Anticorrosion Effect of Silane Type Surface Penetrants on RC Degraded by Carbonation

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Abstract. We studied on the anticorrosion effect by applying silane type surface penetrants on RC degraded by carbonation. Two types of carbonation residue and two types of environmental conditions after accelerated carbonation were prepared and investigation was made on the corrosion behaviour of reinforcing bars by applying surface penetrants. As a result, by blocking water penetration by applying surface penetrants, there was a difference in anticorrosive effect in the behaviour of half-cell potential, polarization resistance, and investigation of reinforcing bar corrosion after the end of exposure. From the above, this paper reports on the possibility of realizing anticorrosion effect by suppressing invasion of moisture from concrete surface to carbonated RC.

1. Introduction
One of the deterioration of concrete structures is carbonation. When the carbonation residue becomes a certain value or less, the alkali component in the concrete disappears and the anticorrosion performance of the reinforcing bar decreases. For this reason, the corrosion rate of reinforcing bars has been reported to be dependent on concrete moisture content and carbonation residue [1]. Also, the past study reported that the concrete had been peeled off remarkably at the rain-hanging place when the carbonation residue of concrete is lower than a certain value, in the actual structures [2]. In this case, it was reported that when the carbonation residue becomes a certain value or less, the spalling of the cover concrete became remarkable at the rain hanging place. In addition, the STANDARD SPECIFICATIONS FOR CONCRETE STRUCTURES-2013 [Main tenance] [3] shows that the splashed area is involved in the durability of concrete structures. Therefore, in order to suppress corrosion of the reinforcing bars of the concrete structure and achieve long-term service, it is considered effective to apply the surface penetrants of silane type to prevent invasion of water which is penetrated from the surface of concrete [4]. However, the case of the discussion on the relationship between the corrosion rate of reinforcing bars and the water content by applying the surface penetrants to the RC whose carbonation residue is lower than the corrosion occurrence limit has been reported few [5]. For this reason, there are many unclear points about the anticorrosive effect by using silane type surface penetrants in a state where carbonation occurs in the actual structure, but cracks do not occur on the concrete surface. If the silane type surface penetrants is
applied in this state and the anticorrosive effect of the reinforcing bars can be confirmed, it is considered to be very advantageous in the management of the structure. In this study, we examined the anticorrosive effect which is obtained by applying a silane type surface-penetrants to carbonated RC.

2. Test methods

2.1. Test parameter of this test

Test parameters and levels were shown in Table 1. In order to investigate the anticorrosive property by applying silane type surface penetrants in the carbonated state, there were two kinds of whether silane type surface penetrants was applied or not. The carbonation residue was classified into two types in order to confirm the effect on corrosion protection performance. In order to confirm the involvement of water in the concrete, two types of drying and water were set for the exposure environment.

| Test parameters       | Levels                                      |
|-----------------------|---------------------------------------------|
| Surface Penetrants    | Penetrants, Non-penetrants (2 levels)       |
| Carbonation Residue   | 0mm, -10mm (2 levels)                       |
| Exposure Condition    | Dry, Water (2 levels)                       |

2.2. Test parameter of this test

Mix promotion of this test was shown in Table 2, and outline of this test was shown in Figure 1. For specimens, reinforcing bars of 13 mm in diameter were placed in prism specimens of 100 mm × 100 mm × 70 mm. For the reinforcing bars embedded in the concrete, corrosion prevention treatment was carried out with tapes of about 10 mm from both ends of the specimens to prevent corrosion at the end portions. Water cement ratio was set at 70%. Adjustment was made with the admixture so that the target slump was 12 ± 2.5 cm and the air amount was 4.5 ± 1.5%. Regarding the maximum size of the coarse aggregate, it was 10 mm because cover thickness of these specimens was 20 mm.

| W/C (%) | W  | C  | S  | G  | AE arrangement (cc) |
|---------|----|----|----|----|---------------------|
| 70      | 171| 244| 956| 914| 33.6                |

2.3. Test condition

Time table of this test was shown in Figure 2. From 14 days after casting, specimens were placed in a carbonation tank under conditions of temperature 20°C and CO₂ concentration 5% in order to carbonate. Accelerated carbonation was continued until predetermined carbonation depth was reached. After reaching the predetermined carbonation depth, the surface penetration was applied to the surface with small cover depth. For the surface penetration, 200g/m² of silane type surface penetrants was applied. Subsequently, the specimens were transferred under dry and water environments and exposed.
Specimens under drying conditions were placed under conditions of 20°C temperature and 60% R.H. As for the water condition, specimens were placed under the conditions of temperature 20°C and R.H. 90% constant, so that the penetration surface was immersed in water. Two specimens were prepared for one factor, and one specimen was crashed in about three months after the exposure. The other one was continuously placed under exposed environmental conditions, and specimens were left until the age of 260 days.

2.4. Test method
After installing the specimens in the carbonation tank, the corrosion condition of the reinforcing bars was monitored using the electrochemical method over time. For this monitoring, we measured the half-cell potential and the polarization resistance. Also, water content of concrete was measured using separately prepared specimens. Using an electric resistance type concrete / mortar moisture meter, measurements were made up to 30 mm in the depth direction by 10 mm. It was conducted every 4 weeks.

Three months after the exposure period, one specimen was taken out and disassembled, and the corrosion condition of the rebar was measured. Measurement items were corrosion area ratio and diameter measurement. The corrosion area was measured by wrapping the taken rebar with tracing paper and tracing the corroded area. In addition, the diameter of the reinforcing bar was measured in two directions orthogonal to one cross section after rust removal according to the JCI-SC 1 method. Measured at intervals of 10 mm, the percentage with sound reinforced bars was taken as the residual diameter ratio.

3. Test result

3.1. Penetration depth
Penetration depth was shown in Figure 3. There was no difference in penetration depth due to the carbonation residue.

3.2. Water contents
The distribution in the depth direction of the water content from the specimen surface under water condition at age of 200 days was shown in Figure 4, and the water content distribution under the drying condition was shown in Figure 5. Under the dry condition and water condition, the water content on the concrete surface was small and the water content tended to increase toward the inner of the concrete. It was considered that the silane type surface penetrants showed the same tendency both in dry condition and in water condition because it had water shielding and moisture permeability [4]. However, since it was difficult for water vapor permeation to prohibit, even in specimens applied with surface penetration in water condition specimens, it was considered that the water content increased as the depth from the surface increased. Under water conditions, it showed a tendency to suppress the water content of about 2% at any depth by application of surface penetration.

3.3. Half-cell potential

Changes with time of half-cell potential under dry conditions were shown in Figure 6. After the accelerated carbonation period, as shown in Figure 6, specimens placed under dry conditions
exhibited nobler potential than -200 (mV vs csv) in any of the carbonation residues. In ASTM C 876, it is judged that "there is no corrosion with a probability of 90% or more". In addition, the presence or absence of application of surface penetration showed a noble tendency in the applied specimens. This was considered to be due to the blockage of water penetration, and it was considered that the surface penetration was more likely to be in a stable state when applied. In addition, irrespective of applied or non-applied surface penetration, it was showed a low potential on the specimens with small carbonation residue.

Changes with time of half-cell potential under water conditions were shown in Figure 7. Under water conditions, half-cell potential showed a low value in any carbonated residue specimens after changing the placement environment. Half-cell potential of the specimens applied with surface penetration changed from -200 (mV vs csv) to -350 (mV vs csv). In ASTM C 876, corrosion potential is a value judged to be "indeterminate". After setting to the water condition, the non-applied specimens were shifted at a base potential lower than -350 (mV vs csv). In ASTM C 876, it is judged that "there is corrosion with a probability of 90% or more". Therefore, as for the comparison of half-cell potential according to the application state of the surface penetration, it was possible to confirm the situation where the applied specimens were shifted at the noble potential during the exposure period. This was thought to be due to the prevention of invasion of water by applying surface penetration. In addition, similar to the drying condition, it can be confirmed that specimens change to the base side as a whole in the specimens with large carbonation residue.

3.4. Polarization resistance

Changes with time of the polarization resistance under dry conditions were shown in Figure 8, and changes with time of the polarization resistance under water conditions were shown in Figure 9. In Figure 8, there was a tendency that the polarization resistance increases with the passage of days. It is thought that resistance to corrosion increases due to the increase in concrete strength with the passage of age. In addition, the specimen applied with the surface penetration showed a tendency that the polarization resistance was small in the specimen with large polarization resistance and small carbonation residue. This indicated that the water content at the rebar position was small in Figure 5, and Iijima et al. pointed out that the rebar corrosion rate depends on the water content and the carbonation residue, and this time it was considered the same [1].

As shown in Figure 9, the polarization resistance tended to decrease with the passage of days until the age of 200 days after changing the exposure environment. However, according to the comparison based on whether or not the surface penetrants was applied, since the specimen applied with the surface penetration had a large polarization...
resistance, corrosion due to blocking invasion of water from the concrete surface could be suppressed. However, after 200 days of age, no clear difference in polarization resistance due to the presence or absence of surface penetration application could be confirmed. Because W/C is 70%, it might be affected by oxygen penetration from the surface not applied with surface penetrants. Therefore, although it was necessary to further consider the behaviour of aged more than 200 days, it was considered that corrosion control effect by applying surface penetration was shown for before 200 days.

3.5. Corrosion area rate
The corrosion area ratio under dry condition was shown in Figure 10, and the corrosion area ratio under water condition was shown in Figure 11 among the rebar which was taken out from the specimen 3 months after changing the exposure environment. From Figure 10, under dry conditions, no corrosion was observed in the carbonation residue 0mm specimen. In the carbonation residue -10mm specimens, corrosion was confirmed irrespective of the presence or absence of the surface penetrants, but both were less than 0.5%. From Figure 11, corrosion was confirmed in all specimens under water conditions. For the applied specimen, no difference was observed due to the carbonation residue, but in the non-applied specimen, the smaller the carbonation residue was, the larger it became. Therefore, it could be confirmed that water is involved in corrosion in specimens that have undergone carbonation.

3.6. Rebar diameter
The average residual diameter ratio of the non-applied specimens to the applied specimens after the rust removal for the rebars in the specimens left under the water condition was shown in Fig 12. In all of the carbonation residues, the diameter of the applied specimen was larger than that of the non-applied specimens. As with the other results, it was considered that the penetration of water into the concrete was suppressed by the application of the surface penetration. In addition, since the corrosion main factor of this test was carbonation, local corrosion hardly occurred [6], so it is considered that there was no large difference in residual diameter ratio due to the carbonation residue. Therefore, in the category of this test, it is considered that the anticorrosion effect can be obtained by applying the silane type surface penetration to RC which has been carbonated. However, as shown in Figure 9, as the time elapses, no difference in polarization resistance due to application of the surface penetration has been confirmed, so it is considered necessary to further study the trend over a longer period.
Conclusions
The purpose in this research is confirmation of the usefulness with applying the silane type surface penetrants for a corrosion prevention to RC which promoted the carbonation. Therefore, we evaluated the corrosion behaviour of the reinforcing bars arranged inside the carbonated RC specimens whose surface had been coated with the surface penetrants of silane type. The main findings obtained in this research are shown below.

1. When silane type surface penetration was applied to concrete subjected to carbonation, there was a tendency that the half-cell potential showed a noble value in both dry and water conditions. When installed under water conditions, polarization resistance also showed a large initial resistance by application of a surface penetration, but no difference was confirmed with the passage of the age.

2. We measured the ratio of the corrosion area of rebar which had been removed from RC specimen. The RC specimen had been put in water during about 3 months. As the result, the ratio of the corrosion area increased with decreasing the carbonation residue.

3. From the above results, it was shown that the anticorrosion effect can be expected by applying the silane type surface penetration to the carbonated RC.

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