Study on the potential change of corroded reinforced concrete in ECE with MPC-CFRP as anode

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Abstract. Aiming at the rust removal requirements of reinforced concrete, the MPC-CFRP composite material was used as the external anode, and the Electrochemical chloride extraction (ECE) method was used to test the polarization curve of the steel bar under different ECE current densities, and the potential changes of the steel bar at different times were analyzed. The results show that the ECE system with MPC-CFRP as the external anode has a good effect of reducing the corrosion rate and the risk of corrosion of steel bars. The current density of $3A/m^2$ is higher than that of $1A/m^2$ in dechlorination efficiency. After 28 days of ECE, the current density of $1A/m^2$ and $3A/m^2$ can re passivate the reinforcement.

1 Introduction

Corrosion of steel bars is the main reason that affects the durability of reinforced concrete structures [1]. Chloride corrosion is the main cause of steel corrosion [2-4]. ECE can effectively inhibit the corrosion of steel bars and improve the durability of corroded reinforced concrete structures [5]. External anode material of ECE is one of the research hotspots at present. Carmona et al. studied the effect of ECE of different anodes, and pointed out that for the isotropic structural elements, the effect of desalting with Ti-RuO_2 as anode and conductive mortar as anode is almost the same [6]. Yeih added carbon rod as auxiliary electrode in concrete, and used two different anode devices, radial type and layer type, to carry out electrochemical desalting. The results showed that the dechlorination effect of layer type device was slightly better than that of radial type device [7]. Saraswathy et al. compared the difference between CCPA (conductive placement paste anode) and traditional metal as ECE anode, pointed out that the cost of CCPA as anode is lower, the desalination performance is the same as that of metal anode, and it is more suitable for long-term application under the current density of $0.5A/m^2$ [8]. CFRP is often used to reinforce reinforced concrete structures [9]. At the same time, CFRP has excellent electrical conductivity, and its performance is still good after accelerated polarization in alkaline solution [10,11].

In this paper, magnesium phosphate cement (MPC) is used as the binder to bond CFRP on the surface of corroded reinforced concrete, forming MPC-CFRP composite as the external anode of ECE. By collecting the polarization curve of steel bars in the process of electrochemical desalting, the change trend of corrosion potential and corrosion current of steel bars in the reinforced concrete columns with and without desalting was analyzed, and the influence of $1A/m^2$ and $3A/m^2$ current density on the efficiency and effect of ECE was compared.

2 Test overview

2.1 Raw materials and mix proportion

The raw materials for manufacturing corroded reinforced concrete columns include: P O42.5 Portland cement; 5~25mm continuous graded crushed stone, with apparent density of $2650kg/m^3$; river sand with fineness modulus of 2.56; polycarboxylic acid water reducer with water reduction rate of 31%. There are two types of reinforcement in the column: HRB400 and HPB300. The concrete mix is shown in Table 1. In order to accelerate the corrosion of reinforcement, the concrete is mixed with 3% sodium chloride of cement mass fraction to discuss the effect of ECE.

Table 1. Concrete mix ratio（kg/m3）and mechanical properties.

Cement	Sand	Stone	Water	Water reducer	NaCl	Compressive strength of 28 days (MPa)	Slump (mm)
325	662	1228	185	0.65	9.75	36	180

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Table 2. Mix proportion and mechanical properties of MPC cement.

P/M	B/M	W/C	Compressive strength (MPa)			
			3h	1d	7d	28d
1/4.5	0.05	0.14	22	32	41	65

The materials used to prepare the ECE anode MPC-CFRP include calcined MgO (M) at 1600℃, chemically pure KH_2PO_4 (P), retarder boric acid B. The mix design and related performance of MPC are shown in Table 2. The thickness of CFRP is 0.19 mm, the ultimate tensile strength and fracture strain are 4200 Mpa and 2%, respectively.

2.2 RC component manufacturing

Fabricate reinforced concrete column (750mm in height × 200mm in diameter), 25mm in concrete protective layer, and the upper end of longitudinal bar extends out of the concrete surface by 150 mm. The geometric dimension and reinforcement of the component are shown in Figure 1.

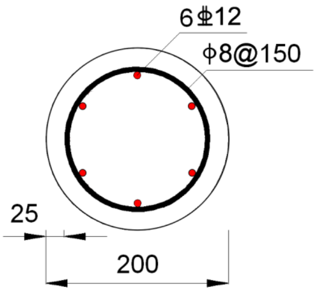


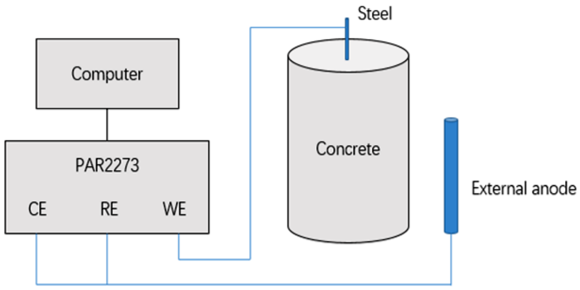
Figure 1. Design dimension of reinforced concretetest piece.

Table 3. ECE design.

Number	Whether there is electric acceleration corrosion before ECE	Extraction age and current density of ECE
A0	No	No ECE
A	Yes	No ECE
A-C1	Yes	28days，$1A/m^2$
A-C3	Yes	28days，$3A/m^2$

2.3 ECE test design and method

Before ECE, the reinforced concrete column was electrified for 24 days by constant current method to accelerate the corrosion of steel bars; then, MPC was painted on the surface of corroded reinforced concrete column and CFRP was pasted as the anode of ECE and the column longitudinal bar as the cathode. After 7 days of curing, it was immersed in saturated $Ca(OH)_2$ solution, and ECE was carried out by DC stabilized voltage source. The electrolyte was changed every 7 days, and the time of ECE was 28 days. The ECE test design and apparatus are shown in Table 3 and Figure 2.



(a) ECE test schematic

(b) ECE experimental device

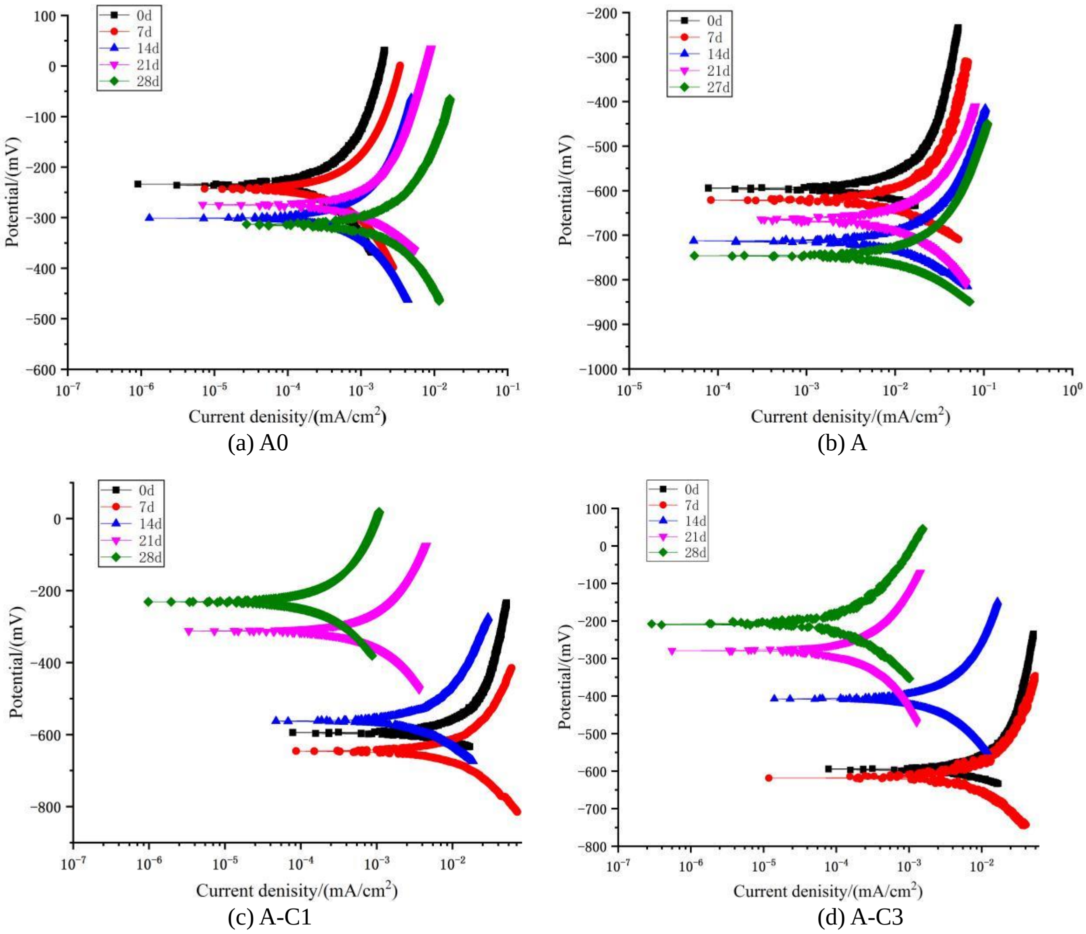
Figure 2. ECE test schematic diagram and actual test device.

3 Results and discussion

3.1 Polarization curve analysis of reinforced concrete specimens

The polarization curve of reinforced concrete column is tested every 7 days after ECE starts, and the polarization curve of reinforcement is shown in Figure 3. The change of corrosion potential (E_{corr}) and corrosion current (I_{corr}) with time in the process of ECE can be calculated from the polarization curve of reinforcement, as shown in Table 4.

It can be seen from Figure 3 and Table 4 that with the increase of test time, the corrosion potential of the reinforced concrete column without ECE treatment in the test piece shifted to the negative pole and the corrosion current moved to the positive pole by a small margin, in which the corrosion potential of A0 and a decreased from -234.57 mV and -609.73 mV to -313.53 mV and -750.63 mV respectively, while the corrosion current increased from 0.32 μA/cm^2 and 10.48 μA/cm^2 to 2.25 μA/cm^2 and 16.42 μA/cm^2; after ECE treatment, the corrosion potential of the reinforced concrete column first shifted to the negative pole, then shifted to the positive pole, and the corrosion current moved to the negative pole. The



(a) A0 (b) A

(c) A-C1 (d) A-C3

Figure 3. Tafel curves of steel bar.

Table 4. Corrosion potential and corrosion current density of rebar.

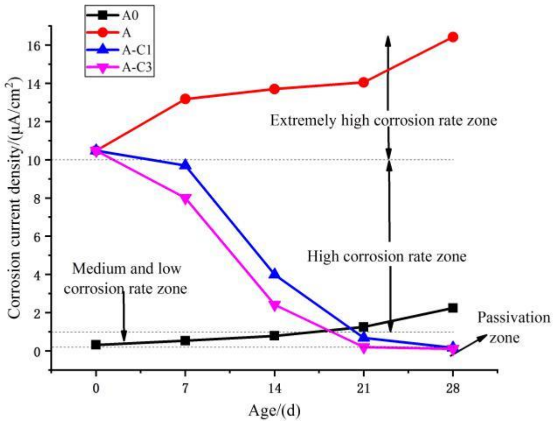
t/d	Number							
	A0		A		A-C1		A-C3	
	E_{corr} (mV)	I_{corr} (μA/cm^2)	E_{corr} (mV)	I_{corr} (μA/cm^2)	E_{corr} (mV)	I_{corr} (μA/cm^2)	E_{corr} (mV)	I_{corr} (μA/cm^2)
0	-234.57	0.32	-609.73	10.48	-609.73	10.48	-609.73	10.48
7	-245.89	0.54	-624.96	13.18	-638.89	9.70	-613.80	8.01
14	-301.28	0.79	-717.12	13.7	-566.32	3.99	-401.65	2.42
21	-279.74	1.26	-664.56	14.05	-310.43	0.69	-272.12	0.21
28	-313.53	2.25	-750.63	16.42	-230.17	0.17	-205.24	0.11

corrosion potential of A-C1 and A-C3 increased from -609.73 mV to -230.17 mV and -205.24 mV respectively, while the corrosion current decreased from 10.48 μA/cm^2 to 0.17μA/cm^2 and 0.11 μA/cm^2 respectively.

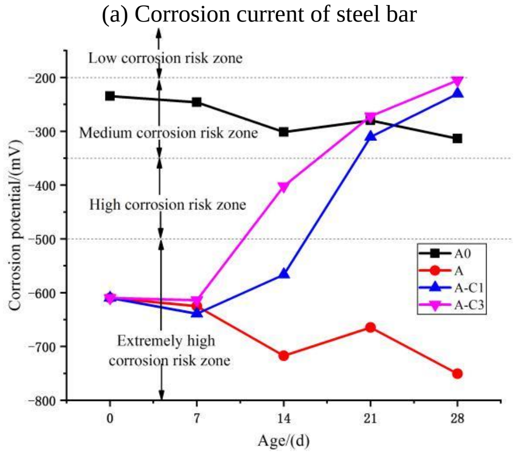
The corrosion current and corrosion potential of reinforced concrete columns A-C1 and A-C3 after electrochemical desalting for 28 days were lower than those of naturally rusted reinforced concrete columns, indicating that the ECE system of MPC-CFRP as an external anode has a good electrochemical dechlorination effect.

3.2 Influence of ECE current density on corrosion rate and corrosion risk of specimens

Figure 4 shows the change of corrosion current and corrosion potential of longitudinal bars in the test piece. The corrosion rate and corrosion risk of the specimens A0 always increased slowly, and that of sample A1 without ECE increased significantly. In contrast, A-C1 and A-C3 perform very differently. After 7 days, the corrosion rate of and corrosion risk sample A-C1 and A-C3 decreased gradually, and by 28 days, the corrosion rate and corrosion risk of sample A-C1 and A-C3 was lower than that of sample A0. Since, during the ECE process, a large number of hydrogen peroxide ions were generated by the cathode reaction, which can continuously reduce the chloride ion content around the reinforcement and decreased the corrosion rate and the corrosion risk of the rebar.



(a) Corrosion current of steel bar



(b) Corrosion potential of steel bar

Figure 4. Corrosion current and corrosion potential of steel bar.

In the process of ECE, the efficiency of desalination is changed at different current densities. The corrosion rate of column A-C3 decreases faster, which shows that current density 3A/m^2 can reduce the corrosion risk of steel bars faster, and the efficiency of dechlorination is higher. After ECE for 28 days, the corrosion current of column A-C1 and A-C3 decreased to 1.62% and 1.05% of the initial value respectively, and the corrosion risk was lower than that of column A0.

4 Conclusions

With MPC as binder, CFRP was bonded on the surface of reinforced concrete to form MPC-CFRP composite as the external anode of ECE. During ECE for 28 days, the polarization curves of steel bars were collected and analyzed every 7 days. The results show that the ECE system with MPC-CFRP as external anode has a good dechlorination effect. After 7 days of ECE, the corrosion rate of steel began to decrease rapidly; after 21 days of dechlorination, the corrosion rate of steel slowed down.

The current density of 1A/m^2 and 3A/m^2 are used for ECE respectively. The results show that the efficiency of ECE is not the same at different current densities, and the efficiency of dechlorination at 3A/m^2 current density is higher than 1A/m^2 current density; after sufficient desalting, the current density of 1A/m^2 and 3A/m^2 can both make the reinforcement passivate again.

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