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ESTIMATING THE DURABILITY OF REINFORCED CONCRETE COVERED WITH A PERMEABLE SHEET AND A WATERPROOFING MEMBRANE

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ABSTRACT

In order to prevent blistering of waterproofing membranes due to evaporation of moisture from the concrete, this paper describes a solution where a permeable sheet was provided between the concrete and the waterproofing membrane. However, if the humidity of the external environment is higher than for the concrete, moisture may enter the concrete. It is important to understand the moisture content of concrete when considering the durability of reinforced concrete. In this study, the moisture content of the concrete and the environmental humidity were used as parameters, and the effect of the construction method of the waterproofing membrane on the moisture content of the concrete and the corrosion rate of reinforcing steel bar were examined.

Keywords: waterproofing membrane, air permeable sheet, corrosion of reinforcing steel bar, moisture content of concrete

INTRODUCTION

In coastal areas, airborne salt penetrates into concrete and cause reinforced steel bar corrosion by destruction of the passive film. In such cases, it may be effective to apply surface protection materials in order to prevent deterioration of the reinforced concrete (RC). This is because the surface protection materials inhibit penetration from the outside environment of substances such as chloride, water and oxygen which promote the corrosion of reinforcing steel bars [1], [2]. However, if the moisture content of the concrete is high when the surface protection materials are applied to the concrete, blistering of the surface protection materials may occur as shown in Figure 1. The blistering is not only an aesthetic issue, but also causes peeling, breakage of the surface protection materials and reduction of the durability of RC structure. In order to prevent blistering, a waterproofing membrane is sometimes constructed by a so-called isolation method [3]. In this method, an air permeable sheet is inserted between the waterproofing membrane and the substrate concrete to allow some air and vapor movement. The air and vapor pressure generated in the concrete is exhausted from an air vent through the air permeable sheet.

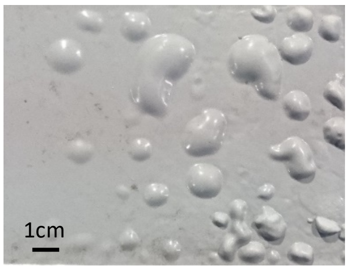


Figure 1: Example of surface coating blistering

Since the design of the air permeable sheets are normally focused on the exhaust performance, a material with very high gas permeability is used. However, it is of concern that this also involves a risk of intrusion of deteriorating substances through the air vent which is in contact with the outside environment.
This study examines the effect of the external humidity environment on the corrosion rate of reinforcing steel bars in concrete applied with the waterproofing membrane by the isolation method.

PREPARATION OF SAMPLES

Materials

Ordinary Portland cement following the Japanese industrial standard was used. The fine aggregate was crushed sandstone with maximum size 4.8 mm and fineness modulus 2.79. The coarse aggregate was crushed greywacke with maximum size 20 mm. In order to maintain workability during casting, 15 kg/m^3 slump retaining and water reducing superplasticizer was added to the mix. Salt load from the environment was reproduced by adding salt at a rate of 5.0 kg/m^3 to the mix water.

Commercial liquid polyurethane, with a specific mass of 1.0 g/cm^3, used for waterproofing in practice was used for the waterproofing membrane. The used permeable sheet was also a commercial product of a nonwoven fabric type with relatively high permeability.

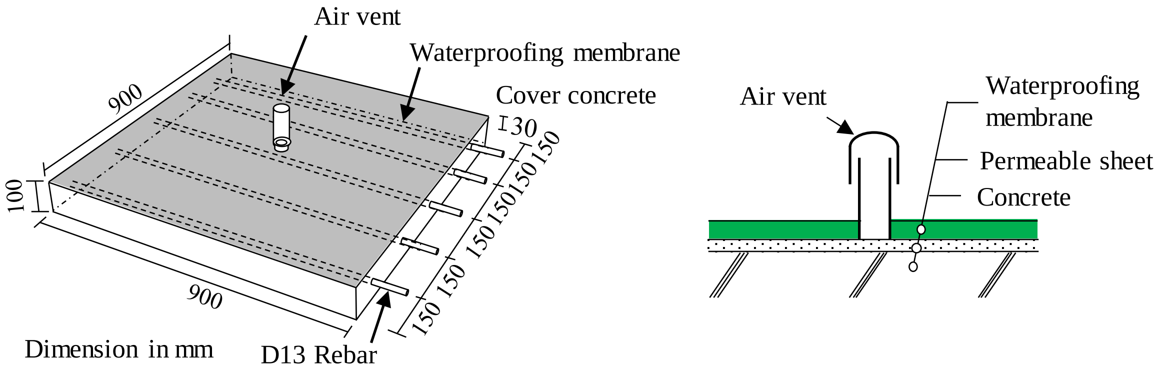
Samples

After casting, the concrete samples were stored in the mold at 20°C, 60% RH during 24 hours. Thereafter, the concrete samples were demolded and covered with wet textile and kept at 20°C during 27 days. Concrete mix composition is shown in Table 1. Three "full size", 100 mm thick, 900×900 mm square concrete slabs were made, reinforced with five Ø13 mm, 1000 mm long bars of deformed steel. The reinforcing steel bars were embedded in concrete with a cover of 30 mm and spaced 150 mm as shown in Figure 2 (a). The exposed surface is 900×900 mm, which is the bottom surface during concrete casting. All surfaces were sealed with epoxy resin except for the exposure surface.

The exposure surface was covered with the permeable sheet and the air vent was fixed to the concrete with anchors. Tiny holes in the permeable sheet allowed the low viscosity polyurethane to penetrate to the concrete surface and ensured sufficient adhesion. The coating thickness of the polyurethane membrane was adjusted to 2.0 mm by controlling the mass as shown in Figure 2 (b) and Figure 3. For comparison three different samples were made: 1) Concrete without membrane as well as 2) concrete

Table 1: Mix proportion of substrate concrete

w/c	s/a	Water	Cement	Sand	Coarse Aggregate	NaCl
		kg/m³				
0.6	0.45	179	298	773	957	8.24



(a) Shape an size of concrete sample

(b) Cross-section of sample around air vent

Figure 2: Sample of corrosion performance tests for reinforcing steel bar in Concrete

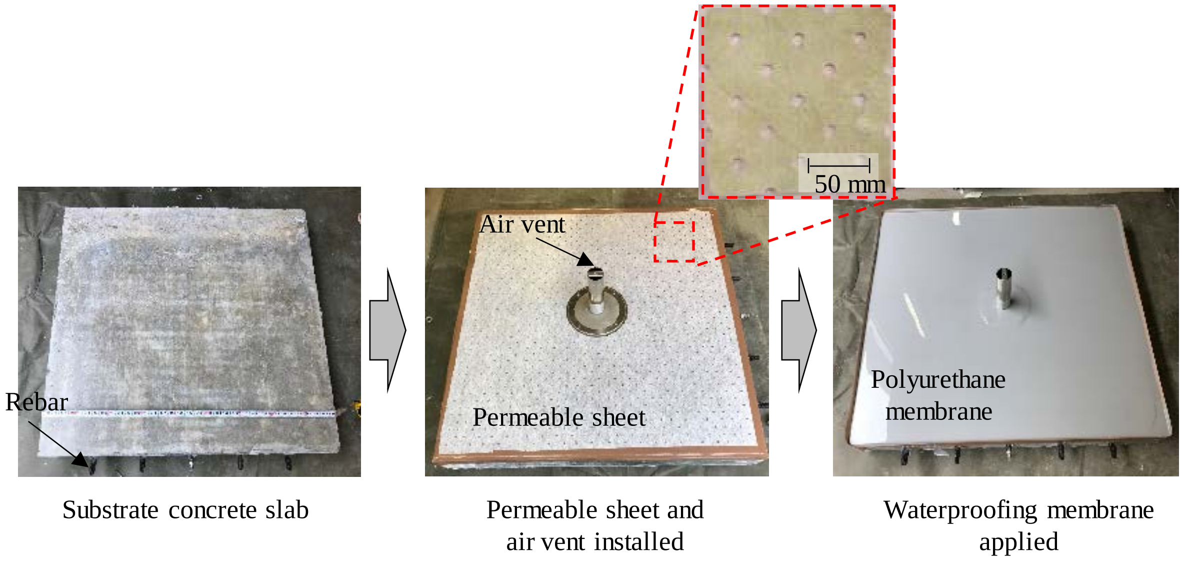


Figure 3: Preparation of concrete sample

with only the polyurethane membrane – without the permeable sheet – and 3) Concrete with both the permeable sheet and the polyurethane membrane. In addition to the 900×900×100 mm full size samples, some smaller samples, 100×400×100 mm, were made in order to follow mass loss by evaporation and internal pressure development.

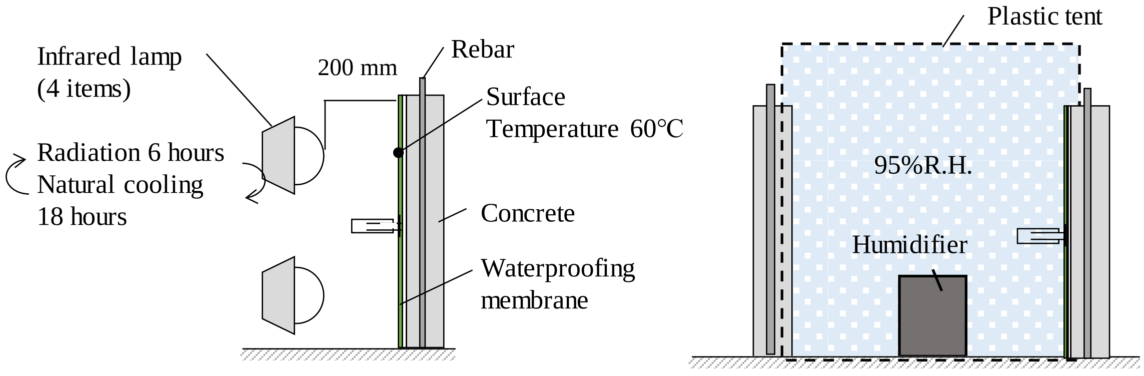
EXPERIMENTAL PROCEDURE

Exposure test under dry and high temperature condition

Standard or dark roof surface temperatures can reach 60°C or more in the summer sun of Japan. To reproduce such a high-temperature roof condition, a 500 W infrared lamp was installed about 200 mm from the concrete surface as shown in Figure 4 (a). The concrete surface temperature was heated to 60°C for 6 hours. Then, it cooled naturally for 18 hours in the laboratory with an average temperature of 16°C. Such daily heating cycles were carried out for 3 weeks, after which the samples were left in laboratory conditions.

Exposure test under moist condition

One important factor to consider for reinforcing steel bar corrosion is the moisture condition of the concrete. In general, the corrosion rate of the steel is low in dry concrete. And close to saturated condition the corrosion rate is also low due to slow transport of oxygen. When the moisture content of



(a) Dry and high temperature exposure condition (b) Humidity exposure condition

Figure 4: Exposure test condition

concrete is at a certain intermediate value, the corrosion rate is at its maximum [4], [5]. After the exposure test under the high temperature condition, test samples were left in a normal indoor environment for 10 months and dried. These test samples were subsequently exposed to humid conditions at an average temperature of 16°C, 95% RH as shown in Figure 4 (b).

Measurement of corrosion rate using electrochemical indexes

In order to determine the corrosion state, the half-cell potential and the polarization resistance of the steel bar, as well as the concrete resistivity were measured by electrochemical techniques. The working electrode was the steel rebar in concrete, the reference electrode was a silver/silver chloride (Ag/AgCl) and the counter electrode was titanium. The measurement point without epoxy resin was installed at the back surface of the test samples at the center of the reinforcement bar, and the measurement was carried out as shown in Figure 5.

Measurements were made on all five steel bars. The results are shown for the position right under the air vent as well as average values for two points at 150 mm from the air vent and two points 300 mm from the air vent. For the test samples without the waterproofing membrane and direct coating method, the results are shown as average values for all five reinforcing steel bars.

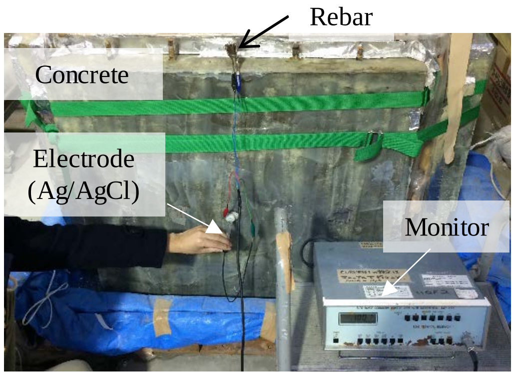


Figure 5: Measurement of corrosion rate using electrochemical indexes

EXPERIMENTAL RESULTS AND DISCUSSION

Steel bar corrosion rate at exposure in dry and high temperature condition

The half-cell potential of all 3 samples was measured on an approximately weekly basis throughout this part of the exposure period, see Figure 6. Negative values of potential were measured from the first measurements, and changed in the noble direction in all test samples during the exposure period. This indicates that the corrosion probability decreases when RC member are exposed to the drying condition.

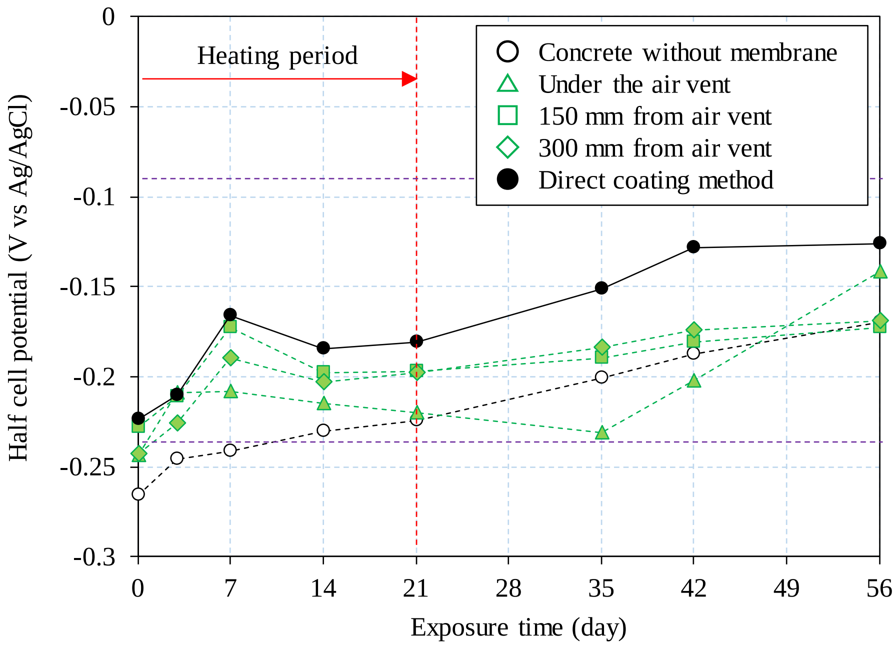


Figure 6: Development of half-cell potential of steel bars in concrete under drying condition

Concrete directly coated with membrane showed the best performance in respect of half-cell potential during the 8 weeks exposure to drying. The influence of the distance of reinforcing steel bar from the air vent was modest.

During the experiment, measurements were made of the amount of water evaporating from the concrete and the water vapor pressure between the membrane and the concrete. Compared with the concrete without membrane, the amount of water evaporated was reduced to 1/3 for the concrete with direct membrane coating and 1/2 for the concrete covered with a permeable sheet and membrane. The water vapor pressure between the waterproofing membrane and the concrete was measured during heating and natural cooling tests with an embedded manometer, see Figure 7. While the pressure of concrete with direct membrane coating increased to 10 kPa during heating, the pressure of the concrete with the air permeable sheet was close to 0 kPa. This shows that the pressure build-up between the membrane and the concrete is completely released by the permeable sheet, so that the waterproofing membrane is effectively prevented from blistering. Also, the concrete with the air permeable sheet, prevents the negative pressure build-up which is generated during natural cooling after heating, so that in this case air will enter from the outside environment. No blistering of the waterproofing membrane has been observed in this situation, but it may be due to the short test period.

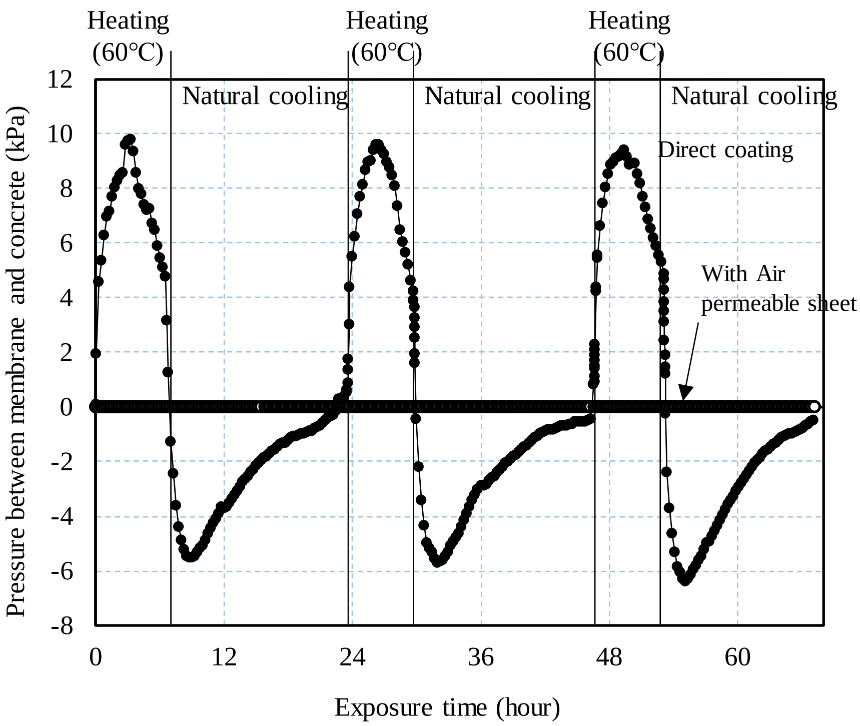


Figure 7: The water vapor pressure between surface membrane and concrete

The moisture condition of concrete affects the corrosion of reinforcing steel bars. Since the membrane applied to the surface of the concrete, blocks both moisture evaporation from the concrete as well as prevents penetration of oxygen from the environment to the concrete, it indicates that the blockage of oxygen supply has a greater effect than reduction of the moisture content of the concrete. The change in half-cell potential during the initial 1 week of heating may be caused by evaporation of water, whereas the slower, subsequent development in half-cell potential may be controlled by oxygen transport. This may be due to the very high initial water content of the concrete. It is probable that the influence of oxygen was less significant because even concrete without membrane was not sufficiently dried during this test period and retained the necessary water to cause corrosion of the reinforcing steel bars. In Figure 8, the initial value (Time = 0), is the data prior to the start of the wet environment exposure test. These values were measured after drying for 1 year. At this time the half-cell potential of all test pieces were more noble than the value after 56 days drying exposure in Figure 6. Even among those, it indicates that the value of concrete without membrane was most noble. As a consequence of the test samples being exposed to long-term drying, the half-cell potential of concrete without membrane and concrete with direct coating of membrane were reversed.

The ASTM standard C876-91 [6], provides general guidelines for the interpretation of the half-cell potential data. According to these guidelines, the probability of corrosion of the reinforcing steel bar is less than 10% if the potential is greater than -0.09 V, whereas potential values lower than -0.24 V indicate a high probability (> 90%) that corrosion is active. Half-cell potential values between these limits indicate areas where the corrosion activity is uncertain.

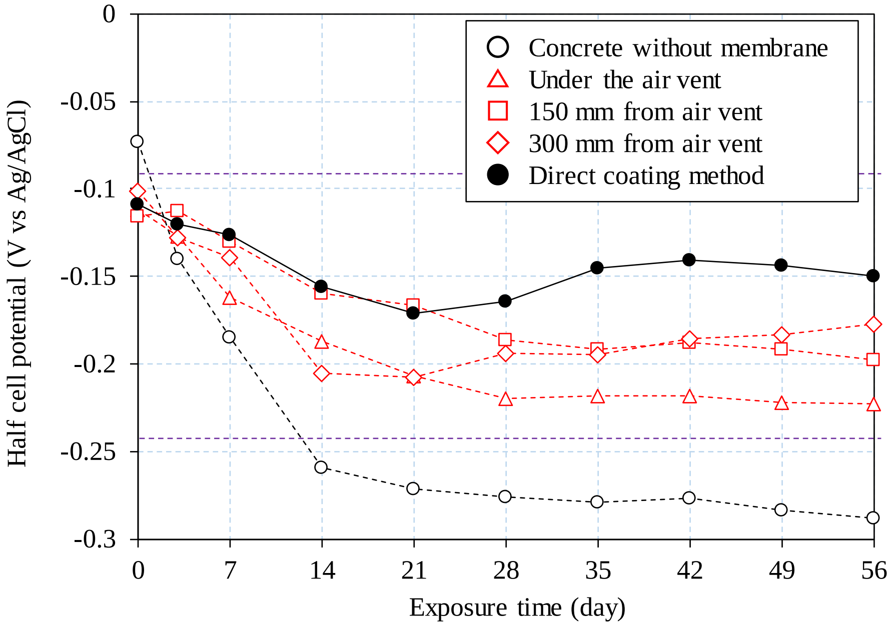


Figure 8: Development of half-cell potential of steel bars in concrete under moist condition

Steel bar corrosion rate exposure in moist condition

Figure 8 shows the results of test samples exposed to a wet environment with 95% RH. During the first 2 weeks of exposure, the half-cell potentials of all test samples shifted in the negative direction. After these 2 weeks of exposure, values remain constant for all test samples. The value for concrete without membrane became lower than -0.24 V, which indicates the possibility of corrosion of reinforcing steel bars. On the other hand, the value for concrete with direct coating of membrane was about -0.15 V during the exposure period of 2 months. The half-cell potential of the reinforcing steel bar right under the air vent in concrete covered with the permeable sheet and the membrane was -0.22 V, which was lower than the value of reinforcing steel bars at 150 mm and 300 mm positions from the air vent. This is because it takes time for the moisture and oxygen to be transported through the air vent and the air permeable sheet and reach the concrete.

The concrete resistance is shown in Figure 9. Concrete resistance is affected by the composition of concrete, the pore structure and the ions in the pore solution. Since concrete test samples are cured for more than one year, and there is no penetration of ions from the outside environment, it is assumed that the concrete resistivity decreased due to the change in moisture content of concrete [7]. The low value for concrete without membrane was due to a higher water absorption. As for the resistivity of the concrete covered with the permeable sheet and the membrane, the value right under the air vent was the lowest, and it seems that moisture is supplied through the air vent, increasing the concrete moisture content.

For the corrosion rate measurements, the concrete test pieces were broken after exposure to wet condition at 56 days. The visual observations of the corrosion of reinforcing steel bars inside the concrete are shown in Figure 10. Based on the visual observation, reinforcing steel bar in concrete without membrane had the largest corrosion areas 21%, the direct coating with membrane of concrete had the smallest corrosion areas 3%, and concrete covered with a permeable sheet and membrane had a moderate corrosion area 5%. This is in agreement with the half-cell potential measurements described above. In order to inhibit the corrosion of reinforcing steel bar, applied waterproofing membrane is effective regardless of the moisture content of concrete and the external humidity environment. Especially, the surface protection is an effective method when external water supply is expected. In addition, surface protection is an effective method for extending the life of existing structures, because even concrete with a certain amount of Cl^- (5.0 kg/m^3) it is effective in inhibiting corrosion of reinforcing steel bars [8]. In concrete covered with a permeable sheet and membrane, since the outside air is allowed to enter through the air vent, the inhibiting effect of the reinforcing steel bar is reduced.

Electrochemical removal of chloride is an effective method to extend the service life of existing reinforced concrete structures. However, concrete treated with this method is likely to have a high water content and a high pH, and it will thus be difficult to apply normal surface protection materials. In such situations, the adoption of an air permeable sheet with a top membrane may be operational.

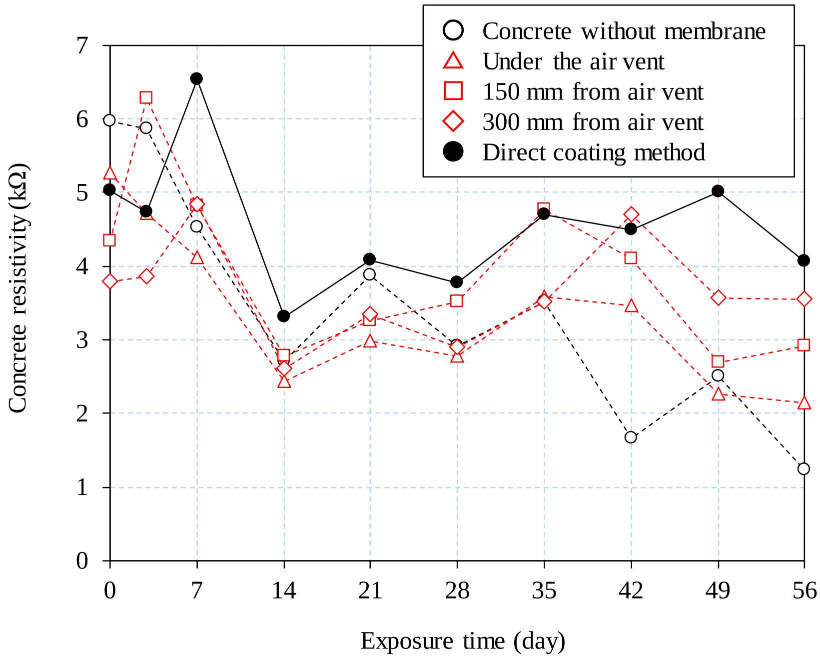


Figure 9: Development of concrete resistivity of steel bars in concrete under moist condition

(a) Without membrane

(b) Membrane with permeable sheet

(c) Direct coating with membrane

Figure 10: Corrosion rate of reinforcing steel bars in concrete

CONCLUSIONS

1. In the dry environment, the half-cell potential shifted to a noble direction in all test samples with or without membrane. The direct coating with membrane of concrete showed the most noble value, and it seems that in the case of relatively high moisture content concrete, the oxygen barrier properties of the membrane had a stronger effect on the corrosion rate of reinforcing steel bar than the evaporation of moisture from concrete.
2. The direct coating with membrane for concrete showed the highest value of half-cell potential in moist environments. The barrier properties of moisture and oxygen supply from the outside of the waterproofing membrane seems to contribute to the inhibition of corrosion of reinforcing steel bars. It is already known that surface protection of concrete is effective to prevent ingress of Cl^- into the concrete and thus reaching the reinforcing steel bar. But even if the Cl^- concentration in the concrete at the surface of the reinforcing steel bar exceeds the corrosion threshold (5.0 kg/m^3), the corrosion rate will be lower when a waterproofing membrane has been applied.
3. In the case of concrete with air permeable sheet and air vent, the influence of moisture transportation from the outside through the air vent into the concrete cannot be ignored. In Japanese roof structures, the air vent is installed in structures in an amount of 1 in 20 per 100 m^2 . Compared with this, the sample examined in the present study was very small, 1 m^2, and well-supplied with one air vent. Since the influence of the external environment is substantial, the set-up needs to be tested in a more challenging environment. So far, the design method with air vent and air permeable sheet is focused on release of moisture and pressure from the substrate concrete. When protective performance of the membrane systems is required, it is not always better to have high air permeability. More research is thus needed regarding these systems.

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