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Corrosion Resistance of Steel in Cracked Reinforced Concrete after Electro-depositon Treatment

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Abstract: An electro-deposition method has been recently proposed to repair cracked reinforced concrete. To evaluate the corrosion resistance of the reinforcing steel in cracked concrete, three different parameters including type of auxiliary electrode, electrode distance, and current density were studied. Tafel polarization curve was used to evaluate the corrosion resistance of the steel. Self-corrosion potential and corrosion current of the steel were tested. The results indicate that the corrosion resistance improvement of the reinforcing steel is optimal as prism titanium mesh is applied as auxiliary electrode, followed by the flaky titanium mesh and the column titanium bar. When the electrode distance is 60 mm, the corrosion resistance improvement of the reinforcing steel is optimal, and with 80 mm electrode distance, the corrosion resistance improvement is the poorest. The property falls in between them when 40 mm electrode distance is used. Moreover, the corrosion resistance improvement of the reinforcing steel increases as the current density goes up.

Key words: electro-deposition; repair of concrete crack; corrosion resistance

1 Introduction

Since the mid-20th century, the durability of reinforced concrete structure is concerned by scholars all over the world^[1,2], and corrosion is the most important factor which causes durability problems^[3-6]. In recent years, researchers have carried out a large number of works in the field of corrosion test for the reinforced concrete structure, including corrosion mechanism of the reinforcing steel, development process, damage level, *etc.* All these play a crucial role in understanding the loading capacity, predicting service life, adopting proper repairing techniques and prolonging service life of reinforced concrete structures^[7-9]. The current test methods of reinforcing steel corrosion include analytical, physical and electrochemical means^[10,11]. Since the nature of steel corroding in concrete is electrochemical corrosion^[10,12], the electrochemical corrosion characteristics become

significant especially when crack exists. Therefore, it is of great advantages to test corrosion resistance of the reinforcing steel by electrochemical method. Electrochemical method has been widely used to detect the position, degree and speed of reinforcing steel corrosion. It is also useful to monitor the corrosion process and analyze the corroding mechanism^[13]. Thus, electrochemical method gains increasing scientific attention and has achieved great development^[14-16].

Electro-deposition technique is a new method emerging in recent years to repair deteriorated concrete structure in both marine environment and buildings on the ground^[17-19]. Previous researches mainly focused on the impermeability and carbonation of concrete, chloride permeability and other durability properties^[20-23]. However, concrete cracks will cause the corrosion of reinforcing steel. This damage of the steel passive film is found to change the electrochemical characteristics of the reinforced concrete structure. Little is known about the effect of electro-deposition technique on the electrochemical characteristics parameters of reinforcing steels^[24]. Additionally, some research reports show that parameters such as types of auxiliary electrode, electrode distance and current density of the electrodepositing have influence on the healing effect, composition and structure of deposits^[25]. Therefore, the objective of this study is

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to investigate the influence of different technological parameters on the electrochemical characteristics of cracked reinforced concrete structure before and after the electro-deposition treatment, and the effect of electro-deposition on the re-passivation of the corroded reinforcing steel is studied using electrochemical test method as well.

2 Experimental

2.1 Raw materials

P·II 42.5 cement produced by China Cement Plant was used. The physical properties of the cement are shown in Table 1 and the chemical composition is given in Table 2. River sand was adopted as fine aggregate, and its physical properties are shown in Table 3.

Table 1 Physical properties of the cement

Flexural strength/MPa		Compressive strength/MPa	
3 d	28 d	3 d	28 d
5.2	8.3	25.0	47.8

Table 2 Chemical composition of the cement/wt%

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃
21.52	5.13	5.25	63.86	1.46	2.28

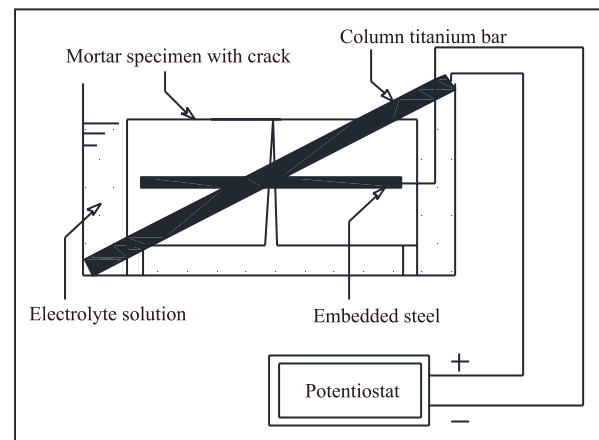
2.2 Specimen preparation

Reinforced mortar prism specimens with dimensions of 40 mm×40 mm×160 mm were prepared. The cover depth of these specimens was 15 mm. The water-cement ratio of the specimens was 0.60 and the cement-sand ratio was 1:2.5. The diameter of the plain steel bar was 6 mm. After curing the specimens under standard conditions ($RH>95\%$, $T=20\text{ }^{\circ}\text{C}$) for 28 days, load-induced cracks with widths of $0.3\pm 0.05\text{ mm}$ on the mortar surface were produced for all the specimens, which were used to simulate the flexural cracks in practical engineering. Except the cracked side of the specimen, all the other five sides were sealed with silicone rubber. Afterwards, the specimens were placed in electrolytic tanks containing electrolyte solutions.

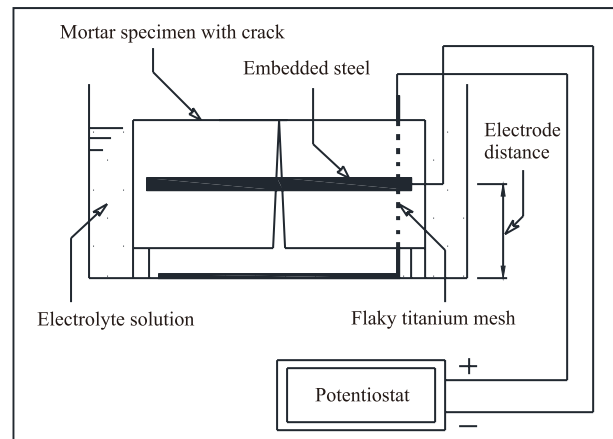
2.3 Experimental procedure

The schematic of experimental setup is shown in Fig.1. Direct current was employed between the embedded reinforced steel and an auxiliary anode

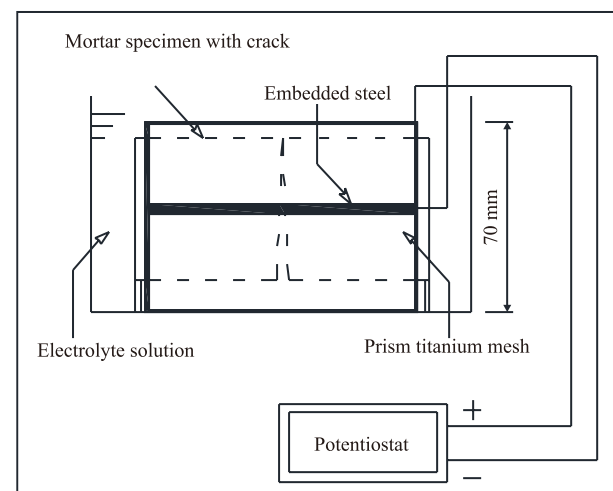
which was immersed in the solution. The steel embedded in the mortar specimens was connected to the negative terminal of the power supply and the external anode was connected to the positive terminal



(a) Column titanium bar acts as auxiliary electrode



(b) Flaky titanium mesh acts as auxiliary electrode



(c) Prism titanium mesh acts as auxiliary electrode

Fig.1 Schematic of experimental setup

Table 3 Physical properties of fine aggregate

Apparent density /(kg/m ³)	Bulk density /(kg/m ³)	Mud content /%	Clod content /%	Fineness modulus	Grading zone
2 620	1 490	0.9	0.0	2.6	II

Table 4 Details of experimental procedure for ZnSO₄ electrolyte solution

No.	Electrolyte solution		Auxiliary electrode	Electrode distance /mm	Current density /(A/m ²)
	Type	Concentration/(mol/L)			
(1)	ZnSO ₄	0.25	Flaky titanium mesh	40	2.0
(2)	ZnSO ₄	0.25	Column titanium bar	—	2.0
(3)	ZnSO ₄	0.25	Prism titanium mesh	—	2.0
(4)	ZnSO ₄	0.25	Flaky titanium mesh	60	2.0
(5)	ZnSO ₄	0.25	Flaky titanium mesh	80	2.0
(6)	ZnSO ₄	0.25	Flaky titanium mesh	40	0.5
(7)	ZnSO ₄	0.25	Flaky titanium mesh	40	3.5

Table 5 Details of experimental procedure for MgSO₄ electrolyte solution

No.	Electrolyte solution		Auxiliary electrode	Electrode distance /mm	Current density /(A/m ²)
	Type	Concentration/(mol/L)			
(1)	MgSO ₄	0.25	Flaky titanium mesh	40	2.0
(2)	MgSO ₄	0.25	Column titanium bar	—	2.0
(3)	MgSO ₄	0.25	Prism titanium mesh	—	2.0
(4)	MgSO ₄	0.25	Flaky titanium mesh	60	2.0
(5)	MgSO ₄	0.25	Flaky titanium mesh	80	2.0
(6)	MgSO ₄	0.25	Flaky titanium mesh	40	0.5
(7)	MgSO ₄	0.25	Flaky titanium mesh	40	3.5

of the power supply. The positive and negative ions in the solution moved respectively to the two electrodes and brought a series of reactions on the electrodes as the current passed through. Then sediment would grow in the cracks of the specimens and thus the crack remediation could be accomplished.

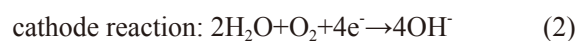
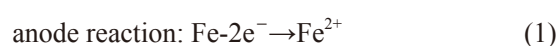
The detailed experimental procedure is listed in Table 4 and Table 5. Two electrolyte solutions, ZnSO₄ and MgSO₄, each with a concentration of 0.25 mol/L, are used in this experiment. Three auxiliary electrodes, *i e.*, column titanium bar (CTB), flaky titanium mesh (FTM) and prism titanium mesh (PTM) were studied. For the CTB, the cylinder has a bottom diameter of 6 mm and a height of 120 mm. For the FTM, the square has a side length of 140 mm. For the PTM, a piece of titanium mesh is folded into four faces and forms a prism. Two faces are rectangular with a dimension of 140 mm×70 mm, and the other two faces are rectangular with a dimension of 140 mm×60 mm. The electrode distance is the distance from the center line of the reinforcing steel to the flaky titanium mesh. Three electrode distances of 40, 60, and 80 mm were tested. Additionally, three current densities of 0.5, 2.0, and 3.5 A/m² to the steel area were provided in the experiment.

The environmental conditions were kept constant throughout the period of investigation. In order to maintain the same concentration, the solutions were

refreshed every 5 days. The electro-depositon repairing treatment duration is 20 days. Meanwhile, the control specimens were immersed in the solutions for 20 days without applying electro-depositon repairing treatment. After the treatment, the steel in the mortar specimens as well as the steel in the control specimens before the electro-depositon repairing treatment were tested with the method of Tafel polarization curve. Each group contained 3 mortar specimens with cracks. The final result of each group was gained from average data of 3 specimens. 48 specimens in total are tested in the experiment.

2.4 Tafel polarization curve method

When the reinforcing steel in the concrete is corroded, the surface of steel will generate two polarization region such as anode and cathode. That is to say, iron oxidative dissolution reaction takes place in the anode region and dissolved oxygen reduction reaction occurs in the cathode region. The anode and cathode reactions are shown in Formula 1 and 2:



If the reinforcing steel disconnects with the external circuit, reaction rate of anode region is equal to that of cathode region on the steel surface, and the

total current of the reinforcing steel is zero:

$$I_{\text{total}} = I_a + I_c = 0 \quad (3)$$

$$I_{\text{corr}} = I_a = -I_c \quad (4)$$

where I_{corr} is the corrosion current of reinforcing steel, and the corresponding potential E_{corr} is the self-corrosion potential of reinforcing steel. Corrosion current is the corrosion speed of reinforcing steel, namely the degree of steel corrosion in unit time. The corrosion rate of reinforcing steel decreases as the corrosion current decreases. Self-corrosion potential indicates the difficulty level of reinforcing steel corrosion. The corrosion resistance of electrode increases with the increase of self-corrosion potential. Both I_{corr} and E_{corr} reflect the corrosion resistance of the reinforcing steel. Corrosion current and self-corrosion potential of the reinforcing steel are often tested by Tafel polarization curve method. This method is a potentiodynamic scanning and measurement method. Dynamic potential scanning is conducted against polarization potential through controlling the current density and the potential scanning range is often -250 to $+250$ mV relative to the self-corrosion potential. A relation curve between polarization current density and polarization potential E for the reinforcing steel can be obtained, as shown in Fig.2.

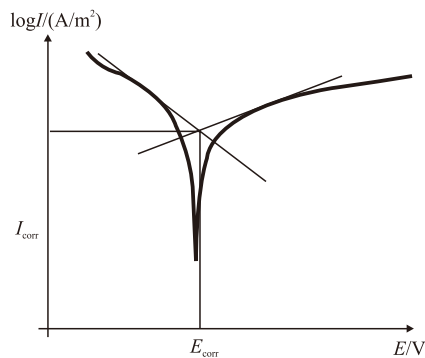


Fig.2 Tafel polarization curve of iron electrode

Based on slope and intercept of polarization curve, E_{corr} , which is relative to the saturated calomel electrode (SCE), and I_{corr} , can be determined to evaluate the corrosion status of the reinforcing steel.

3 Results and discussion

After the circuit was turned on, some air bubbles appeared near the the mortar specimens and titanium mesh electrode, and white deposits could be observed on the surface as well as in the cracks after 20 days of

electro-deposition treatment.

3.1 Influence of auxiliary electrode

The Tafel polarization curves of the reinforcing steels are shown in Figs.3 and 4. The influence of auxiliary electrode on the reinforcing steel corrosion status after electrodeposition treatment is shown in Table 6 and Table 7.

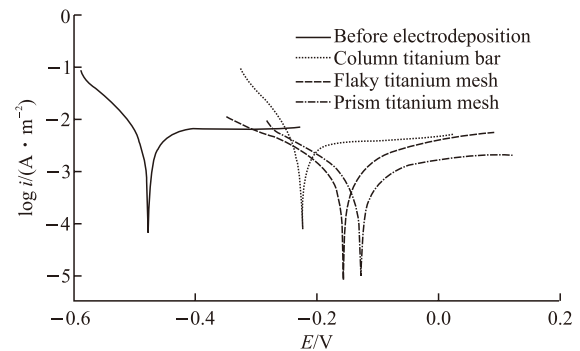


Fig.3 Tafel polarization curve of the reinforcing steel for ZnSO_4 solution

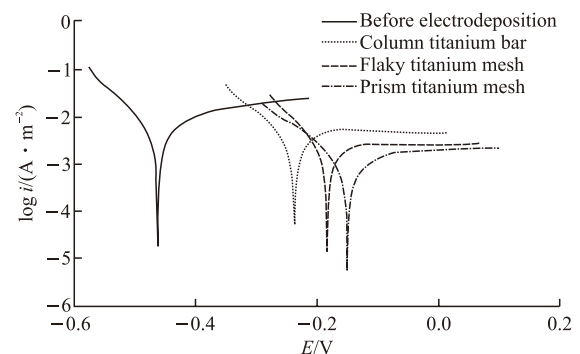


Fig.4 Tafel polarization curve of the reinforcing steel for MgSO_4 solution

These slopes of cathodic and anodic branches of Tafel curves are listed in Table 6 and Table 7. It can be found that the slopes for these three kinds of auxiliary electrodes are larger than those of the control one, indicating a higher corrosion resistance. Moreover, slopes of steel where the prism titanium mesh was applied show larger values compared to the others. As seen from Table 6, the self-corrosion potential of reinforcing steel in the control specimens is -0.480 23 V and the corrosion current is 0.005 72 A/m^2 when ZnSO_4 solution was applied. The column titanium bar, flaky titanium mesh and prism titanium mesh are selected to be auxiliary electrodes for electrodeposition repairing treatment. The maximum self-corrosion potential of reinforcing steel in the specimens is -0.130 19 V, and the minimum value is -0.224 25 V, and the improvement percentage is 53.3%–72.9%, compared with the control specimens. The corrosion current of reinforcing steel is 0.001 35– 0.003 13 A/m^2 , which

Table 6 Influence of auxiliary electrode on corrosion status of steel for ZnSO₄ solution

Corrosion status of steel	Before electrodeposition	After electro-deposition		
		Column titanium bar	Flaky titanium mesh	Prism titanium mesh
b_a	3.098	3.189	3.345	4.989
b_c	4.980	6.490	8.890	12.894
E_{corr} (V vs SCE)	-0.480 23	-0.224 25	-0.161 87	-0.130 19
I_{corr} (A/m ²)	0.005 72	0.003 13	0.001 96	0.001 35

Table 7 Influence of auxiliary electrode on corrosion status of steel for MgSO₄ solution

Corrosion status of steel	Before electro-deposition	After electrodeposition		
		Column titanium bar	Flaky titanium mesh	Prism titanium mesh
b_a	2.797	3.289	3.145	4.489
b_c	4.267	5.890	8.256	12.494
E_{corr} (V vs SCE)	-0.491 83	-0.238 92	-0.182 37	-0.147 31
I_{corr} (A/m ²)	0.006 02	0.003 42	0.002 13	0.001 62

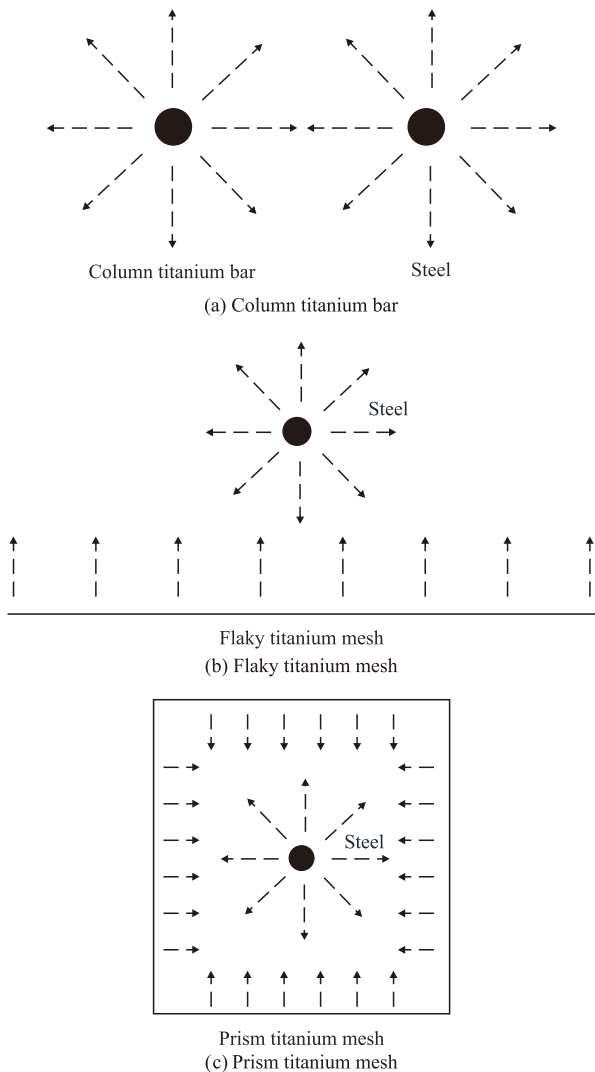


Fig.5 Electric field distribution between different auxiliary electrodes and reinforced steel

reduces by 45.3%-76.4%, compared with the control specimens. From Table 7, it is found that the self-

corrosion potential of the reinforcing steel in the control specimens is -0.491 83 V, and the corrosion current is 0.006 02 A/m² with the MgSO₄ electrolyte solution. After electro-depositon, the maximum self-corrosion potential of reinforcing steel in the control specimens is -0.147 31 V, and the minimum value is -0.238 92 V, and the improvement percentage is 51.4%-70.0%, compared with the control specimens. The corrosion current of the reinforcing steel is 0.001 62-0.003 42 A/m², which reduces by 43.2%-73.1%, compared with the control specimens.

Independent of type of solution, the improvement of self-corrosion potential and reduction of self-corrosion current of the reinforcing steel after electrodepositing repairing are the maximum when prism titanium mesh is applied as auxiliary electrode. The corrosion resistance improvement of the reinforcing steel is optimal using prism titanium mesh, followed by flaky titanium mesh and the column titanium bar. The reason is that at the same current density, the electric field distribution and utilization of electric flux in the electro-depositon repair system will change with alteration of the auxiliary electrode^[25]. Fig.5 illustrates the electric field distribution between different auxiliary electrodes and reinforced steel.

As can be seen from the Fig.5, a closed circular electric field is formed between the prism titanium mesh electrode and the reinforced steel, and the effective utilization of electric flux is the highest. The open face electric field is formed between the titanium mesh electrode and the reinforced steel, and the utilization of electric flux is reduced. The column titanium electrode and reinforced steel form

a line electric field, with the lowest utilization of electric flux. The utilization efficiency of electric flux determines the electrodepositing repairing effect and thus influences the improvement of corrosion resistance of the reinforcing steel. In the case of high utilization efficiency, effective quantity of electric charge is large in unit time. Thus the probability of the precipitation reaction of the depositional ions such as Zn^{2+} , Mg^{2+} and OH^- etc is increased, which improves the corrosion resistance of the reinforcing steel.

3.2 Influence of electrode distance

Fig.6 and Fig.7 show the Tafel polarization curve of the reinforcing steel. The influence of electrode distance on the corrosion status of the reinforcing steel after electrodepositon treatment is shown in Table 8 and Table 9.

From Table 8 and Table 9, it can be observed that the slopes of steel after electro-deposition are all larger than those of the control one in different conditions of electrode distance. Moreover, it can be found that when the electrode distance is 60 mm, the corrosion resistance improvement is optimal. As can be seen in Table 8, the self-corrosion potential of the reinforcing steel in the control specimens is $-0.480\ 23\ V$ and the corrosion current is $0.005\ 72\ A/m^2$ with the $ZnSO_4$ electrolyte solution. The 40, 60 and 80 mm electrode distances are applied to repair concrete cracks by electrochemical technique. The maximum self-corrosion potential of reinforcing steel in the specimens is $-0.137\ 82\ V$, and the minimum value is $-0.213\ 51\ V$, and the improvement percentage is 55.5%-71.3%, compared with the control specimens. The corrosion current of reinforcing steel is $0.001\ 32\text{-}0.002\ 55\ A/m^2$,

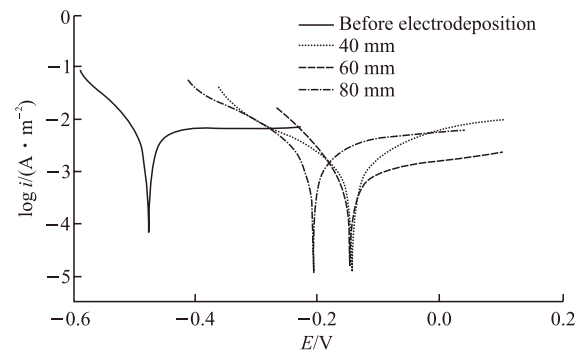


Fig.6 Tafel polarization curve of the reinforcing steel for $ZnSO_4$ solution

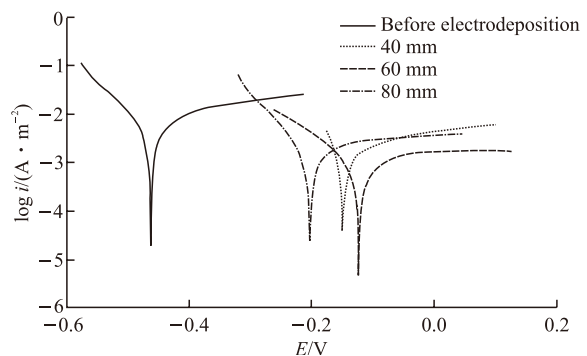


Fig.7 Tafel polarization curve of the reinforcing steel for $MgSO_4$ solution

which reduces by 55.4%-76.9%, compared with the control specimens. From Table 9, we can find that the self-corrosion potential of reinforcing steel in the control specimens is $-0.491\ 83\ V$, and corrosion current is $0.006\ 02\ A/m^2$ with the $MgSO_4$ electrolyte solution. After electro-depositon, the maximum self-corrosion potential of reinforcing steel in the control specimens is $-0.182\ 37\ V$, and the minimum value is $-0.301\ 24\ V$. The improvement percentage is 38.5%-62.9%, compared with the control specimens. The

Table 8 Influence of electrode distance on corrosion status of steel for $ZnSO_4$ solution

Corrosion status of steel	Before electrodeposition	After electrodeposition		
		40 mm	60 mm	80 mm
b_a	3.098	3.489	4.518	3.248
b_c	4.980	8.670	13.146	7.556
E_{corr} (V vs SCE)	$-0.480\ 23$	$-0.161\ 87$	$-0.137\ 82$	$-0.213\ 51$
I_{corr} (A/m^2)	0.005 72	0.001 96	0.001 32	0.002 55

Table 9 Influence of electrode distance on corrosion status of steel for $MgSO_4$ solution

Corrosion status of steel	Before electrodeposition	After electrodeposition		
		40 mm	60 mm	80 mm
b_a	2.797	3.215	3.725	3.089
b_c	4.267	9.113	8.356	7.449
E_{corr} (V vs SCE)	$-0.491\ 83$	$-0.182\ 37$	$-0.151\ 83$	$-0.301\ 24$
I_{corr} (A/m^2)	0.006 02	0.002 13	0.001 83	0.002 82

corrosion current of reinforcing steel is 0.001 83-0.002 82 A/m², which reduces by 53.2%-64.6%, compared with the control specimens.

Independent of the type of the solution, the improvement of self-corrosion potential and reduction of corrosion current of the reinforcing steel after electrodepositing repairing are the maximum, 71.3% and 76.9% respectively if the 60 mm electrode distance is applied. And the corrosion resistance improvement of the reinforcing steel is optimal. With 80 mm electrode distance, the improvement of self-corrosion potential and reduction of corrosion current of the reinforcing steel are the minimum, 55.5% and 55.4% respectively. The corrosion resistance improvement of the reinforcing steel is the poorest. For the 40 mm electrode distance, the corrosion resistance improvement of the reinforcing steel fall in between them. The reason is analyzed as below. The electric field intensity of overall electrodepositing repairing system increases with the decrease of the electrode distance. Meanwhile, an approximate surface electric field is formed between the flaky titanium mesh electrode and the reinforcing steel. If the distance becomes smaller, the reinforcing steel may be taken as a piece of thread, which reduces the effective utilization of the electric flux. At this time, the corrosion resistance improvement of the reinforcing steel is mainly attributed to the increased electric filed intensity. If the electrode distance is larger, the electric filed intensity of the system is weakened, and the reinforcing steel may be approximately taken as a surface so as to improve the effective utilization of the electric flux and help generate deposits. And the corrosion resistance improvement of the reinforcing

steel is mainly attributed to increased effective electric flux. In conclusion, with the combination of the above two effects, when the electrode distance reaches a critical value, the corrosion resistance performance improvement of the reinforcing steel reaches to be optimal.

3.3 Influence of current density

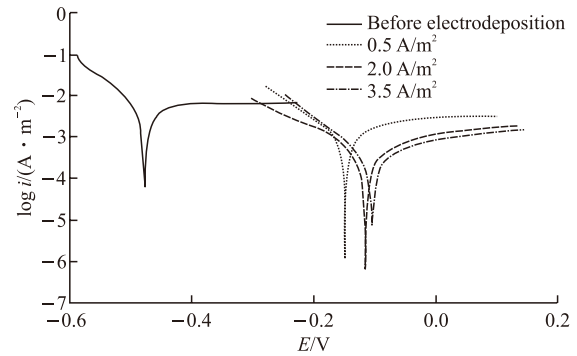


Fig.8 Tafel polarization curve of the reinforcing steel for ZnSO₄ solution

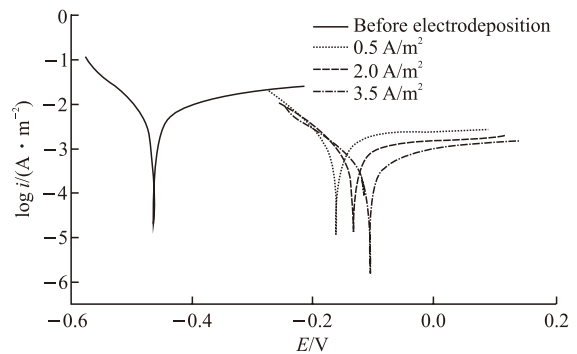


Fig.9 Tafel polarization curve of the reinforcing steel for MgSO₄ solution

Fig.8 and Fig.9 show the Tafel polarization curve of the reinforcing steel. Based on Fig.8 and Fig.9, the

Table 10 Influence of current density on corrosion status of steel for ZnSO₄ solution

Corrosion status of steel	Before electro-deposition	After electrodeposition		
		0.5 A/m ²	2.0 A/m ²	3.5 A/m ²
<i>b_a</i>	3.098	3.269	5.238	5.989
<i>b_c</i>	4.980	8.569	13.142	13.894
<i>E_{corr}</i> /(V vs SCE)	-0.480 23	-0.161 87	-0.119 62	-0.112 84
<i>I_{corr}</i> /(A/m ²)	0.005 72	0.001 96	0.000 93	0.000 89

Table 11 Influence of current density on corrosion status of steel for MgSO₄ solution

Corrosion status of steel	Before electro-deposition	After electro-deposition		
		0.5 A/m ²	2.0 A/m ²	3.5 A/m ²
<i>b_a</i>	2.797	3.138	4.145	5.489
<i>b_c</i>	4.267	8.113	9.681	10.944
<i>E_{corr}</i> /(V vs SCE)	-0.491 83	-0.182 37	-0.139 53	-0.137 11
<i>I_{corr}</i> /(A/m ²)	0.006 02	0.002 13	0.001 12	0.001 08

influence of current density on the reinforcing steel corrosion status after electrodeposition treatment is shown in Table 10 and Table 11.

Slopes of anodic and cathodic branches of Tafel curves for steel after electro-deposition using different current density are presented in Table 10 and Table 11. Similar to the above analysis, increase of slopes of steel after electro-deposition can be observed compared to those of the control one. Besides, the slopes of branches, especially the anodic one, show increasing tendency with the increase of current density. From Table 10, it can be found that the self-corrosion potential of the reinforcing steel in control specimens is $-0.480\ 23\ \text{V}$, and the corrosion current is $0.005\ 72\ \text{A}/\text{m}^2$ with the ZnSO_4 electrolyte solution. Three current densities of 0.5 , 2.0 , and $3.5\ \text{A}/\text{m}^2$ are selected for the electrodeposition repairing treatment. The maximum self-corrosion potential of the reinforcing steel in the specimens is $-0.112\ 84\ \text{V}$, and the minimum value is $-0.161\ 87\ \text{V}$. The improvement percentage is 66.3% - 76.5% , compared with the control specimens. The corrosion current of the reinforcing steel is $0.000\ 89$ - $0.001\ 96\ \text{A}/\text{m}^2$, which reduces by 65.7% - 84.4% , compared with the control specimens. As can be seen from Table 11, the self-corrosion potential of the reinforcing steel in control specimens is $-0.491\ 83\ \text{V}$, and the corrosion current is $0.006\ 02\ \text{A}/\text{m}^2$ when the MgSO_4 electrolyte solution is applied. The maximum self-corrosion potential of the reinforcing steel in control specimens is $-0.182\ 37\ \text{V}$, and the minimum value is $-0.137\ 11\ \text{V}$. The improvement percentage is 62.9% - 72.1% , compared with control specimens. The corrosion current of the reinforcing steel is $0.001\ 08$ - $0.002\ 13\ \text{A}/\text{m}^2$, which reduces by 64.6% - 82.1% , compared with the control specimens.

For MgSO_4 and ZnSO_4 solution, the improvement of self-corrosion potential and the reduction of corrosion current of the reinforcing steel all increase as the current density goes up after electro-deposition. Additionally when the current density is increased from 2.0 to $3.5\ \text{A}/\text{m}^2$, the improvement of self-corrosion potential is approximately equal to the reduction of corrosion current of the reinforcing steel, and the influence on the corrosion resistance of the reinforcing steel is small. As is known, increased current density accelerates ion migration rate of electrodeposition repairing system. A small current density cannot well complete crack healing, so the corrosion resistance improvement of the reinforcing

steel is low. When the current density reaches a critical value, the crack of the specimen can be fully healed. At this point, further increasing the current density has little effect on the corrosion resistance of the reinforcing steel. From an economic point of view, increasing the current density is favorable. The ion migration rate is accelerated as the current density goes up, and the crack healing period is shortened. However, at technological level, larger current density does not imply better results. Firstly, the increased current density results in greater harm to the concrete. Besides, it accelerates out-migration rate of OH^- ion nearby the cathode and reduces the pH value around the reinforcing steel, which deters generation of the steel passivation film. Therefore, after comprehensive consideration of cost and properties, proper current density should be selected for the electrodeposition repairing treatment, which not only makes the concrete crack healing quickly but also ensures minimum concrete damage. Moreover, application of a high current in electric treatment can lead to the decrease of bond strength between steel and concrete^[26]. This problem has been investigated by many researchers. Pokder *et al*^[27] reported that when the current density is lower than $5\ \text{A}/\text{m}^2$, it would have little harm on the reinforced concrete structure. N M Ihekwa *et al*^[28] found that the bond strength reduction at an impressed current density of $1.0\ \text{A}/\text{m}^2$ is about half the reduction at current density of $3.0\ \text{A}/\text{m}^2$. For safety, the current density is suggested to be $2.0\ \text{A}/\text{m}^2$ for electro-deposition repairing treatment under the experimental conditions.

4 Conclusions

a) The corrosion resistance improvement of the reinforcing steel is optimal when the prism titanium mesh is applied as auxiliary electrode, followed by the flaky titanium mesh and the column titanium bar.

b) When the $60\ \text{mm}$ electrode distance is adopted, the corrosion resistance improvement of the reinforcing steel is optimal. With $80\ \text{mm}$ electrode distance, the corrosion resistance improvement is the poorest. The property falls in between the above two when the $40\ \text{mm}$ electrode distance is used.

c) The corrosion resistance improvement of the reinforcing steel increases as the current density goes up. Additionally, when the current density is increased from 2.0 to $3.5\ \text{A}/\text{m}^2$, the improvement is small.

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