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CORROSION INHIBITION OF REINFORCING STEEL BY USING ACRYLIC LATEX

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ABSTRACT

Acrylic latex was introduced into steel-reinforcing steel concrete as concrete admixtures or rebar coatings in order to prevent corrosion of steel reinforcements. The results showed that applying the latex by both methods took effect in different ways, while the latter was more noticeable. The corrosion prevention mechanism and the surface state of the steel rebar were also explored, based on which suggestions for enhancing the corrosion-resistant ability were made. *© 1998 Elsevier Science Ltd*

Introduction

It is generally accepted that the embedded steel rebars in concrete are immune to corrosion by the highly alkaline environment provided by the surrounding concrete. However, the passive steel rebars can begin to corrode when the concrete is subject to carbonation and/or chloride attack. Various methods have been devised to combat corrosion of the rebars; these methods include variation of concrete formulation, cathodic protection, addition of inhibitive admixtures, utilization of epoxy coated or galvanic rebars, and so on. In 1994, we reported the use of amino-terminated polyurea polyurethane modified epoxy as rebar coatings (1). Because of the ease of application of polymer latex to reinforcing concrete, as well as its cheapness, safety, and its hygienic properties due to freedom of organic solvent, our interests have been diverted to the application of polymer latex to mitigate the corrosion of steel rebars in concrete. In the present paper, the corrosion-protective properties of acrylic latex used as concrete admixtures or reinforcement coatings are reported.

Experimental

A steel bar (Φ 8 × 150 mm) was embedded in the center of a Portland concrete cylinder (Φ 50 × 150 mm); w/c and c/s of the concrete were 0.6 and 0.5 respectively. The inserted length

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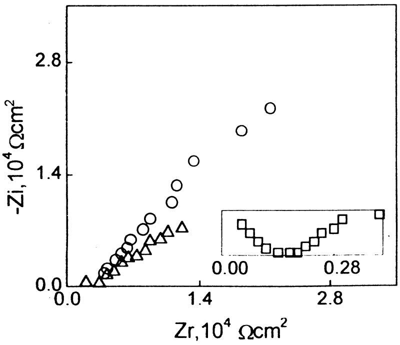

FIG. 1.
Impedance responses for specimen A. Immersion Time: –○– 3 days, –△– 20 days, –□– 60 days.

of the steel bar was 120 mm, and therefore the contact area between steel and concrete was 28.15 cm^2. Each bar was mechanically polished and degreased with acetone. Specimen A was made of bare steel embedded in plain concrete as a control. Twenty percent acrylic latex (wt. in cement) was added to the concrete of specimen B. In specimen C, the bare steel was substituted by a latex coated bar. The acrylic latex used was a copolymer of methyl methacrylate, butyl methacrylate, and acrylic acid (50:50:1). The solid content was 42%. It was neutralized to weak alkalinity by triethnolamine before use. All specimens were demoulded after 24 h and cured in limewater at ambient temperature for 28 days. After curing, they were transferred in 3% NaCl solution to start accelerating corrosion test.

Electrochemical testing was performed in a three-electrode cell. Electrochemical impedance spectroscopy (EIS) was used to detect the corrosion situation of the steel bar in each specimen. The testing medium was 3% NaCl solution. Saturated calomel electrode (SCE) and platinum foil were used as reference and auxiliary electrodes, respectively. Impedance data were obtained at corrosion potential, using a 1250 frequency response analyzer connected to a Solartron SI 1287 electrochemical interface. The test was performed periodically up to 60 days.

Results and Discussions

The impedance responses for specimen A at different immersion times are given in Figure 1. It behaved like a capacitor, initially. However, the capacitive behavior distorted seriously after 20 days' immersion as the diagram at low frequency range had changed from a straight line to an arc. The trend became more pronounced after 60 days' immersion.

Generally, the steel/concrete system can be depicted by an equivalent circuit showed in Figure 3 (2). R_s is the resistance of concrete. R_f and C_f are the resistance and capacitance of the steel/concrete interface. R_{ct} and C_{dl} are charge transfer resistance and double electric layer capacitance, respectively. Zd is diffusion impedance.

According to the Pourbaix diagram (3), the steel bar is in the state of passivity when it is surrounded by a concrete pore solution of high alkalinity. Anodic process is intensively restrained, and the electrode resembles a pure capacitor because R_{ct} approaches such high levels. After 20 days' immersion, a considerable amount of NaCl solution permeated through

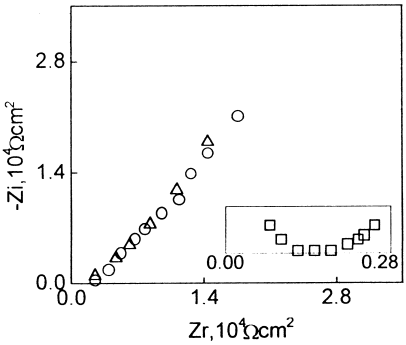

FIG. 2.

Impedance responses for specimen B. Immersion Time: –○– 3 days, –△– 20 days, –□– 60 days.

the loose steel/concrete interface to the steel surface, and the passive layer was damaged seriously; R_{ct} decreased swiftly to 28 kΩcm^2. After 60 days, R_{ct} was only 2.5 kΩcm^2, and then general corrosion occurred.

Figure 2 is the impedance responses of specimen B at different immersion times. The diagram is similar to specimen A at the early period. It remained passive after 20 days while specimen A had already suffered from severe damage on its passive layer. This indicates that addition of acrylic latex to concrete may influence the corrosion behavior of reinforcing steel. In the process of hydration of the concrete, a protective lime-rich layer formed on the surface of the steel bar (4); meanwhile, some latex particles might also be absorbed on the steel surface. The resulting latex film was not very compactive and integrative, due to the moist environment around the film (5). Although the areas between the latex particles were susceptible to corrosion by chloride ions, the latex-covered areas still preserved the passive state. Therefore, disruption of the whole passive layer could be deterred until chloride ions penetrated the latex film to the steel surface. This is shown in the plotting over 60 days in Figure 2. In addition, the large number of pores of various sizes in concrete at such high water/cement ratio in this study made it difficult for the added latex to clog them up completely. The lack of change between Figure 1 and Figure 2 at high frequency range indicates this situation. Therefore, the corrosion-resistant properties of latex admixtures here may not originate from their filling action.

The impedance plot of specimen C is shown in Figure 4. The responses are remarkably different from specimens A and B. The Nyquist plot assumes a gradually shrinking semicircle at high frequency range and an arc of different radius at low frequency range. When using coated rebar, the steel surface was isolated by a layer of latex film from concrete. Therefore, R_f and C_f in the equivalent circuit in Figure 3 should be ascribed to latex film

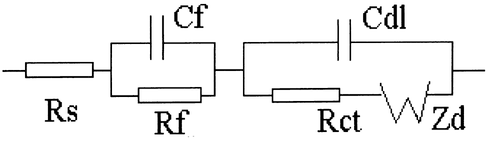

FIG. 3.

Equivalent circuit for steel reinforcing concrete.

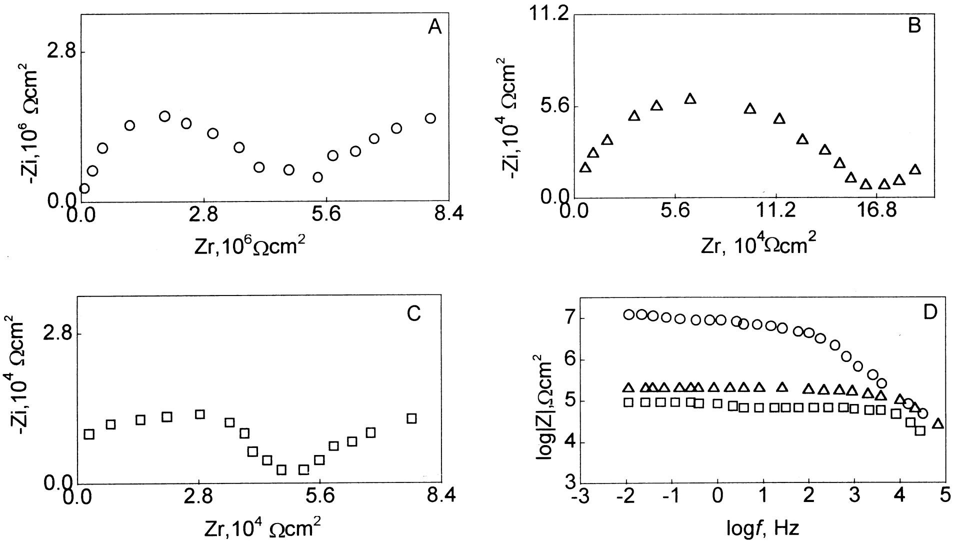

FIG. 4.

Nyquist (A, B, C) and Bode (D) plots for specimen C. Immersion Time: –○– 3 days, –△– 20 days, –□– 60 days.

instead of the lime-rich concrete/steel interface for specimens A or B. In the immersion period, water, oxygen, and electrolyte in pore solution permeated the latex coatings so that the coating resistance R_f decreased progressively. Similarly, R_{ct} reduced from the initial 7000 kΩcm^2 to 120 kΩcm^2 after 60 days. Nevertheless, it was still about two powers bigger than that of specimen A, i.e., the corrosion rate was reduced dozens of times with a layer of latex coatings than the bare counterpart.

It was reported that the transportation of ions, especially anions, through polymer coatings was more difficult than neutral species such as water and oxygen (6). Therefore, the beneficial hydroxyl anions cannot access the steel surface easily. This implied that the steel surface could not be passivated by the hydroxyl anions, i.e., it was in active state. The large value of R_{ct} merely resulted from the lack of corrosive species screened by the latex coatings. The corrosion process has been controlled by cathode reduction instead of normal anode oxidation as in specimens A and B. In order to verify this conclusion, specimens C and A were polarized to -3V vs. SCE for several minutes and then their respective impedance responses were measured.

The result is given in Figure 5. The Bode plot of specimen A changed dramatically. The capacitive behavior disappeared. It became almost a pure resistor. The dramatic change indicated that the steel surface had transformed from passive state to active state through intensive cathodic polarization. However, there was virtually no change for specimen C before and after cathodic activation. These phenomena denote that the latex-coated steel had already been in active state before polarization. Consequently, two methods can be used to improve corrosion resistance of the acrylic latex for concrete rebars: 1) adding corrosion inhibitive pigments, such as Zinc Yellow or red, lead to the latex to passivate the steel surface when water permeates the coatings; 2) modifying the latex with silane or mercapto compound to reinforce the steel/coating interface (7).

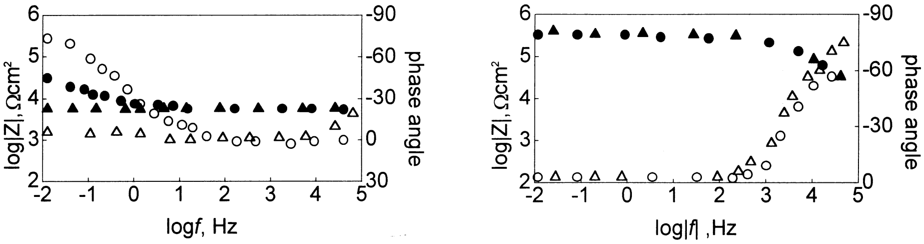

FIG. 5.

Bode plots for specimen A and C before and after cathodic polarization. –●– impedance before polarization, –▲– impedance after polarization, –○– phase angle before polarization, –△– phase angle before polarization.

Conclusion

1. The addition of acrylic latex to concrete deterred the breakdown of passive layer on steel rebar surface.
2. Acrylic latex coatings greatly reduced the corrosion rate of steel rebars.
3. Acrylic latex coatings changed the corrosion state of steel rebars, while latex admixtures did not.
4. Acrylic latex has a future in the field of corrosion control of steel reinforcements in concrete.

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