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Corrosion Characteristics of Reinforced Steel Bar Emedded in Multiple Mortar Specimen(W/C:0.5) Aged 5 Years in Seawater

Kyung-Man Moon[1] Oki Takeo[2], Jong-Pil Won[1], Dong-Hyun Park[1], and Yun-Hae Kim[1*]

[1]*Dept. of Marine Equipment Engineering, Korea Maritime University, Dong Sam-Dong, Yong Do-ku, Busan, Korea*
[2] *Nagoya University, Motoyama , Aichi, Japan*

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Abstract

Reinforced concrete structures have been increasingly widely used in numerous industrial fields. These structures are often exposed to severely corrosive environments such as seawater, contaminated water, acid rain, and the seashore. Thus, the corrosion problems that occur with the steel bars embedded in concrete are very important from the safety and economic points of view. In this study, the effects of the cover thickness on the corrosion properties of reinforced steel bars embedded in multiple mortar test specimens immersed in seawater for 5 years were investigated using electrochemical methods such as the corrosion potentials, polarization curves, cyclic voltammograms, galvanostat, and potentiostat. The corrosion potentials shifted in the noble direction, and the value of the AC impedance also exhibited a higher value with increasing cover thickness. Furthermore, the polarization resistance increased with increasing cover thickness, which means that the oxide film that is deposited on the surface of a steel bar surrounded by alkali environment exhibits better corrosion resistance because the water, chloride ions and dissolved oxygen have difficulty penerating to the surface of the steel bar with increasing cover thickness. Consequently, it is considered that the corrosion resistance of reinforced steel can be improved by increasing the cover thickness. However, the corrosion resistance values of a steel bar estimated by measuring the corrosion potential, impedance and polarization resistance were not in good agreement with its corrosion resistance obtained by polarization curves.

Keywords: Mortar specimen, Corrosion potential, Cover thickness, Polarization curves, Cyclic voltammogram, AC impedance

1. Introduction

The use of reinforced concrete structures in marine environments has been increasing in numerous industrial fields. These structures are exposed to severely corrosive environments such as onshore, offshore, and contaminated seawater conditions. Therefore, corrosion problems with the steel bars embedded in reinforced concrete are very important from the safety and economic points of view. In particular, the corrosion of embedded steel bars presents a more serious problem because of the use of sand mixed with seawater, and the fact that these concrete structures are often exposed to increasingly contaminated marine environments. In order to control these corrosion problems, the cover thickness and water-to-cement ratio(W/C) of the concrete seem to be very important. Numerous protection methods have been devised to control the corrosion embedded steel bars. For example, numerous studies have examined the corrosion of reinforced concrete[1-8], and others have examined the cover thickness, W/C

*Corresponding author. Tel.: + 82-51-410-4355, Fax.: +82- 51-410-4350
E-mail address: yunheak@hhu.ac.kr

ratio, and other parameters[9-13]. However, in a case where numerous mortar specimens are manufactured to examine corrosion properties, their physical and electrochemical properties may initially be different from each other because such specimens would generally be made under different environmental conditions, including the manufacturing time, room temperature, humidity, and the others. In this study, a complex body mortar specimen with a W/C ratio of 0.5 was fabricated with six steel bars embedded in the complex body at once, that is, these steel bars had different cover thicknesses respectively. Consequently, six types of mortar specimens were made with the same environmental conditions. Therefore, it is considered that the electrochemical properties of the steel bars in this complex mortar specimen could be correctly evaluated under the same conditions. In addition, after this specimen was immersed in natural seawater for 5 years, the effect of the cover thickness on the corrosion properties were investigated using electrochemical methods. The results obtained by these electrochemical methods and the application of complex body specimens may provide available data for evaluating the corrosion properties embedded steel bars. Furthermore, the complex body specimen may serve as good reference data in the design and for successful maintenance of concrete structures in marine environments.

2. Experimental Procedure

2-1 Production Of Test Specimens

The size of the molding box for the complex body test specimens was 37 cm x 20 cm x 17 cm. It was made of 1cm thick pieces of wood. Holes that were 1.5 cm in diameter were punched at distances of 2, 4, 6, 8, 10, and 12 cm from the upper side of the molding box, where the clearance of each hole was 5 cm. The length of each steel bar was 26 cm, and they had a diameter of 1 cm(Ø). The bars were polished with sand paper from No. 200 to No. 2000, degreased with acetone, and inserted into each hole of the molding box.

With exception of 1 cm^2 in the center area, the surfaces were insulated with silicon epoxy. The molding box was filled with mortar, which had a sand-to-cement ratio of 2:1, and a water-to-cement ratio(W/C)of 0.5. Fig. 1 shows the molding box with the inserted steel bars and a multiple mortar test specimen passed one month after the mortar was poured into the molding box. We used Portland cement made in Korea with the chemical composition shown in Table 1.

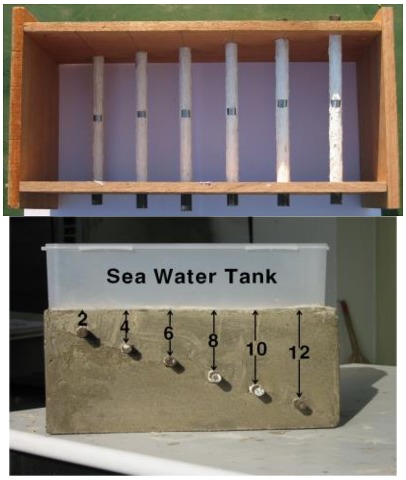

Fig. 1 Schematic diagram of mold box and multiple mortar test specimen

2-2 Experimental Method

Table 1. Chemical properties of Portland cement and a multiple mortar test specimen specimenspecimen(B).

Item	Chemical Composition						Ignition Loss (ig.loss)	Insoluble Residue
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3		
Portland Cement	21.0~22.5	4.5~6.0	2.5~3.5	36.5~66.0	0.9~3.3	1.0~2.0	0.5~1.3	0.2~0.9

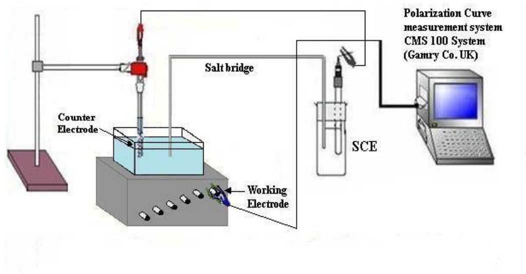

Fig. 2 Experimental apparatus for electrochemical measurements

The tank was established upper side of the multiple mortar test specimen, and it was filled with seawater for 5 years as shown in Fig.1. The seawater was replaced with fresh seawater once a month. After 5 years, the corrosion potential, polarization curve, impedance, and cyclic voltammogram were measured at the steel bar for each cover thickness using the experimental apparatus shown in Fig. 2.

3. Result and Discussion

Fig. 3 shows the corrosion potentials of the steel bars with different cover thicknesses for the mortar specimen with the W/C ratio of 0.5 after being immersed in natural seawater for 5 years. The corrosion potential of the 2cm cover thickness of was -0.387V(SCE), which was more negative than those of the other cover thicknesses, while the potential for the 12cm thickness was -0.063V(SCE). Moreover, it was observed that the corrosion potential shifted in the noble direction with increasing cover thickness. For example, we can see that the corrosion potential for the 12cm thickness shows a nobler value of 0.324 V than that of 2 cm thickness. As a result, it is considered that it was comparatively difficult for the water, dissolved oxygen, and chloride ions to penerate to the oxide film on the surface of the steel bar with an increase in the thickness because the cover thickness played the role of a barrier between the steel bar and seawater. It has generally been reported that there is a relationship between the corrosion potential and corrosion possibility for a steel bar embedded in concrete, as shown in Table 2[14]. Thus, from Table 2, we can expect that the thickness ranges of 2cm to 4cm and 6cm to 12cm indicate corrosion possibilities of 90% and 10%, respectively.

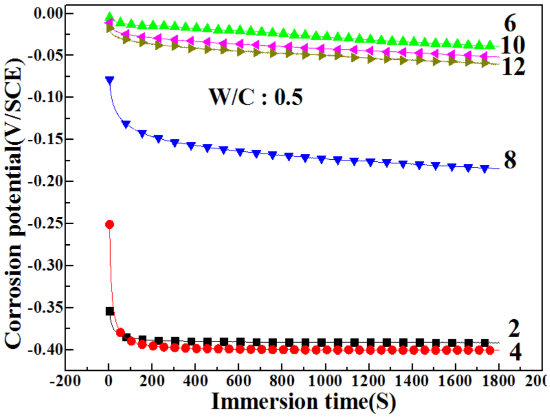

Fig. 3Variation in corrosion potential with cover thickness after being immersed in seawater 5ears

Table 2 Relation between corrosion potential and corrosion possibility

Thickness (mm)	Ecor (mV/SCE)	Corr. possibility
2	-387	90%
4	-400	90%
6	-38	10%
8	-175	10%
10	-56	10%
12	-63	10%

* ASTM, C876 : Ecor and Corro. Possibility 0~200mV: 10%, -200mV~350mV: 50%, -350mV~500mV : 90%

Fig. 4 shows a comparison of AC impedances and cover thicknesses after being immersed in seawater for 5 years. The AC impedance exhibited a higher value with increasing cover thickness, that is, the cover thicknesses of 2cm and 12cm exhibited the lowest and highest values of impedance at 0.1Hz, respectively. According to the potential-pH equivalent diagram[15], an oxide film on iron can be produced in a strong alkali environment. Thus, this indicates that an oxide film formed on the surface of the steel bars due to the strong alkali environment caused by the hydration reaction between the cement and water(Cement + H_2O → Cement gel + $Ca(OH)_2$, pH:12~14), which would exhibit a better corrosion resistance, having a higher value of impedance with increasing cover thickness. However, the value of the impedance caused by the resistance of the cover thickness may be more or less involved in the total impedance.

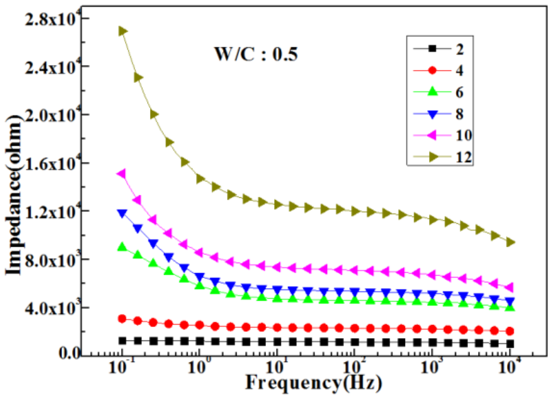

Fig. 4 Comparison of AC impedances with cover thicknesses after immersion in seawater for 5 years5ears

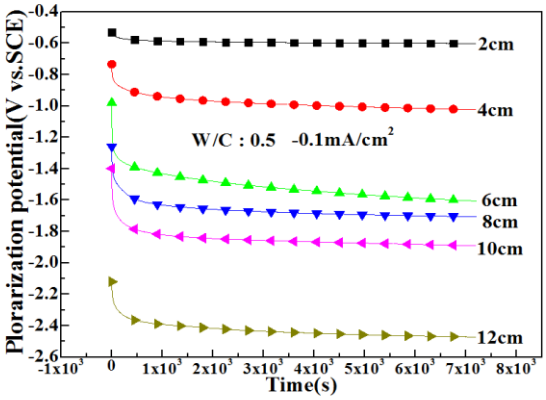

Fig. 5Variation in cathodic polarization potential at constant cathodic current density of 0.1mA/cm^2

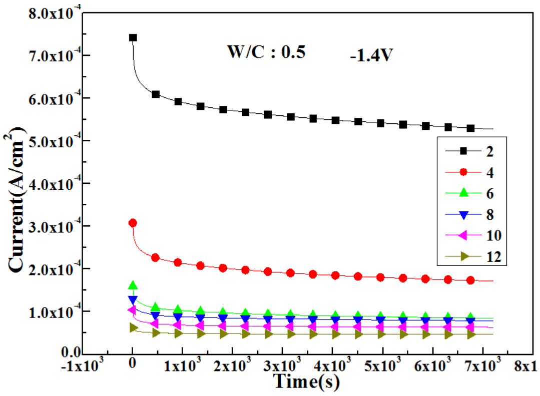

Fig. 6 Variation of cathodic current density at constant polarization potential of -1.4V -1.4Vortar test specimen (B).

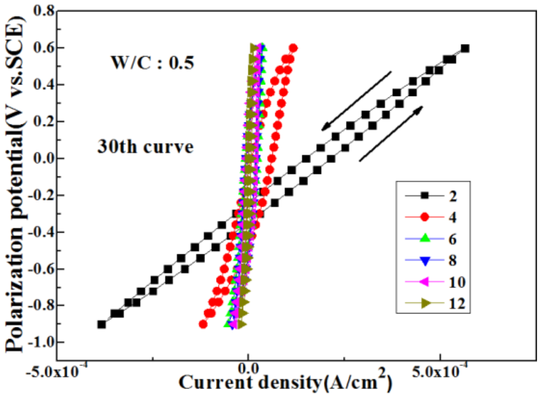

Fig. 7 Comparison of cyclic voltammogram curves with cover thickness in seawater

Fig. 5 shows the variation of the polarization potential with the cover thickness at a constant cathodic current density of 0.1mA/cm^2. As shown in Fig. 5, the polarization potential exhibited an increasingly greater negative value with increasing cover thickness. For example, the cover thickness of 2cm had a value -0.595V(SCE), while a polarization potential of -2.482V(SCE) was observed at a cover thickness of 12cm. The more negative polarization potential with increasing cover thickness is considered to be a result of an increase in the polarization resistance associated with the cover thickness, as well as the oxide film deposited on the surface of the embedded steel bar.

Fig. 6 shows the variation of the cathodic current density at a constant polarization potential of -1.4V(SCE).

The cathodic current density increased with decreasing cover thickness. Thus, we can see that the cathodic polarization potential contains a larger amount of polarization resistance with increasing cover thickness.Thus, from the results of Figs. 3, 4, 5 and 6, it is suggested that the polarization resistance on the surface of an embedded steel bar apparently depends on the cover thickness.

Fig. 7 shows a comparison of the cyclic voltammogram curves after immersion in seawater for 5 years. The cyclic curves for the cover thickness of 2cm and 12cm exhibited patterns that mostly declined to the right and left sides, respectively. It is generally well known that the corrosion resistance decreases or increases if the cyclic curves decline to the right or left sides respectively. Therefore, the results of Fig. 7 are considered to be in good agreement with the results of Figs. 4, 5, and 6.

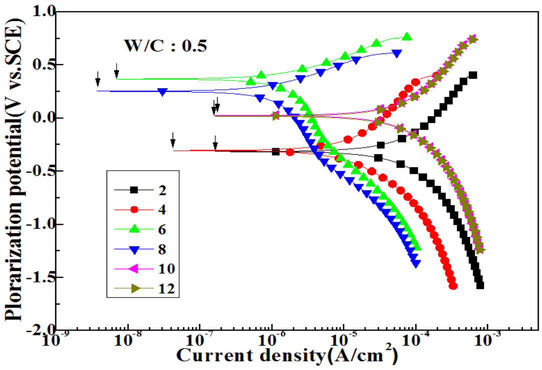

Fig. 8 Variation of polarization curves with cover thickness in seawater

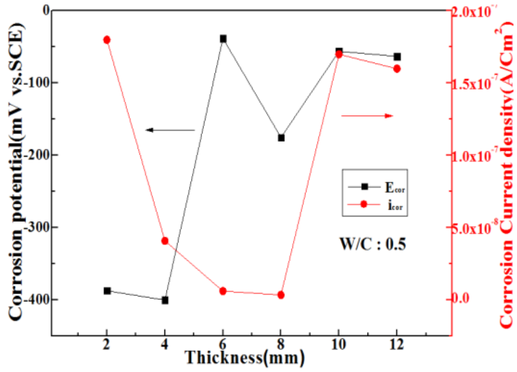

Fig. 9 Relationship between corrosion potential and corrosion current density.

Fig. 8 shows the cathodic and anodic polarization curves with the cover thickness. The arrows on the polarization curves indicate the approximate corrosion current density of the steel bar, which is equivalent to the corrosion potentials of the cathodic and anodic polarization curves. As shown in Fig. 8, the corrosion current densities for the cover thicknesses of 6 and 8cm had smaller values than those for the cover thicknesses of 10 and 12cm. Furthermore, the values for the cover thicknesses of 6 and 8cm are nearly the same as those for the cover thicknesses of 2 and 4cm. As a result, the cover thicknesses of 10 and 12cm exhibited qualitatively worse corrosion resistances than those of the cover thicknesses of 6cm and 8cm. Furthermore, their corrosion resistance are nearly the same as those for the cover thicknesses of 2 and 4cm.

Fig. 9 shows the relationship between the corrosion current density and corrosion potential. In the cases of thicknesses of 6 and 8cm, there are good relationships between the corrosion current density and corrosion potential, that is, the corrosion current density decreased with a nobler corrosion potential compared to the other cover thicknesses. However, the cover thickness of 4cm exhibited a smaller value of corrosion current density in spite of a lower corrosion potential, and the corrosion current densities for the cover thicknesses of 10 and 12cm increased with more noble corrosion potentials. Consequently, we can see that the corrosion resistances obtained by the polarization curves do not somewhat match the resistances predicted by corrosion potential measurements.

4. Conclusion

After a mortar specimen was immersed in seawater for 5 years, the corrosion resistances of reinforced steel bars embedded in it investigated using electrochemical methods. The corrosion potentials exhibited nobler and lower values with increasing and decreasing cover thicknesses respectively, and their polarization resistances calculated by impedance, galvanostat, potentiostat, and cyclic voltammogram also exhibited higher values with increasing cover thickness. Consequently, it is considered that the corrosion resistance of a steel reinforcing bar increases with increasing cover thickness. Thus, its resistance can be improved by increasing the cover thickness. However, the evaluations of the corrosion resistances estimated by measuring the corrosion potentials were not in good agreement with the corrosion current densities obtained by the polarization curves.

Acknowledgements

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