Comparative Study on Electrochemical Corrosion and Natural Corrosion of Reinforced Concrete Components

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Abstract: Based on the study of the corrosion characteristics of reinforced concrete members under electrochemical corrosion and natural corrosion, such as the corrosion principle, product formation, morphology and microstructure of steel corrosion pits, the differences and similarities of the basic mechanical properties of steel bars and the mechanical properties of concrete members under two corrosion states are analyzed, and the applicability of accelerated corrosion of steel bars in concrete is discussed. In the study of the mechanical properties of corroded steel bars, the non-uniform electrochemical corrosion can be used to replace the natural corrosion. When the research object needs to consider the corrosion expansion force and the corrosion current density model, the difference between the two cannot be ignored.

Keywords: Concrete Component; Corrosion of Reinforcement; Electrochemical Corrosion; Natural Corrosion

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Introduction

Rebar corrosion will cause the reduction of rebar cross-section, and the reduction of rebar cross-section and stress concentration caused by pit corrosion will reduce its own mechanical properties. In addition, the corrosion of steel bar is filled at the interface between concrete and steel bars, which will cause the deterioration of the bonding performance between concrete and steel bars, and the accumulation of rust to a certain extent will cause rust expansion and cracking of the concrete protective layer, thereby affecting the normal use performance and safety performance of components [1]. In order to study the problem of steel corrosion, the commonly used methods for preparing corroded steel bars are: natural exposure method, replacement component method, artificial climate environment method and electrochemical accelerated corrosion method. The first three methods are the closest to the actual environmental rust situation, and are generally considered to be equivalent to natural rust specimens, but the three methods are difficult to prepare rust specimens due to long rust time, difficulty in obtaining specimens, and high equipment requirements [2]. Compared with other rust methods, electrochemical accelerated corrosion method is widely used due to its short rust time, simple method, and easy control. However, the method of electrochemical accelerated corrosion method and natural corrosion are quite different in terms of rust mechanism, rust products, and rust form. Song Hua et al. [3] discussed the applicability of electrochemical accelerated corrosion simulation of steel corrosion in natural environment by comparing cracking of concrete protective layer in electrochemical accelerated corrosion method with rust expansion and that in natural environment.

At present, there are relatively few studies on the scope and application of electrochemical accelerated corrosion method. Therefore, this paper compares the differences between natural corrosion and electrochemical accelerated corrosion from the aspects of the essential principle of rust, the composition and morphology of rust products, and the morphology of rust pits. On this basis, the differences in the mechanical properties of reinforced concrete components in the two corrosion states were analyzed, and the applicability of electrochemical accelerated corrosion method was discussed.

1. The essential principle of rust

The natural corrosion of steel bars can be regarded as anodic oxidation and cathodic reduction simply from the principle. The matrix of steel bar for construction is mainly composed of Fe, C and Si, Mn, P, S and other trace elements, and different metallographic structures in the steel bar matrix are formed according to different manufacturing processes and combination ratios, such as ferrite (C dissolved in α-Fe), cementite (iron carbon compound Fe_3C) and pearlite (ferrite and cementite exist with each other). However, due to the different Fe content in different metallographic structures, resulting in the formation of inter metallographic potential or potential difference, once the steel matrix contacts the water film with dissolved oxygen, it is easy to form a micro battery [4], resulting in the dissolution of the high-potential metallographic structure. This is a typical spontaneous redox reaction characterized by the occurrence of rust followed by electric current. Literature [5] shown that acid Cl- has the most serious effect on the rebar passivation film in the natural environment, especially the dissolution of the passivation film on the surface of the rebar.

The electrochemical accelerated corrosion method mainly shortens the de-passivation time of the steel bar surface by first applying current to the corroded steel bar and accelerating the external Cl^- infiltration (Cl^- internal doping, Cl^- salt solution immersion and Cl^- electroosmosis). Because the internal current of the steel bar to be corroded accelerates its internal electron flow, the applied current acts as a catalyst in the redox reaction to accelerate the purpose of steel corrosion. Its essential principle is that the electrons of the steel bar to be rusted at the positive electrode lose electrons and undergo an oxidation reaction, while the auxiliary electrode of the cathode obtains electrons for a reduction reaction.

2. Components of corrosion products

SEM scanning electron microscopy was used to obtain the composition of rust products from different working conditions [5]. It can be seen that under the condition of electrochemical accelerated corrosion, the composition of steel corrosion products in concrete under different working conditions (before cracking and cracking, different steel bar types, current density and energization mode) in concrete is basically the same and mainly Fe_2O_3 and Fe_3O_4, and a small amount contains FeO (OH), FeO, etc. Because the reaction speed of reinforced concrete specimens in the process of accelerated corrosion is too fast, the product oxidation is not sufficient, especially before the cracking of the specimen, so the corrosion products before the cracking of the specimen are mainly Fe_3O_4, and after cracking, it contains more Fe_2O_3 and FeO(OH).

However, because the main component phase of its rust products accounts for a very large proportion of the total, it plays a leading role in the process of volume expansion, and the difference in the qualitative composition of the two corrosion types can be ignored. Therefore, it can be preliminarily considered that the electrochemical accelerated corrosion has good similarity with the natural corrosion in the composition of the corrosion products, because the highest content of Fe_2O_3 in nature corrosion is consistent with the main components of the corrosion products obtained subject to the electrochemical accelerated corrosion under different working conditions.

3. Corrosion product morphology

The morphology and microstructure of the corrosion products of the accelerated corrosion and natural corrosion specimens were observed and analyzed in Reference [5]. The natural corrosion and electrochemical accelerated corrosion products were amplified by three thousand times. Two corrosion products have great differences in morphological characteristics. Natural corrosion products have obvious good crystalline flake crystals, good stability and no gel distribution around,. The main reason is that the natural corrosion process is relatively slow, so that the corrosion products have sufficient formation and accumulation time. However, the pores of the accelerated corrosion products are loose, and there are many pores on the surface and no obvious flaky crystals in the interior. It is a porous continuous network structure or flocculent structure, and the compactness is much lower than that of natural corrosion products.

4. Applicability of electrochemical accelerated corrosion

The section corrosion rate under natural corrosion is greater as the yield platform of steel bar is disappearing[6]. Due to the inhomogeneity of natural corrosion and the stress concentration of pit rust, the yield platform degradation of steel bars is more obvious and more discrete under the same mass corrosion rate. With the increase of steel corrosion rate, reinforced concrete beams will change from ductile failure to brittle failure, and the corrosion rate of natural corroded reinforced concrete beams will be lower when the failure mode changes. The surface of the steel bar under accelerated corrosion has better uniform rust in the direction of the rib, and its bonding performance degradation and stiffness degradation is more obvious[7].

Therefore, it can be used to replace the natural corrosion process to obtain rust bars when the non-uniform distribution of corrosion pit by the accelerated corrosion is similar with that by natural corrosion. If the research object is the internal corrosion expansion force and corrosion current density model of corroded reinforced concrete, it is not recommended to use the electrochemical accelerated corrosion scheme instead of the natural corrosion process.

6. Conclusion

(1) Electrochemical accelerated corrosion and natural corrosion are essentially redox reactions. Different from this, the external Cl^- penetration accelerates the depassivation time of the steel surface, and the applied current acts as a catalyst to accelerate the corrosion of the steel.

(2) Due to the inhomogeneity of natural corrosion and the stress concentration of pit corrosion, the yield platform degradation of steel bars under the same mass corrosion rate is more obvious and more discrete.

(3) The corrosion rate of naturally corroded reinforced concrete beams is lower when failure mode change from suitable reinforcement failure to brittle failure. Under the condition of accelerated corrosion, the bond performance and stiffness degradation between steel and concrete are more obvious.

References

[1] Jin WL, Zhao YX. Durability of Concrete Structures (Second Edition), Science Press, 2014.

[2] Jin NG, He JH, Fu CQ, et al. Accelerated non-uniform corrosion test method and corrosion morphology of steel bars, Journal of Zhejiang University: Engineering Edition, 2020, 54 (3) :8.

[3] Song H, Niu TT. Similarity analysis of electrochemical rapid corrosion and natural environment reinforcement corrosion, Journal of Xi 'an University of Architecture and Technology: Natural Science Edition, 2009, 41(4):4.

[4] Torresacosta AS, Navarrogutierrez J, Teranguillen. Residual flexure capacity of corroded reinforced concrete beams, Engineering Structures, 2007, 29(6): 1145-52.

[5] Wen T. Research on the applicability of energized corrosion test of reinforced concrete members, Hubei: Three Gorges University, 2014.

[6] Cao MT. Experimental and theoretical study on steel bar rust expansion failure based on actual central initial defects, Shenzhen : Shenzhen University, 2015.

[7] Shan Y, Guo YC, Zeng L. Numerical analysis of mechanical properties of corroded steel bars, Industrial Building, 2007, 37: 944-6.

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