Table 2 prove that AAR cannot be sufficiently inhibited only by crack injecting/filling method.

Exposure period / Injecting/filling materials	1 year and 7 months	3 years and 1 month	5 years and 1 month
1) Rigid epoxy resin	1), 2) 0.04 100%	1), 2), 3) 0.38 100%	1), 2), 3) 0.51 100%
2) Flexible-1 epoxy resin	1), 2) 0.13 60%	1), 2) 0.21 80%	1), 2), 3) 0.53 100%
3) Flexible-2 epoxy resin	1), 2) 0.29 80%	1), 2), 3) 0.45 100%	1), 2), 3) 0.86 100%
4) Flexible-3 epoxy resin	1), 2) 0.25 40%	1), 2) 0.46 100%	1), 2) 0.42 100%
5) Polyurethane	1), 2) 0.08 20%	2) 0.28 80%	2) 0.42 100%
6) Acrylic polymer cement base	1), 2) 0.12 60%	1), 2), 3) 0.44 100%	1), 2), 3) 0.60 100%
7) Epoxy polymer cement base	2), 3) 0.08 40%	1), 2), 3) 0.41 100%	1), 2) 0.49 100%
8) Super-fine grain cement base	1), 2) 0.16 100%	1), 2), 3) 0.40 100%	1), 2), 3) 0.42 100%
9) Polysulfide base sealant	1) 0.16 60%	1), 3) 0.32 100%	1), 3) 0.74 100%

** Numbers given in [upper stage] indicate classifications of cracks. 1) represents extension of cracks on repaired portion, 2) represents re-cracks on repaired portion and 3) represents new cracks that take place near the cracks on repaired portion.*
** Numbers given in [lower left] indicate a mean value (mm) of the maximum crack widths on all planes of specimens.*
** Numbers given in [lower right] indicate the incidence of cracks (the number of planes on which cracks take place/the total number of planes on specimens).*

Table 2 Results of exposure test on the specimens repaired with crack injecting/filling materials

Effects of surface coating materials

Table 3 gives the results of the exposure test on the specimens repaired only with the eleven different kinds of surface coating materials, ignoring the origins of aggregates, while briefly arranging them in terms of a mean value of the maximum crack widths on all the respective planes of the specimens, the incidence of cracks and the appearance of the coats.

Results shown in Table 3 prove that only the fabric-layered flexible epoxy resin coats and fabric-layered flexible rubber coats are not damaged at all after the five-year exposure period. These two kinds of fabric-layered surface coats need further examination so as to determine the time when abnormal conditions would arise.

Effects of techniques combining crack injecting/filling materials and surface coating materials

Table 4 gives the results of the exposure test on the specimens repaired by techniques combining crack injecting/filling materials and surface coating materials, ignoring the origins of aggregates, in terms of the appearance of the surfaces coating materials.

Results shown in Table 4 prove that the techniques combining nine different kinds of crack injecting/filling materials and eleven different kinds of surface coating materials are so effective through the five-year test period as to prevent cracks. It is therefore determined that the combined use of crack injecting/filling materials and surface coating materials provides high inhibiting effects which are expected to sustain five years or more. This combination technique needs further research and examination to determine not only the time when abnormal conditions would arise but also possible differences in inhibiting effects among the injecting/filling materials since such differences have not yet been found.

Table 3 Results of the exposure test on the repaired specimens

Surface coating materials	Outdoor exposure test					
	1 year and 7 months		3 years and 1 month		5 years and 1 month	
Flexible epoxy resin base (200 μm)	0.27	47%	0.35	80%	0.55	87%
Flexible urethane resin base	0.16	30%	0.26	50%	0.50	80%
Flexible epoxy resin base (500 μm)	0.00	0%	0.00	0%	0.00 swell	10%
Flexible rubber base	0.00	0%	0.08	7%	0.45	60%
Fabric-layered flexible epoxy resin base	0.00	0%	0.00	0%	0.00	0%
Fabric-layered flexible rubber base	0.00	0%	0.00	0%	0.00	0%
Epoxy resin base glass flake	0.13	40%	0.20	60%	0.52	60%
Flexible polymer cement base	0.21	40%	0.37	73%	0.67	87%
Flexible resin fluoride base	0.00	0%	0.04	10%	0.15	40%
Concrete primer penetrating material base	0.64	100%	0.74	100%	1.10	100%
Acrylic resin base	0.05	34%	0.24	47%	0.58	60%
Uncoated	0.54	100%	0.63	100%	–	–

Upper left : Crack width (mm)
Upper right : Incidence of cracks (the number of planes on which cracks take place/the total number of planes on specimens)
Lower stage : Appearance of coat (No entry means that no abnormal condition is observed.)
– : Material has not been examined or not tested.

Table 4 Results of the exposure test on the specimens repaired by techniques combining crack injecting/filling materials and surface coating materials

Crack injecting/filling materials	Surface coating materials	Exposure period		
		1 year and 7 months	3 years and 1 month	5 years and 1 month
1) Rigid epoxy resin	Flexible thick film epoxy resin (500 μm)	Normal conditions	Normal conditions	Normal conditions
2) Flexible-1 epoxy resin	ditto	ditto	ditto	ditto
3) Flexible-2 epoxy resin	ditto	ditto	ditto	ditto
4) Flexible-3 epoxy resin	ditto	ditto	ditto	ditto
5) Polyurethane	ditto	ditto	ditto	ditto
6) Acrylic polymer cement base	ditto	ditto	ditto	ditto
7) Epoxy polymer cement base	ditto	ditto	ditto	ditto
8) Super-fine grain cement base	ditto	ditto	ditto	ditto
9) Polysulfide base sealant	ditto	ditto	ditto	ditto

INHIBITING EFFECTS PROVIDED BY NEWLY-DEVELOPED RE-REPAIR TECHNIQUES

Concrete specimens

Damaged ones from among the concrete specimens repaired only with surface coating materials and exposed for five years to outdoor environment as described in "2. Inhibiting effect of various kinds of repair techniques" were used as concrete specimens for re-repair.

Re-repair

The specimens under the exposure conditions were re-repaired at the 5-year outdoor exposure test site using re-repair methods given in Table 5 in combination and held exposed continuously to the exposure conditions. It is to say that re-repair works were carried out in the following procedure using, in combination, domestic repair techniques developed up to the time of re-repair and are expected to demonstrate outstanding inhibiting effects: (1) With respect to the specimens coated with surface coating materials of 1) flexible epoxy resin base (200 μm), 2) flexible urethane resin base (200 μm) and 3) flexible epoxy resin base (500 μm), only the cracked portions were re-repaired after the removal of the existing coats and the remaining undamaged portions were left as they were. The cracked portions were repaired with injecting materials 1) and 2), then coated with an intercoating materials of the same base. Finally, the specimens were coated with a finish coating material over the surface. (2) For the other specimens, the existing coats were firstly removed from the entire surfaces. Then, the cracked portions were repaired with injecting materials 3) through 5). Finally, the specimens were coated over the surface with surface coating materials 4) through 10). (3) For the portions buried underground, earth was removed to the extent that approximately 10 cm of the portions appeared above the ground to permit observation for cracks. Then, the portions were re-buried in the ground. (4) Magiclon treatment and disk-sander treatment were compared to study surface treatment methods for existing concrete surface coating materials in the case of re-repair.

Outdoor exposure test

The re-repaired specimens were continuously held in the exposed conditions, as with 2.3, on the premises of Public Works Research Institute of Ministry of Construction (in Tsukuba City, Ibaraki Prefecture).

Results of 1-year re-repair test and consideration of the test results

Table 5 gives combinations of re-repair techniques, specimen Nos. and the results obtained though the one-year outdoor exposure following the re-repair works.

Inhibiting effects of newly-developed re-repair techniques
Following results are obtained from Table 5.
(1) For the repair technique using cement base injecting material added with modified zeolite and aqueous silane (concentration 30 %) coating material in combination (R-6-7) and that using epoxy flexible injecting material 1) and oil silane coating material in combination (R-1-7), cracks were observed on all of the five surfaces of the specimen.
(2) For the repair technique using cement base injecting material added with modified zeolite and aqueous silane (concentration 60 %) coating material in combination (R-6-6) and that using epoxy

Table 5 Re-repair techniques and results of outdoor exposure test

Coating materials / Injecting materials	1) Flexible epoxy [3] 200 µ	2) Flexible urethane [3] 200 µ	3) Flexible epoxy [3] 500 µ	4) Ep CFRP [4] 1200 µ	5) Acrylic rubber [5] 1200 µ	6) Aqueous silane [6] Condensation 60 %	7) Aqueous silane [6] Condensation 30 %	8) Solvent type [6]	9) Inner water escaping type 1) [5] 1200 µ	10) Inner water escaping type 2) [5] 400 µ	Untreated
1) Epoxy flexible type 1) [3]	2 Small R-1-1	Normal conditions R-1-2	Normal conditions R-1-3				5 Large R-1-7	4 Medium R-1-8	Normal conditions R-1-9	2 Small R-1-10	
2) Epoxy flexible type 3) [3]	Normal conditions R-3-1	2 Small R-3-2	Normal conditions R-3-3								
3) Epoxy rigid standard [3]				Normal conditions R-4-4							
4) Nitrous acid lithium [5]					Normal conditions R-5-5						
5) Modified zeolite [6]						4 Large R-6-6	5 Large R-6-7				
Untreated											5 Large

*Note) Specimen No. and evaluation * [3] through [6] indicates references.*

2	*:The number of planes on which cracks are observed*
Small	*:Crack*
R-3-2	*:Specimen No.*

The extent of cracks is evaluated in accordance with the maximum crack width: Large > 0.4. 0.4 ≥ Med > 0.2. 0.2 ≥ Small (unit: mm)

flexible injecting material 1) and oil silane coating material in combination (R-1-8), cracks were observed on four of the five surfaces of the specimen.

(3) For the repair technique using epoxy flexible injecting material 1) and inner water escaping type coating material 2) in combination (R-1-10), that using epoxy flexible injecting material 1) and flexible epoxy coating material 200 µ in combination (R-1-1) and that using epoxy flexible injecting material 3) and flexible urethane coating material in combination (R-3-2), cracks were observed on two of the five surfaces of the specimen.

The aforementioned repair techniques are judged to provide insufficient AAR inhibiting effects.

For the remaining combinations of injecting materials and coating materials, abnormal conditions including cracks are not observed after the one-year exposure to the outdoor environment.

Study on surface finished technique for existing concrete surface coating materials in the case of re-repair

No abnormal conditions such as lifting, blistering and peeling are not observed on any surface finished by the disk-sander or Magiclon treatment using conventional concrete surface coating materials.

This experiment is to be continued toward the future and further experimental study using larger specimens to achieve the goal of the research assuming the intended use for foundations and retaining walls of a bridge.

SUMMARY

The results obtained from this experiment are summarized as follows:

Repair techniques

(1) The repair only by crack injecting/filling technique does not provide reaction inhibiting effects.

(2) In respect of the repair only by surface coating, only two kinds of fabric-layered flexible type coating materials (i.e., fabric-layered flexible epoxy resin base 1200 μm and fabric-layered flexible rubber base 1200 μm).

(3) In respect of the repair technique combining crack injecting/filling and surface coating, it has been found that reaction inhibiting effects that will last over five years are expected by combining crack repairing and flexible thick film epoxy resin base surface coating materials (not layered with fabric).

(4) No difference in crack inhibiting effects with kinds of injecting/filling materials on one and the same surface has been noticed. This means further study and examination works are necessary to determine the time when abnormal conditions arise and the difference among various kinds of injecting/filling materials in terms of the inhibiting effects.

Newly-developed re-repair techniques

(1) In the following combinations of re-repair techniques, no crack was observed on the specimens in the one-year outdoor exposure test:

1) Flexible epoxy resin injecting material-1 or -3 and flexible thick film epoxy resin base (500 μm) surface coating material

2) Flexible epoxy resin injecting material-1 and inner water escaping type 1 (1200 μm) coating material

3) Rigid epoxy resin injecting material and epoxy CFRP (1200 μm) surface coating material

4) Nitrous acid lithium base injecting material and acrylic rubber base (1200 μm) surface coating material

(2) No abnormal conditions such as lifting, blistering and peeling were observed on any surface finished by the disk-sander or Magiclon treatment using conventional concrete surface coating materials.

(3) This experiment is to be continued toward the future and further experimental study using larger specimens to achieve the goal of the research assuming the intended use for foundations and retaining walls of a bridge.

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