ISSN 2663-1563 Vol. 3, Issue 1: 32-40, DOI: 10.25236/AJAGE.2021.030106

Quantitative determination of corrosion status of rebar by electrochemical parameters

Moujie He[1,*], Xinrong Li[2]

[1]*Development and Reform Bureau of Pidu District, Chengdu, China*
[2]*Ande Sub-district Office, Pidu District, Chengdu, China*
**Corresponding author: 453564016@qq.com*

Abstract: *In this paper, the relationship between electrochemical parameters and corrosion status of rebar was analyzed by measuring macro-current and potential difference of self-made anode ladder monitoring system under different environmental conditions.Laboratory tests show that the anode ladder monitoring system can better judge the corrosion status of steel bars and provide a basis for structural durability evaluation and remaining life prediction. Reinforced concrete is the most widely used building material in engineering. The durability of reinforced concrete structure gradually declines under the long-term action of unfavorable factors in using environment. At present, there are many "models" for predicting the durability life of concrete published in the world, and more researches are being carried out. The most studied "model" is the "model" related to corrosion, especially the relationship between reinforcement corrosion and concrete durability, is the most common and in-depth research. The problem of durability of reinforced concrete structures caused by corrosion of reinforcing bar has been paid more and more attention in engineering field. Early detection and diagnosis of reinforcement corrosion is an important prerequisite for durability evaluation, remaining service life prediction and maintenance scheme selection of reinforced concrete structures.The development of accurate and reliable on-site monitoring technology of reinforcement corrosion has become the focus of scholars at home and abroad. In order to monitor the corrosion of reinforcement in concrete, some electrochemical parameters need to be measured by sensors. These electrochemical parameters include: potential distribution, macrocurrent, concrete resistance, and so on. Among them, the measurement of macrocurrent is a relatively simple and easy method, which has been widely used in the measurement of reinforcement corrosion. Using this method, in recent years, many countries have developed anodic sensor systems for monitoring reinforcement corrosion, a typical non-destructive monitoring system for the embedded durability of TRAPEZOIDAL anode ladder concrete structure is developed by the Institute of Civil Engineering, Aachen University of Technology, Germany, the corrosion degree and depth of steel bar in concrete can be measured for a long time by embedding steel bar sensors with different depths in concrete, which has been put into engineering application in many countries. In this paper, a self-made multi-group anode ladder monitoring system is designed in the laboratory. The corrosion status of each anode steel bar and the change of electrochemical parameters are obtained by using the method of half-cell potential test in the environmental solution of different concentrations, the criterion of electrochemical parameters to determine the corrosion status of rebar was obtained.*

Keywords: *electrochemical parameters, macro-current, potential, durability*

1. Mechanism of reinforcement corrosion

The corrosion of steel bar is the process of the chemical reaction between the surface of steel bar and the surrounding medium. Concrete is an alkaline material with a PH value of more than 12. In this highly alkaline environment, rebar will form a very dense passivation film, this film attached to the surface of the rebar, play a role in protecting the rebar, but by salt pollution, the rebar in concrete will rust. As with other steel corrosion, the main chemical reaction of steel corrosion in concrete is electrochemical reaction, that is, forming cathode and anode at different points on the surface of steel, and the surface of anode is in an active state, the electrons can be released freely, and there is enough oxygen and water on the surface of the rebar at the cathode. The electrochemical reaction equation and schematic diagram of reinforcement corrosion are shown in Fig. 1 [1-5].

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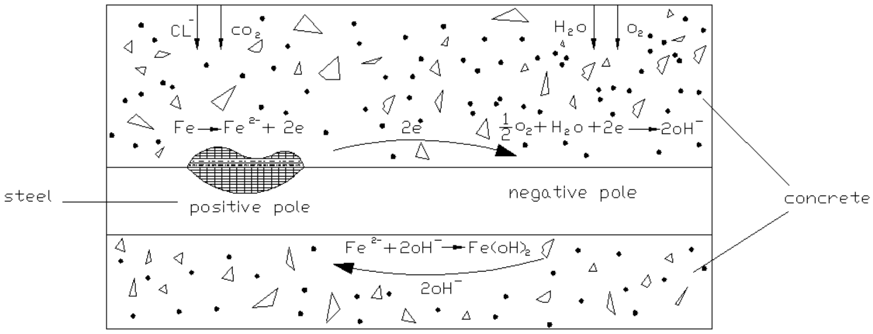

Figure 1: Schematic diagram of electrochemical reaction

The corrosion of steel bars in concrete is divided into uniform corrosion and spot corrosion according to the form, and the corrosion mechanism is divided into micro-cell corrosion and galvanic corrosion. For the depassivation caused by the carbonization of the protective layer, no obvious cathode and anode can be formed, and the anode electrode changes at any time, which becomes the corrosion of the micro battery. Chloride ion erosion leads to depassivation and corrosion of steel bars, which basically belongs to macro cell corrosion.

2. Monitoring principle

In the 1980s, the Institute of Civil Engineering of RWTH Aachen University first invented the embedded anode ladder monitoring system. This monitoring system consists of a set of reinforced ladder sensors poured into concrete, interconnected lead-out structure wires and a cathode. Composition. The vertical rods on both sides of the "ladder" are made of stainless steel and insulated from the steel bars. The wires are installed in the middle holes of the vertical rods and fixed by resin. They are installed obliquely in the concrete protection layer of the monitoring part, so that each section of the steel bars is connected to the concrete surface. Keep a different distance [6].

In order to test the macro current, a macro battery system composed of anode and cathode needs to be formed in the system. Figure 2 shows the composition of the macro battery of this monitoring system

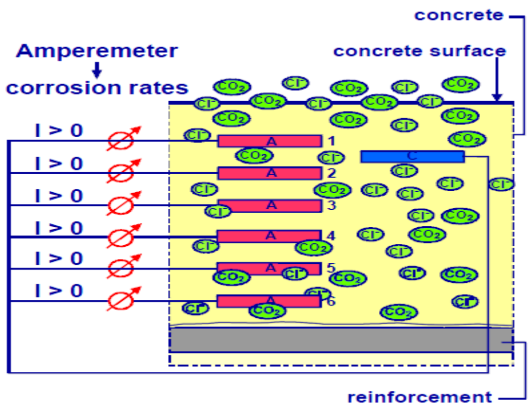

Figure 2: Composition of macro current of monitoring system

The anode is composed of steel bars, while the common cathode section is a titanium rod coated with platinum oxide. The cathode section has a very high positive potential. The concrete between the anode and the anode acts as a medium in the macro battery system, because two metals with different potentials pass through The wire can form a galvanic cell, so when the steel bar is blunt, the loop macro current between the steel bar segment and the titanium rod will change.

In the general environment, concrete structures are mainly affected by moisture, dryness and carbonization. The corrosion mechanism of steel bars in different environments is different, but the corrosion of steel bars must have three factors: sufficient oxygen, moisture and suitable temperature. When studying the quantitative relationship between the electrochemical parameters of the anode ladder monitoring system and the corrosion of steel bars, it is planned to use the research method of dry and wet cycles in different environmental solutions [7-11]

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3. Experimental research

3.1 Monitoring system production

Process a number of light round steel bars with a diameter of 1cm and a length of 15cm. The ends of each bar are drilled, pickled, rinsed with water, neutralized with lime, and stored in a desiccator for 6 hours. Use an analytical balance to measure each bar. Weight. Each group of steel bars are assembled into an anode ladder monitoring system, threaded, and fixed with epoxy resin. After the epoxy resin is solidified, each anode ladder monitoring system is numbered.

Figure 3: Fabrication of anode ladder monitoring system

3.2 Test procedure

First of all: in this experiment, the titanium rods and the anode steel bars are kept parallel, and the spacing is 5cm. The number of each anode steel bar is shown in Figure 3-2. At the same time, in this experiment, the concentration of the solution has a greater impact on the electrochemical reaction of the steel bars, so in the experiment, always keep its concentration unchanged

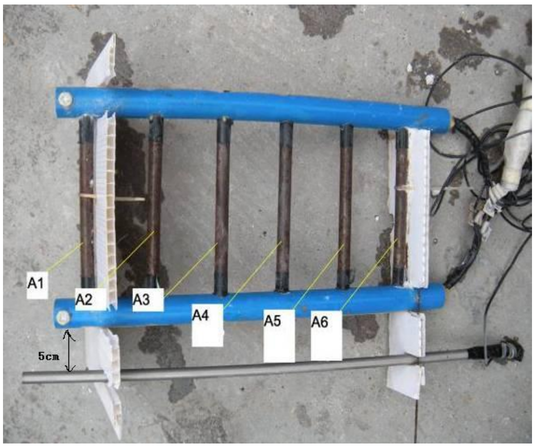

Figure 4: Self made anode ladder monitoring system

Set different rust environments as independent variables. During the test, set 6 groups of different environments and corresponding anode ladder monitori**ng systems (as shown in Table 1**)

Table 1: Correspondence between different corrosion environment conditions and anode ladder monitoring system

number	Environmental conditions	name
1	3.5% NaCl solution	Homemade No. 1
2	Shimizu	Homemade No. 2
3	saturated $Ca(OH)_2$ solution	Homemade No. 3

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Figure 5: Test site layout

3.3 Test results

(1) Environmental condition 1: The corrosion status of each anode steel bar after self-made anode ladder is immersed in 3.5% NaCl solution for 30 days is shown in Figure 6. The steel bars A1 and A2 were severely corroded and pitting corrosion occurred in a large area. A3 was moderately corroded and pitting corrosion occurred in a small area, A4 to A6 were slightly corroded, and pitting corrosion occurred on the surface of each anode steel bar.

(a) Corrosion of steel bars after 6 days

(b) Corrosion of steel bars after 12 days

(c) Corrosion status of steel bars after 20 days

(d) Corrosion of steel bars after 30 days

Figure 6: Corrosion status of steel bars in each group of anode ladder

The electrochemical parameters of each anode steel bar measured by the monitoring system are shown in Figure 7 and Figure 8. At the beginning, the macro current and potential difference of each group of anode steel bars are roughly the same in the time interval of 20 days to 30 days. , The potential difference between A1 and A2 anode steel bars and the macro current have a rising trend, combined with Figure 6, it can be seen that the corrosion macro current of A1-A2 always remains in the range of 0 ~ -300 microamperes, and the range of change is 200 ~ 300 microamps, the electrochemical parameter

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stroke diagram of this anode ladder monitoring system is shown in Figure 7 and Figure 8

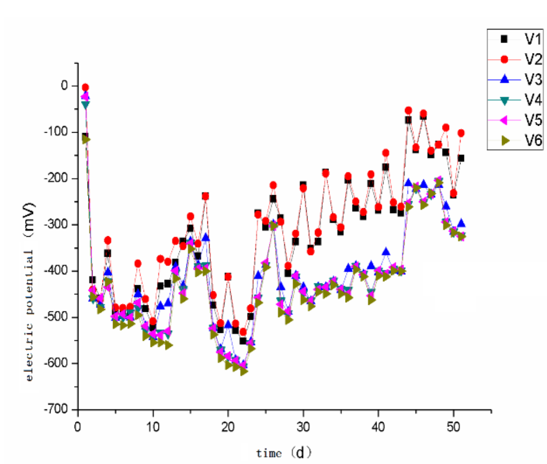


Figure 7: Potential difference stroke diagram

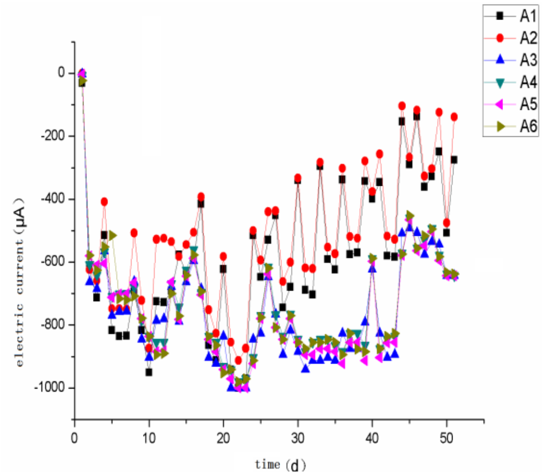
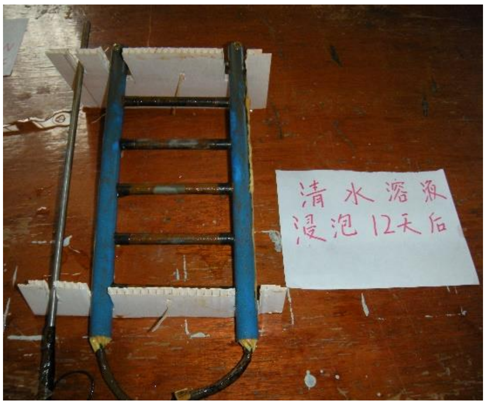


Figure 8: Macro current stroke diagram

(2) Environmental condition 2: The corrosion status of each anode steel bar after the self-made anode ladder is soaked in clean water for 30 days is shown in Figure 9. From Figure a, it can be found that the A2 and A1 steel bars have begun to corrode, and the corrosion situation has further developed in the subsequent tests. In Figure 9: A1 and A2 steel bars have severely corroded, and pit corrosion has occurred in a large area; A3 has moderately corroded Pitting corrosion occurred in a small area; slight corrosion occurred in A4～A6, and pitting corrosion occurred on the surface of each anode steel bar.

(a) Corrosion of steel bars after 6 days



(b) Corrosion of steel bars after 12 days

(c) Corrosion status of steel bars after 20 days

(d) Corrosion of steel bars after 30 days

Figure 9: Corrosion status of steel bars in each group of anode ladder No. 2

The measured potential difference and macro current stroke diagram of each anode steel bar in each time period are shown in Figure 10 and Figure 11:

Academic Journal of Architecture and Geotechnical Engineering
ISSN 2663-1563 Vol. 3, Issue 1: 32-40, DOI: 10.25236/AJAGE.2021.030106

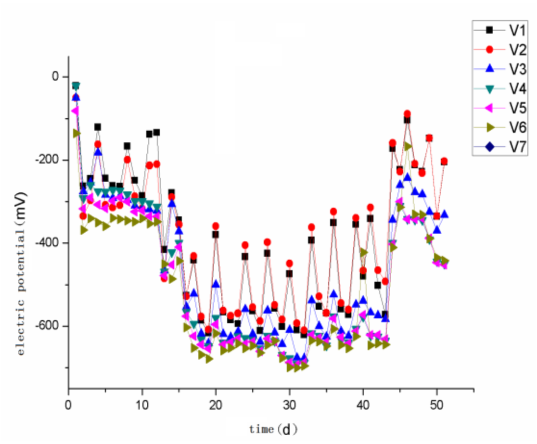


Figure 10: Potential difference stroke diagram

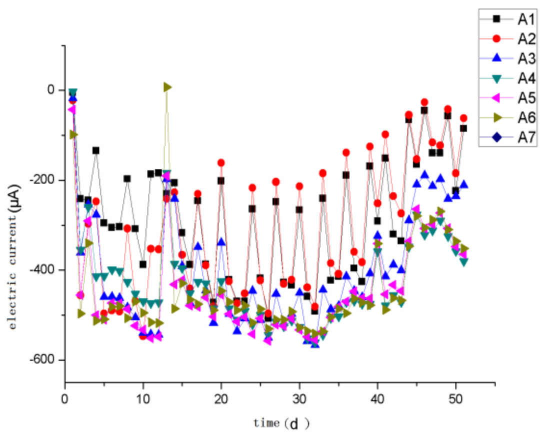


Figure 11: Macro current stroke diagram

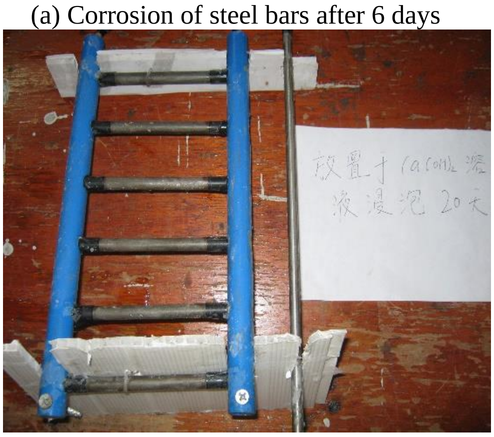
From Figure 9, it is not difficult to see that in the first 20 days, only the A1 and A2 anode rebars were corroded, while the A1 and A2 rebars had been severely corroded at 30 days. During the whole experiment, A3 anode steel bar had moderate corrosion, and A4~A6 had slight pitting corrosion.

In Figure 10 and Figure 11, in the first 20 days, the potential difference and macro current change trends of each group of anode steel bars are roughly the same, while within 20 days to 30 days, the macro current change trends of A1 and A2 anode steel bars are relatively different Big. The corrosion macro current values of the two are between -200 to 0 microamperes, and the range of change is 200 to 300 microamperes.

(3) The corrosion development of No. 3 anode ladder immersed in saturated $Ca(OH)_2$ Homemade anode ladder is shown in Figure 12

(a) Corrosion of steel bars after 6 days

(b) Corrosion of steel bars after 12 days



(c) Corrosion status of steel bars after 20 days

(d) Corrosion of steel bars after 30 days

Figure 12: Corrosion status of steel bars in each group of anode ladder No. 2

Since the anode ladder monitoring system of this group is always immersed in saturated chromium

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hydroxide solution and the anode steel bars are always in an alkaline environment, there is no pitting corrosion on the surface of the anode steel bars, and the surface of the steel bars is relatively bright. The electrochemical parameter stroke diagram of this anode ladder monitoring system is shown in Figure 13 and Figure 14

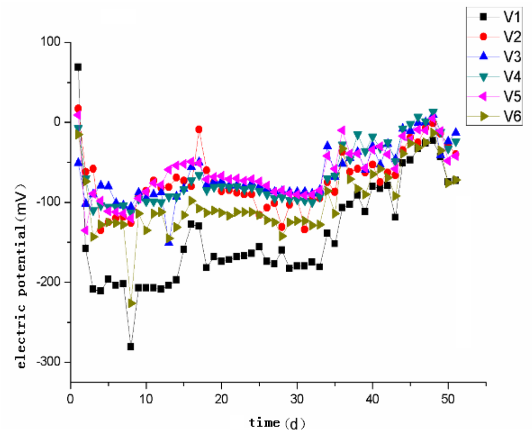

Figure 13: Potential difference stroke diagram

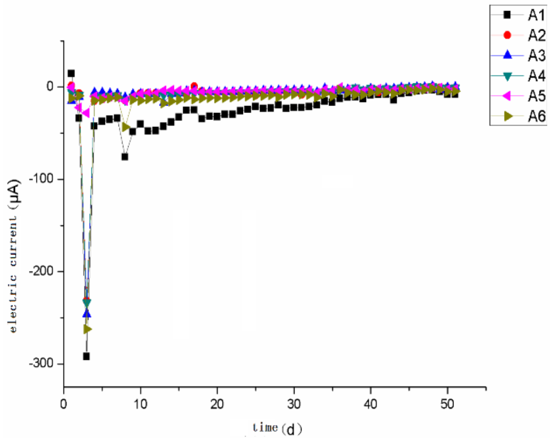

Figure 14: Macro current stroke diagram

It can be seen from Figure 14 that the self-made No. 9 anode ladder system is always placed below the level of the $Ca(OH)_2$ saturated solution during the entire experiment, and each group of steel bars is not in contact with the air. Therefore, the monitoring system for each group of anodes in the picture, No rust has occurred.

In Figures 13 and 14, the potential difference and macro current of each group of anode steel bars have less variation and tend to be stable. The potential difference and macro current of all anode steel bars gradually move closer to a straight line, and the macro current is roughly -20 ~ 0 μA

3.4 Analysis of test results

(1) During the entire test process, the anode ladder monitoring system was placed in the solution first, and then placed in the air. Through this dry-wet cycle method, the corrosion of each anode steel bar is accelerated, resulting in different degrees of corrosion of the anode steel bar. Then, the embedded anode ladder test system is used to test the different corrosion conditions, and the test results are combined with the steel bar corrosion meter to determine the basis of the steel corrosion condition. Make a comparison to determine the test value range of the potential and current of the embedded anode ladder monitoring system under different corrosion conditions, so as to give the evaluation criteria for steel corrosion;

(2) Design different test environment solution conditions, test the embedded anode ladder monitoring system with steel bars with different degrees of corrosion under different test environmental conditions, and compare the test results with the test results of the steel bar corrosion meter under the same test conditions. The research is different The Influence of Test Conditions on the Test of Embedded Anode Ladder Monitoring System;

During the entire test and research process, the embedded anode ladder monitoring system was immersed in clean water under the test conditions, Temperature is 25℃ ±5℃, The critical point of macro current and potential difference of anode steel corrosion is obtained as a benchmark, and the influence of other different test conditions on the critical value of electrochemical parameters of steel corrosion is obtained.

Electrochemical parameters of steel corrosion under benchmark test conditions (immersed in clean water, temperature 25°C±5°C):

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Table 2: Critical values of electrochemical parameters of steel corrosion at 25 ℃±5 ℃ immersed in clean water

Test loop Environmental conditions	Judgment basis		Rust degree	Remarks
	Macro current	Potential difference		
Soak in clean water, the temperature is 20℃~30℃	-22.5±10μA	-50±10mV	No rust	Intact
	-134.6±20μA	-180±20mV	Mild rust	Pitting
	-317.2±20μA	-345±20mV	Moderate rust	Approximately 30% of the area is pitted
	-421.8±20μA	-566±20mV	Severe rust	More than 60% of the area is pitted

Table 3: Critical values of electrochemical parameters of steel corrosion under different test immersion conditions (temperature 25 ℃±5 ℃)

Test environment conditions	Judgment basis		Rust degree	Remarks
	Macro current	Potential difference		
3.5%NaCl	-35±10μA	-60±10mV	No rust	Intact
	-146±20μA	-196±20 mV	Mild rust	Pitting
	-324±20μA	-385±20 mV	Moderate rust	Approximately 30% of the area is pitted
	-387±20μA	-594±20mV	Severe rust	More than 60% of the area is pitted
Saturated $Ca(OH)_2$ solution	-30±10μA	-50mV±10mV	No rust	Intact
	none	none	Mild rust	
	none	none	Moderate rust	
	none	none	Severe rust	

In the above experimental results, the macro current and potential difference of the embedded anode ladder monitoring system immersed in NaCl solution are much larger than other solutions. It is mainly because it acts as a catalyst in the electrochemical reaction process of steel corrosion in the solution containing NaCl and promotes ion transfer between the anode and the anode, because the formation of current is formed by the directional movement of ions; secondly, the dry and wet cycles are simultaneously formed The penetration is accelerated, so the electrochemical parameters measured in this solution are larger than the others.

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