Corrosion and Protection Monitoring by Use of Macro-cells in Concrete Structures

F. Pruckner[1]

Protector AS
N- 3408 Tranby, Norway

O.E. Gjørv[2,†]

Norwegian University of Science and Technology- NTNU
N-7934 Trondheim, Norway

ABSTRACT

In order to carry out corrosion and protection monitoring on existing concrete structures, cores with a diameter of 20 mm were removed for instrumentation and then reinstalled in the structure. In the cores, the embedded rebars were connected to zero resistance amperemeters.

So far, results from the monitoring indicate that the rebars close to the concrete surface act as anodes, while the rebars further in act as cathodes. It was also observed that the ambient temperature strongly affects the galvanic activity. By applying a cathodic protection to the structure, the galvanic currents in the macro-cells became more negative.

The establishing of macro-cells in existing concrete structures appears to be a valuable approach both to corrosion monitoring and to the control of the efficiency of cathodic protection.

1. INTRODUCTION

Measurements of galvanic currents have occasionally been used for obtaining information about the corrosion rates due to macro-cell action under defined conditions (Raupach, 1996). The method has the advantage of providing direct indication of electrochemical activity in the system without the need for sophisticated instrumentation. Usually, this technique is used as a test method in the laboratory, but the technique can also be applied in the field if the connections between different parts of the rebar system can be safely broken for current measurements. The currents are usually measured by means of zero-resistance amperemeters (ZRA's), which are easy to operate even by a non-skilled person (Baboian, 1993.

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[1] DDr
[2] Professor
[†] Corresponding author (odd.gjoerv@bygg.ntnu.no)

Usually, ZRA's are used for monitoring couples of metals. However, by using one ZRA for each part of the rebar system, the galvanic activity of each reinforcing bar can be measured with respect to the others. Actively corroding rebars will show positive currents, while passive rebars will show negative currents (Alonso, 1998).

In general, it can be expected that rebars close to the surface will act as anodes, while rebars embedded deeper in the concrete will act as cathodes. The galvanic activity can also be expected to be dependent on the ambient temperature. In this work, however, the objective was to investigate how the galvanic activity of a rebar-assembly would respond to externally applied currents as a monitoring tool for quality control of cathodic protection (CP).

2. EXPERIMENTAL

As a first step, measurements were carried out by use of an experimental set-up as shown in Fig. 1a. Electrodes of mild steel in saturated $Ca(OH)_2$ solutions were used, of which the one chamber also contained 1 molar sodium chloride. The two chambers were connected by a salt bridge.
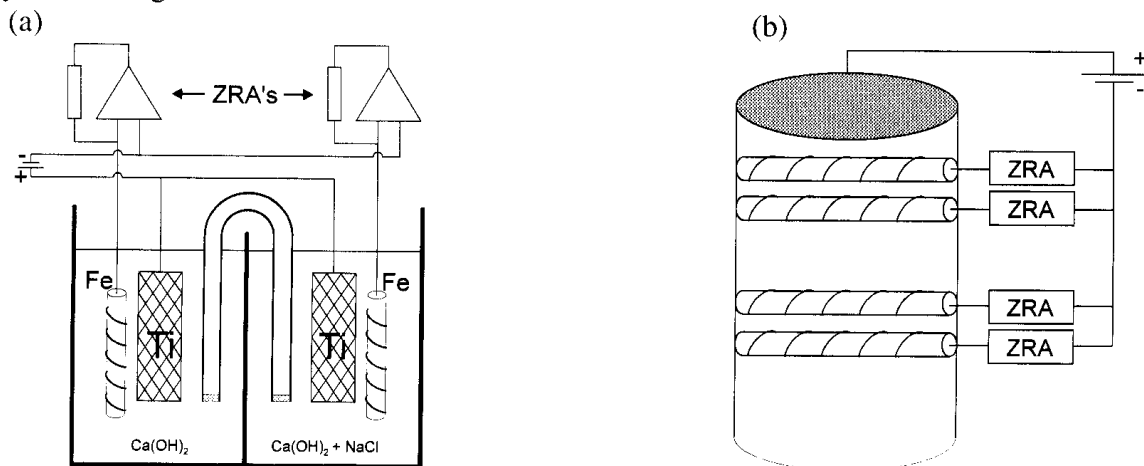

Fig. 1: (a) Principles of experimental setup for measuring macro-cell currents in $Ca(OH)_2$ solutions (reference electrodes in each compartment are not shown); (b) Principles for the setup of macro-cell measurements in a concrete deck (cores) (reference electrodes are not shown).

For the measurement of currents, two ZRA's were used; one in the anode sub-circuit and another in the cathode sub-circuit. The potentials of local anode and local cathode were measured by use of saturated calomel reference electrodes (SCE). Additionally, the voltage between a Ti-mesh counter electrode and the macro-cell was also measured.

First, the corrosion potentials of the anode and of the cathode as well as the partial anodic and partial cathodic currents were measured. These currents had to be of the same magnitude but with opposite sign, since the net current should be zero. Then, the voltage between the Ti-mesh and the macro-cell was increased in steps. Simultaneously, the applied voltage, potentials of anode and cathode as well as the galvanic currents were recorded.

As a second step, measurements were carried out by use of a moist sand bed instead of saturated $Ca(OH)_2$ solutions. This was considered more comparable to field conditions. The experimental setup was similar to Fig. 1a: One (the anodic) reinforcement bar (100 mm long, $\varnothing$ 36 mm) was embedded in a salt contaminated, alkaline sand (1 kg sand + 20 mL 1M NaCl, $Ca(OH)_2$ saturated), while the other (the cathodic) rebar (same dimensions) was embedded in

a non-salt containing alkaline sand (1 kg sand + 20 mL $Ca(OH)_2$ saturated solution). The resistivity of the corrosive sand was approximately 7 kΩcm, while the resistivity of the non corrosive sand was approximately 137 kΩcm when measured by use of a Wenner device. The corrosive and non-corrosive sands with the rebars, together with two calomel reference electrodes (one for the anode and one for the cathode) and a Ti-mesh electrode (to cathodically polarize the macro-cell) were separately put into a chamber, which was insulated in order to maintain moisture and alkalinity conditions. A salt-bridge was not considered necessary.

As a third step, field measurements were carried out on an existing concrete structure, where the concrete deck was going to be cathodically protected due to rebar corrosion. Cores with a diameter of 200 mm were removed from the deck for instrumentation and then reinstalled in the structure. Each core contained 4 to 5 embedded rebars with different concrete covers and surface areas. After establishing electrical connections to the rebars and installing reference electrodes, a conductive paint was applied before the cores were reinstalled using epoxy glue (Fig. 1b).

For the measurements of galvanic currents in the rebar system, one ZRA for each reinforcing bar was used. The potential of the local anodes and local cathodes were measured by use of embedded Ag/AgCl reference electrodes. The voltage between the conductive paint serving as a CP anode and the rebars was continuously recorded.

3. RESULTS AND DISCUSSION

By sufficient cathodic polarization, the potentials of both anodic and cathodic rebars shifted towards cathodic directions. The cathodic current of the local cathode became more negative and the anodic current of the local anodes decreased first and became cathodic. Fig. 2 shows how the voltage, potentials and local currents of the active and passive steel developed with increased cathodic protection current. It is clearly shown that the passive steel was easier to polarize than the active steel.
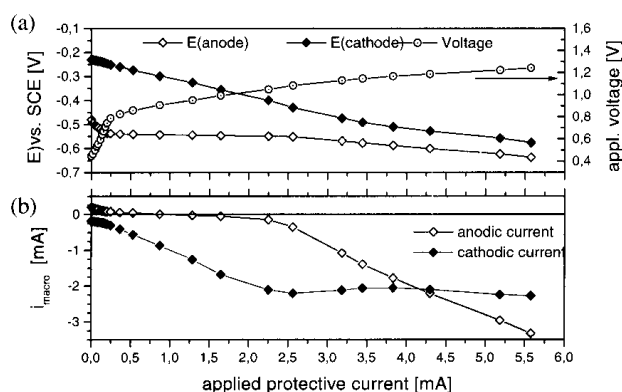

Fig. 2: (a) Development of voltage and potentials on active and passive steel with applied protective current in $Ca(OH)_2$ solutions. (b) Development of the corresponding local currents with applied cathodic protection current.

Fig. 3 shows the local anodic and cathodic currents versus the applied protective current for the samples in the sand bed. When no protective current was applied, the anodic and cathodic currents were of the same magnitude but of opposite sign. Again, the cathodic

current of the local cathode became more negative with increasing protective current, while the anodic current decreased and became negative at sufficient protection.
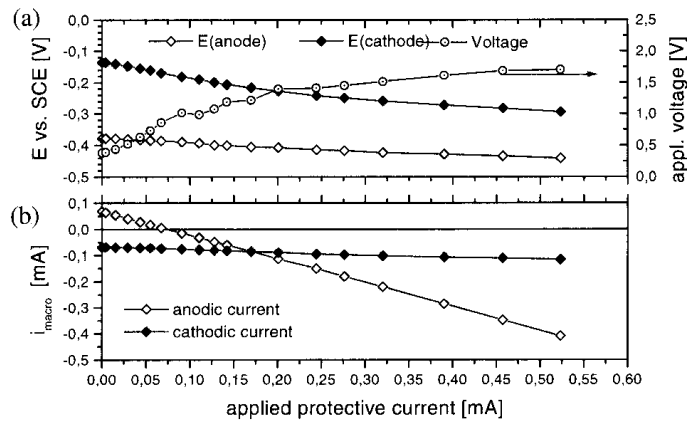

Fig. 3: (a) Development of potentials on active and passive steel with applied protective current in sand bed. (b) Development of the corresponding local currents with applied cathodic protection current.

Fig. 4 shows how the galvanic currents in a system of four rebars in the concrete core with different concrete covers changed with the temperature. The rebars with the lowest concrete cover showed anodic activity, while the rebars embedded deeper in served as cathodes. The measurements are showing that the galvanic activity was highly dependent on the ambient temperature, which is in accordance with previous observations (Raupach, 1997).

Fig. 5 shows how the local galvanic currents of a system of four rebars in the concrete core developed with time during cathodic protection. Similar current densities were absorbed by the different reinforcing bars no matter of cover. No high voltage was necessary to sufficiently polarize the steel bars with respect to the cathodic protection criteria (EN 12696, 2000).
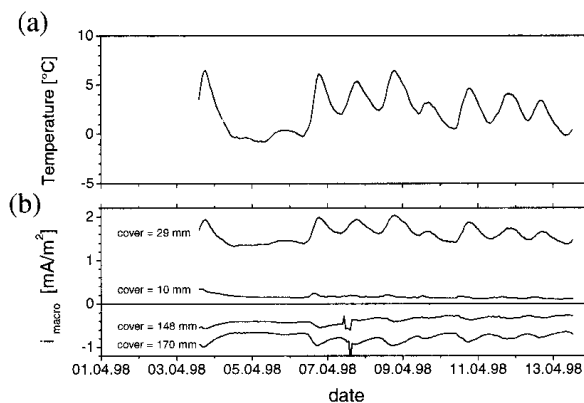

Fig. 4: Galvanic activity of the rebars in the core taken from the concrete deck. (a) Temperature, (b) Galvanic currents.
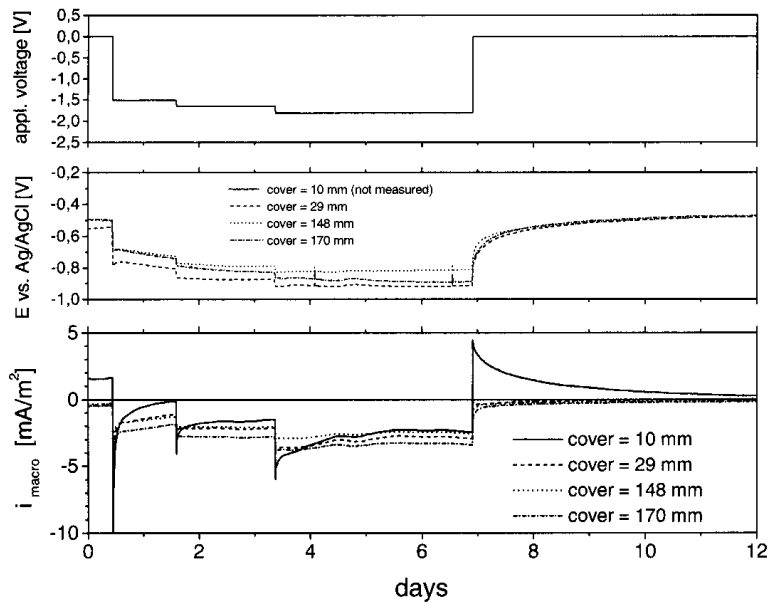
Fig. 5: Development of rebar potentials and local currents with time of cathodic polarization.

The measurements on all different systems showed that the local cathodes were much easier to polarize than the local anodes. According to the electrochemical theory, the shift of potential is roughly the product of the polarization resistance (R_P) of the rebar times the applied current density. Since R_P of the passive rebar was much higher than R_P of the active rebar, it was clear that the potential shift of the passive rebars should be higher than the active rebars.

The field measurements showed that the concrete cover had not so much effect on minimizing the absorbed cathodic current density than would be expected from previous experience (Bennett, 1990). Similar current densities where measured on all rebars independent of the distance from the anode.

From the measurements carried out, it appears that the method of measuring the galvanic activity of a rebar system in existing concrete structures can be used for monitoring and control of an applied cathodic protection system. The objective of a cathodic protection is to eliminate anodic and cathodic differences in order to minimize corrosion due to galvanic activity. This is the case when the whole rebar system is polarized sufficiently negative.

Since, the inner part of the rebar system in most cases will act as local cathodes compared to the outer part, which acts as anodes due to carbonation or chloride ingress, it should be expected that corrosion would be sufficiently reduced when the galvanic activity between the reinforcement in different depths was eliminated. Therefore, the application of ZRA's should be a good approach both for monitoring and control of the applied CP system.

4. CONCLUSIONS

Based on the investigations carried out, it appears that the establishing of macro-cells in existing concrete structures is a valuable approach both to corrosion monitoring and control of the efficiency of cathodic protection. Measurements of the galvanic activity of the rebars in

different depths by use of ZRA's were used both to monitor and control the CP system. The galvanic activity did also demonstrate a strong dependence on the ambient temperature. The amount of cathodic current density that a separated piece of rebar absorbed was less dependent on the cover depth but more dependent on the electrochemical state of the rebar itself. The polarization necessary for protection of the rebars was quite low.

5. REFERENCES

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