



# The micro-solution electrochemical method to evaluate rebar corrosion in reinforced concrete structures



Yuwan Tian<sup>a,b</sup>, Chaofang Dong<sup>a,\*</sup>, Xuequn Cheng<sup>a</sup>, Yingqi Wan<sup>a</sup>, Gui Wang<sup>b</sup>, Kui Xiao<sup>a</sup>, Xiaogang Li<sup>a</sup>

<sup>a</sup> Corrosion and Protection Center, University of Science and Technology Beijing, Beijing 100083, China

<sup>b</sup> Engineering College, Ocean University of Guangdong, Zhanjiang 524088, China

## HIGHLIGHTS

- A micro-solution electrochemical method is used to evaluate the rebar corrosion.
- The corrosion rate of HRB400 in the micro-solution is much lower.
- The reason for this difference is the anodic polarization in the micro-solution.
- The micro-solution electrochemical method agreed well with the real site studies.

## ARTICLE INFO

### Article history:

Received 11 September 2016

Received in revised form 28 May 2017

Accepted 1 June 2017

### Keywords:

Rebar corrosion

Corrosion rate

Micro-solution

Electrochemical technique

Real site

## ABSTRACT

An electrochemical method by submersing the HRB400 rebar specimen in simulated micro pore solution (47.125  $\mu\text{L}$ ) is proposed to rapidly evaluate the corrosion rate of HRB400 in concrete. The results show that the corrosion rate of HRB400 in micro-solution is about five times lower than that in bulk solution. The reason for this difference is the anodic polarization caused by the higher concentration of dissolved iron ions in micro-solution. There is a small relational dispersed degree of corrosion rate measured by the optimized electrochemical cell in micro-solution and the real site studies.

© 2017 Elsevier Ltd. All rights reserved.

## 1. Introduction

Most areas of degradation in reinforced concrete primarily originate from the corrosion of its steel reinforcement [1]. Corrosion rate is the most important parameter in the corrosion of rebar in the reinforced concrete, and is used to describe the durability of reinforced concrete structures.

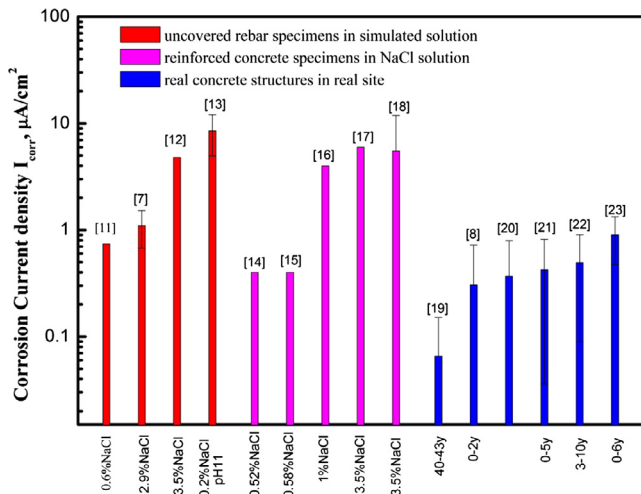
In the real site studies, corrosion rate ( $I_{\text{CORR}}$ ) is often calculated by the polarization resistance  $R_p$  based on the liner polarization curve, because corrosion of the steel reinforcement is essentially an electrochemical process [2,3]. The value of corrosion rate in real site studies is the most accurate and authentic. However, initiation of corrosion for concrete structures in the real environment may occur after a long period of time. This shortcoming of time consuming obviously impedes the development of new materials and rapid material selection in engineer.

In order to evaluate the rebar corrosion rapidly and shorten the test period, the most commonly used method is electrochemical measurement in the laboratory. The common execution is to submerge an uncovered rebar specimen (surface area of  $1\text{ cm}^2$ ), a reference electrode, and a counter electrode in bulk solution (volume of 0.5–1 L), and then to connect these three electrodes to a potentiostat [4–7]. This method has the advantages of simplicity in the specimen preparation and a short test period. However, the corrosion rates measured using this method do not agree very well with those measured by the long-term real site method. Fig. 1 shows a summary from published references of corrosion rates measured in the laboratory and real site. The corrosion rate  $I_{\text{CORR}}$  obtained in laboratory is relatively higher [8–10].

In the laboratory results, most of the corrosion current densities  $I_{\text{CORR}}$  ranged from 0.1 to  $10\text{ }\mu\text{A}/\text{cm}^2$ . The maximum  $I_{\text{CORR}}$  reached about  $100\text{ }\mu\text{A}/\text{cm}^2$  in some research [24]. The majority of  $I_{\text{CORR}}$  values measured in the laboratory were several  $\mu\text{A}/\text{cm}^2$ . Generally, the  $I_{\text{CORR}}$  value of laboratory reinforced concrete specimens is lower than that of uncovered rebar specimens.

\* Corresponding author.

E-mail address: [cfdong@ustb.edu.cn](mailto:cfdong@ustb.edu.cn) (C. Dong).



**Fig. 1.** Summary of corrosion rates from published data, including uncovered rebar specimens in the simulated pore solution (red), and reinforced concrete structures in NaCl solution (pink), and real marine concrete structures in the field (blue). (See above-mentioned references for further information.) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In real site studies of corrosion rates, reinforced concrete in environments with  $\text{Cl}^-$  exhibited significant corrosion rates during the initial days, which thereafter dropped and then stabilized. The stabilizing  $I_{\text{CORR}}$  values for reinforcement steel ranged from 0.001 to  $1 \mu\text{A}/\text{cm}^2$  for several years [2,19,25–28]. The majority of measured on-site  $I_{\text{CORR}}$  values had a magnitude of  $0.1 \mu\text{A}/\text{cm}^2$ . Even in real concrete structures contaminated with chlorides,  $I_{\text{CORR}}$  values higher than  $5 \mu\text{A}/\text{cm}^2$  are seldom recorded [29]. As the process of carbonation and increases in the  $\text{Cl}^-$  concentration continued, the corrosion rate increased. The maximum corrosion rates ranged from 0.5 to  $1 \mu\text{A}/\text{cm}^2$ , which is interpreted in the engineering field as the onset of corrosion damage.

The reason for the difference in the laboratory and real site corrosion rates is the change in the surrounding environment of the reinforcement. The corrosion of reinforcement in the real concrete structure occurs in the micro-solution rather than the bulk solution. As we know, there are a large number of micro-pores primarily containing alkaline solution on the surface of reinforcing steel rebar, due to incomplete hydration and air entrapped [30]. The micro-pore liquid in uncracked concrete is the main culprit in the corrosion of rebar. That is, the micro-pore liquid plays the role of electrolyte in the corrosion of the millions of micro-anodes (Fig. 2).

Therefore, in this paper, electrochemical measurement in the micro-solution was studied to measure the corrosion rate rapidly. Much like the electrodes that are used in analytical chemistry [31],

we introduce the concept of a three-electrode cell in a micro pore solution to simulate the actual service conditions of a steel-concrete system. Potentiodynamic polarization curves and electrochemical impedance spectroscopy were used as main measuring techniques. The difference in corrosion rates measured in micro-solution and bulk solution was studied. The relation dispersed degree between the corrosion rates measured in the laboratory and real site was also investigated.

## 2. Materials and methods

### 2.1. Materials and solution

The chemical composition (% mass) of the material HRB400 corrugated reinforcing steel is 0.19% C, 0.57% Si, 0.57% Mn, 0.024% S, 0.017% P and residual Fe, and the HRB400 was provided by Nanjing Iron and Steel Group Company (China). Prior to the experiments, the samples were mechanically polished; then degreased in acetone, deionized water, and ethanol; and then dried under a cold air stream.

For the experiments, the saturated calcium hydroxide solution containing different concentrations of sodium chloride after deoxygenation was chosen as the simulated concrete solution. The concentrations of chloride salt admixed in a concrete pore solution in different tests were 0, 0.5, 1.5, 2.5, and 3.5 wt.% respectively. For all the tests, 0.2 g of calcium hydroxide and the given amount of sodium chloride were mixed in a 100 g solution. All the chemical reagents applied in the present work were analytic grade and the experimental water was deionized.

### 2.2. Electrochemical measurements in bulk solution

The electrochemical method in the bulk solution was performed with a three-electrode cell with a volume of 0.5 L. The working electrode was a HRB400 specimen, the counter electrode was a platinum sheet, and the reference electrode was a saturated calomel electrode. The geometrical surface area of the working electrode exposed to the solution was  $1 \text{ cm}^2$ .

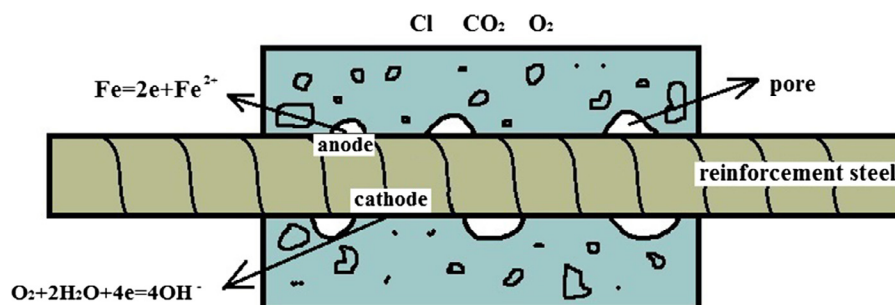
Electrochemical tests were performed by means of a 2273 Partstat potentiostat. Prior to the measurements, the working electrode was submerged in the simulated concrete pore solution for 30 min to obtain the small fluctuation of the potential ( $<0.008 \text{ mV/s}$ ) and stable steel-solution interface. The impedance measurements were measured in a frequency domain ranging from 10 mHz to 100 kHz and a potential perturbation of 10 mV at the open circuit potentials. Polarization curves were measured with a scan rate of  $1 \text{ mV/s}$ , and a scan range from  $-250 \text{ mV}$  for open circuit potential to  $+80 \text{ mV}$  for pitting potential.

### 2.3. Electrochemical measurements in micro-solution

Electrochemical measurement in the micro-solution is based on the same principles as that of the three-electrode cell in bulk solution, with a HRB400 specimen as the working electrode, a saturated calomel electrode as the reference electrode and a platinum wire as the counter electrode. The novelty of this measurement is the small volume of the simulated pore solution. In this measurement, the geometrical surface area exposed to the solution was  $0.203 \text{ cm}^2$ , the volume of the micro-solution was  $47.125 \mu\text{L}$ , and the thickness of the micro-solution was  $500 \mu\text{m}$  (Fig. 3). The other parameters were the same as those in the bulk solution.

### 2.4. Surface morphology after potentiodynamic polarization

The surface morphology of the HRB400 after potentiodynamic polarization in the 3.5 wt.% NaCl bulk solution and micro-solution was observed. The stop potential of potentiodynamic polarization was  $+80 \text{ mV}$  for pitting potential. To measure the 3D shape of the pits, a high resolution VHX-2000 digital microscope (Keyence, Japan) was used.



**Fig. 2.** Schematic representation of micro pores in reinforced concrete.

Download English Version:

<https://daneshyari.com/en/article/4918215>

Download Persian Version:

<https://daneshyari.com/article/4918215>

[Daneshyari.com](https://daneshyari.com)