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DEVELOPMENT OF EMBEDDED MINI-SENSOR FOR DIAGNOSIS OF CORROSION OF STEEL REINFORCEMENT IN CONCRETE NONDESTRUCTIVELY

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Corrosion of steel reinforcement embedded in concrete is one of the main causes of degradation of reinforced concrete structures. Degradation occurs in reinforced concrete structures from corrosion caused by the Chloride ingress into concrete. That degradation has a severe impact on the structure in terms of maintenance and rehabilitation costs. Therefore, early detection of reinforcement corrosion is important for efficient maintenance, repair and planning. Meanwhile, the evaluation of the corrosion of reinforcement by non-destructive measurements have been used a lot. In particular CM-II (corrosion meter) is used to measure the polarization resistance, but has some disadvantages. Embedded mini-sensor has been developed in order to overcome these disadvantages. In this study, measurement of corrosion by using the mini-sensor is compared with the measured results by CM-II to verify the validity of the newly developed mini senor. Results show that there are agreement in trends of the parameters measured and as such the developed mini sensor has a promising start to be used.

Keywords: Structure, Polarization, NDT, Detection, Resistivity.

1 INTRODUCTION

Occurrence of corrosion in reinforced concrete structures begins at the inner surface of reinforced concrete. Therefore, when there is crack or rust on the concrete surface it means that the corrosion of rebar is considerably advanced. Corrosion of the embedded rebar in concrete has become a major cause of early deterioration and collapse of reinforced concrete structures (Seok 2008). Deterioration caused by corrosion that occurs in reinforced concrete structures causes enormous costs in terms of maintenance and rehabilitation of structures in addition to the time required that is also difficult to determine. Therefore, prediction and early detection of corrosion of reinforcement in concrete is critical for establishing effective repair plan (Song *et al.* 2009).

CM-II (corrosion meter) which can measure the polarization resistance is being utilized a lot. The principle of CM- II meter is to obtain the polarization resistance to diagnose the degree of corrosion from the AC impedance of the reinforcement in the concrete by calculating a corrosion rate (Mecater 2004). However, due to the fact that CM-II meter measures from concrete surface, there are some drawbacks that generate a number of errors in the measurements by the different environments of the concrete and that decrease the accuracy of the corrosion evaluation.

In order to overcome these problems, a proposed mini sensor attached to reinforcing bar in concrete is used. Although mini-sensor can be used to directly measure corrosion development of the steel surface in concrete; it is still in early stage of development and as such more research is needed.

2 EXISTING LITERATURE

2.1 Polarization Resistance Method

Polarization resistance method is practical because it can be applied in estimating the corrosion status in both laboratory measurement and on site. Table 1 shows the relationship between the polarization resistance and corrosion rate. High rate of corrosion can be evaluated when polarization resistance is low. Table 2 shows the criteria for evaluating the corrosion of the reinforcement according to the polarization resistance. It can be determined by measuring the polarization resistance, corrosion current density and the corrosion depth. On the other hand, the main electrical field is being utilized for the measurement of corrosion rate and chemical polarization method with a long measurement time DC polarization resistance and ac resistance (AC impedance).

Table 1. Relationship between polarization resistance and corrosion rate (BRE, 2001).

polarization resistance Rp (kΩcm^2)	corrosion rate
more than 250	passive state
250~25	low/middle
25~2.5	high
2.5~0.25	very high

Table 2. Corrosion of rebar by polarization (BRE, 2001).

current density of corrosion i_{corr},(μA/cm^2)	corrosion depth i_{corr},(μA/cm^2)	corrosion rate
Up to 0.2	Up to 2	passive/low
0.2 ~ 0.5	2 ~ 6	low/middle
0.5 ~ 1.0	6 ~ 12	middle/high
> 1.0	> 12	high

2.2 AC Impedance Method (A /C impedance)

AC impedance method is to measure the resistance when applying 10 ~ 20 mv (Alternative Current) on a specimen. The frequency of the alternating current is between 100 kHz ~ 1m Hz. Figure 1 shows a schematic illustration of the measurement method using CM- II. In the case of AC impedance measurements include measuring time is relatively long, and frequency response analysis device or a transfer function analyzer is required additionally, by the practicability requires less technical knowledge to interpret the test results.

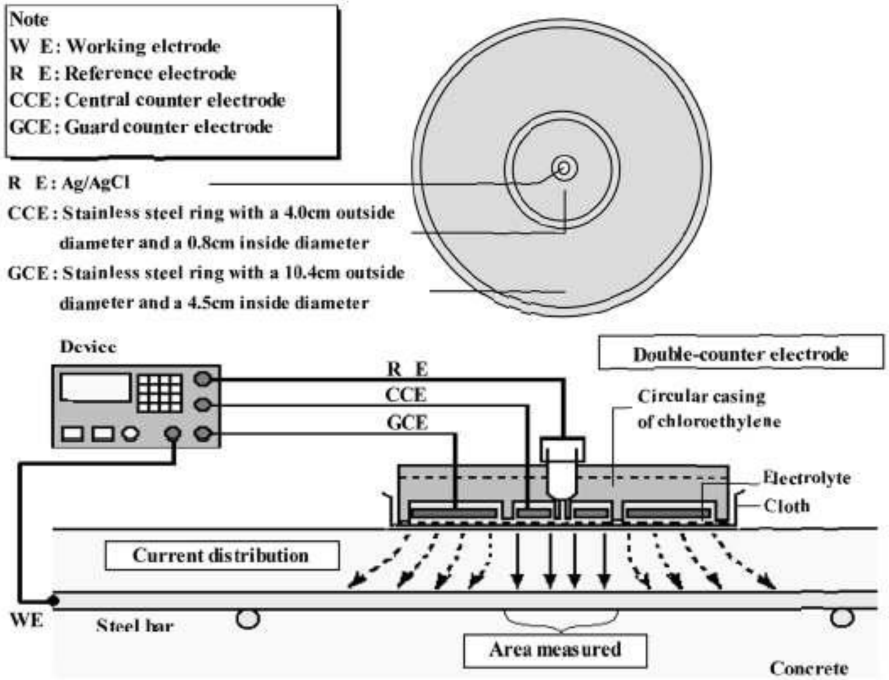
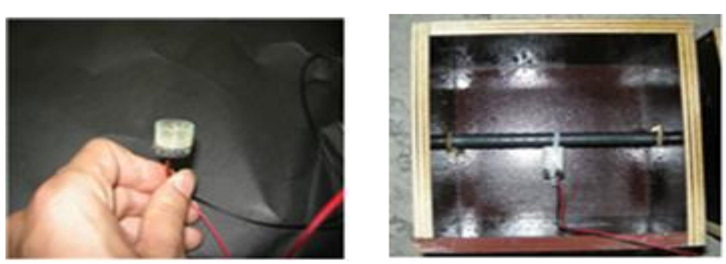


Figure 1. Measurement using CM-II.

3 OVERVIEW AND EXPERIMENTAL METHODS

3.1 Experimental Program

Mortar was used to fill in between mini sensor and rebar. Mortar made with cement and sand ratio of 1:2 and, W / C was set to 60%. The size of a specimen was 200 x 200 x 100 mm. from the specimen surface, reinforcement installed at depth of 20 mm. 13 mm diameter rebar was used. Settlement was reinforced by a cable tie to attach the sensor is integral with the reinforced mortar. Mini Sensors reinforced mounting process is shown in Figure 2. Figure 3 illustrates a measuring method and a shape. CM-II is measured at the concrete surface, and is embedded in a mini-sensor measures the specimens.



(a) Keep 5 mm depth (b) Adhere to rebar

Figure 2. Processing mini-sensor adhere to rebar.

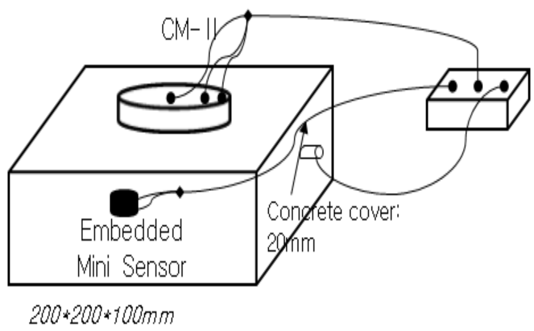


Figure 3. Measurement method and figuration.

Details of concrete mix proportions are shown in the Table 3.

Table 3. Concrete mix proportion.

W/C (%)	Unit weight (kg/㎥)			
	Water	Cement	Sand	NaCl
60	180	300	600	18

A humidity chamber was used to apply accelerated corrosion cycle. One cycle consists of RH 35% - 60 ℃ for 24 hours, and caught up after 24 hours at RH 95% -60 ℃ then measurement was done in the following 24 hours. Schematic diagram of accelerated corrosion cycle is shown in Figure 4.

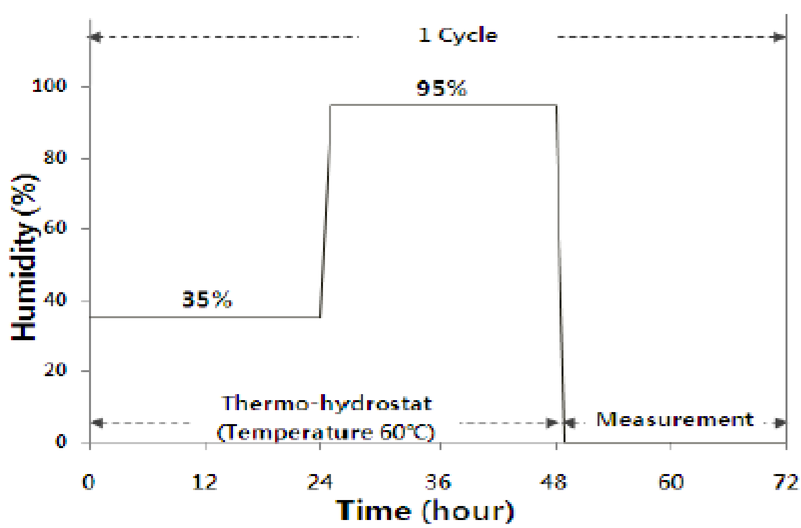


Figure 4. Condition of accelerated corrosion cycle.

3.2 Measuring Parameters

After promoting corrosion, CM-II (corrosion meter) measured the polarization resistance by an AC impedance method and also mini-sensor was used to measure the same parameter.

4 EXPERIMENTAL RESULTS

Figure 5 shows the corrosion of the reinforcement at the end of the experiments. While corrosion of the reinforcement is noticed, corrosion did not occur in the electrodes of the mini sensor. Mini sensor through which it was found that there is no problem caused by the corrosion of the electrode material for measuring the corrosion of rebar in a mortar.

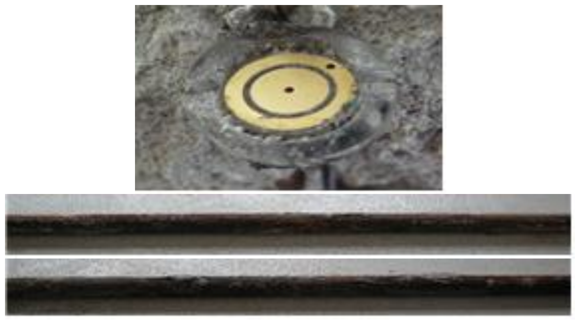


Figure 5. The status of rebar and mini-sensor at the end of experiment.

4.1 Polarization Resistance Measurements

Figure 6 shows the actual measurement data values of polarization resistance by CM-II. The frequency range of the measured data from the body between 10 Hz and 0.03162 Hz. The horizontal axis represents the real part (real) and the vertical axis is the imaginary part data appeared as (imaginary).

Each point on the plot was calculated for each data of the polarization resistance at the same frequency, the dotted part in the actually measured value and the data of each frequency, to shape the diameter (Nyquist Plot) of a semi-circular polarization resistance to the diameter of the semicircular polarization resistance Rp that was calculated.

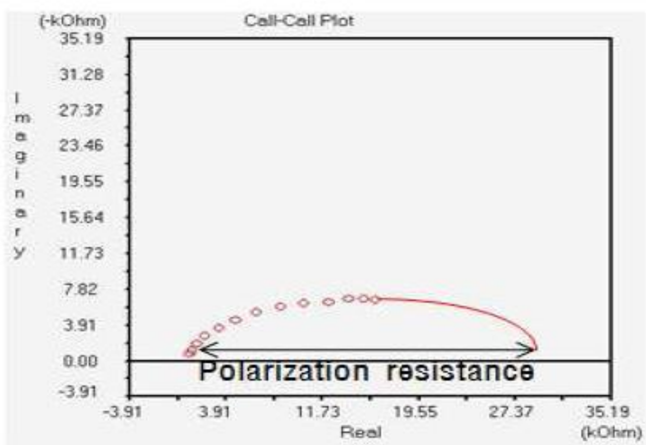


Figure 6. Actual measurement of polarization resistance.

Figure 7 shows the relationship between the polarization resistance obtained by the CM-Ⅱ and that obtained by mini-sensor. The correlation coefficient R^2 is 0.992.

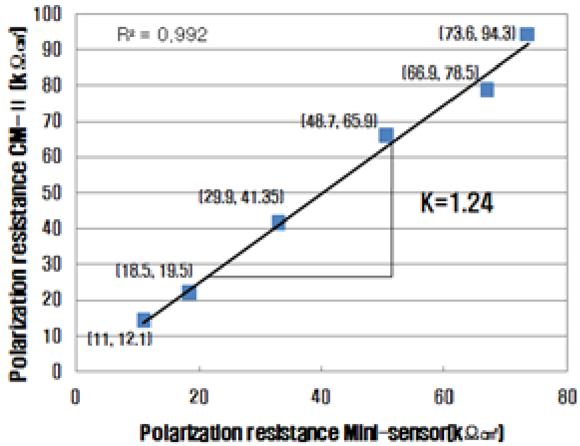


Figure 7. Polarization resistance correlation between CM-II and mini-Sensor.

5 CONCLUSIONS

This study was carried out by non-destructive corrosion promotion tests to verify the validity of measuring polarization resistance by CM-Ⅱ in comparison with the developed mini sensor. Results showed that polarization resistance can be measured by both technique and similar trend was observed.

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