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Autor: Gulikers, Joost
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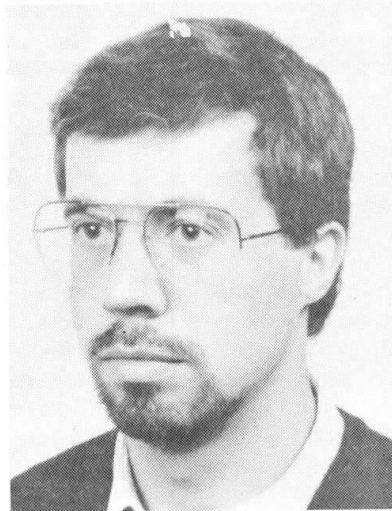
Influence of Local Repairs on Corrosion of Steel Reinforcement

Influence des réparations locales sur la corrosion des aciers d'armature

Beeinflussung der Korrosion der Bewehrung durch örtliche Instandsetzungsarbeiten

Joost GULIKERS

Civil Engineer
Univ. of Technology Delft
Delft, The Netherlands



Joost Gulikers received his Master of Science degree at Delft University of Technology, The Netherlands, in 1986. Since then he is a research engineer at the Stevin Laboratory and is involved in research projects on durability of concrete structures.

SUMMARY

In this paper a description is given of a concrete corrosion cell which has been developed to investigate the mutual influence, between rebars in carbonated concrete and rebars embedded in repair mortar, on the corrosion processes. This influence is qualitatively analyzed and preliminary test results are presented.

RÉSUMÉ

Une description est donnée d'une cellule d'essais de corrosion de béton permettant d'examiner l'influence mutuelle entre des barres enrobées de béton carbonaté et des barres enrobées de mortier de réparation, sur le processus de corrosion. Cette influence est analysée qualitativement et des résultats préliminaires sont présentés.

ZUSAMMENFASSUNG

Eine Betonkorrosionszelle wird zur Untersuchung der gegenseitigen Beeinflussung zwischen Bewehrung in karbonatisiertem Beton bzw. der Bewehrung umgeben von Reparaturmörtel und dem Korrosionsvorgang beschrieben. Diese Beeinflussung wird qualitativ erfasst und vorläufige Versuchsergebnisse werden vorgelegt.



1. INTRODUCTION

Non-carbonated and chloride-free concrete normally provides reinforcement with excellent corrosion protection. The high alkalinity of the pore-water in concrete ($\text{pH} > 12.5$) results in the formation of a tightly adhering iron oxide film on the steel surface, preventing the ionic dissolution of iron. Corrosion of steel, however, can occur if the concrete is not of adequate quality, the structure was not properly designed for the service environment, or the environment was not as anticipated or changed during the service life of the concrete. Carbonation of concrete due to the ingress of carbondioxide from the air results in the reduction of the pH-value below 10, thereby permitting corrosion of reinforcing steel. The presence of chloride-ions in concrete can cause severe corrosion to occur when the chloride content at the steel surface exceeds a critical limit. The rate of corrosion is strongly influenced by environmental factors. Both carbonation- and chloride-induced corrosion can occur only if sufficient oxygen and moisture are available.

Because the corrosion products (rust) occupy a greater volume than the steel and exert substantial stresses on the surrounding concrete, corrosion results in deterioration of concrete. At the exterior surface this may demonstrate as staining, spalling and cracking of the concrete. Durability, structural and esthetic aspects can be the reason for repairing the damaged structure. If only a part of the total concrete surface is damaged it may be decided that only those parts should be repaired. In practice it is observed that local repairs can negatively affect the corrosion behaviour of rebars embedded in the non-repaired concrete. The effects of local repairs on the corrosion processes in carbonated concrete are studied by means of a concrete corrosion cell with which the influences of all relevant practical parameters can be quantitatively determined under different conditions. The principles of the corrosion cell will be described and the first results will be presented.

2. ELECTROCHEMICAL PRINCIPLES

Corrosion of steel in concrete is an electrochemical process which can be divided in an anodic and a cathodic part: at the anode electrochemical oxidation takes place and at the cathode electrochemical reduction occurs. Any metal surface on which corrosion is taking place is a composite of anodes and cathodes being electrically connected through the body of the metal itself. At the anode, which is the negative pole, the dissolution of ferrous ions takes place as a result of the oxidation of iron:



The ferrous ions are subsequently changed to oxides of iron by a number of complex reactions. At the cathode, which is the positive pole, reduction takes place. In a high alkaline environment and an adequate supply of oxygen, as is the case in concrete, the cathodic reaction is represented by:



If the cathodic process is the slower process, the corrosion is considered to be cathodically controlled. Conversely, if the anodic process is slower, the corrosion rate is said to be anodically controlled. In concrete, one or two types of corrosion-rate-controlling mechanisms normally dominate. One is cathodic diffusion, where the rate of oxygen diffusion through the concrete determines the rate of corrosion. The other type of controlling mechanism involves the development of a high resistance path. When steel corrodes in concrete, anodic and cathodic areas may be as much of several decimeters apart, therefore the resistance of the concrete may be of great importance [5].

The corrosion process can proceed only if certain conditions are fulfilled. For the situation where depassivation due to carbonation of the concrete has occurred, these principal conditions are shown schematically in fig. 1:

Anodes develop as a result of depassivation; cathodic reactions can occur in both passivated and depassivated areas of the steel surface when sufficient water and oxygen are available. The ferrous and hydroxyl ions dissolve in the pore water; the released electrons travel through the steel from the anode to the cathode nearby.

Depassivation of steel caused by carbonation of concrete leads to the formation of micro

corrosion cells on the steel surface. The cathodic and anodic reactions proceed directly side by side and will cause a uniform corrosion rate along the steel surface. Under certain conditions it may be possible that in carbonated concrete corrosion areas develop where the cathodic reactions dominate the anodic reactions. This overcharge of cathodic activity can support the anodic reactions in corrosion areas nearby.

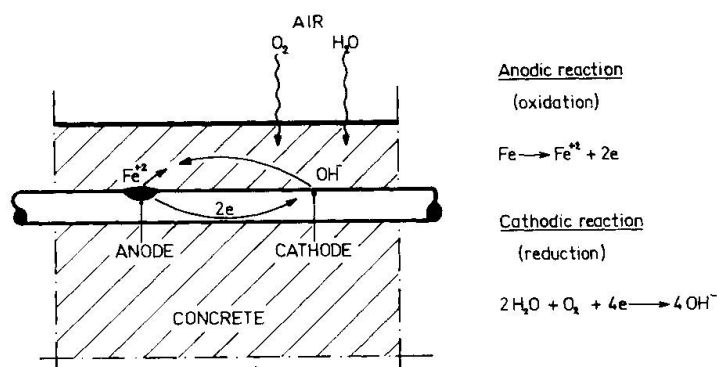


Fig. 1 Schematic representation of corrosion processes after depassivation by carbonation

The presence of chloride-ions in concrete usually gives rise to the formation of a macro-cell, i.e. localized anodic and cathodic regions of the steel surface are separate from one another. This situation is especially dangerous when large cathodic regions are opposed to small anodic regions. This so-called pitting corrosion results in a significant dissolution of metal advancing in the interior of the rebar.

In this paper repair of reinforced concrete with carbonation induced corrosion is subject of research.

3. EXPERIMENTS

3.1 Description of the concrete corrosion cell

The concrete corrosion cell is shown in fig. 2; a similar corrosion testing cell was previously developed by Schiessl [1]. Each specimen is made of solid concrete (see Appendix for composition and curing conditions) and contains initially 4 electrodes (steel rebars) at fixed places: 3 electrodes (A, B and D) at the upper surface with a concrete cover of 10mm and an

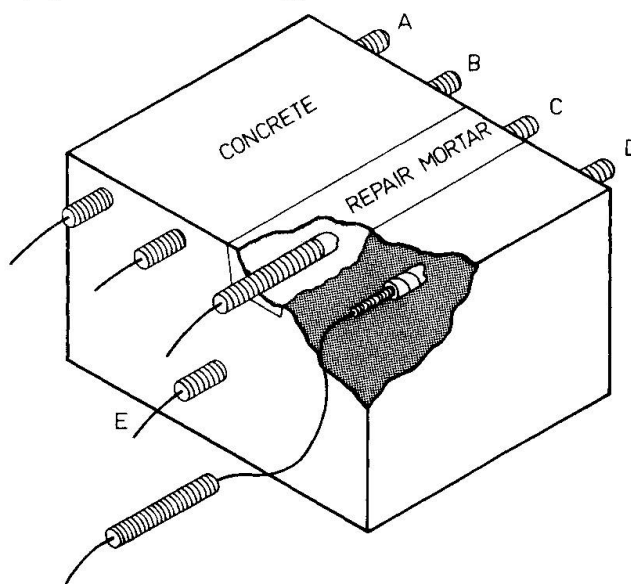


Fig. 2 Concrete corrosion cell



in-between distance of 50mm, and 1 electrode (E) at a distance of 50mm to the basis. At the upper surface a slot is made with a depth of 30mm. All electrodes have an effective corrosion length of 100mm and a surface area of $37.7 \times 10^3 \text{ mm}^2$. After accelerated carbonation (80 days at 5% (v/v) CO_2 and 50% R.H.) the three upper electrodes are positioned in carbonated concrete and as a consequence they are in a potential state of corrosion. Micro corrosion cells will develop dependent on the environmental conditions, viz. relative humidity and the availability of oxygen. The electrode E is surrounded by non-carbonated concrete and can act only as a cathode (macro cathode); this electrode is used for reference measurements. After accelerated carbonation the four vertical surfaces of the specimen are sealed with a tight epoxy coating permitting access of oxygen and moisture only through the upper and lower surfaces of the specimen. The electrodes are externally conductively connected, enabling the corrosion current to flow. Any corrosion due to micro cell formation cannot be detected until at the end of the test the specimens are split and the weight of rust for each electrode is determined.

In each specimen the electrically conductive connection between the electrodes A - B and D - E was established directly after the period of accelerated carbonation. After three months the fourth electrode (C) at the upper surface is placed in the slot and embedded in repair mortar. Two days after repair the connections between the electrodes A - B and C - D were established.

It is emphasized here that the only purpose of this type of concrete corrosion cell is to measure the mutual influence between rebars embedded in carbonated concrete and rebars embedded in repair mortar on the corrosion processes.

3.2 Description of the measuring system

To determine the very small corrosion currents a special developed measuring system is set up (see fig. 3). Each electrical circuit consists of two electrodes (A - B and C - D) which are continuously interconnected by means of a copper wire through a resistor. The resistance is relatively low to limit any external interference of the natural corrosion process; in the present situation a resistance of 1Ω is chosen. Between 10 corrosion circuits and a multimeter (type: Philips PM 2535) 1 multiplexer (type: Philips PM 2121) is placed; in total 60 circuits are monitored. A PC (type: Hewlett Packard Vectra ES) is connected with the multimeter to start the measuring cyclus and to buffer the received corrosion current data.

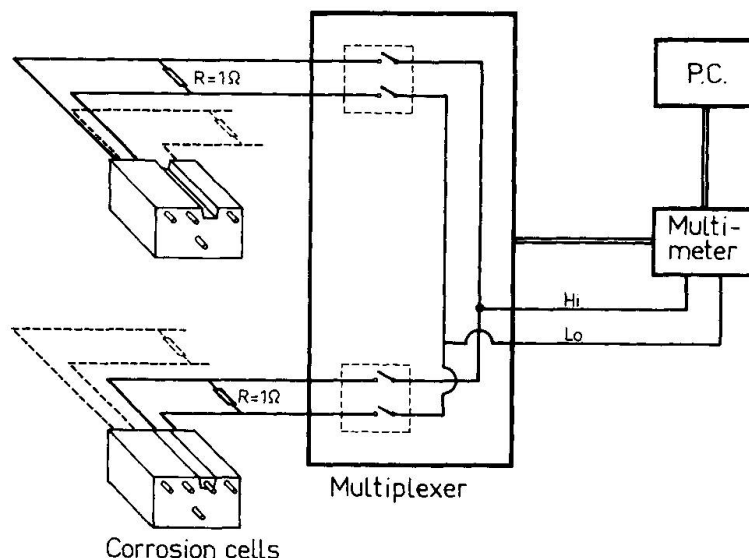


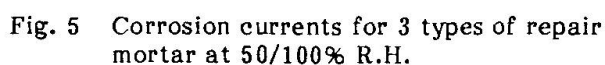
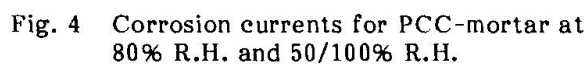
Fig. 3 Measuring system

3.3 Variables

In the first stage of the research program only two parameters are taken into account, viz. the relative humidity of the air and the type of repair mortar:

Repair mortar : 1) CC-mortar;
2) PCC-mortar;
3) PC-mortar.

The results of the first three weeks after repair are shown in figs. 4 and 5 for different climate conditions and different types of repair mortar.





5. DISCUSSION

The steel reinforcement in the carbonated concrete area is in a potential state of corrosion; the steel surrounded by repair mortar cannot corrode i.e. at the steel surface no anodic reactions can proceed. In a mineral mortar (CC- and PCC-mortars) the alkaline environment re-establishes a protective oxide film on the steel surface (repassivation). In a PC-mortar, e.g. epoxy mortar, permeability and porosity are very low and as a result cathodic and anodic reactivity will be very slow. Rebars embedded in mineral mortars can develop into macro cathodes, the rate of their reactivity being mainly determined by the diffusion of oxygen. When these macro cathodes are electrically connected with rebars in carbonated concrete an acceleration of their anodic processes will occur. This can be especially dangerous if the acceleration is concentrated on a small steel area. In that case a situation identical to pitting corrosion is possible. For rebars partly embedded in repair mortar and partly in carbonated concrete it is likely that the small macro anode will occur next to the large macro cathode. Whether cathodic or anodic reactions dominate at steel surfaces of rebars surrounded by PC-mortar mainly depends on the porosity and permeability of the repair mortar and the corrosion controlling factors at the rebars in carbonated concrete nearby.

In the period about which tentative results are presented, the measuring system is tested and further developed; the time period is too short to draw any definite conclusions from the results. The program is continued to investigate the long-term effect of local repairs on corrosion processes; in due time these results will be presented and discussed.

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APPENDIX

Concrete composition: 300 kg/m³ bfsc; w/c = 0.60; aggregate 8-16mm: 24%; 4-8mm: 20%; 2-4mm: 20%; 1-2mm: 10%; 0.5-1mm: 9%; 0.25-0.5mm: 9%; 0.125-0.25mm: 8%.
Curing conditions: 2 weeks 100% R.H.