



## Process control of reinforcement corrosion in concrete. Part 1: Effect of corrosion products



Yong-sheng Ji<sup>a,b,\*</sup>, Guangmei Zhan<sup>b</sup>, Zhongchao Tan<sup>c,\*</sup>, Yijie Hu<sup>b</sup>, Furong Gao<sup>b</sup>

<sup>a</sup>State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou 221116, China

<sup>b</sup>Jiangsu Key Laboratory of Environmental Impact and Structural Safety in Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221008, China

<sup>c</sup>Department of Civil and Environmental Engineering, University of Waterloo, Ontario, Canada

### HIGHLIGHTS

- FeOOH can replace oxygen to be a new cathodic depolarizer once the corrosion begins.
- Total corrosion current is sum of corrosion currents from oxygen and FeOOH depolarization.
- The maximum of  $I_{\text{corr}}$  appears where concrete is saturated.
- The control type of corrosion process of rebar in concrete is mixed control.
- Oxygen is one of the key factors influencing rebar corrosion but not the controlling factor.

### ARTICLE INFO

#### Article history:

Received 23 May 2014

Received in revised form 9 November 2014

Accepted 27 December 2014

Available online 23 January 2015

#### Keywords:

Process control

Degree of pore saturation

Oxygen

Corrosion products

Polarization curve

### ABSTRACT

The effect of degree of pore saturation ( $PS$ ) in concrete on corrosion current is investigated in this paper. Results showed that the maximum of corrosion current appeared in the saturated concrete and it decreased in dried concrete. After the corrosion products were enough, FeOOH in corrosion layer could act as a depolarizer instead of oxygen. As a result, the corrosion rate remained high even when the concrete was completely water saturated. Therefore, oxygen is not the factor controlling corrosion process of steel rebar in concrete, although it is one of the key factors. When the concrete drying process starts from water saturation, there is little difference between the control degree of cathodic reaction and the control degree of anodic reaction on corrosion process; the control type of corrosion reaction is mixed control. Part I of this article presents experimental results obtained from the thermostatic drying tests and the effect of corrosion products on process control of reinforcement corrosion in concrete. The time-dependent dominating factors of rebar corrosion process under different environmental conditions will be discussed in Part 2.

© 2015 Elsevier Ltd. All rights reserved.

## 1. Introduction

Steel-reinforced concrete is an extensively used structural material for bridges, buildings and platforms as well as for underground structures because of its low cost, ease of construction. Therefore, the durability of reinforced concrete structures, especially those exposed to aggressive environments, is of a great concern to the society because it affects everything from safety of the public to the economy of country [1,2]. A study in 2002 by the U.S. Federal Highway Administration (FHA) revealed that the annual

direct cost of corrosion was estimated to be \$276 billion. It is estimated that of this cost, 30% is related directly to corrosion in steel reinforced concrete structures [3].

Earlier research showed that the corrosion of steel reinforcement in concrete is one of major reasons for concrete structure deterioration [4–6]. The corrosion of steel reinforcement results in a loss of ductility and load bearing capacity of the structure [7–9]. As the corrosion of steel bars occurs, the resultant products on the surface of the bar increase the rebar by 2–5 times of its original condition [10–11].

Modeling the corrosion rate of steel reinforcement in concrete is an important basis work for predicting service life of reinforced concrete structures. The model of deterioration rate of reinforced concrete elements can be built based on the model of corrosion rate of steel reinforcement in concrete. Prediction of service life

\* Corresponding authors at: State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou 221116, China. Tel.: +86 137 7598 6533 (Y.-s. Ji), +1 519 888 4567x38718 (Z. Tan).

E-mail addresses: [jyongsheng@cumt.edu.cn](mailto:jyongsheng@cumt.edu.cn) (Y.-s. Ji), [tanz@uwaterloo.ca](mailto:tanz@uwaterloo.ca) (Z. Tan).

of reinforced concrete structures will be based on the model of deterioration rate of concrete elements. However, modeling the corrosion rate of rebars in concrete is a complex electrochemical problem, and corrosion of rebars in concrete (CORIC) is a complex electrochemical process [12]. It is affected by many factors including, but are not limited to, the chloride content [13], the alkalinity of the solution surrounding the rebar [14], the properties of concrete [15], and the surface characteristics and the chemical composition of steel [16]. Most researchers believe that there must be one dominating factor of CORIC, which is also referred to as “controlling factor” [17,18]. Once the controlling factor is determined, the predictive model for the rate of CORIC can be established on the basis of varying tendency of the controlling factor.

Extensive studies about controlling factor of CORIC have been conducted by researchers all over the world [19–21]. Most researchers believe the CORIC is a complicated oxygen depolarization [22–25]. Corrosion of rebar requires the existence of oxygen and water, whose supply is related to environmental relative humidity. Gonzalez [26] suggested the CORIC will not happen if the relative humidity in the atmosphere is less than 35% due to the lack of moisture, while Geng [27] believed it will not occur either in an high humid environment due to lack of oxygen. Jun Ying [28] reported that the rate of oxygen diffusion in concrete decreased as relative humidity (RH) of atmosphere in surrounding environment increased. Hans [29] stated that the diffusion coefficient of oxygen in water is 40 times lower than that in air. However, the moisture of concrete rises as RH increases. Thus, a well-acknowledged point is that the importance of cathodic and anodic reactions to the corrosion of rebar depends on environmental relative humidity, and the rate of corrosion is relatively high at a moderate humidity as shown in Fig. 1 [30,31]. The controlling factor will change under a critical humidity, at which the atmospheric relative humidity is called critical relative humidity, denoted by  $RH_{cr}$ . The corresponding pore saturation degree PS in concrete is known as critical PS, denoted by  $PS_{cr}$ . At atmospheric RH larger than  $RH_{cr}$ , the rate of CORIC reduces with increasing of RH. The corrosion is primarily controlled by oxygen diffusion. While at atmospheric RH smaller than  $RH_{cr}$ , the rate of CORIC grows with increasing of RH. The corrosion is then controlled by anode reaction or the resistance of concrete.

Gonzalez [32] investigated the quantitative relations between the corrosion rate of steel in concrete and the electrolyte supply and suggested the corrosion rate of steel is coinciding with the maximum when PS in concrete is 70%, and is controlled by  $O_2$  diffusion when PS in concrete is more than 70%. Enevoldsen’s investigation [33] suggested the corrosion rate of rebar reaches the maximum when the RH in concrete is 80–90%. The investigation

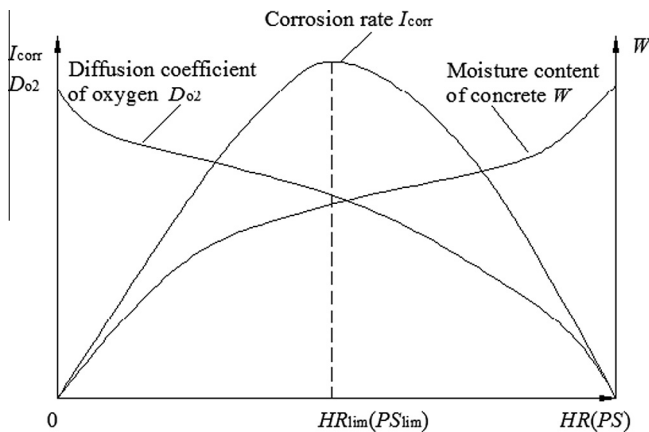


Fig. 1. Effect of RH (or PS) on  $I_{corr}$  in concrete.

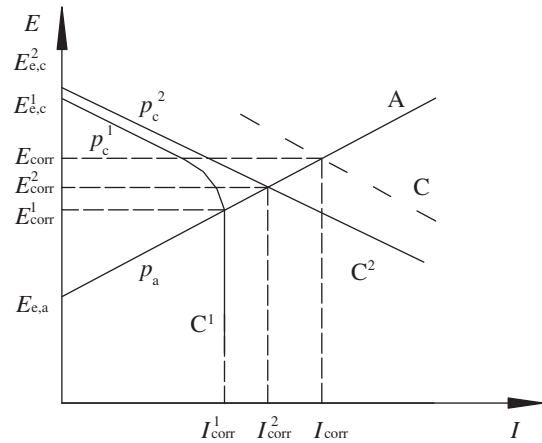


Fig. 2. Evans diagram of steel corrosion after the corrosion products formed on steel surface.

of Raupach [34] showed that the diffusion of oxygen is a significant limiting factor for the corrosion rate only when the concrete around the reinforcement is water saturated. In the case of common outdoor structures being exposed to rain and not submerged or constantly water saturated due to other reasons, no reduction of the corrosion rate induced by limited oxygen diffusion is therefore to be expected.

Although it is debatable with regard to controlling factor of the corrosion of rebar, the assumption that CORIC is an oxygen diffusion controlled (anode controlled) process is well accepted in the modeling of corrosion rate of rebar by using results of oxygen corrosion in metal corrosion science [35–38]. For the oxidized corrosion in metal Corrosion Science, metal is in a solution such as water and soil. Its corrosion is indeed controlled by oxygen diffusion; however, the CORIC in atmospheric environment is different.

Glass [39] reported that the rate of CORIC steadily increased with increasing environmental humidity till complete water saturation, which is entirely contrary to the varying tendency of oxygen diffusion rate. This finding cannot be explained by traditional models. Ashworth [40] suggested that the breakdown of passivity followed by corrosion was stifled by the formation of corrosion products that would cover corrosion pits. Duffo [41] found that rust of steel reinforcement in concrete is the mixture of  $\alpha$ - $Fe_2O_3$ ,  $\gamma$ - $Fe_2O_3$ ,  $Fe_3O_4$ ,  $\alpha$ - $FeOOH$ ,  $\gamma$ - $FeOOH$ ,  $\beta$ - $FeOOH$ , and  $FeO$ . Marcotte [42] considered that the type of corrosion products formed would affect the final corrosion rate as denser products such as magnetite ( $Fe_3O_4$ ) might offer increased resistance to further chloride ingress than a product like haematite ( $\alpha$ - $Fe_2O_3$ ). Wei [43] and Tamura [44] presented that some corrosion products will replace oxygen as new depolarization agent in the cathode process during the formation of corrosion products, i.e., high-valence iron ions in the rust at the rebar surface are reduced. The corrosion mechanism of traditional oxygen as a single cathode depolarizing agents is facing severe challenges. Modeling the corrosion rate of steel rebar in concrete has become more complex because of a lack of important information concerning the variation in corrosion rates and the corrosion products that form.

The objective of this research is experimental determination and clarification of the influence of the coupled effects of oxygen and corrosion products on the corrosion process of reinforcement in concrete structures. Evans diagram is one of important methods to study corrosion mechanism of metals. This is the first of two papers and it completely explains the corrosion mechanisms of the steel surface before and after depassivation and the corrosion processes of the reinforcing bar in concrete with the polarization curve diagrams. In order to show the effect of corrosion products

Download English Version:

<https://daneshyari.com/en/article/257192>

Download Persian Version:

<https://daneshyari.com/article/257192>

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