B-1-3 Long term repair performance of silicate-based surface penetrant material for concrete cracks under various exposure environments

Takashi Kubota
School of Civil Engineering, Fukuoka University, Fukuoka, Japan.
td167003@cis.fukuoka-u.ac.jp

Hirotaka Hazehara
Department of civil engineering, Fukuoka University, Fukuoka, Japan.
hazehara@fukuoka-u.ac.jp

Dhruva Narayana Katpady
Research and Development division, Infratec Co.Ltd., Kagoshima, Japan.

Masashi Soeda
Department of Civil Engineering, Fukuoka University, Fukuoka, Japan.
msoeda@fukuoka-u.ac.jp

Masatake Yamada
School of Civil Engineering, Fukuoka University, Fukuoka, Japan.
td177008@cis.fukuoka-u.ac.jp

ABSTRACT: Effectiveness of silicate based surface penetrant material (SSIM) at concrete cracks was evaluated by long term exposure test using cracked concrete specimens at marine atmosphere and volcanic acid rain environment for 10 years. In case of marine environment, chloride ion penetration into concrete crack with SSIM specimens decreased up to 30-60 % in the vicinity of rebar and its corrosion area ratio decreased to 7-25 % in the 10th year in comparison with control specimen without SSIM. Re-application of SSIM to specimens in 3rd year confirmed high effects of repair regardless of SSIM type in comparison with the concrete cracks repaired early in development. In case of specimens exposed to volcanic environment, progress of neutralization in the crack with SSIM was not confirmed between 1 year and 6 years exposure. Therefore, crack repair using SSIM has a long term effect on concrete crack and can be re-applied. Especially, SSIM is considered effective for crack widths less than 0.2 mm.

KEY-WORDS: Silicate based surface penetrant material, concrete crack, neutralization depth, chloride ion, rebar corrosion, exposure test.

INTRODUCTION

Concrete structures develop cracks due to aged deterioration and early fault with construction. Early corrosion of rebar occurs due to penetration of water and chloride ion etc. into the cracks of concrete. Therefore, currently in Japan, over 0.2 mm crack in concrete is repaired proactively by injection method [1-4].

However, in case of injection from bottom to upper side through the crack, depth of injected material is often confirmed from 1cm to 20 mm as shown in Fig. 1. Even in the case of cracks under 0.2 mm, penetration of deterioration factors into cracks is governed by surface tension. Therefore, it is considered that countermeasure/repair is necessary in the case of fine cracks too. These will promote early deterioration of concrete structure.

Fig.1. Current status of actual structures

In recent years, silicate based penetrant material able to repair crack under 0.2 mm have been regarded as one of the way for repair method. This material has advantages of penetrating into deep area in crack due to the viscosity of this material being lower than common epoxy resin. This material produces C-S-H crystals in crack by reacting with free calcium ion and water in concrete and repairs the crack. Effects of repair by penetrants material have been confirmed for cracks under 0.2 mm by accelerated test and water permeability test.

However, long term effect of penetrants materials on concrete crack has not been clear in actual environment.
In this study, to evaluate the effect of silicate based surface penetrants material (SSIM) at concrete cracks, were carried out a long term exposure test using concrete with repaired cracks specimens at marine atmosphere and volcanic acid rain environment for 10 years.

EXPERIMENTAL

Outline of volcanic acid rain environment

Table 1. The factors and parameters considered for the experiment.

Exposure Environment	Volcanic Acid Rain				Marine Atmosphere
W/C	70%				50%
Crack	—		○		○
Repair	○	—	○	—	○
Type	A B	—	A B Reaction Gel A	—	A B
Repair Method	Application	—	Application, Injection	—	Application
Exposure Period(Max)	10 years	6 years	10 years	6 years	10 years

Table 1 shows the factors and parameters considered for the experiment. Table 2 shows the mix proportion of concrete exposed to volcanic acid rain environment. Ordinary Portland cement is used for concrete with crushed stone with nominal maximum size of 20 mm as coarse aggregate and river sand as fine aggregate. Water cement ratio is 70 %.

Cylindrical specimens of φ 100 × 200 mm with rebar at the 70 mm and 130 mm from the bottom (Fig. 2) are prepared and cured in water for 28 days. Cracks were induced with width from 0.1 mm to 0.2 mm. After inducing crack, specimens were cut at height 100 mm by concrete cutter. Concrete cover was taken as test surface and remaining sides except test surface were coated with epoxy resin.

Type A and type B penetrant materials were used for non-crack and crack specimens. Main component of any SSIM used are sodium and silicate with over pH 11.0.Method of application on non-crack concrete specimens was done as shown in Fig. 3.On the other hand, specimens with crack were injected using injector with air pressure as shown in Fig. 4. Injected volume of materials was 2.3 cm^3 regardless of crack width. After injection, SSIM was applied to concrete surface except for crack in a similar way as shown in Fig. 3.

Table 2. The mix proportion of concrete exposed to volcanic acid rain environment.

W/C (%)	s/a (%)	Unit Amount (kg/m³)				Air Volume (%)
		W	C	S	G	
70	49	191	273	906	936	1.5

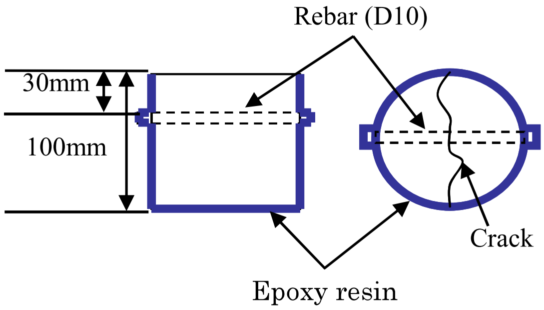

Fig.2. Specimen overview

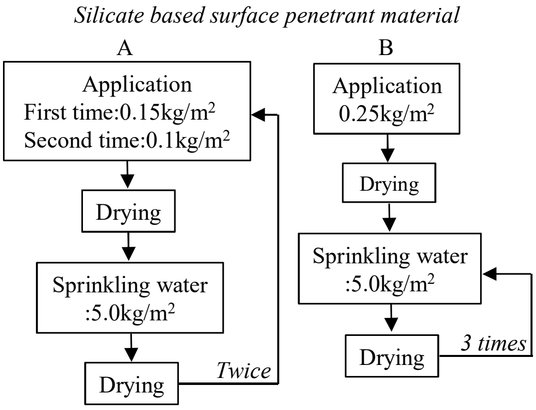

Fig.3. Application process

Outline of marine atmosphere environment

Table 3. The mix proportion of concrete exposed in marine environment.

W/C (%)	s/a (%)	Unit Amount (kg/m³)				Air Volume (%)
		W	C	S	G	
50	45	195	390	785	949	4.6

Table 3 shows the mix proportion of concrete exposed in marine environment. Ordinary Portland cement is used for concrete of water cement ratio 50 % with crushed stone as coarse aggregate and river sand as fine aggregate. 100 mm × 100 mm × 600 mm concrete specimen with rebar embedded at 30 mm from the concrete surface were prepared and cured in water for 28 days.

After the cracks were induced in concrete, crack width was controlled by tightening a bolt placed between two specimens as shown in Fig. 5.SSIM was injected to crack and applied to concrete surface in accordance with Fig. 3 and 4. A part of specimens were re-applied with SSIM after 3 years.

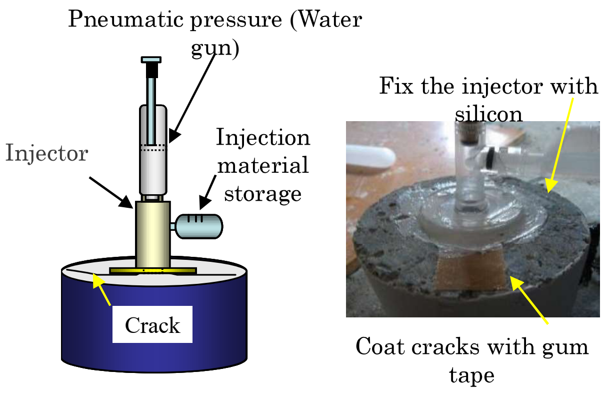

Fig.4. Injection method and situation

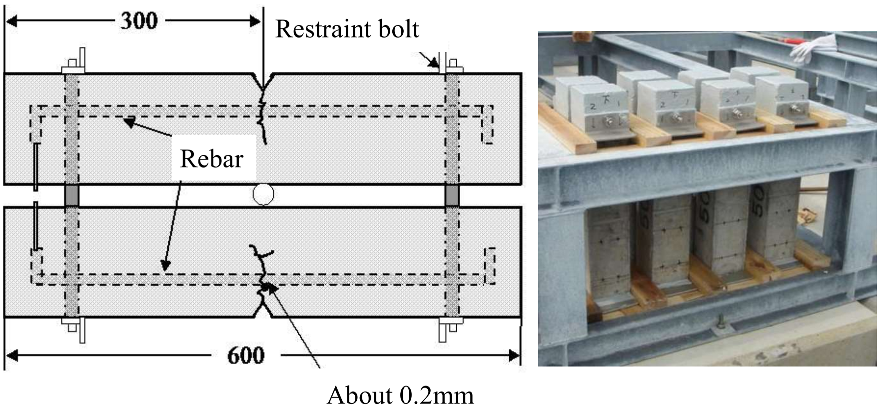

Fig.5. Outline of specimen and exposure condition

Measurement item and method

(1) Measurement of potential of rebar

Natural potential of rebar measured at the crack by using lead as reference electrode.

(2) Measurement of neutralization depth (volcanic acid rain environment).

Natural potential of rebar measured at the crack by using reference electrode of lead.

(3) Measurement of total chloride ion volume in concrete (marine environment).

Chloride ion volume was measured using drilled powder taken at determined depth intervals at the area of crack and non-crack.

(4) Measurement of rebar corrosion area and volume (both environment).

Corrosion area ratio was calculated by dividing corrosion area by total superficial area of rebar. Corrosion area was measured by picture processing. Corrosion volume was measured as decrement volume from difference of the rebar volume of before and volume after immersed in 10 % ammonium citrate solution for 2 days.

RESULTS AND DISCUSSION

Concrete exposed to volcanic environment

Fig. 6 shows the relationship between neutralization depth and crack width exposed for maximum 10 years. Neutralization depth of non-crack specimens without SSIM exposed for 1 year was 4 mm, and specimens with SSIM did not show neutralization in any case.

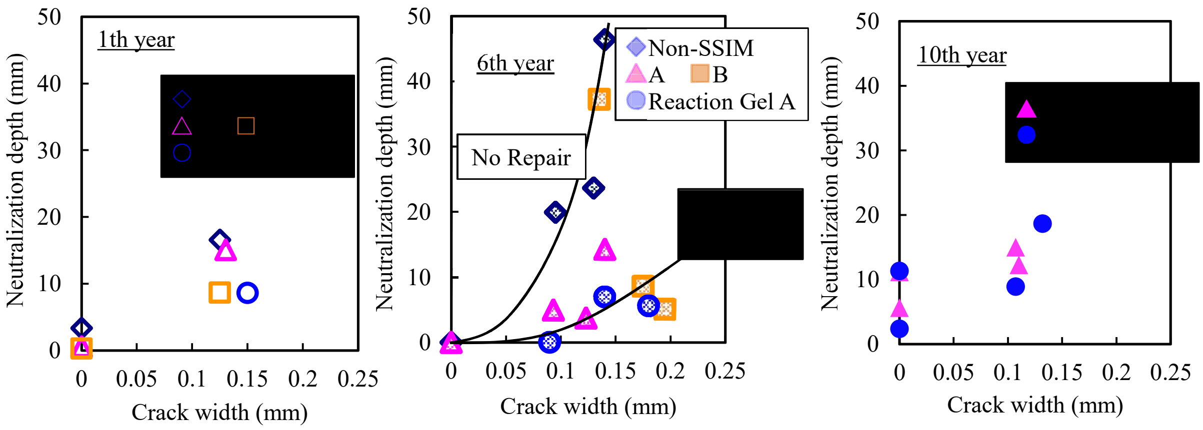

Fig.6. The relationship between neutralization depth and crack width.

On the other hand, all cracked specimens showed neutralization. However, neutralization of specimens those injected with SSIM into cracks was lower than for specimens without SSIM. And, SSIM type A showed higher inhibition. Up to 6 years of exposure, it was observed that neutralization depth tends to increase with increasing crack width. However, neutralization of SSIM injected specimens clearly reduced in comparison with specimens not injected with SSIM.

And comparison between 1 year and 6 years of exposure showed that neutralization depth of SSIM did not progress much. It was considered that crack was obstructed as time passed due to the injected SSIM continuously reacted with calcium ion in concrete and water constantly supplied by rain [2] [5].

Neutralization coefficient of 0.15 mm width was 19.2 (mm/$\sqrt{}$year) with non-SSIM specimens, and specimens with SSIM was about 4.1 (mm$\sqrt{}$year). Neutralization progress of SSIM specimens were less than 75 % in comparison with non-SSIM specimens.After 10 years of exposure, a part of specimens were lost due to a volcano eruption. Focusing on specimens undamaged, it can be seen that neutralization depth with crack was lower than result of non-SSIM specimen for 6 years exposure.

Fig. 7 shows the relationship between corrosion area ratio and crack width. After 6 years exposure, corrosion area tends to increase with increasing crack width. Injected SSIM specimens confirmed corrosion inhibition in comparison with non-SSIM specimens for 0.15 mm crack width. It was considered that corrosion inhibition was due to less progress of neutralization.Corrosion area ratio of injected SSIM with crack after 10 years exposure was same as non-SSIM specimen after 6 years exposure.

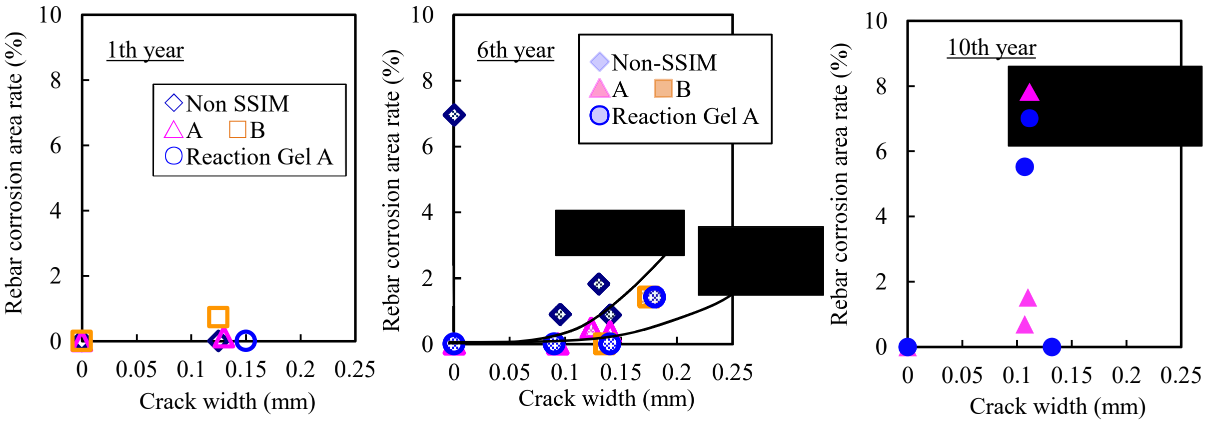

Fig.7. The relationship between corrosion area ratio and crack width.

From these results, effect of SSIM on concrete cracks is observed on a long term basis, its effects were confirmed for crack widths lower than 0.15 mm exposed to volcanic environment.

Concrete exposed to marine environment

Fig. 8 shows the total chloride ion volume distribution from crack surface.

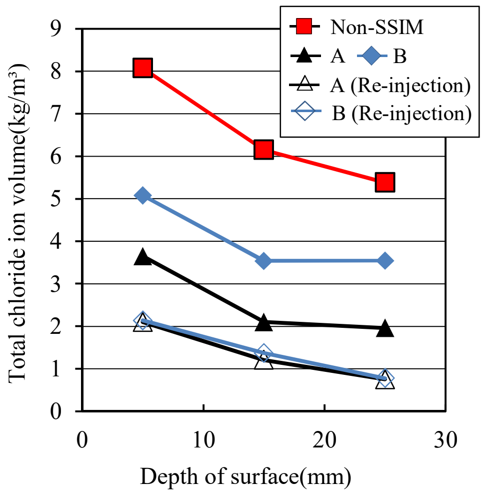

Fig.8. The total chloride ion volume distribution from crack surface.

Penetrated chloride ion volume of specimens with SSIM was lower than non-SSIM specimens in any case. Total chloride ion volume at 25 mm as covering depth was 5.4 kg/m^3 in non-SSIM specimen, type A and type B of SSIM was 2.0 kg/m^3 and 3.6 kg/m^3, respectively. Penetrated chloride ion were inhibited form 30 % to 60 % for concretes exposed to 10 years, injected with SSIM into crack.And, for type of SSIM, penetrated chloride ion was less for type A in comparison with type B.It was considered that crack could be filled and closed at deep area due to the viscosity of type A lower than type B.

On the other hand, for re-injected specimens with SSIM after 3 years, total chloride ion in any type of SSIM was less than 1.0 kg/m^3. It was found that SSIM has effect of re-injection into crack. Re-injection could have filled up the crack which was not filled up during first injection.

Fig. 9 show the relationship between natural potential after 10 years exposure and corrosion rebar ratio. Corrosion of rebar was confirmed at the crack point in any case. Corrosion area ratio tends to decrease with decreasing natural potential.Corrosion area ratio of non-SSIM specimen was 7.2 %, and type A and B were 0.7 % and 1.8 %, respectively. On the other hand, in case of re-injected specimens, corrosion was clearly inhibited and it was about 0.2 %.

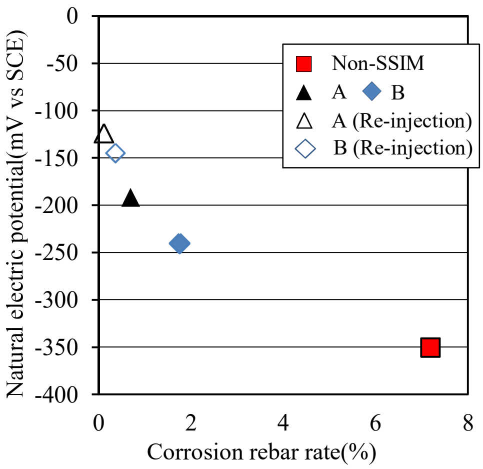

Fig.9. The relationship between natural potential after 10 years exposure and corrosion rebar ratio.

CONCLUSIONS

1. Repair effect of SSIM on crack under 0.2 mm width was confirmed by exposed concrete under the volcanic and marine environment for 10 years.

2. Neutralization depth at the crack surface decreased by 25 % by SSIM in comparison with non-SSIM specimen.

3. In case of SSIM injection only once, in concrete exposed to marine environment, chloride ion volume decreased from 30 % to 60 % at covering depth. In case of re-injection of SSIM, corrosion area was insignificant even up to 10 years of exposure.

4. For fine cracks which are difficult to repair, this method is considered to be one of effective ways to improve durability.

REFERENCES

[1] Japan Society of Civil Engineers. (2012). Concrete library 137.

[2] H. HAZEHARA, K. TAKEWAKA, A. YAMAGUCHI, N. SHIRASAWA. *Study on water-blocking effect by crack repair using silicate based surface penetrant material*, Concrete engineering annual paper, 31 (2009): 1933-1938.

[3] H. HAZEHARA, K. TAKEWAKA, J. MATSUMOTO, S. MAEDA. *Fundamental study on penetration depth of silicate based surface penetrant material and improvement of concrete quality in penetration area*. Concrete engineering annual paper. 29 (2007): 547-552.

[4] H. HAZEHARA, K. TAKEWAKA, T. YAMAKUCHI, M. SOEDA. *Fundamental study on properties of silicate based surface improvement material and coverage for concrete structures.* Int. Cong. on durability of concrete. (2012). (ICDC), USB, B4-1.

[5] K. KANAHORI, H. HAZEHARA, M. SOEDA, D. NISHIJIMA. *Fundamental Study on improvement of concrete quality using silicate based surface penetrant material and calcium Solution*. Concrete engineering annual paper, 137 (2012) 1657-1662.