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Evaluation and Observation of Autogenous Healing Ability of Bond Crack along Rebar

Choonghyun KANG[1*], Minoru KUNIEDA[2], Takamasa KANO[2], Naoshi UEDA[2] and Hikaru NAKAMURA[2]

[1]*Nagoya University, Republic of KOREA*
[2]*Nagoya University, JAPAN*
[*]*Department of Civil Engineering, Nagoya University, Furo-cho Chikusa-ku, Nagoya JAPAN*
kangcivil@gmail.com

ABSTRACT

Micro cracks occurred in concrete around tensional rebar were well known phenomenon. However, these micro cracks are difficult to detect until cracks develop to the surface of concrete, and it is not easy to repair the micro crack. In this study, autogenous ability of bond cracks along rebar was evaluated through air permeability test. Air permeability coefficients became larger by cracks along rebar due to tensile loading, and became smaller by the recuring in water condition. Observation of cracks pattern helped to understand the change of air permeability coefficients. Several small cracks along rebar were observed after the pre-cracking test, and most cracks along rebar were not found after water recuring. On the other hand, the crack pattern with air recuring condition did not change. These results indicate that bond cracks along rebar closed by generated product of autogenous healing, and it causes the decreasing of air permeability coefficients.

Keywords. Autogenous healing, Bond cracks, Air permeability test, Crack pattern, Ink injection

1. INTRODUCTION

Autogenous healing of cementitious composite was well known phenomenon as recovery of cracks automatically. The applied and limited target of autogenous healing is micro cracks, which cause the defects of deterioration of concrete structure. Bond crack is one of the initial defect occurred around rebar, which was reported by Goto (Goto 1971). Bond cracks are induced by bond behaviour between rebar and concrete, and several mechanism of bond behaviour are investigated, such as chemical bond strength, friction, shape of rib, etc. The main problem is that the micro cracks accelerate the penetration of substance such as water and gas, and it also make rebar corrosion area wider. It may be appropriate that these micro cracks should be repaired before development of significant deterioration. However, how can detect these micro cracks under several thickness of concrete cover and what method can be applied to repair are the primary problem for in this case.

In this study, autogenous healing was investigated for recovery of these micro cracks along rebar. Autogenous healing is a proper method because cracks along rebar distributed widely but small enough. Detecting method is air permeability test, which is a non-destructive method using surface measurement. Measured air permeability coefficient is used for measuring degree of deterioration by bond cracks, and evaluating effect of autogenous healing. In addition, crack pattern observation by ink injection explains how much area will be recovered by autogenous healing visually.

2. EXPERIMENTAL PROGRAM

2.1 Specimen

Figure 1 shows the shape specimen. Rectangle specimens with size of 150×150×500mm were prepared. The size of cross section was considered for measuring of air permeability test. The D22 rebar was embedded in the center of specimen section for inducing tensile force. Notches having a depth of 20mm and a thickness of 3mm were induced at both sides of specimen at the midpoint.

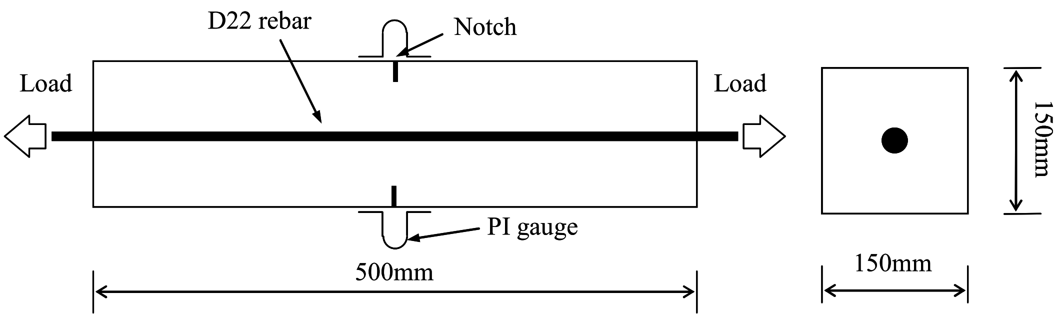


Figure 1. Shape of Specimen

A normal concrete and fly ash concrete were used in this study. Termkhajornkit reported that C-S-H gel produced by the pozzolanic reaction of fly ash act to seal micro cracks, and it help healing effect consequently (Termkhajornkit, 2006 and 2009). The mix proportions were tabulated in Table 1. The water to cement ratio (W/C) was 45% in all mix, and properties of each material were as follows. An ordinary Portland cement with a density of 3.15g/cm^3, sand with surface-dry density of 2.51g/cm^3, a coarse aggregate with surface-dry density of 2.58g/cm^3 and with the maximum size of 20mm were used. A fly ash (Type II of JIS A 6210), which has a density of 2.38g/cm^3, was used.

Table 1. Mix proportions

Case	W/C (%)	s/a (%)	Unit Content (kg/m^3)					Admixture (cc/m^3)
			Water	Cement	Sand	Gravel	Fly Ash	AEA†
NC	45	47	170	377	780	903	-	0.97
FC	45	47	170	377	716	903	58	0.97

AEA† : Air Entraining Agent

2.2 Air Permeability Test

A sensitive index should be selected for evaluation of deterioration degree by bond cracks and recovery effect of autogenous healing ability. Air permeability test was conducted using the Torrent Permeability Test (TPT), proposed by Torrent (Torrent 1992). As shown in Figure 2, the device is consisted by a chamber, a vacuum pump, a pressure sensor, and a logger. To prevent spurious ingress of air along the skin, there are two chambers; outer chamber and inner chamber. After the desired level of vacuum has been attained, pump just act on the outer chamber, and a logger records the history of change of inner chamber. A spurious ingress from concrete surface is evacuated by outer chamber, and uniaxial air flow can be measured through the pressure of the both chamber, as shown in Figure 3.

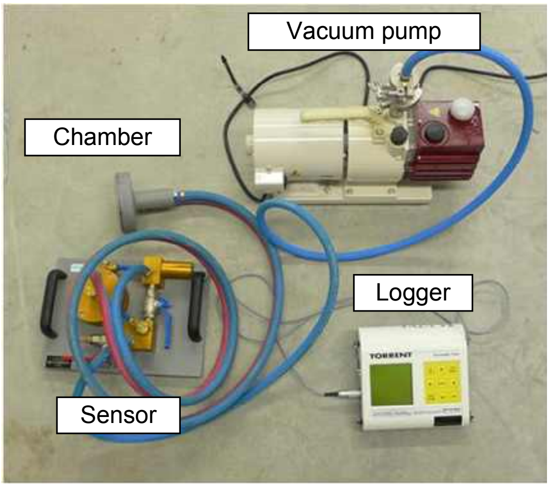


Figure 2. Torrent Permeability Tester

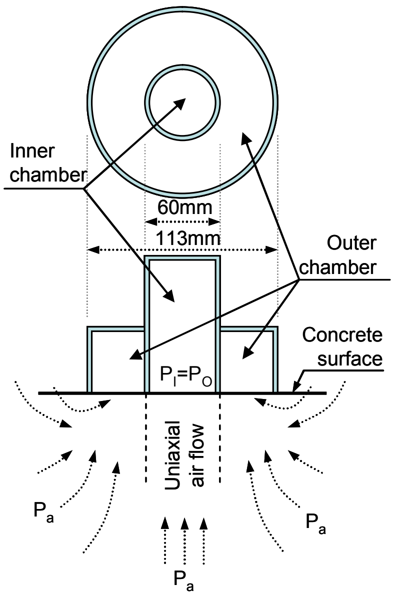


Figure 3. Conceptual diagram of the chamber

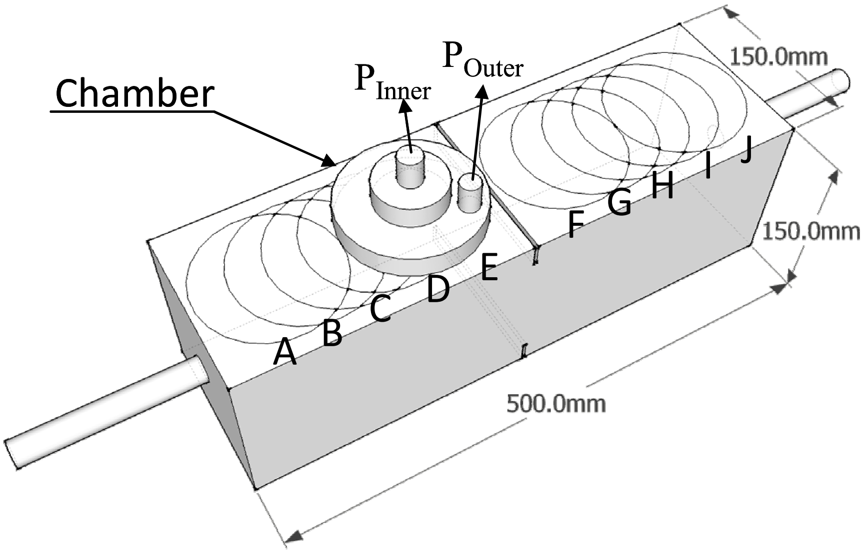


Figure 4. Measurement points of air permeability test

Ten measurement points along rebar were selected and named A to J, as shown in Figure 4. Three times of measurement were performed as before and after deterioration and after autogenous healing. Each air permeability coefficient was compared to evaluate deterioration and recovery effect.

2.3 Observation of Crack Pattern

Observation of Crack pattern was performed to evaluate healing effect. Used specimen size was the same as the specimen as shown in Figure 4, but rebar was different. Slits for ink injection were induced both side of rebar, as shown in Figure 5, which was referred to the previous experimental report (Maruyama 2007). Slits were cut by had grinder, and were filled with Styrofoam to prevent filling by cement paste. Styrofoam was removed before just ink injection. Red ink was injected through these slits, and specimen was split in half by concrete cutter. Dyed crack showed crack pattern.

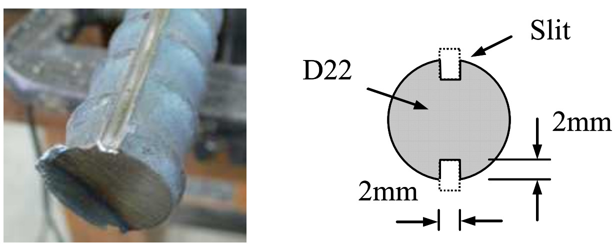


Figure 5. Slits for ink injection

2.4 Procedures

All specimens were demoulded at 24 hours after casting, and cured in 20℃ water condition. The pre-cracking test was performed at 28 days of age, and recuring period was 28 days after the pre-cracking test. Loading was controlled by crack opening displacement, which was measured by two PI gauges attached on the specimen surface over the induced notches. Figure 6 shows the experimental setup and load-displacement relationship.

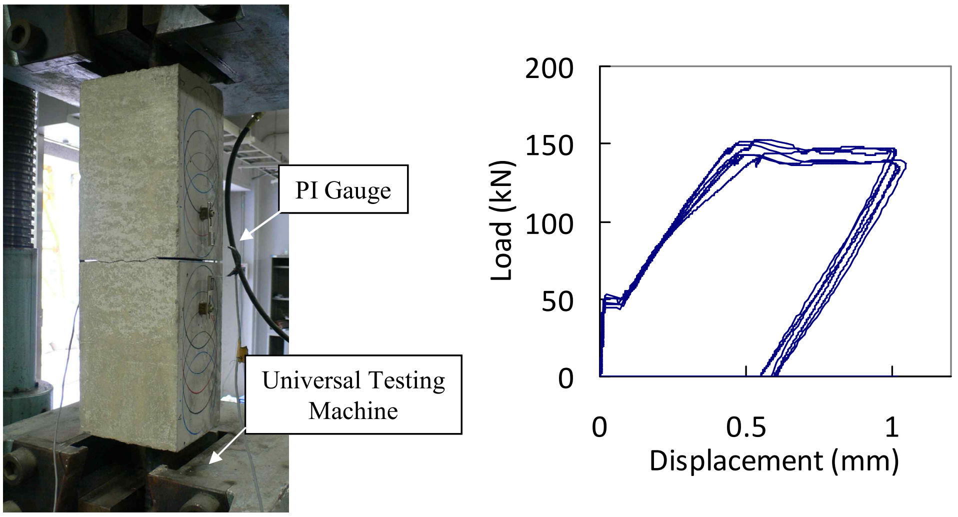
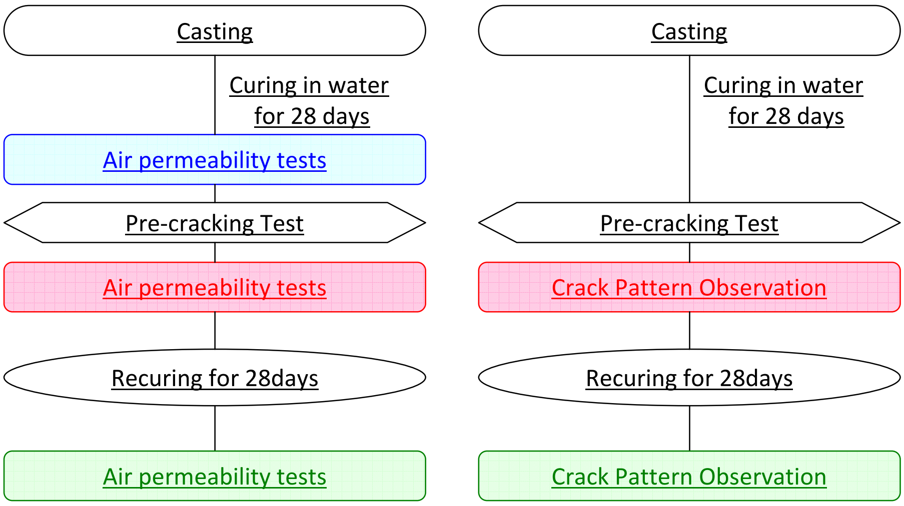


Figure 6. Experimental setup and load-displacement relationship

There were three specimens for air permeability test. After the pre-cracking test, one specimen was recurred in air condition in curing room (20℃ and RH 70~80%). Other two specimens were recurred in water condition in 20℃. By comparison with air and water recuring condition, more appropriate circumstance for autogenous healing could be investigated.

Another three specimens were prepared for crack pattern observation. Crack pattern observation was performed just after the pre-cracking test, firstly. Other two specimens were recurred after the pre-cracking test in air and water condition respectively. After the recuring, the effect of autogenous healing was investigated by each crack pattern observation.

Figure 7 illustrates the outline of the experimental procedures schematically.



(a) For air permeability test (b) For crack pattern observation

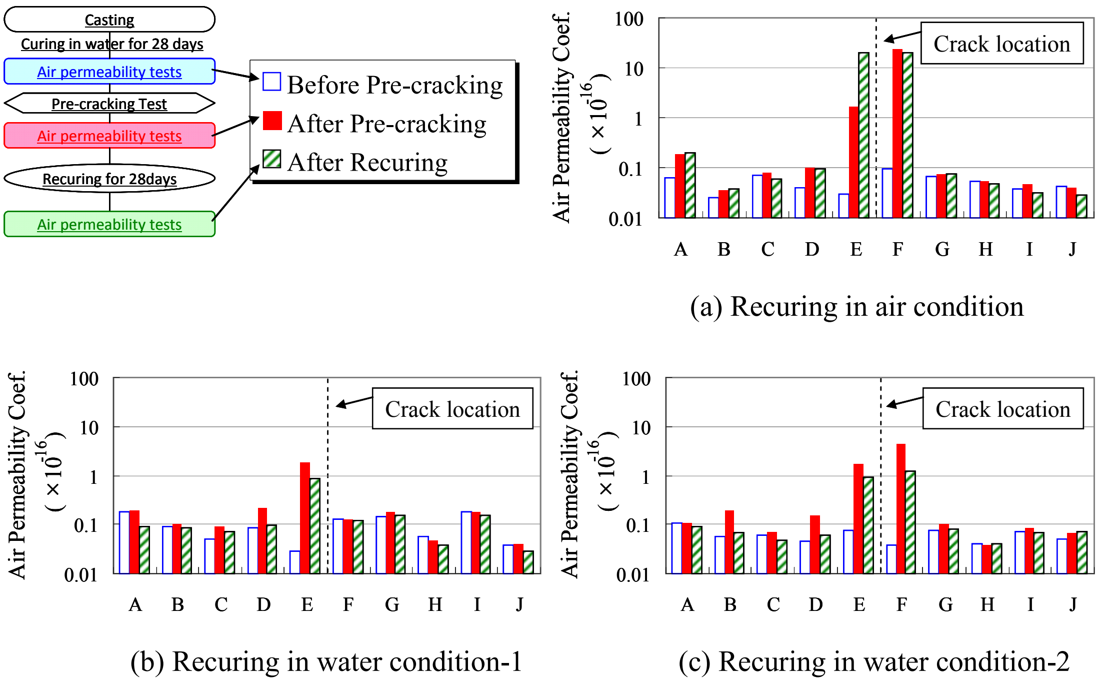
Figure 7. Experimental procedures

3. EXPERIMENTAL RESULT

3.1 Results of air permeability test

Figure 8 shows the air permeability coefficients of each normal concrete specimen before the pre-cracking test, after the pre-cracking test, and after the recuring, respectively. Air permeability coefficients of all specimens before the pre-cracking test showed almost same level near 0.1×10^{-16}. After the pre-cracking test, air permeability coefficients became larger, and relatively big change was showed at D~G locations. It seemed to be influenced by the main crack due to notches. After the recuring, air permeability coefficient showed different aspect depended on recuring condition. Air permeability coefficient became smaller in specimens recurred in water condition, and it seems that recovery of micro cracks along rebar was occurred in water recuring condition. However, there was no tendency of recovery in specimen recurred in air condition.

Figure 9 shows the results of fly ash concrete specimen. Regardless of the measurement step, average value of air permeability coefficients of fly ash concrete showed a little smaller than that of normal concrete. Normally, about 70~80% values were showed before the pre-cracking test, and those were not exceed 0.1×10^{-16} even after the pre-cracking except E~F location (beside the main crack). And some damaged parts showed very big recovery by recuring in water condition (E location in Figure 9-(b) and F location in Figure 9-(c)). It seems that fly ash influenced the permeability of concrete lower and it was continued after damage and recuring. A general aspect by recuring conditions as air condition and water condition was similar with that of normal concrete, and insignificant different was observed.

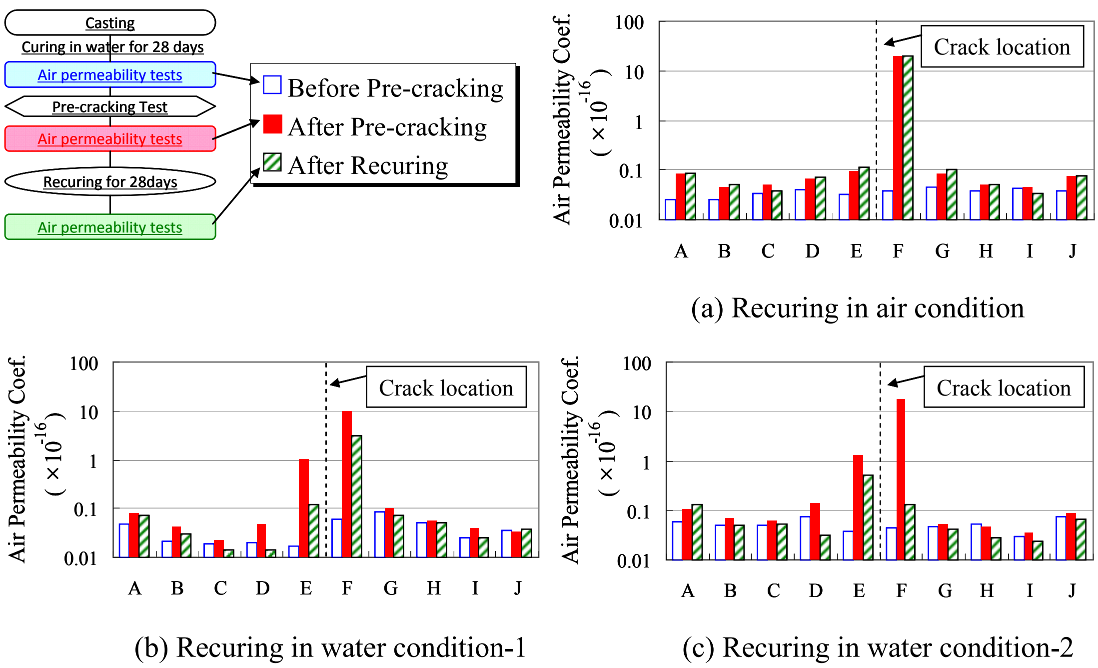


(a) Recuring in air condition

(b) Recuring in water condition-1

(c) Recuring in water condition-2

Figure 8. Results of air permeability test of normal concrete



(a) Recuring in air condition

(b) Recuring in water condition-1

(c) Recuring in water condition-2

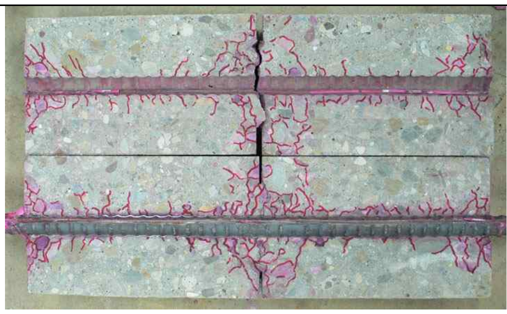
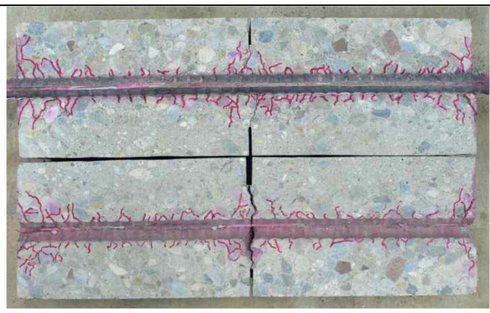
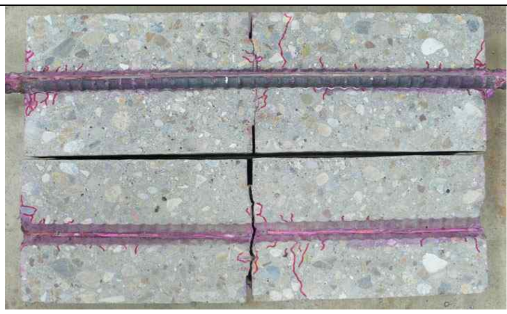
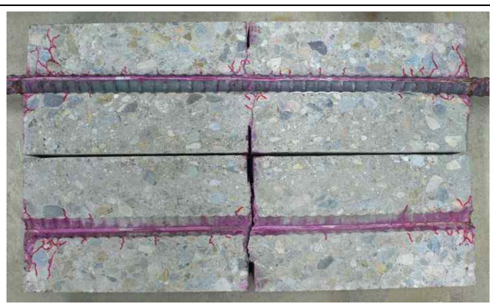
Figure 9. Results of air permeability test of fly ash concrete

3.2 Results of observation of crack pattern

Recuring effect was more visually provided by crack pattern observation. Table 2 shows the dyed crack pattern of each specimen. After the pre-cracking test, small cracks with length of less than 2mm were observed near rebar. Regarding different concrete, a few cracks were observed after water recuring. It seems that generated products due to autogenous healing filled the micro cracks, and it also influenced air permeability coefficient. However, the observed crack pattern with specimens recurred in air condition was similar to that just after the pre-cracking test. It means that autogenous healing in air condition was less effective than water condition.

Although air permeability coefficients showed lower values with fly ash concrete than normal concrete, it is difficult to find significant different in crack patterns between normal concrete and fly ash concrete. It can be reason that air permeability coefficient is more sensitive than observation by the naked eye.

Table 2. Observed crack patterns

	Normal concrete	Fly ash concrete
After pre-cracking		
Recuring in air condition		
Recuring in water condition		

4. CONCLUSIONS

In this study, autogenous healing ability of bond cracks along rebar was experimentally evaluated through air permeability coefficient and crack pattern observation, and following conclusions can be obtained:

1) Bond cracks along rebar influence on air permeability coefficients measured from surface of concrete. Air permeability coefficient became larger due to deterioration, and it became smaller with recuring in water condition. It can be supposed that recovery by autogenous healing ability influenced to decrease air permeability coefficient. In this study, recuring period was 28 days, and more significant recovery can be supposed with longer recuring period.

2) Average values of air permeability coefficient of fly ash concrete showed a little smaller than those of normal concrete not only in deterioration but also in recovery by autogenous healing. It indicated that fly ash make concrete higher resistant to permeability. But, an insignificant different between normal concrete and fly ash concrete was showed aspect of recovery by recuring condition.

3) Crack pattern observation provides visually to reduce air permeability coefficient after recovery by autogenous healing. The deterioration degree of bond cracks was investigated by crack pattern observation just after the pre-cracking test, and recovery effect was also observed after the recuring. A little cracks was observed with recuring in water condition, on the other hand, crack patterns with recuring in air condition were almost the same with those just after the pre-cracking test. With results of air permeability test, it indicated that recuring in water condition is more appropriate circumstances for autogenous healing ability.

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