CORROSION MONITORING USING A NEW SENSOR SYSTEM FOR INSTALLATION INTO EXISTING STRUCTURES

Corrosion monitoring into existing structures

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Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 365-375.

Abstract

Since recent years modern sensor systems are used to monitor the corrosion risk for the reinforcement of concrete structures, i.e. the depth of the critical chloride content initiating corrosion. The Anode-Ladder-System has e.g. been used successfully since 1990 world-wide in structures exposed to aggressive environment. As these systems have to be installed before placement of the concrete, the new Expansion-Ring-System has been developed, which can be installed into drilled holes of existing structures. It consists of 6 anode rings within the main sensor and a cathode bar, both with special expansion mechanisms. Using this sensor system the time-to-corrosion can be determined continuously, enabling the owners of buildings to initiate preventive protection measures before damages due to corrosion of the reinforcement like cracks and spalling have occurred.

Keywords: Corrosion, monitoring, steel, concrete, reinforcement, anode, cathode, sensor

1 Introduction

Corrosion of the reinforcement has become a major problem world-wide, especially for structures exposed to aggressive environments such as bridges, parking decks, tunnels, offshore structures or other buildings exposed to seawater or deicing salts. As result, the repair costs nowadays constitute a major part of the current spending on the infrastructure.

Many new systems and materials have been developed to repair the damages and to increase durability, e.g. high performance concretes. However, there is only limited long-term experience with these developments. Therefore sensor systems are needed enabling the owners of the structures to monitor the corrosion risk and to take protective measures *before* the damaging processes start.

As known, the costs for repair measures increase more than proportionally with time, when the reinforcement already has started to corrode. However, the traditional monitoring systems like reference cells only show the local onset of corrosion, but not the time-to-corrosion, which is measurable using the Anode-Ladder-System or the new Expansion-Ring System.

2 Basic principle to determine the time-to-corrosion

The basic measuring principle is to place electrodes into different depths related to the concrete surface and to measure the onset of corrosion of these electrodes one by one (see Fig. 1).

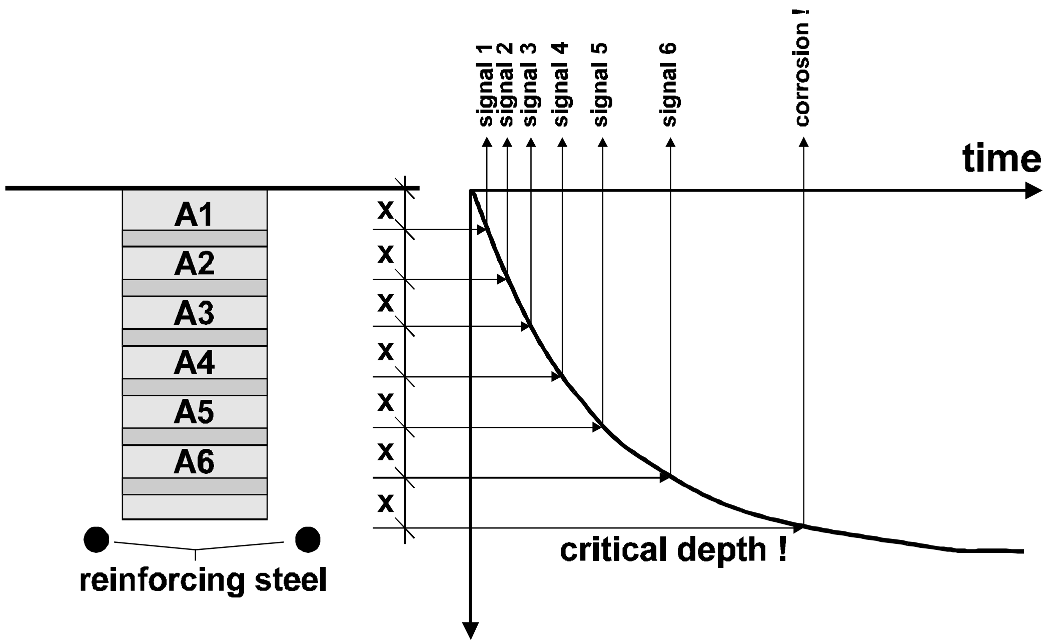

Fig. 1: Basic principle to determine the time-to-corrosion

The measuring electrodes are made of steel with a similar composition as reinforcing steel to ensure that they will start to corrode at the same time, when a rebar at the same depth would start to corrode. Comparative tests have been carried out at the Institute for Building Materials Research of the RWTH Aachen, showing that there was no significant difference in the corrosion behaviour of the steel used for the measuring electrodes (anodes) and reinforcing steel with different degrees of pre-rusting before installation into the concrete specimens.

Using adequate calculation models the time to corrosion can be determined at any time provided that the cover thickness of the reinforcement is known. If necessary the concrete cover can be measured using covermeters.

3 Development of the expansion-ring-system

The development of the corrosion monitoring systems has been carried out based on an extensive research program on chloride-induced corrosion of steel in concrete at the Institute for Building Materials Research of the Technical University of Aachen. More than 500 concrete specimens with different concrete compositions have been investigated under varying environmental conditions using macrocell current measurements as testing method (see e.g. [1]-[5]).

The tests have shown, that this technique can also be used to monitor the ingress of aggressive substances like chlorides or carbonation by measuring electrical signals between different steel bars installed at defined locations.

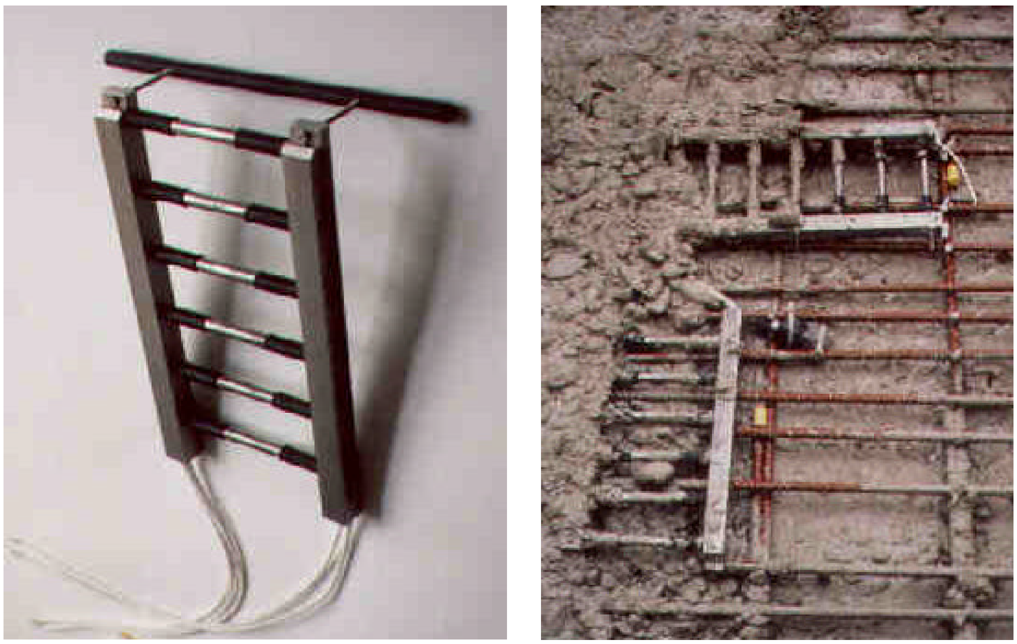

Fig. 2:Photographs of the Anode-Ladder-System to monitor the corrosion risk of the reinforcement installed during construction

Since 1990 the so called Anode-Ladder-System (see Fig.2) has been used world-wide in different types of structures to monitor the corrosion risk for new reinforced concrete structures in aggressive environment [6]. More than 600 Anode-Ladders have been installed into tunnels, bridges, foundations and other structures exposed to agressive environment in Germany, Austria, Denmark, Hong Kong, Japan, Croatia, Egypt, Switzerland, The Netherlands, Sweden, Taiwan and Australia.

The six steps of the ladder made of steel will be depassivated one after the other by chlorides or carbonation of the concrete showing the actual critical depth, where the reinforcement is not any more protected by the passive layer induced by the alcalinity of the pore solution of the concrete.

This sensor can only be installed before or during placement of the concrete into new structures. As further development the Expansion-Ring-System is able to monitor the corrosion risk also for existing structures by inserting the sensors into drilled holes.

4 Description of the expansion-ring-system

The Expansion-Ring-System consists of the Expansion-Ring-Anode and a cathode-bar. Both electrodes are inserted into holes, which have to be drilled into the concrete surface. The holes for the Expansion-Ring-Anode shall not be drilled by hand without fixed drilling equipment, because the geometry of the holes has to be very exact. Usually the hole to be drilled to fix the drilling equipment by a dowel is later used to insert the cathode-bar into the concrete. Fig. 3 shows the installation- and measurement-procedure schematically.

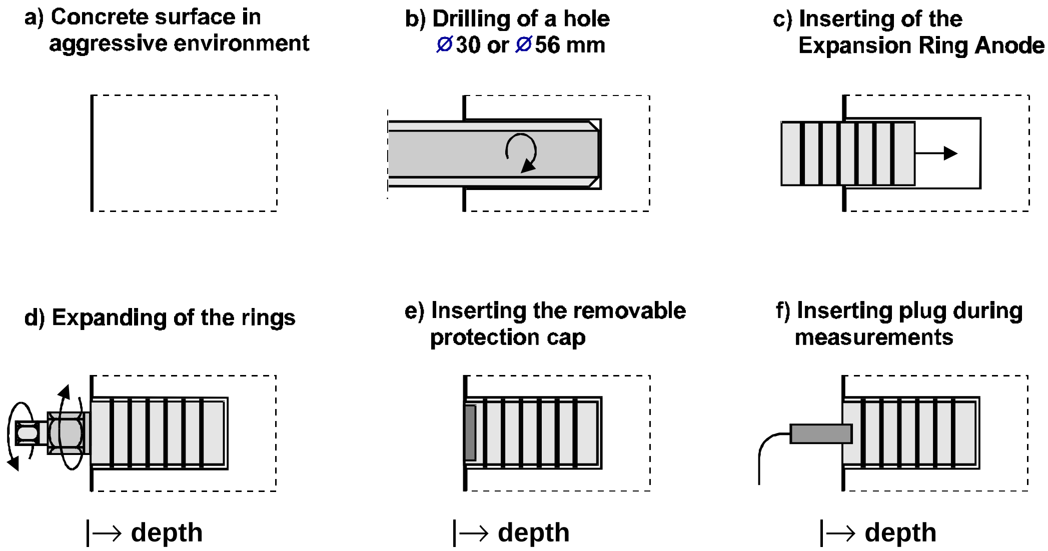

Fig. 3: Installation procedure of the new Expansion-Ring-Anode

The main measuring sensor is the Expansion-Ring-Anode (see Fig.4, (A)). Similar to the six bars of the Anode-Ladder-System [6] the Expansion-Ring-Anode consists of six measuring rings in different distances from the concrete surface, in 1 cm-steps from 1 to 6 cm. In this way the ingress of chlorides and/or carbonation from the concrete surface into the concrete and the subsequent corrosion risk of the reinforcement can be measured as it was presented in section 2. Above, between and below these metal rings altogether seven insulation rings are established to seal the area between the rings, i.e. to prevent water or chlorides penetrating along the drilled surface deeper into the hole of the Expansion-Ring-Anode.

The cathode (see Fig. 4, (B)) consists of two pieces of a platinum-coated bar to be expanded by a special mechanism to ensure a durable contact to the concrete.

The Expansion-Ring-Anode and cathode bar are connected to the concrete by turning nuts at the upper part of the sensors, leading to an expansion of the rings in a way that both sensors can be tightened sufficiently strong. During installation of the sensors the torque of the sensors will be measured to ensure that the tension between sensor and concrete is sufficient for a durable contact and not to high to induce problems of cracking of parts of the sensor or the concrete. To prevent cracking of the concrete, the sensors should not be installed at edges or near the ends of concrete elements.

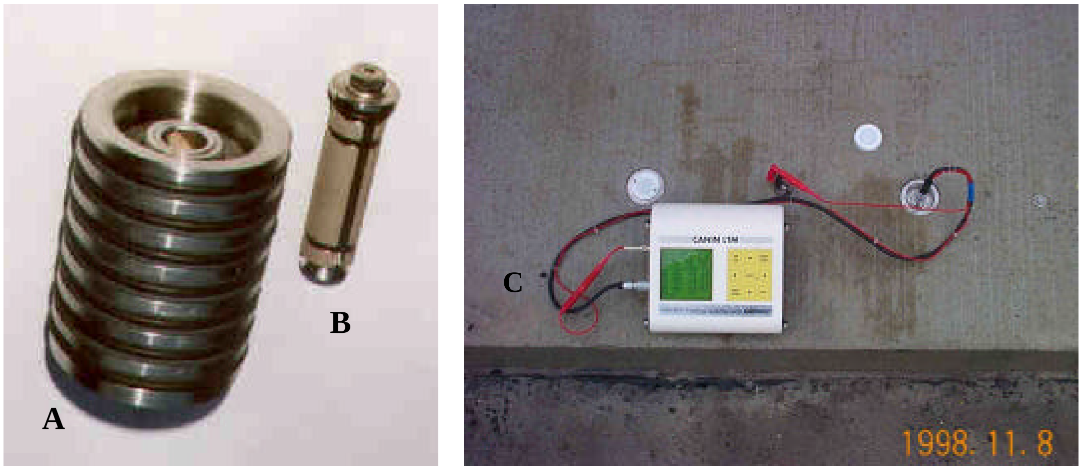

Fig. 4: Design of the Expansion-Ring-Anode (A) and cathode-bar (B) and photograph of the Expansion-Ring-System installed into a bridge cap in Germany during measurement with removed protection cap (C)

The distance between anode and cathode should be in the range of 15 cm. Additionally the electrolytic resistance between the rings can be measured to check the electrical contact between the rings and the concrete.

In the head of the Expansion-Ring-Anode a socket is integrated, which allows to insert a plug of the measuring instrument. Between the measurements a sealing cap is put onto the socked to protect it from corrosion. Cables are lead from the measuring rings to this integrated socket inside of the Expansion-Ring-Anode. After production of the electrode all inner open spaces are filled with resin and sealing material to insure that no water or chlorides can penetrate to the inner part of the sensor.

Laboratory tests have shown that the formation of rust at the first anodes after depassivation has an additional sealing effect. Therefore, the depth of the critical chloride front is not influenced by the presence of the sensors, because chlorides can only enter into the concrete besides the Expansion-Ring-Anode through the existing concrete.

4 Measurements and evaluation

To detect the onset of corrosion of the anode-rings the electrical currents, voltages, electrical resistances and temperatures of the embedded sensors are measured using a specially developed hand instrument e. g. one to four times a year.

As long as the critical chloride content and the carbonation depth have not reached the surface of the outer anode-ring, all electrical currents between the anode-rings and the cathode-bar are low. In the course of time the anodes will be depassivated one after the other. By measuring the electrical currents and voltages between anode-rings and cathode-bar in regular intervals, the critical depth regarding reinforcement corrosion is measurable continuously.

To be able to estimate additionally the potential corrosion behaviour of the reinforcement after depassivation, the electrical AC-resistance-distribution of the concrete between the six single anodes is also measured. Generally the maximum possible corrosion rates decrease with increasing resistance of the concrete. Additionally the temperature is measured using an integrated PT 1000 sensor.

For the measurements an automatic portable instrument CANIN-LTM has been developed. Using this battery-powered instrument the electrical currents, potentials, electrolytic resistances and the temperature are measured automatically after pressing the start-button. The critical values are indicated simultaneously within the large display. The data of the measurements of 1.000 sensors can be stored and transferred to a personal-computer by the integrated serial port. For further evaluation of the data software is available, which builds up a database and shows the data versus time including alarm-values (see section 6).

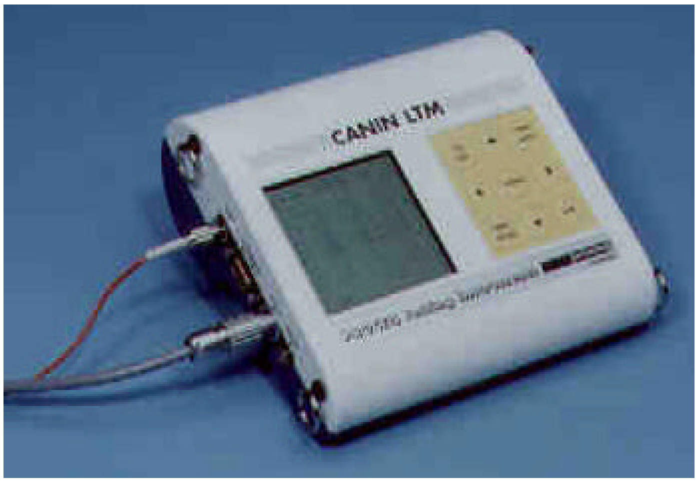

Fig. 5: Measuring instrument CANIN-LTM

The CANIN-LTM is also used to check the proper contact of the anode-rings during installation. From the first experience it is known, that the electrical resistances between the anode-rings have to be in the range between 1 and 10 kΩ.

6 Results of laboratory tests

To investigate the correct functioning of the Expansion-Ring-System comparative tests have been carried out using concrete specimen with embedded Anode-Ladder according to [6]. Expansion-Ring-Anode and cathode have been installed 137 days after placement of the concrete. At this stage the first two anodes of the Anode-Ladder indicated activity showing that the critical depth related to reinforcement corrosion was between 2 and 3 cm as the single anodes have been installed in 1 cm - steps. To achieve this situation a chloride solution containing 1 % Cl^- had been applied onto the concrete surface beginning from 1 week after placement of the concrete. After installation water has been applied onto the concrete surfaces in regular intervals (see Figs. 6 and 7) to investigate the influence of wetting and drying on the measured data.

Figs. 6 and 7 show the standard plots produced by the MACRO-software developed for the monitoring systems. To get a direct overview of all data, the time-dependant values of voltage of all anodes against the cathode, electrical currents 5 seconds after coupling of the anodes against the cathode, the AC-resistance at 100 Hz between neighboured anodes and temperature of the integrated PT 1000 sensor are plotted on 1 page. As limit values for activity of the single anodes under usual conditions 150 mV and 15 µA after a short circuit time of 5 seconds are used from experience. For special conditions regarding concrete composition or environment, e.g. for permanently submerged concrete, other limit values might be relevant, which can be determined easily by calibration tests using the same concrete under the same conditions.

Fig. 6 and 7 show the data taken from both sensor systems beginning at the time of installation of the Expansion-Ring-Anodes during cyclic application of the 1 % Cl^- solution, which can especially be seen at the data of the outer anodes near the exposed concrete surface. Voltages and currents of the Anode-Ladder show that the 2 outer anodes 1 and 2 are depassivated, while the remaining anodes 3-6 are passive (Fig. 6).

Fig. 7 shows that it takes about 1 month until voltages and currents of the single anodes of the Expansion-Ring-Anode above and below the critical depth separate clearly from each other. This can be explained by the fact that it takes a certain time until the surfaces of the rings passivate due to the alkalinity of the surrounding concrete and until the chlorides cause an activation. After this period the further ingress of chlorides can also be monitored.

The differences in the absolute values for the electrical currents and resistances are caused by the different geometry of both types of sensors. For these comparative tests an Expansion-Ring-Anode with a diameter of 30 mm has been used.

This preliminary test shows that the Expansion-Ring-System is suitable to monitor the critical depths related to corrosion of the reinforcement. The long-term-tests are still running and will be presented later.

7 Fields of application

The corrosion monitoring system has the following advantages compared to other monitoring methods:

- It is not only shown, whether the reinforcement corrodes or not, but it can also be estimated, when the reinforcement will start to corrode.
- The corrosion monitoring system shows directly the depth of the critical chloride content and not the absolute chloride contents. Compared to the measurement of chloride profiles this is a decisive advantage, because as known from experience the interpretation of absolute chloride contents is often difficult. Therefore the installation of corrosion monitoring sensors can not be replaced only by taking concrete samples for chloride profiles.
- The use of the corrosion monitoring system is especially economic in not accessible locations, e. g. at the outer surfaces of tunnels or in the tidal zones of pier shafts, etc..

When the corrosion monitoring systems are used as an effective integrated part of the maintenance program, the operating costs i.e. the inspection, maintenance and repair costs, can be reduced significantly. Possible fields of application are the following:

- Reinforced concrete structures exposed to aggressive environments (offshore structures, buildings near the coast, bridges, parking structures, tunnels, foundations, etc)
- Areas with difficult or without access (outer areas of tunnels and pipes, foundations and tanks, piers, piles of bridges near the water level, etc.)
- Monitoring of the durability of special protection systems for new structures especially with a high designed service life, e.g. 100 years (high performance concrete, coatings, inhibitors, etc.)
- Monitoring of the durability of special repair systems (cathodic protection, desalination, coatings, inhibitors, etc.)

8 Outlook

Laboratory tests and first installations on site have shown, that it is possible to monitor the critical depth related to reinforcement corrosion using the Expansion-Ring-System.

Since September 1998 the Brite Euram Project “Smart Structures” is running to develop an integrated monitoring system for concrete structures. One task of this project is the further development of the Expansion-Ring-System, especially optimisation of the installation procedure and testing in different concretes in laboratory and in critical locations of bridges. The further results will be presented within the next years

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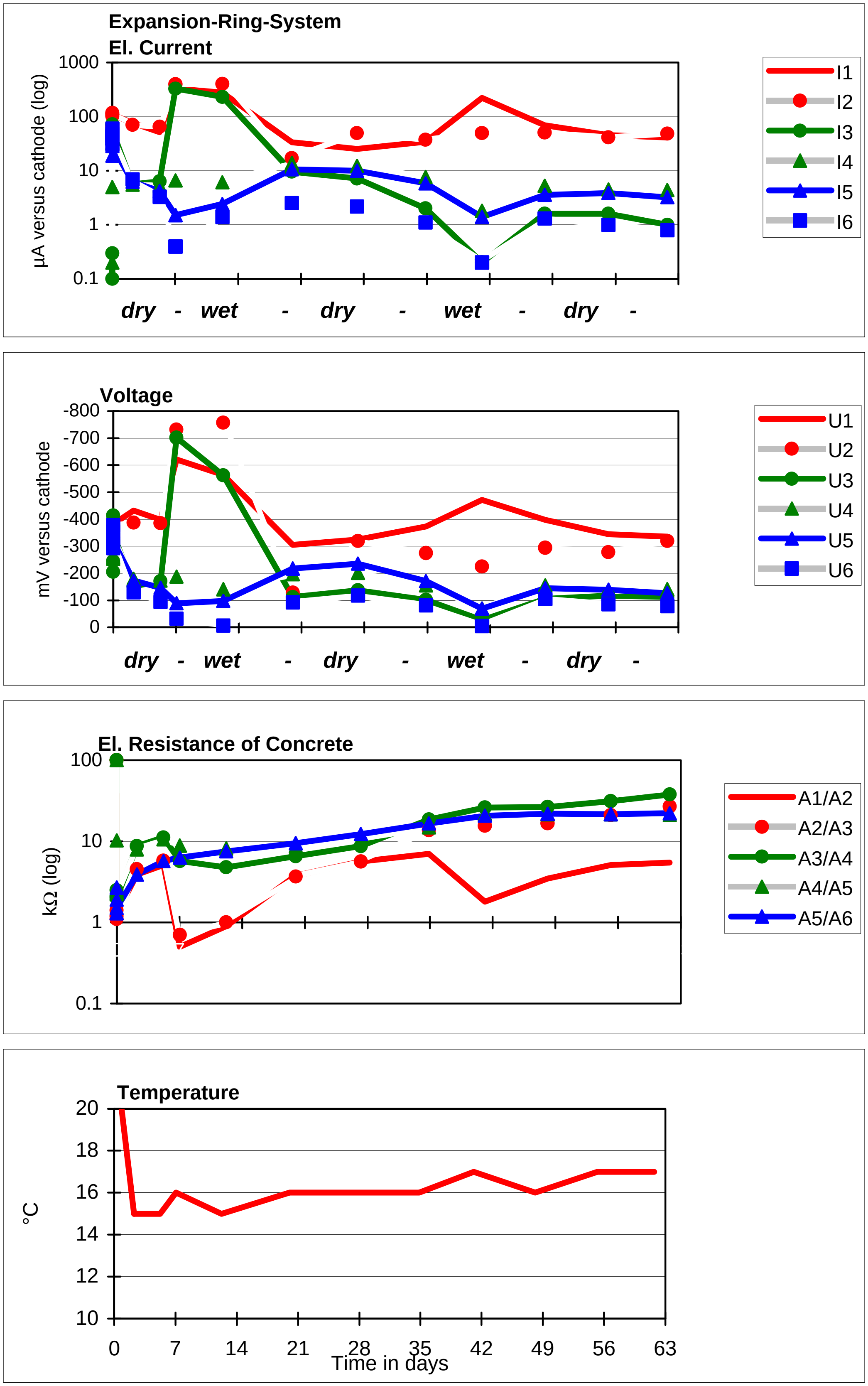

Fig. 7: Results of the Expansion-Ring-System installed near the Anode-Ladder; compare to Fig. 6 (A1 is the single anode next to the concrete surface, etc.)

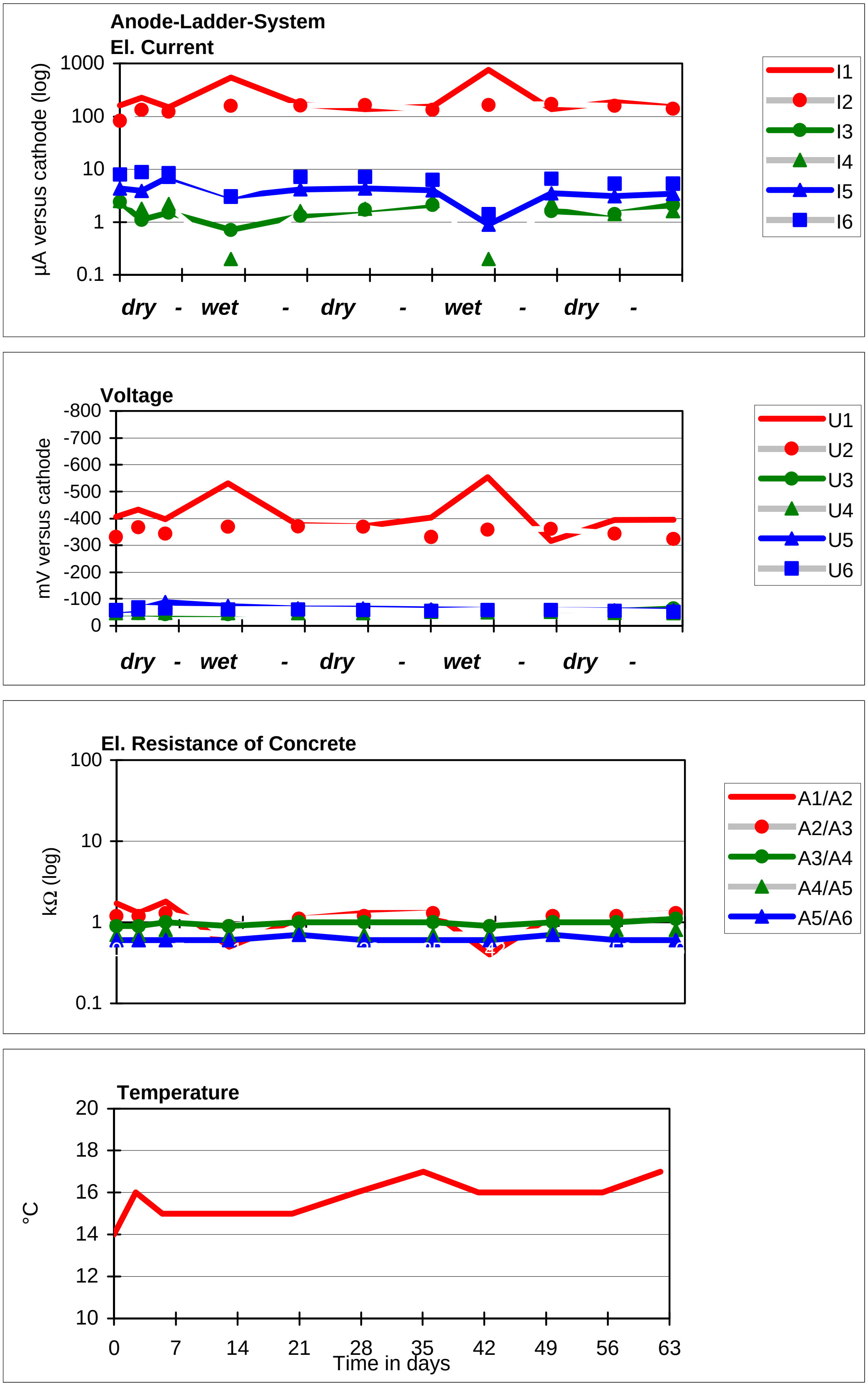

Fig. 6: Results from a laboratory test of the Anode-Ladder-System under cyclic water application (A1 is the single anode next to the concrete surface, ect)