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Distribution of Cathodic Protection Potential for Concrete Slab Specimens at Diverse Environmental Conditions

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Abstract

This study represents the recent laboratory results from cathodic protection (CP) system with the use of sacrificial anodes at different environmental conditions (temperature of 10℃ and 40℃). Specimens were slab type with a dimension of 500mm × 50mm × 100mm, and concrete cover thickness were 25mm. Zinc mesh and/or bulk type anodes were installed at the center of specimen to confirm the distance that CP system has influences on the specimen to distribute uniform CP current to rebar. Two different kinds of temperature condition were applied to verify the effect of temperature. Experiments were conducted for 60 days, and the distribution of potential and current that supplied from anode to rebar was measured. From the results, CP potential was varied with time, and temperature played an important role in CP potential variations. Current was also changed with time, and current distribution could be improved by installing additional bulk type anode.

Keywords: Cathodic protection, Concrete, Potential distribution, Sacrificial anode, Temperature

1. Introduction

Concrete has a very alkaline condition with high pH of 12-14. In this condition, steel in concrete forms a compact passive layer, which contributes to protect or mitigate corrosion reactions [1]. However, deterioration is occurred in severe environmental conditions, and ingressions of chloride and carbon dioxide are typical examples. These corrosion factors can initiate and propagate corrosion by decreasing pH of concrete locally or entirely [2]. Especially, chloride ion that can cause pitting corrosion is very critical in corrosion. Chloride ion that acts as catalyst in corrosion is not consumed in the reactions, but it helps a break-down of the passive film on the steel surface as shown in Fig. 1. If corrosion is initiated, follow reaction is occurred [3].

$$Fe2+ + 2OH- \rightarrow Fe(OH)2 \text{ Ferrous hydroxide} \quad (1)$$

$$Fe(OH)2+O2+2H2O \rightarrow 4Fe(OH)3 \text{ Ferric hydroxide} \quad (2)$$

$$2Fe(OH)3 \rightarrow Fe2O3\bullet H2O+2H2O \text{ Hydrated ferric oxide} \quad (3)$$

Most critical influence of corrosion is increases in volume. As reactions are processed, the volume of the steel/concrete interface is increased up to 6~7 times as shown in Fig. 2 [3], which leads to the cracking and spalling of concrete structures.

Specifically, in case of removing the damaged concrete that is anodic areas rather than cathodic ones, it is essential to patch the area. However, when patch is conducted, the patched area is changed from anode to cathode. This is because old structures' potential has been dropped constantly; however, patched areas' potential is relatively higher. Thus, rest areas changed to anode, which leads to corrosion of rest regions [3].

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Table 1. Mixed design of concrete specimens.

Gmax	Slump	Air	W/C
10mm	10cm	5%	0.5
Water	Cement	S	GA
210kg	420kg	845kg	752kg

* Gmax: Maximum size of coarse aggregate
GA: Coarse aggregate
S: Fine aggregate
W/C: Water cement ratio

To solve corrosion problem, various protection methods have been adopted, and the use of stainless steel rebar and CP system has been recognized as very impressive methods [4]. In particular, CP is an electrochemical technique to prevent or to mitigate the corrosion of steel in concrete exposed to conductive environments such as seawater [5]. There are two kinds of CP system i.e., sacrificial anode CP and impressed current CP. The principle of each CP system is identical; however, there are some differences. Sacrificial anode CP is one of protection method. To protect corrosion of rebar, more active metal such as magnesium, zinc, and aluminum was electrically connected to steel in concrete. The sacrificial anode CP has many advantages as used in concrete structure. Especially, sacrificial anode CP system is easy to install, not necessary a power supplier to supply current, and cost effective. Thus, this system has been widely utilized to protect corrosion in reinforced concrete structures [6].

However, uniform current distribution is one of most important factors when the sacrificial anode CP system was installed. In case of complex structures, it is difficult to obtain uniform current distribution because sacrificial anode has low driving energy. As a result, in this study, potential and current distribution was mainly dealt with and it was focused on the distance that CP system could have a positive influence on corrosion protection of specimens as sacrificial anode CP was installed at the center of reinforced concrete specimen. In addition, two temperature conditions were selected to confirm the effect of temperature.

2. Experimental Method

2.1 Specimen of Experimental Method

Fig. 3 shows specimens that were used in this experiment. Four specimens were manufactured, and specimens were concrete slab type with a base of 500mm × 500mm and a height of 100mm (Each two specimens were exposed to 10℃ and 40℃). Used rebar was a deformed type manufactured by a typical carbon steel with diameter of 10mm. Rebar was arranged as shown in Fig. 4, and total 20 rebar was used. Mixed design of concrete specimens was given in Table 1. Water cement ratio was 0.5, and coarse and fine aggregates were proportionally added to amount of cement and water. Concrete cover thickness was 25mm. Corrosion monitoring sensor was also installed to measure resistivity as shown in Fig 5. The monitoring sensor was consisted of working and counter electrodes (WE & CE), two probes (resistivity measurement), and thermo-couple, which was manufactured in order to measure potential, corrosion rate, resistivity, and temperature.

To begin with, casting was carried out excepted for the area where anode was installed. After casting of this portion, zinc mesh with a dimension of 50mm × 50mm and/or zinc bulk anodes with a dimension of 10mm × 50mm× 10mm were also installed at the center of specimen, and casting was also conducted. In addition, curing was conducted at room temperature of 20 ± 2℃ for 28 days. After curing, the specimens were corroded in salt water (15 wt.%) by weekly aging cycles for six months to create corrosion environment, which was conducted by wetting for four days and drying for three days.

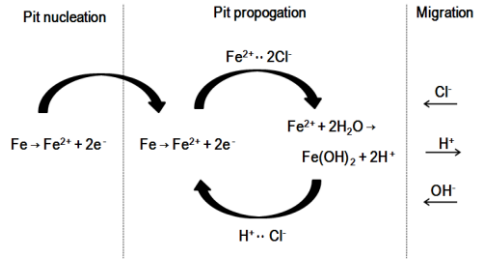

Fig. 1 Electrochemical reactions that lead to corrosion damage.

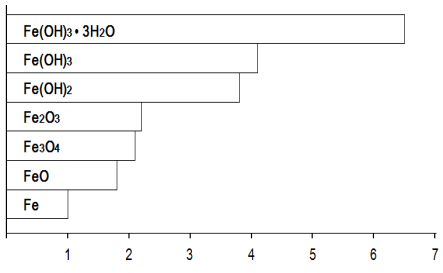

Fig. 2 Increases in volume of iron and its oxides [3].

Fig. 3 Specimen after anode was installed

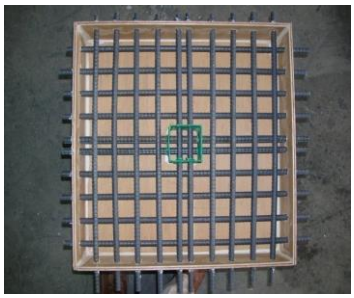
Fig. 4 Rebar and anode arrangement

Fig. 6 Test equipment in the experiment

2.2 Test Factors and Equipment of Experimental Method

Fig. 6 shows the used test equipment. Test factors were CP potential, CP current, resistivity, and 4-hour depolarization potential. CR-1212 Corrosion Monitoring Unit (CORREL Technology) was utilized to measure CP potential, CP current, and 4-hour depolarization potential. Used reference electrode was silver-silver chloride reference electrode (SSCE). To embody the temperature condition, Temp & Humidity Chamber (HANBAEK SCIENTIFIC CORPORATION) was used to identify the influence of temperature on specimens as sacrificial anode was applied. Resistivity was measured by means of corrosion monitoring sensor, which was conducted by connecting two resistivity probes of the sensor with resistivity meter (Nilsson Soil Resistivity Meter)

2.3 Experimental Procedures of Experimental Method

Experiments were conducted at different temperature conditions (10℃ and 40℃). Before controlling temperature, specimens were exposed to natural seawater for 10 hours without the connection to zinc anode. After 10 hours, zinc mesh was connected to rebar, and temperature was set. Measurement was conducted once a day, and total experimental period was 60 days. In addition, as potential measurements were conducted, natural seawater was removed for a short period of time.

Results

CP Potential Variations of Results

Fig. 7 shows the CP potential at different temperature of 10℃ and 40℃ after a day of CP application. As shown in Fig. 7, temperature played a significant role in CP potential variations. The higher temperature was, the lower CP potential of rebar was confirmed. In case of specimens exposed to 40℃, CP potential at the center of specimen (closed to anode) was about -930mV vs. SSCE; however, CP potential at the border of specimens was slightly higher, which was about -750 ~ -800mV vs. SSCE. In contrast, in case of specimens exposed to 10℃, CP potential at the center of specimen was about -750mV vs. SSCE. In addition, CP potential constantly rose, when distance from anode was increased, and CP potential at edge of specimens was about -590mV vs. SSCE. The potential of -590mV vs. SSCE was less than 100mV variation compared to no application of CP. From the results, it was confirmed that potential of sacrificial anode CP was highly influenced by the distance from anode.

Fig. 8 shows CP potential variation after 60 days of CP application at temperature of 10℃ and 40℃. As shown in Fig. 7 and 8, potential of specimen exposed to 40℃ was maintained to -930mV vs. SSCE at the center of specimen. In addition, at border of specimen, potential was dropped from -730 ~ -760mV vs. SSCE to -900 ~ -920mV vs. SSCE. This was thought that resistivity was reduced as temperature was increased. The increase in temperature affected the increase in the viscous flow of water, which dropped resistivity as shown in Fig. 9. In addition, CP current of specimen was increased through rises in temperature. In contrast, at temperature of 10℃, the CP potential drop was focusing on the center of specimen. Compared to center of specimen, CP potential did not changed in the border of specimen.

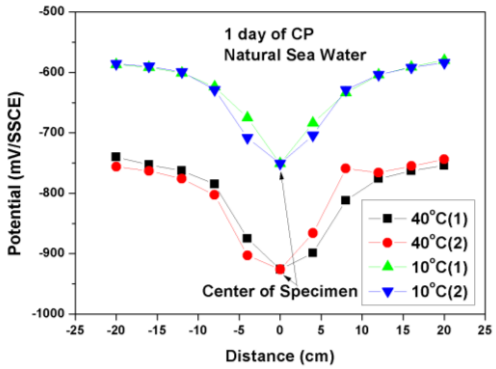

Fig. 7 Potential variations after one day of CP application at temperatures of 10℃ and 40℃.

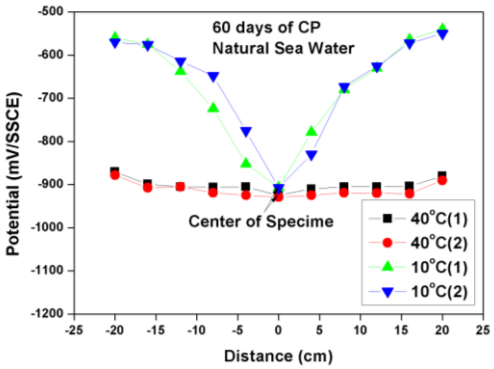

Fig. 8 Potential variations of 60 days of CP application at temperatures of 10℃ and 40℃

CP Current Variations of Results

Fig. 10 Shows the CP current variation before and after zinc bulk anode was applied. First of all, higher current was identified at temperature of 40℃ than that of 10℃. In this experiment, two times higher current was flowed on the specimen at temperature of 40℃. Compared to the results of potential variations, similar inclinations were also confirmed in the current result. In addition, as bulk anode was applied, higher current was supplied to rebar. In this case, 4~ 6 times higher current was supplied with the use of zinc bulk anode. Furthermore, with the used of zinc bulk anode, enough current was supplied to rebar that was hard to protect.

4-hour Depolarization Potential of Results

Depolarization tests were regularly carried out by disconnecting anode from rebar for four hours. In particular, in this study, 100mV depolarization criterion was applied to verify CP effect of specimens [7]. Fig. 11 shows the 4-hour depolarization potential after 60 days of CP application. At temperature of 40℃, specimens showed high depolarization more than 300mV. Some part of specimens exposed to temperature of 10℃ showed high depolarization potential more than 200mV; however, in rest portion about 10cm from center of specimen, it was confirmed that depolarization potential was less than 100mV. It was coincide to the results of potential results. From the results, it could know that to supply enough current to rebar, anode side, position, and arrangement were properly determined before the application of sacrificial anode CP. In order to solve the low depolarization problem at temperature of 10℃ in this experiment, anode size or capacity should be increased and/or additional anodes should be installed at the positions of 15cm far from center of specimens, which was meant that the distance between sacrificial anodes had to be lower than 15cm in order to obtain uniform potential distributions.

Conclusions

This study has been focused on the distribution of CP potential at diverse temperature conditions. From the experiment, follow results have been obtained.

1) CP potential was varied with time, and different inclination was confirmed at temperature of 10℃ and 40℃. In case of specimens at temperature of 10℃, potential was focused on the center of specimen. However, potential of specimens at temperature of 40℃ was uniformly lower, which was 900 ~ 920mV vs. SSCE.

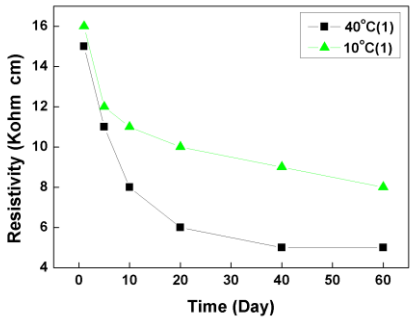

Fig. 9 Resistivity variations measured by the corrosion monitoring sensor after CP application at temperatures of 10℃ and 40℃

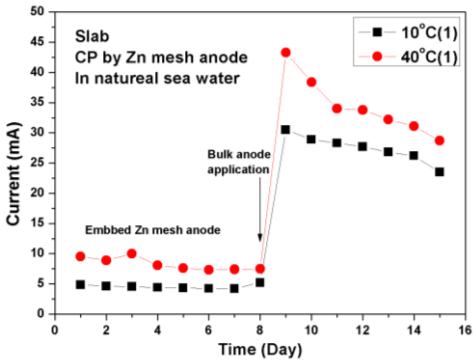

Fig. 10 CP current variations before and after the application of zinc bulk anode at temperatures of 10℃ and 40℃

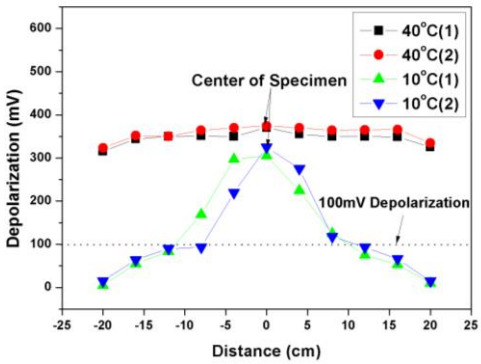

Fig. 11 4-hour depolarization potential after 60 days of CP application at temperatures of 10℃ and 40℃

2) Specimens at temperature of 40℃ were higher current supply to rebar than that at temperature of 10℃. In addition, as zinc bulk anode was connected, 4~6 times higher current was flowed to rebar.

3) At temperature of 40℃, depolarization potential was uniformly higher than 100mV. In contrast, in some areas, depolarization was less than 100mV at temperature of 10℃. To manage the problem, anode size and capacity should be increased, and additional anodes were installed with consideration of depolarization distribution.

4) In this case, the distance between sacrificial anodes had to be lower than 15cm, in order to obtain uniform potential distribution in reinforced concrete structures.

Acknowledgement

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