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Short Communication

Effect of Calcium Phytate on the Corrosion Behavior of 304 Stainless Steel as Coral Concrete Reinforcement in a 3.5% Sodium Chloride solution

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The corrosion-inhibition behavior of calcium phytate on AISI 304 stainless steel in coral concrete is investigated by application of open circuit potential, linear polarization resistance, and electrochemical impedance spectroscopy. The results suggest that calcium phytate increases the open circuit potentials, polarization resistance, and charge transfer resistance of 304 stainless steel in chloride-contaminated coral concrete. Corrosion of the stainless steel rebar can be effectively suppressed by calcium phytate, which can be reduced by 90% via the addition of 0.1% of calcium phytate. Calcium phytate mainly promotes passivation and inhibits corrosion of the reinforced stainless steel, and it does not influence the coral concrete layers.

Keywords: coral concrete, stainless steel, corrosion inhibitor, electrochemical test, EIS

1. INTRODUCTION

In the past few years, concrete materials made from coral sands and coral aggregates have attracted considerable research attention. Many scientists have attempted to improve the compressive strength of coral concrete by reducing its water–cement ratio [1], increasing the cement content [2], adding an admixture [3], and prewetting and strengthening the coral aggregates [4, 5]. On the other hand, some researchers have tried to enhance its strength by mixing fibers into coral concrete [6, 7]. In general, coral concrete possess a low or moderate compressive strength, and it was suggested to be applied in low-slung buildings. As coral concrete contains many aggressive ions, like SO_4^{2-} and Cl^-, it has been recommended to not use steel reinforcement in coral concrete structures [8].

The corrosion resistance of stainless steel reinforcement is much higher than that of its carbon steel counterpart in concrete environments [9]. For example, Feng and co-authors compared the corrosion rate of stainless steel in coral concrete to that of carbon steel in ordinary concrete [10, 11]. They noticed that the corrosion rates of the former samples were less than 1/10 of the rates of latter. Simultaneously, the stainless steel reinforcement was found to have been passivated in the coral concrete samples after the samples had been corroded for 750 days in a 3.5% NaCl solution. Therefore, stainless steel reinforced coral concrete appears to be a promising and durable construction material for use on islands far from the mainland.

In the present study, the corrosion-inhibition property of calcium phytate on 304 stainless steel in coral concrete is studied using different electrochemical tests. The results could provide some references for the use of high-durability concrete structures on coral islands.

2. MATERIALS AND METHODS

2.1 Materials

Coral waste with sizes ranging from 0.5 to 2.0 cm was used as a coarse aggregate, and coral debris smaller than 0.3 mm was used as sand when preparing the coral concrete. P.O 32.5 cement as well as a 3.5% NaCl solution were adopted to prepare the coral concrete. The calcium phytate was supplied by Shanghai Macklin Biochemical Co., Ltd. (Shanghai, China). The water–cement ratio of the coral concrete was 0.7. The ratio of sands to coarse aggregate, and that of the coral materials to cement, were 1.5 and 3.0, respectively. AISI 304 stainless steel rebar with a size of Φ 10 × 50 mm was adopted in the present study, and copper wire was welded at one end of the rebar samples for the electrochemical tests. Then, the two ends of the rebar were covered with epoxy resin. The 304 stainless steel rebar were immersed in the center of cylindrical coral concrete samples of size Φ 50 × 75 mm. To investigate the effect of calcium phytate on the corrosion behavior of the 304 stainless steel in the coral concrete, different contents of calcium phytate, 0%, 1%, 3%, 5%, and 7% by weight of cement, were added in the coral concrete. Twenty-four hours after being prepared, the coral concrete samples were removed from their molds and immersed in a 3.5% NaCl solution.

2.2 Methods

A CS350 electrochemical workstation was used for the electrochemical tests. A saturated calomel electrode, a platinum electrode, and the stainless steel rebar in the coral concrete sample were connected to the reference electrode, counter electrode, and working electrode, respectively. Electrochemical tests, including open circuit potential (OCP), linear polarization resistance (LPR), as well as electrochemical impedance spectroscopy (EIS) of the stainless steel samples were measured at different times. The LPR measurements were performed in the range from −15 to 15 mV vs OCP, at a scan rate of 10 mV/min. The EIS tests were carried out from 10^5 to 10^{-2} Hz, with a disturbance potential of 10 mV around the OCP.

3. RESULTS AND DISCUSSION

3.1 Open circuit potentials

Figure 1 displays the OCP values of the 304 stainless steel samples in the coral concrete with various contents of calcium phytate. As Figure 1 shows, the OCP of the stainless steel rebar gradually increased with time in the coral concrete, which could be attributed to passivation of the rebar, as well as to hydration reactions of the coral concrete cover layer [11, 12]. Moreover, the potentials of the stainless steel in the coral concrete containing calcium phytate were much higher than that of their counterpart in the concrete without calcium phytate. This situation suggests that the addition of calcium phytate can inhibit corrosion of stainless steel in chloride-contaminated coral concrete.

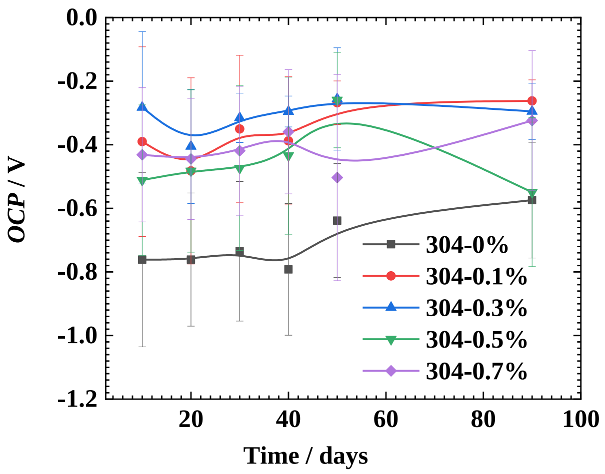

Figure 1. OCPs of the 304 stainless steel rebar in the coral concrete created with different contents of calcium phytate immersed in a 3.5% NaCl solution.

3.2 Linear polarization resistances

Figure 2 shows the linear polarization resistances of the stainless steel reinforcements in the coral concrete created with different contents of calcium phytate. As Figure 2 shows, the polarization resistances obviously fluctuated for the stainless steel in the calcium phytate containing coral concrete, while that of the control sample in the concrete without calcium phytate did not show significant undulations. Additionally, the polarization resistances of the former samples were much higher than that of the latter stainless steel sample. Thus, the polarization resistances, together with the OCP results, suggest that the addition of calcium phytate can suppress corrosion of 304 stainless steel in coral concrete.

Moreover, the average values of the linear polarization resistance, R_p, in the experiments were analyzed, and the inhibition efficiencies of the calcium phytate were calculated, the results of which are presented in Figure 3. Clearly, the average R_p values of the stainless steel in the calcium phytate containing coral concrete were several times larger than that of the counterpart in the concrete without calcium phytate, as Figure 3(a) shows. Simultaneously, for the stainless steel rebar in the coral concrete, about 90% of its corrosion was suppressed by the addition of calcium phytate, even if the content of calcium phytate was only 0.1% that of cement.

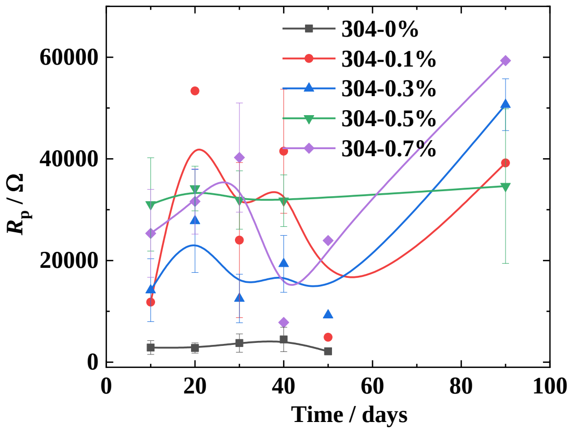

Figure 2. The linear polarization resistances of the samples of 304 stainless steel rebar in coral concrete with different proportions of calcium phytate in a 3.5% NaCl solution.

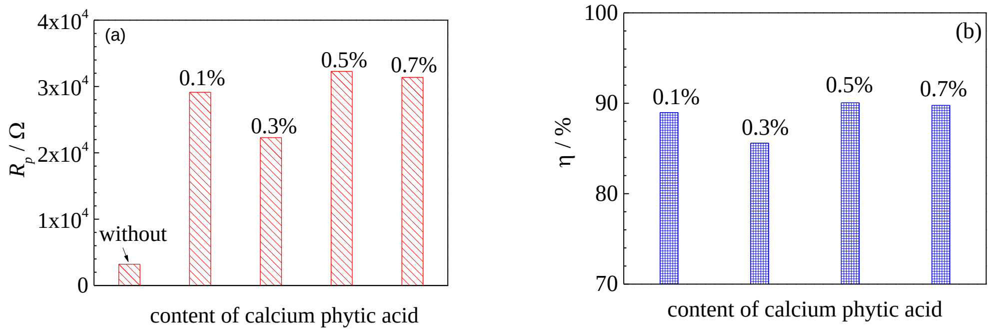

Figure 3. (Left) Average R_p of the 304 stainless steel rebar during the experiment, and (right) inhibition efficiency of the calcium phytate on the stainless steel in the coral concrete in a 3.5% NaCl solution.

3.3 Electrochemical impedance spectroscopy

EIS of the samples of stainless steel in the coral concrete with different proportions of calcium phytate were tested, and the results are presented in Figure 4 as Nyquist plots, whereby two arcs can be observed [11]. In general, the radii of the arcs gradually increased with time, which is consistent with the OCP results. Furthermore, the arc radii also increased as the content of calcium phytate in the coral concrete increased, which indicates that the calcium phytate can effectively inhibit corrosion of stainless steel.

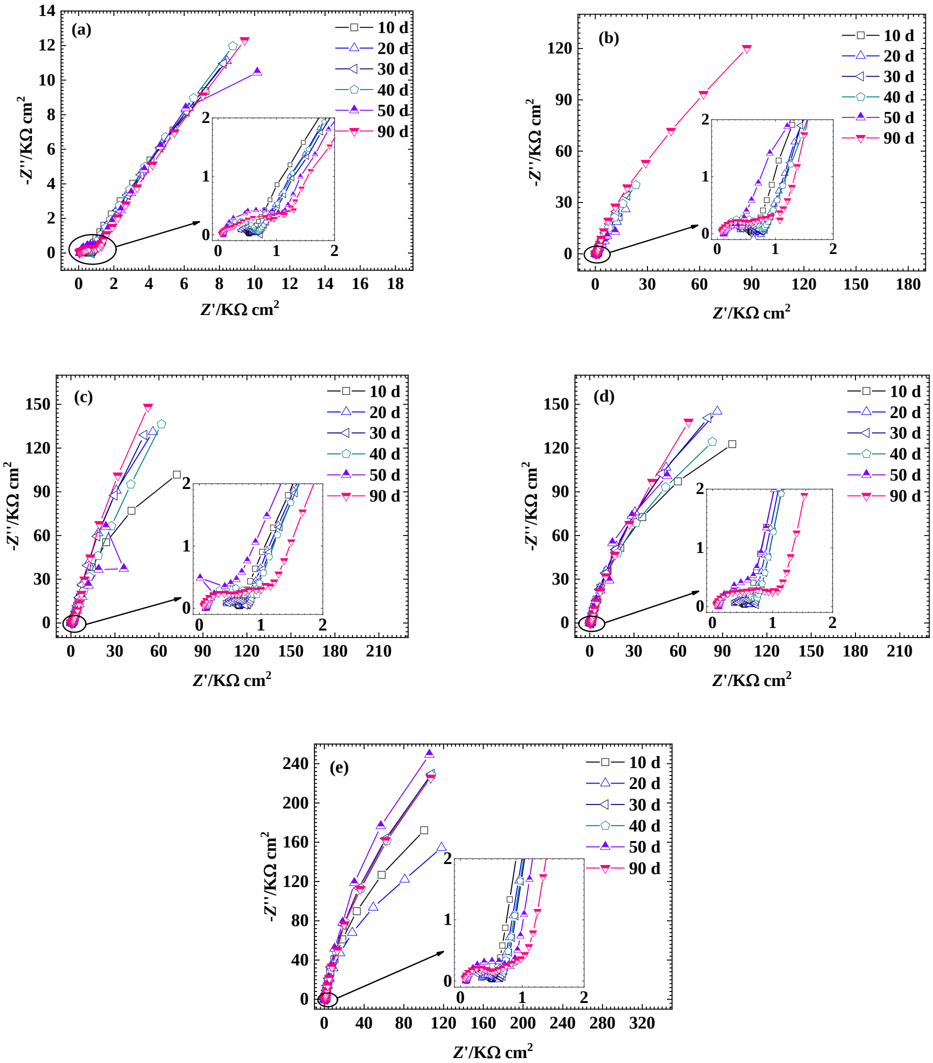

Figure 4. Nyquist plots of the 304 stainless steel rebar in the coral concrete with different proportions of calcium phytate after being immersed in a 3.5% NaCl solution for different times: (a) without calcium phytate, (b) 0.1% calcium phytate, (c) 0.3% calcium phytate, (d) 0.5% calcium phytate, and (e) 0.7% calcium phytate.

The impedances of the stainless steel reinforcements at 0.01 Hz also were analyzed, and the results are shown in Figure 5. The impedances values at 0.01 Hz obviously increased as the content of calcium phytate in the coral concrete increased. To further analyze the EIS results, an equivalent electrical circuit [11, 12], as shown in Figure 6, was introduced to fit the EIS data, in which R_s represents the solution resistance, R_{con} and R_{ct} are the resistance of the concrete cover layer and charge transfer resistance, respectively, and Q_{con} and Q_{ct} are the concrete capacitance and double layer capacitance, respectively.

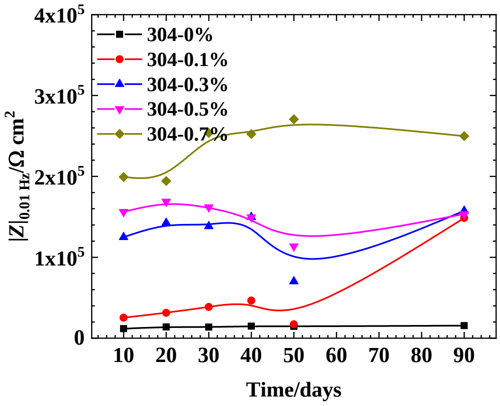

Figure 5. Impedance values at 0.01 Hz for the 304 stainless steel rebar in the coral concrete with different contents of calcium phytate after being immersed in a 3.5% NaCl solution for different times.

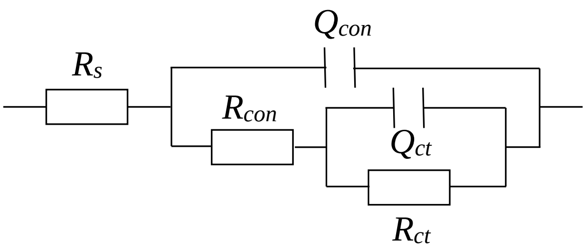

Figure 6. Equivalent electrical circuit used to simulate the EIS results of the stainless steel rebar in the coral concrete.

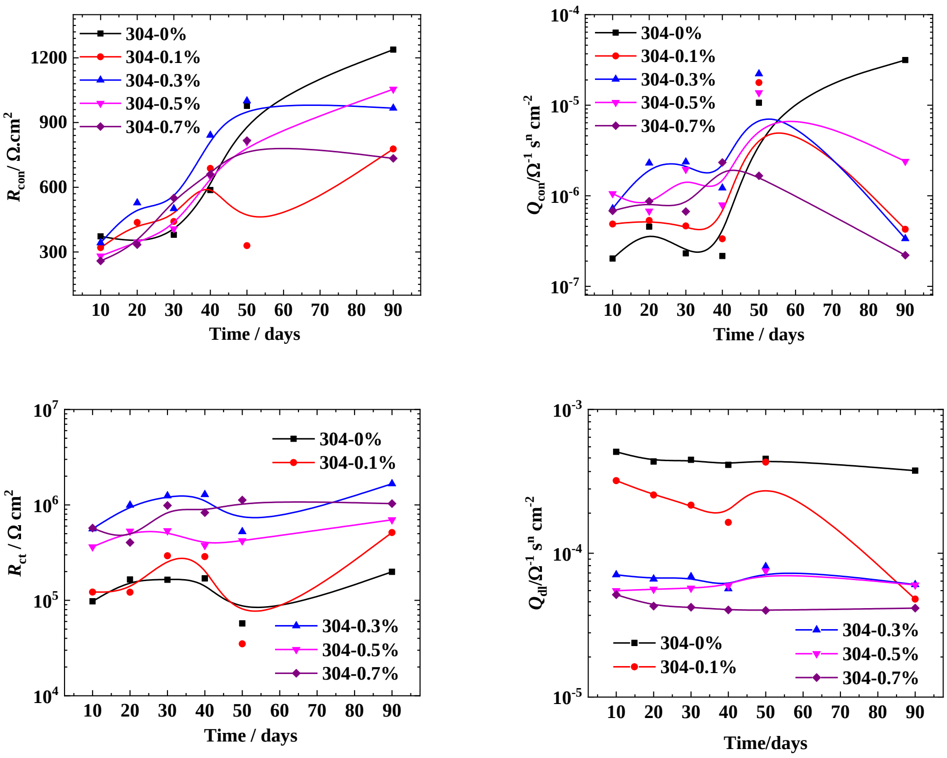

Figure 7. Best-fitting results of the EIS data: (a) R_{con}, (b) Q_{con}, (c) R_{ct}, and (d) Q_{ct}.

The best-fitting results of the EIS data are shown in Figure 7. As the results show, the resistances of the concrete cover layers obviously increased with time (Figure 7(a)), which is consistent with the OCP (Figure 1) and linear polarization resistance (Figure 2) results. This situation could be related to passivation of the stainless steel and hydration reactions of the coral concrete [11]. Simultaneously, the concrete resistances (R_{con}) did not show any significant changes due to the addition of calcium phytate. On the other hand, the charge transfer resistances (R_{ct}, Figure 7(d)) increased, and the double layer capacitances (Q_{ct}, Figure 7(d)) decreased as a function of the immersion time, which also could be attributed to passivation of the stainless steel in the coral concrete. Furthermore, the values of the charge transfer resistance (R_{ct}) significantly increased as a function of the content of calcium phytate, which suggests the addition of calcium phytate can effectively suppress corrosion of stainless steel in coral concrete. Therefore, the concrete resistances (R_{con}) and charge transfer resistances (R_{ct}) imply that calcium phytate mainly promotes passivation of stainless steel and suppresses its corrosion, and that it does not significant influence the resistance of coral concrete.

4. CONCLUSIONS

The results of this study are summarized in the following.

(1) The addition of calcium phytate can significantly increase the OCP, linear polarization resistance, and impedance of 304 stainless steel reinforcement in coral concrete created with a 3.5% NaCl solution.

(2) Calcium phytate can effectively suppress corrosion of the stainless steel rebar in chloride-contaminated coral concrete. Corrosion of stainless steel reinforcement can be reduced by 90% when the proportion of calcium phytate was 0.1% that of the cement in the coral concrete.

(3) The addition of calcium phytate mainly promotes passivation of stainless steel rebar and inhibits steel reinforcement corrosion in coral concrete, but it does not significantly influence the resistance of the coral concrete layer.

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