CORROSION MONITORING USING EMBEDDED MINISENSORS ON REBARS IN CONCRETE REHABILITATED WITH A VCI

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ABSTRACT

Two series of tests were conducted using minisensors embedded in the vicinity of rebars in concrete, measuring the three electrochemical characteristics of natural potential, polarization resistance and electrolyte resistance, with the concrete cover effects minimized. Both corroded area and weight loss of rebars were also measured in each test.

In the first test, corrosion of rebars in concrete with chloride ion contents of both Okg/m^3 and $3kg/m^3$ under moist conditions were investigated. In the second test, rebars in both repaired with a volatile corrosion inhibitor (VCI) and unrepaired concrete containing $3kg/m^3$ chloride ion were investigated under accelerated alternately wet and dry conditions.

According to the interim test results, the following concluding remarks were obtained.
(1) The readings obtained by minisenors provided an effective basis for estimating the state, rate and environment of rebar corrosion.
(2) A volatile corrosion inhibitor (MCI 2020) showed the effectiveness of suppressing rebar corrosion chloride-contaminated concrete.

Keywords: rebar, corrosion monitoring, embedded sensor, minisenor, electrochemical characteristics, corrosion state, corrosion rate, corrosion environment.

INTRODUCTION

Development and testing of minisensors have been carried out for the quantitative evaluation of rebars in concrete structures [1]. The accelerated corrosion tests reported here have been conducted in order to investigate the effectiveness of a volatile corrosion inhibitor (VCI) on the rehabilitation of corroded rebars in chloride-contaminated concrete by means of corrosion monitoring using embedded minisenors. The minisenors were embedded in the vicinity of rebars in concrete specimens with chloride ion contents of Okg/m^3 and $3kg/m^3$, testing for rebar corrosion in a damp environment (Test 1). Further corrosion tests have been conducted in a corrosion-accelerating environment on corroded specimens from Test 1 with a chloride ion content of $3kg/m^3$ repaired by a contractor according to the manual, using a volatile corrosion inhibitor, and another set of unrepaired specimens (Test 2). As reported below, it was found as a result of these tests that there is a strong possibility of quantitative evaluation of the state, rate and environment of corrosion of rebars in concrete based on the measurements of electrochemical characteristics obtained by embedded minisensors. Furthermore, based upon not only these non-destructive monitoring measurements, but also destructive measurements such as corroded area and weight loss of rebars, it was also found that a volatile corrosion inhibitor (MCI 2020) showed the effectiveness of suppressing rebar corrosion in chloride-contaminated concrete. In this paper, the interim test results on the accelerated corrosion tests are shown.

TEST METHOD

Both test 1 and 2 were conducted as follows. Reinforced concrete specimens with a W/C ratio of 65% were prepared with two polished rebars of 13mm in diameter and 100mm long embedded horizontally with a concrete cover of 20mm and 30mm, respectively (see Figure 1).

Test 1: For corrosion monitoring, minisensors were embedded in the vicinity of rebars in concrete specimens with a chloride ion content of Okg/m^3 and $3kg/m^3$. The minisensors were embedded at a distance of 1mm from the top, bottom and sides of the rebars with a concrete cover of 2cm and 3cm (see Photos 1 and 2). The concrete specimens were demolded one day after casting of concrete, and monitored continuously at hourly intervals for 60 days while being kept in a damp environment at 20° C, relative humidity 100%.

Test 2: Specimens with $3kg/m^3$ chloride ion content prepared at the same time as the specimens for Test 1 were permeated with a VCI from the concrete surface after the 60-day initial curing (as in Test 1). These repaired specimens, together with unrepaired specimens, were subjected to alternately wet (40° C, 100% RH) and dry (50^oC, 30% RH)

curing in cycles of approximately one week. Corrosion monitoring was continuously carried out at two-hour intervals from the start of curing.

In both tests, control specimens prepared to confirm the corrosion state were broken open and the rebars were removed; the corroded area and weight loss were then measured.

TEST RESULTS AND DISCUSSIONS

Test 1

1) The natural potential measurements relating to the corrosion state were approximately OmV against the specific reference electrode of the minisensor and -200mV for the specimens with a chloride ion content of Okg/m^3 and $3kg/m^3$, respectively. Converted to silver-silver chloride reference electrode potential, these measurements give approximately -100mV and -300mV (details of potential conversion to be reported at a later date), which corresponded to the corrosion state in the extracted bars (see Figures 2,3.1 and 3.2).

2) The polarization resistance measurements relating to the corrosion rate showed different tendencies depending on the chloride ion content. In the specimens without chloride ion, the polarization resistance start at around 10k Ω and increased with time, whereas in the specimens with $3kg/m^3$ chloride ion, measurements repeatedly fell below 10k Ω, although showing an overall tendency to increase (see Figures 4.1 and 4.2).

3) The electrolyte resistance measurements relating to the corrosion environment showed different tendencies depending upon the chloride ion content.   The measurements remained more or less constant within a range of 1 ~ 5k Ω in the specimens without chloride ion, whereas in the specimens with 3 kg/m^3 chloride ion, low readings were found at the underside of the bars, with a marked variation depending on the location of the minisensor. This fact was thought to be due to irregularities in corrosive environment adjacent to rebars (see Figures 2, 5.1 and 5.2).

Test 2

1) According to the destructive test results, differences could be clearly observed between the repaired and unrepaired specimens in the form and extent of rebar corrosion after the accelerated curing (see Figure 6.1 and 6.2).

2) Based upon the weight loss measurements obtained from each two duplicate specimens, suppressing effects of the VCI on corrosion could be clearly identified in terms of corrosion rate (see Figure 7).

3) By means of non-destructive corrosion monitoring, above mentioned tendencies could be also observed as follows. Representative monitoring results on both repaired and unrepaired specimens with cover thickness of 2cm are shown in Figures 8.1, 8.2, 9.1, 9.2 10.1 and 10.2.

4) Natural potential readings were fluctuated between around -300mV and 100mV in both repaired and unrepaired specimens, however the differences between the two readings

could be clearly identified as follows: In repaired specimens, natural potential steadily increased with some fluctuations from the less noble values just after repairing to the noble values at around 600 days after repairing. On the other hand, unrepaired ones clearly showed a cyclic change of natural potential measurements (see Figures 8.1 and 8.2).

5) Polarization resistance readings fluctuated between around 0.01k Ω and 1000 Ω in both repaired and unrepaired specimens, however the differences between the two readings could be clearly identified as follows: In repaired specimens, the readings clearly showed an increasing tendency with time. On the other hand, in unrepaired ones, the lower readings of around 0.1k Ω have been continuously recorded at the early ages until an age of around 250 days. As a result of corrosion-accelerated curing, in all of the unrepaired specimens longitudinal cracks around 0.15mm in width appeared after approximately 200 days. The clear change in the readings of around 250 days after curing is thought to be due to these crackings (see Figures 9.1 and 9.2).

6) The electrolyte resistance readings fluctuated between around 0.01k Ω 1000 Ω in both repaired and unrepaired specimens, however the differences between the two readings could be clearly identified as follows: In repaired specimens, the readings clearly showed an increasing tendency with time with a few exceptions. On the other hand, in unrepaired ones, some lower readings less than 0.1k Ω were recorded at some time, such as just after the initial cracking at around 200 days, and at later ages of around 550 days (see Figures 10.1 and 10.2).

CONCLUSIONS

According to the test results, the following concluding remarks were obtained.
(1) The readings obtained by minisensors provided an effective basis for estimating the state, rate and environment of rebar corrosion.
(2) A volatile corrosion inhibitor (MCI 2020) showed the effectiveness of suppressing rebar corrosion in chloride-contaminated concrete.

REFERENCES

1.   K. Shimozawa, H. Tamura and M. Nagayama: "Rebar corrosion monitoring using embedded minisensor", Proc. of JCI Ann. Meeting, Vol. 16, No. 1, pp. 793 ~ 798, 1994.

PHOTO - 1   Rebar arrangement in a mold
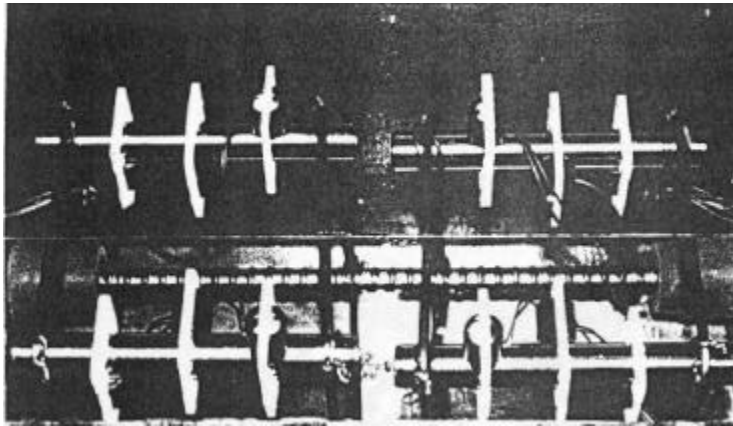
INTRODUCTION

In order to accurately monitoring rebar corrosion in concrete, embedded sensors are desirable not only for preventing concrete cover effect on monitoring measurement, but also for continuous long-term monitoring.

Minisensors can be installed in both newly constructed structures and existing ones. The sensors developed are only 10mm in diameter and 12mm in depth so they will never affect the durability of structures of the load carrying capacity. This paper reports one part of experimental results on rebar corrosion monitoring tests using embedded minisensors.

PHOTO-2 Minisensor attached to a rebar.
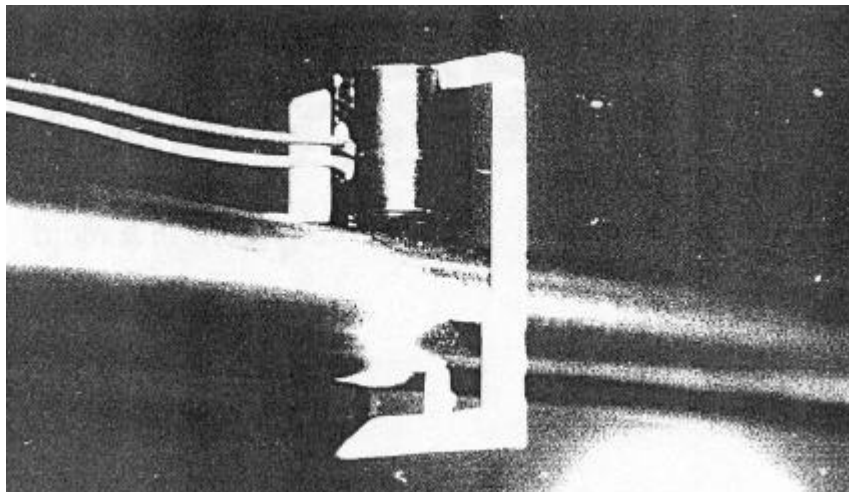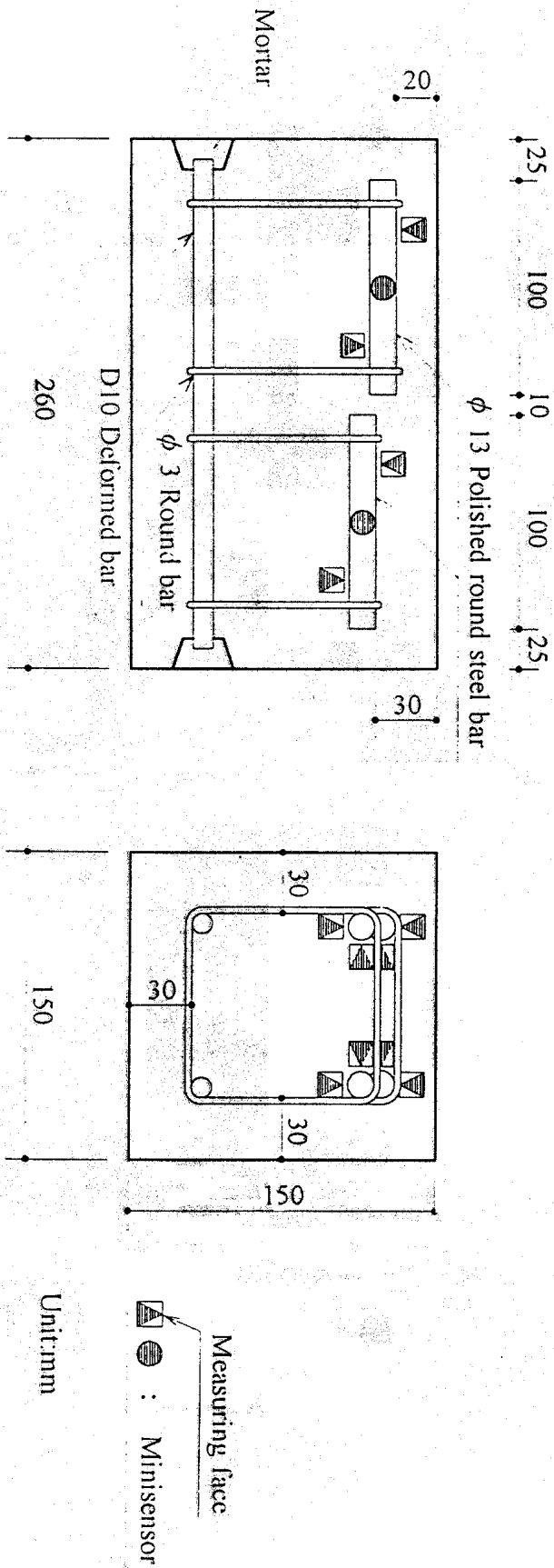
FIGURE-1   Reinforced concrete specimen

FIGURE - 2 Corrosion map after initial 60-day wet curing

Cover thickness=2cm
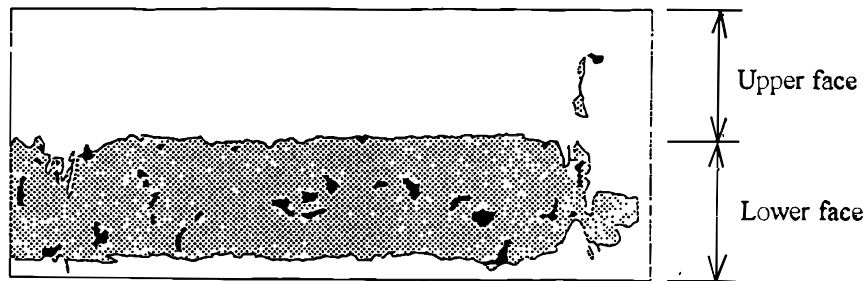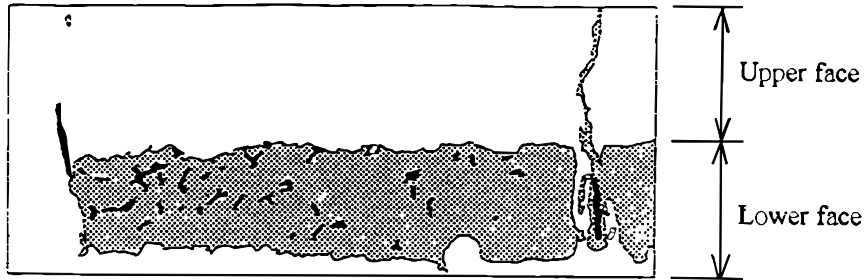
Cover thickness=3cm
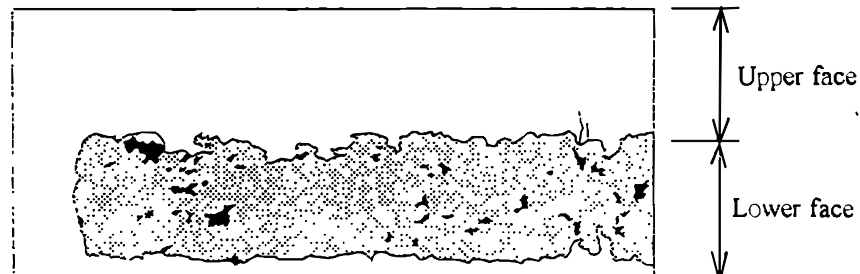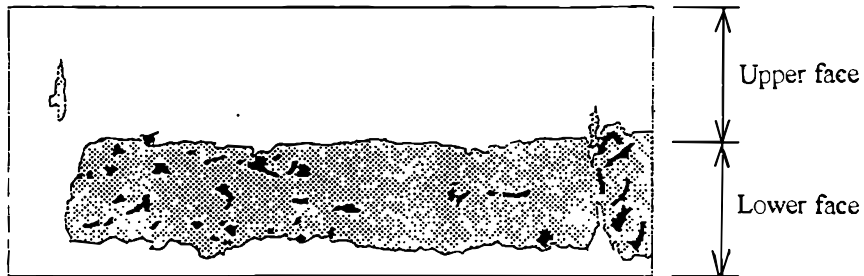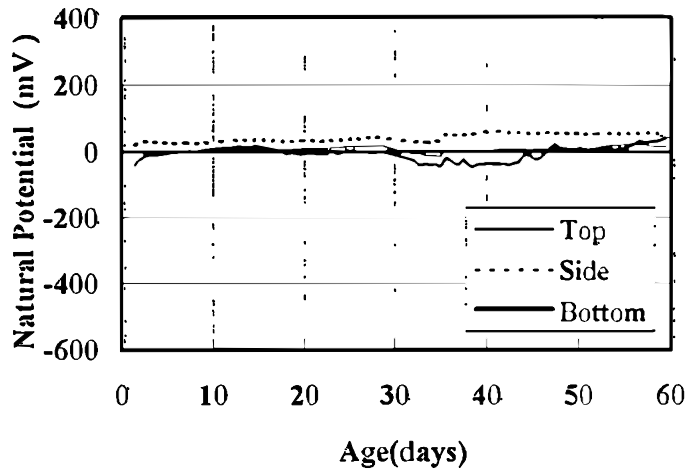
FIGURE-3.1 Changes in natural potential with time
(initial 60-days wet curing, Cl=0kg/m³,
cover thickness=3cm)
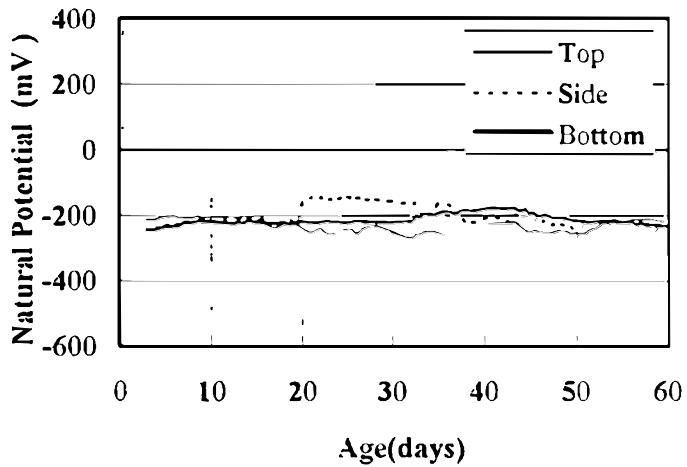
FIGURE-3.2 Changes in natural potential with time
(initial 60-days wet curing, Cl=3kg/m³,
cover thickness=3cm)
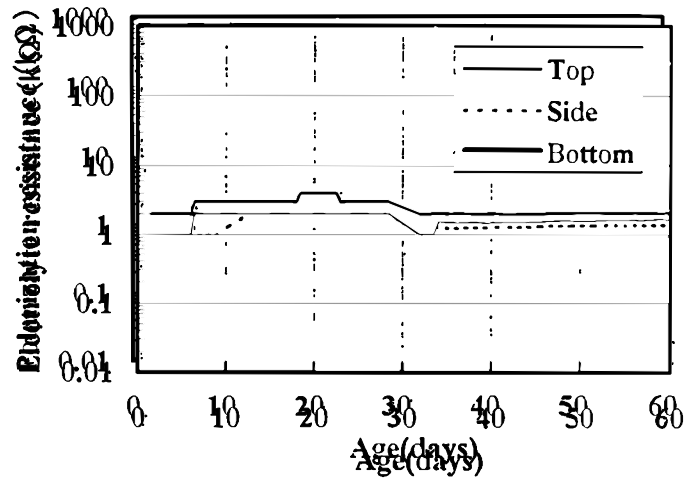
FIGURE=4.1 Changes in polarization resistance with time
(initial 60=days wet curing, Cl=0kg/m³,
cover thickness=3cm))
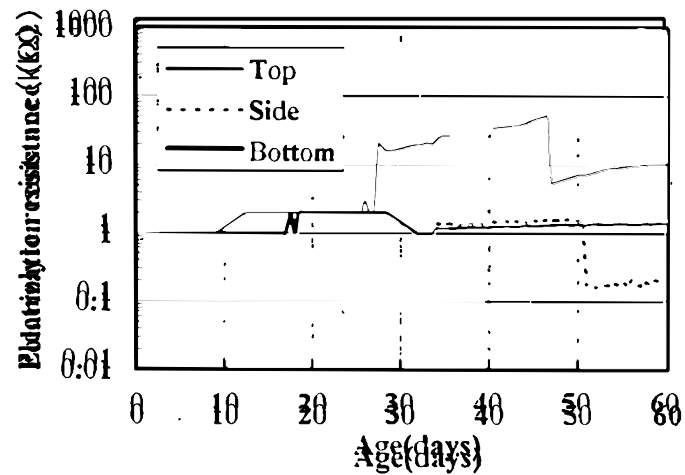
FIGURE=4.2 Changes in polarization resistance with time
(initial 60-days wet curing, Cl=3kg/m³,
cover thickness=3cm))

Cover thickness=2cm

Upper face

Lower face

Upper face

Lower face

Cover thickness=3cm

Upper face

Lower face

Upper face

Lower face
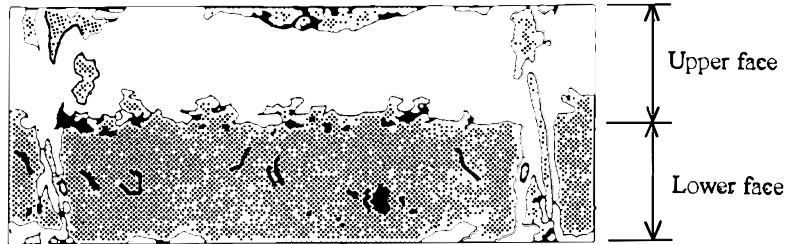
: General corrosion

: Pitting corrosion

FIGURE-6.1   Corrosion map of specimens repaired with MCI2020
(428-day alternately drying &wetting curing)

Cover thickness=2cm

Upper face

Lower face

Upper face

Lower face

Cover thickness=3cm

Upper face

Lower face

Upper face

Lower face
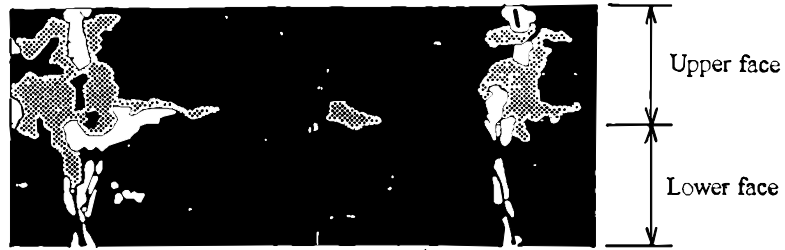
[ ] : General corrosion

[ ] : Pitting corrosion

FIGURE-6.2   Corrosion map of unrepaired specimens
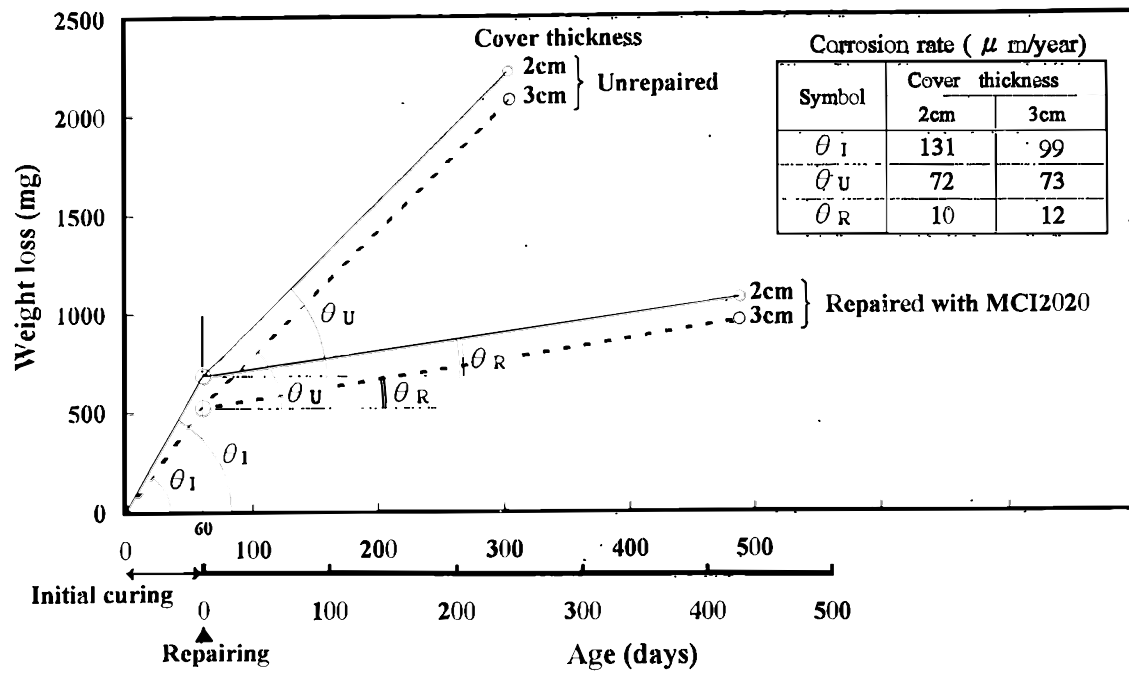   (243-day alternately drying &wetting curing)
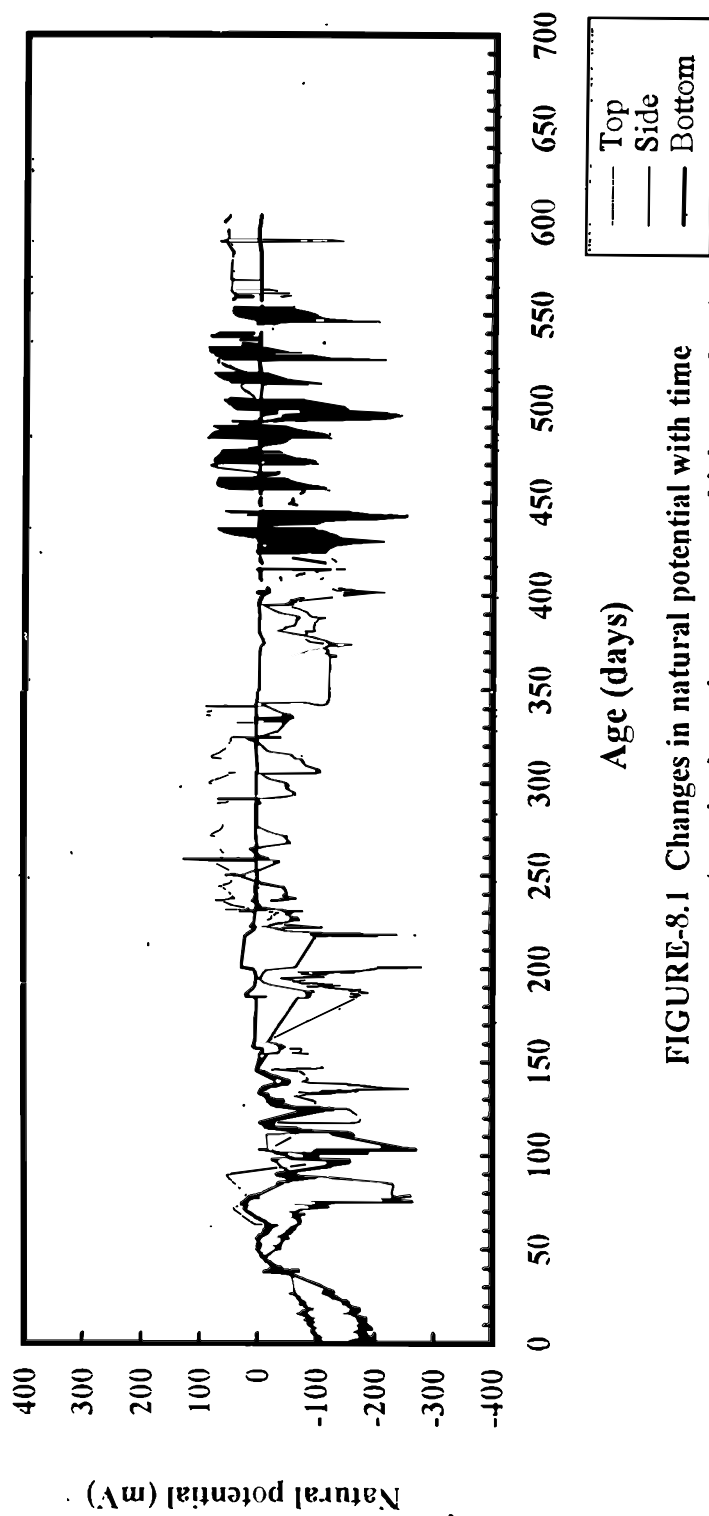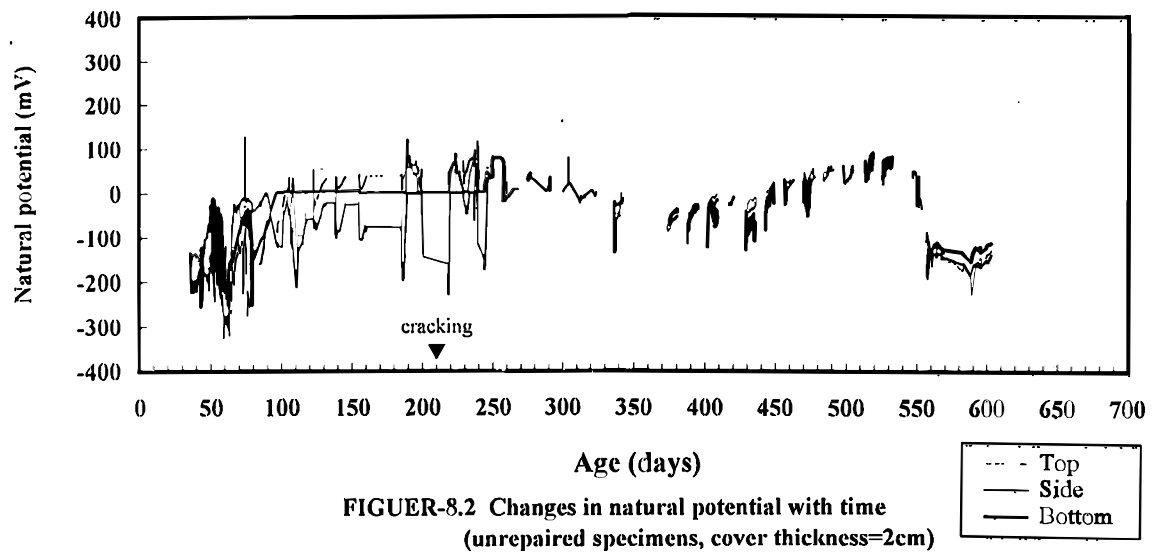
FIGURE-7   Comparison of corrosion rate

FIGURE-8.1 Changes in natural potential with time (repaired specimens, cover thickness=2cm)

Legend:
- Top
- Side
- Bottom

X-axis: Age (days) — 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700

Y-axis: Natural potential (mV) — 400, 300, 200, 100, 0, -100, -200, -300, -400

FIGUER-8.2 Changes in natural potential with time (unrepaired specimens, cover thickness=2cm)
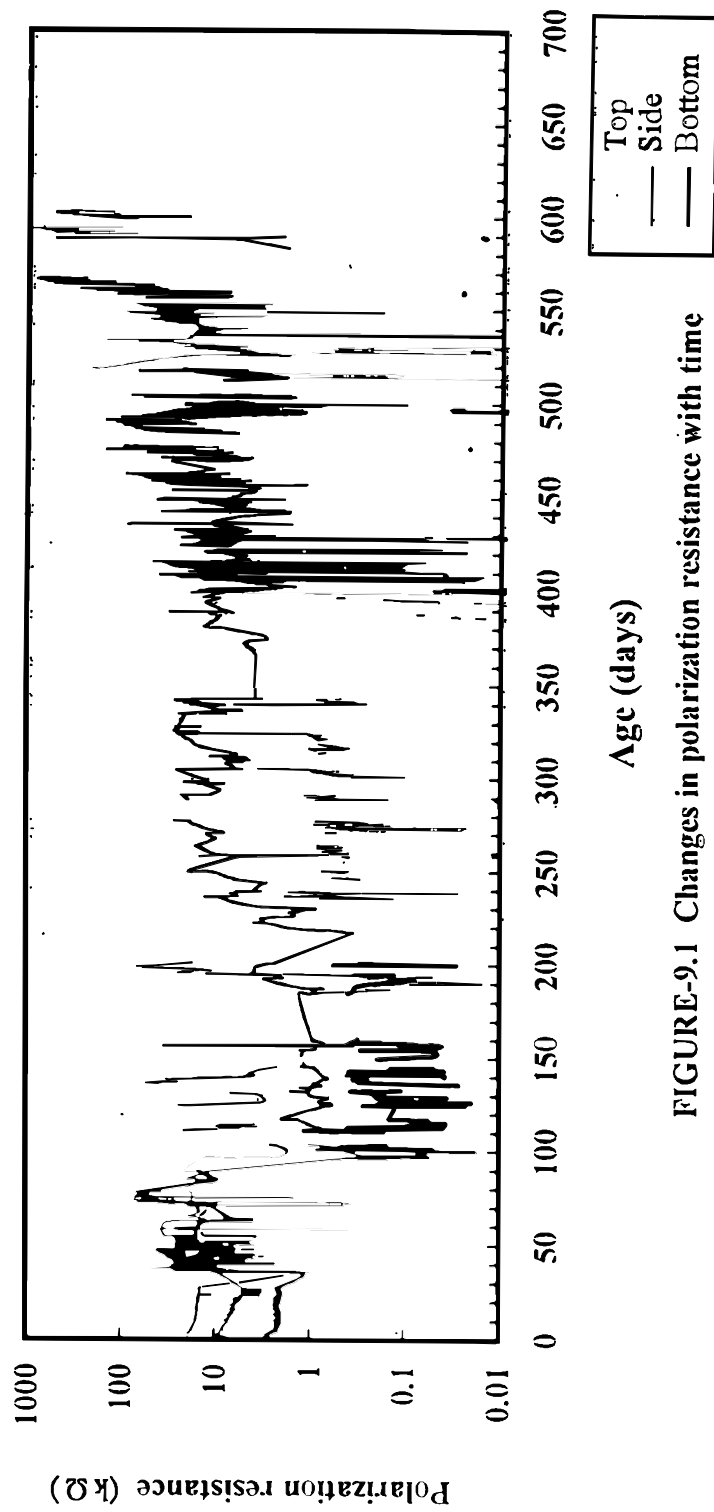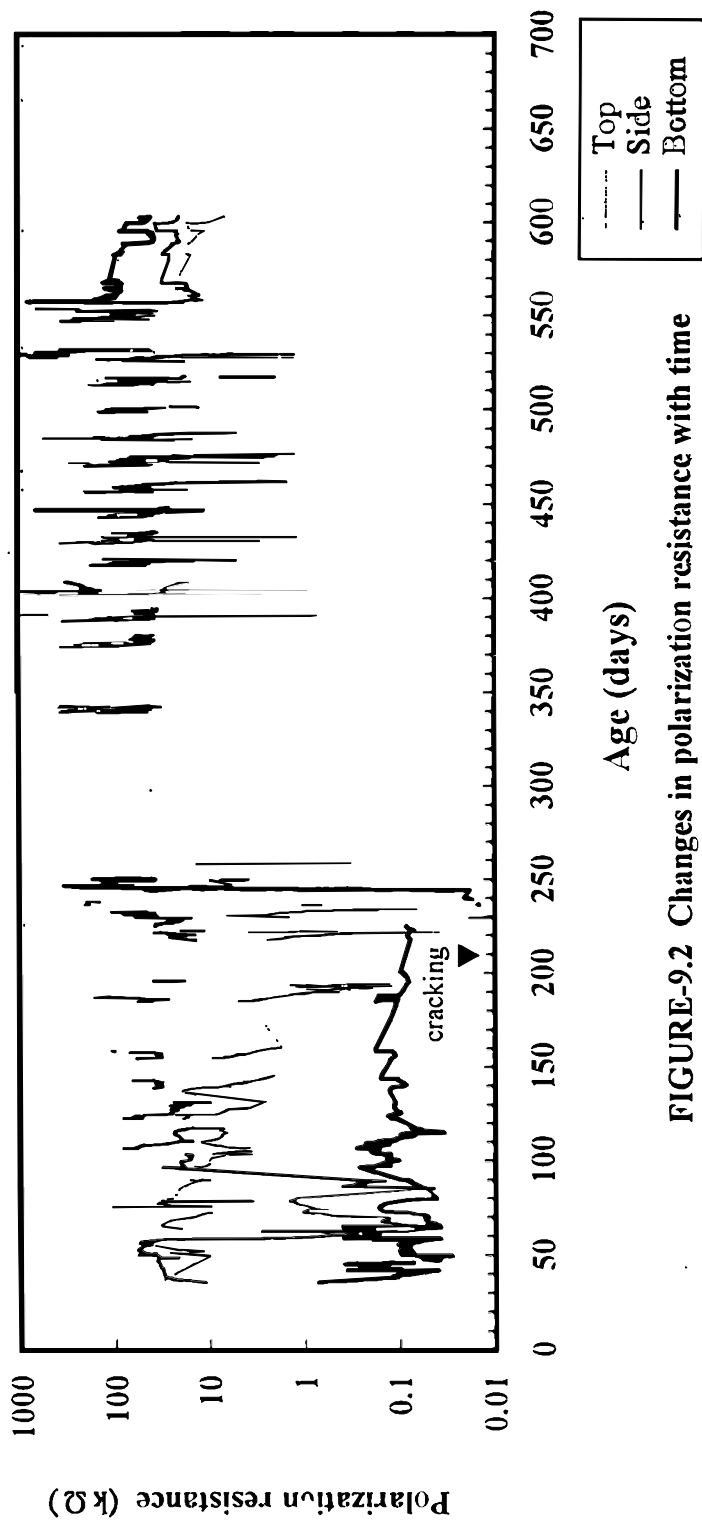
FIGURE-9.1 Changes in polarization resistance with time (repaired specimens, cover thickness=2cm)

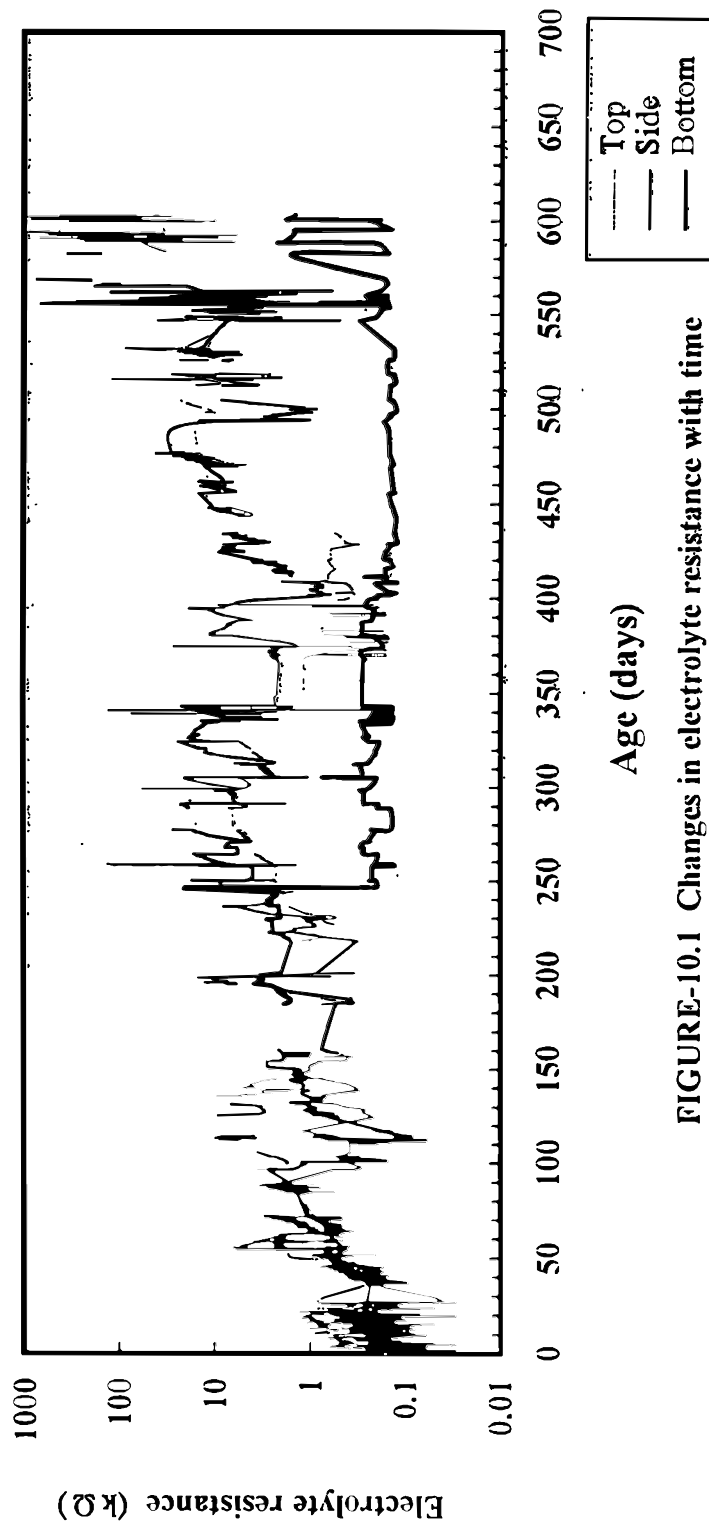**FIGURE-9.2 Changes in polarization resistance with time (unrepaired specimens, cover thickness=2cm)**

FIGURE-10.1 Changes in electrolyte resistance with time (repaired specimens, cover thickness=2cm)

1000

1

0.01

0

byte