

Corrosion current distribution of macrocell and microcell of steel bar in concrete exposed to chloride environments



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HIGHLIGHTS

- The corrosion characteristics of rebar in concrete are decided by the corrosion current distribution.
- Both macrocell and microcell corrosion mechanisms could play significant roles.
- I_g not only affects the distribution of the corrosion current, but expedites the corrosion of the entire steel.
- One part of I_g contributes to the increase in the corrosion current.
- The total corrosion current equals to the anodic dissolution current in the active steel.

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ABSTRACT

The corrosion morphology of rebar in concrete was observed and the corrosion current distribution along the circumference of the steel bar was analyzed theoretically and verified by experiments. The results show that the macrocell corrosion must co-exist with microcell corrosion of reinforcements in concrete. The microcell corrosion takes place in active zone of the rebar surface facing the concrete cover. The macrocell corrosion current I_g between the internal and external surfaces not only further expedites the corrosion process on the surface of the steel bar facing the concrete cover, but also forms cathode protect from the corrosion of the side of steel bar opposite to the concrete cover. Both macrocell and microcell corrosion mechanisms could play significant roles, and the total corrosion could be underestimated if either of them is overlooked. The total corrosion current equals the sum of microcell corrosion current I_{corr2} of active steel and anodic dissolution current (ΔI_{corrA}) caused by I_g .

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1. Introduction

In recent years, various reinforced concrete structures worldwide have suffered rapid deterioration. Therefore, the durability of concrete structures, especially those exposed to aggressive environments, is of great concern. Many deterioration causes and factors have been investigated. The corrosion of steel reinforcement is found to be one of major deterioration problems [1,2]. Consequently, the problem that the corrosion mechanisms of the rebar embedded in concrete is recognized accurately and that the durability of existing concrete structures is estimated needs urgently to be resolved in the engineering field.

Chloride contamination is one of the main causes that induce the corrosion of steel in concrete [3]. The recent research [1,2,4–13]

done in the last 10 years have one thing in common that it is a general assumption that chlorides lead to a local breakdown of the protective oxide film on the reinforcement in alkaline concrete, so that a subsequent localized corrosion attack takes place and the zone of corrosion is limited to certain points in the metal. During the corrosion process, there is distinctive separation between anodic zone and cathodic zone with larger areas of cathodic zone than anodic zone. Consequently, corrosion is concentrated at certain location. As shown in Fig. 1, the anodic and cathodic processes may take place preferentially on separate areas of the surface of the reinforcement, leading to a macrocell between active and passive areas of the reinforcement [4–6]. Current circulating between the former, which are less noble and thus function as anodes, and the latter, which are more noble and thus function as cathodes, accelerates the corrosion attack on active surfaces while further stabilizing the protective state of passive ones [7,8]. The magnitude of this current, known as the macrocell current, increases as the difference in the free corrosion potential between passive and active rebar increases, and decreases as the dissipation produced by the

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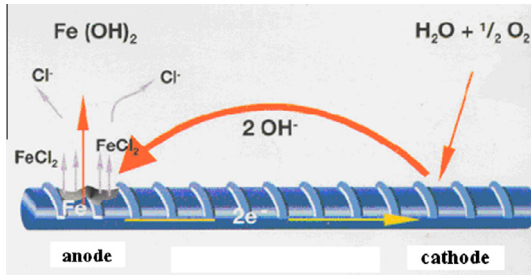


Fig. 1. Chloride-induced corrosion of steel bar in concrete.

current itself at the anodic and cathodic sites and within the concrete increases [9,10].

This assumption, implicit or explicit, plays an important part in many evaluations of lifetime performance. Many models of macrocell corrosion rate of the reinforce steel were based on this assumption [11–13]. It is valid for the uniform concrete, where the steel surface of the weakest point in the concrete reaches the critical chloride concentration first, and consequently, pit corrosion starts. With the development of corrosion, however, the chloride concentration at other locations along the steel bar facing the concrete cover will reach the critical value, and many pits will be formed by the corrosion. When the pits are connected to each other, the entire half surface of the steel bar facing the cover become corroded, thus the morphology of pitting will be less evident.

However, our previous studies showed [14] that, before the cracking of the reinforced steel, corrosion of the steel was concentrated only on the surface that is facing the concrete cover, whereas there is no corrosion on the other side of the steel. Therefore, microcell corrosion is taking place in the active zones facing the concrete cover, and as a result, the corrosion mechanism become more complicated with both microcell and macrocell corrosions. This confirms that the assumption does not accord with the actual corrosion morphology characteristics of steel in concrete, so the corrosion mechanism of steel need to be explained again.

This paper is aimed at presenting a theoretical examination of the understanding of the corrosion mechanisms as well as an experimental demonstration to validate the suggested mechanisms. This study will attempt to clarify fundamental mechanism of the corrosion in concrete and enhance the current understanding of the importance of the microcell corrosion and its relation to the macrocell corrosion.

2. Corrosion morphology and mechanism analysis of reinforcing steel in concrete

2.1. Corrosion morphology of reinforcing steel in concrete

It can be seen from Fig. 2 that before corrosion cracking, the corrosion distributes on the half circumference of the steel bar facing

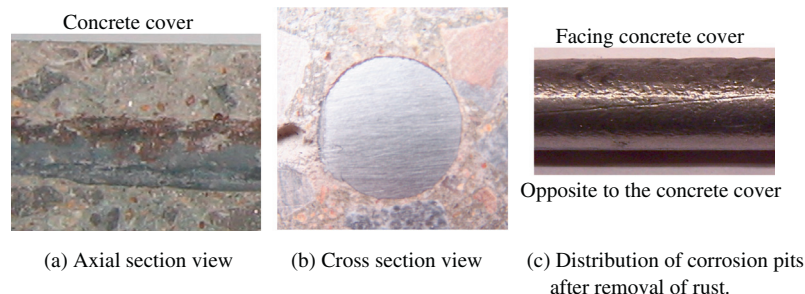


Fig. 2. Corrosion morphology on the steel surface invaded by chloride [14].

the concrete cover only, and the distribution has the shape of a half ellipse [14]. The maximum corrosion level is located on the nearest point from the concrete cover. After removal of the rust from the surface of the reinforced steel (Fig. 2c), one can see sparsely corrosion pits and thickly corrosion dots on the surface of the reinforced steel facing the concrete cover. This implies that chloride-induced corrosion of reinforcing steel in concrete can be approximated as a general corrosion comprised of a large area uniform corrosion and sparsely localized pitting corrosions.

2.2. Electrochemical reaction model of steel bar corrosion in concrete

Chloride ingress is a gradual process from the concrete surface to the inside. For uniform concrete, the chloride concentration must reach the critical value at the weakest points on the surface of the reinforced steel facing the concrete cover, where point corrosion starts. With the progress of the corrosion process, the chloride concentration reaches critical value gradually at other locations in the steel facing the cover, resulting crowd corrosion pits on the external surface of the steel. These corrosion pits are connected eventually to each other forming a corroded surface along the reinforced steel.

On this corroded surface there are incalculable dense and tiny corrosion pits. A galvanic corrosion coupling comes into being between the steel in each corrosion pit and weeny area surrounding the pit, the sizes of these galvanic corrosion macrocells are very small, so that the morphology of pitting will be less evident. Therefore, on a macroscale, the corrosion on the external surface of the reinforced steel is general. The countless dense and tiny galvanic corrosion macrocells can be viewed as microcell corrosion.

There is the electrochemical potential difference between active area as an anode on the side of the rebar facing concrete cover and passive area as a cathode on the opposite side of the rebar, which is the driving force for the macrocell corrosion. The macrocell corrosion current between the internal and external surfaces further expedite the corrosion process. Fig. 3 is a sketch of the corrosion process and shows that the anodes of electrochemical corrosion reaction is mainly located on the bar surface facing the concrete cover. Therefore, the corrosion distribution mainly occurred on the surface of the steel bar facing the concrete cover. According to corrosion electrochemical basic principle, it is concluded that the macrocell corrosion must co-exist with microcell corrosion of reinforcements in concrete. Rust grows on the external surfaces of the reinforced steel. The expansion stress increases with the growth of rust, and eventually results in the cracking of concrete the cover [1,16].

2.3. Corrosion current distribution of steel bar in concrete

2.3.1. Microcell corrosion

The corrosion of steel in concrete is an electrochemical process involving the transfer of electrons from one chemical species to another [15]. Microcell corrosion refers to a corrosion process in

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