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The AC response of polymer-coated mortar specimens

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Abstract

Polymeric coatings are widely used for the repair of reinforced concrete. In this paper, the influence of coatings on the permeability was studied using alternating current impedance spectroscopy (ACIS). Two types of polymer coatings [styrene–butadiene rubber latex (SBR) and chlorinated polyvinyl chloride solution (CPVC)] were used. The AC impedance spectra of the polymer-coated mortar specimens displayed a semicircle at the high-frequency range, and the diameter of the semicircle indicated the permeability of the coatings. It was also found that the thickness of coatings had different effects on the impedance spectrum, depending on the type of coating. Comparison of the impedance spectra of the coated mortar specimens before and after the chloride migration test demonstrated that the SBR was suitable for repairing chloride-contaminated concrete because the resistance of the coating increased after the migration test. However, the CPVC was not suitable for repairing because the resistance of the coating was enormously reduced after the migration test. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Cement mortar; Polymer coating; ACIS; Permeability

1. Introduction

For the restoration of reinforced concrete subjected to chloride corrosion, a polymer coating with high resistance to chloride diffusion is commonly used [1]. In recent years, there have been many studies on the surface treating of mortar and concrete in order to prevent the permeation of chloride, and to repair and protect the concrete structure [2–4]. Carter [2] pointed out that the protection of concrete bridge decks is of the same importance as the protection of steel structures. The cost of the restoration and protection of concrete structures through surface treatments is much lower than the cost of rebuilding. For example, the cost of sealing the decks and piers of a 61-m-long bridge is less than 1% of the cost of replacing the structure. Although it is necessary that the surface treatment be renewed about every 5 years, the cost is still less than that of the replacement [5]. For the evaluation of the chloride diffusivity of the coatings, some studies were carried out by Gabrera and Hassan [6], Buenfeld et al. [7,8], and Zhong et al. [9]. However, it would also be profitable to find new methods for the determination of the permeability of the coatings. In this paper, the alternating current impedance spectroscopy (ACIS) was used for this purpose.

2. Experimental

2.1. Specimen preparation

The mortar substrates were prepared by mixing Portland cement (Type P II 525R according to GB175), standard sand (GB 178), and water, with a water/cement ratio of 0.55 and a sand/cement ratio of 2.5. The mixture was cast into plastic molds of 10-mm thick and 105 mm in diameter. The specimens were demolded after 2 days. The surface, which would be coated later, was plastered with cement paste to obtain a pore-free and flat surface. After 1 day, the specimens were then cured in water until they were 28 days old.

Before coating, the substrates were kept in air for 7 days. Two coatings were used in this research: styrene–butadiene rubber (SBR) latex and a cyclohexanone solution of chlorinated polyvinyl chloride (CPVC). For the CPVC coating, the surface was first cleaned with gauze dipped in acetone. The specimens were coated several times depending on the thickness required. The time between any two coatings was

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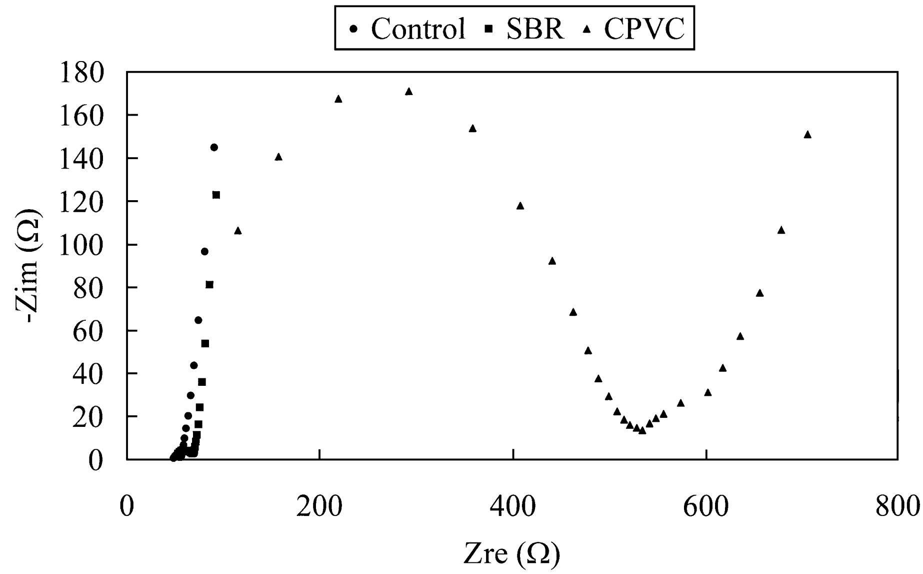

Fig. 1. Comparison of the impedance spectra of the mortar specimens with different coatings.

not less than 2 h. After coating, the specimens were kept in air for further 7 days.

2.2. AC impedance measurement

The specimens were vacuum saturated with a water solution of 0.3 mol/l NaOH before the AC impedance measurement; the vacuum saturation process was that described in Ref. [8]. The procedure involves applying a vacuum to the specimens to dry them for 1 h, and then introducing the water solution into the vacuum and maintaining the vacuum for 12 h. Finally, the specimens were moistured in the solution without vacuum for 12 h. The specimens were kept in the solution for the AC impedance measurements.

Two stainless steel sheets with diameters of 106 mm were used as electrodes. Two layers of tissue paper wetted with the 0.3-mol/l NaOH were placed between the electrodes and the specimen to ensure good contact between the specimens and electrodes.

The AC impedance measurements were performed with a Potentiostat Model 273A and Lock-in Amplifier Model 5210 manufactured by EG&G PARC. A sinusoidal voltage at an amplitude of 5 mV was used. The frequency range was 100 kHz−1 Hz.

Two measurements were made for all specimens. After the first measurement, all specimens were subjected to chloride migration test. The migration test set-up is similar to the diffusion cell described in Ref. [8], except that two electrodes consisting of a copper wire net were placed on the two sides of the specimen. After the chloride migration test, AC impedance measurements were made for the second time.

3. Results and discussion

3.1. Measurement prior to the chloride migration

The impedance spectra of the uncoated specimen (Control), the specimen with latex coating (SBR), and the specimen with solution coating (CPVC) are shown in Fig. 1. It is can be seen by comparison between the coated and uncoated specimens that the spectra of the coated specimens have a well-developed semicircle at the high-frequency range. This semicircle represents the character of the coating. The impedance response of the coated specimens can be described by the equivalent circuit shown in Fig. 2. R_f and C_f in Fig. 2 are the resistance and capacitance of the coating, respectively, and can be obtained from Fig. 1. The R_f and C_f of the SBR coating are 25 Ω and 2.52 μF, respectively, while the R_f of the CPVC coating is 500 Ω, and the C_f of the CPVC coating is only 79 nF. The resistance is much higher than that of the SBR coating, and the capacitance of the CPVC coating is much lower than that of the SBR coating. It can be expected that the permeability of the CPVC coating will be much lower than

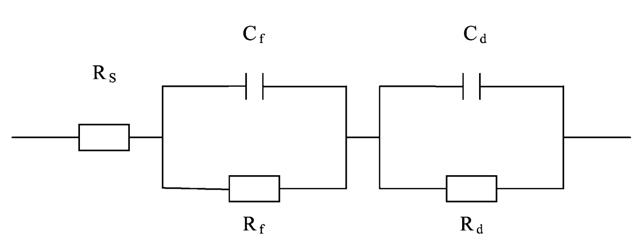

Fig. 2. Equivalent circuit of Fig. 1.

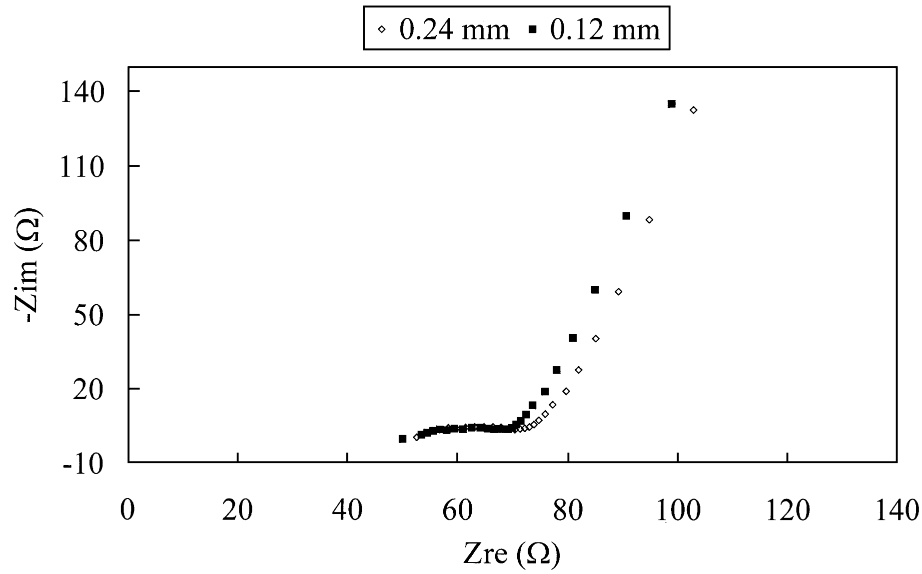

Fig. 3. ACIS of specimens with different thicknesses of SBR coatings.

that of the SBR coating. This is confirmed by the chloride migration test [10].

The influence of the coating thickness on the impedance response is shown in Figs. 3 and 4. It is clear from Fig. 3 that the thickness of the SBR coating in the range of 0.12–0.24 mm has no marked effect on the impedance response, while the thickness of the CPVC coating does have a marked effect. The electric properties of the CPVC-coated mortar with different coating thicknesses are shown in Table 1.

It can be seen from Figs. 3 and 4 that the permeability of the SBR coating is not affected by its thickness in the abovementioned range, while the permeability of the CPVC coating is visibly lower when its thickness increased from 40 to 65 μm. These results are consistent with the results of chloride diffusivity evaluated from the migration test [10].

3.2. Measurement after chloride migration

After the chloride migration test, the impedance responses of the specimens were recorded again. A comparison of the impedance spectra of the SBR-coated specimen is illustrated in Fig. 5. The electric properties of the SBR-coated specimen before and after the chloride migration test are given in Table 2. It can be seen that the

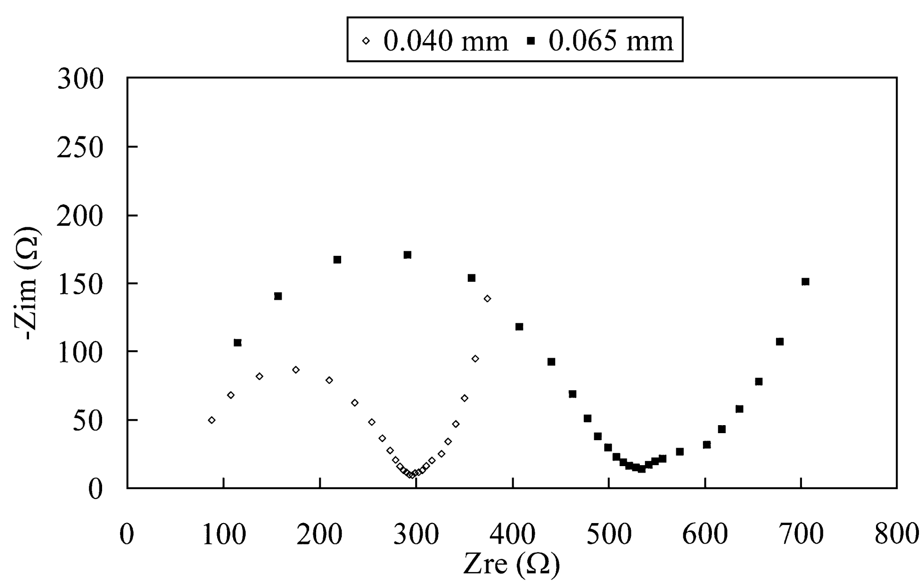

Fig. 4. ACIS of specimens with different thicknesses of CPVC coatings.

Table 1
Electric properties of CPVC-coated mortar specimens with different coating thicknesses

Thickness of coating (μm)	R_s (Ω)	R_f (Ω)	C_f (nF)
40	50	250	160
65	50	500	79

Table 2
Electric properties of the mortar specimens coated with SBR latex before and after the chloride migration test

	R_s (Ω)	R_f (Ω)	C_f (μF)
Before migration test	52	20	3.15
After migration test	40	40	0.63

electric properties of the SBR coating after chloride migration are better. This means that the coating shows a lower permeability after the chloride migration test. One possible reason may be the densification of the coating. After the chloride migration test, some white substances adhered to the surface of the SBR coating. Its analysis by DSC and energy spectroscopy indicated that the white substances were compounds of calcium (mainly calcium hydroxide). During the migration test, the movement of the electrolyte slowed down in the coating so that it congregated in the original micropores (defects in the coating film formed from latex) and blocked them. This is similar to the observation by Beeldens et al. [11] for polymer-modified mortar under biogenic sulphur attack. In their work, the

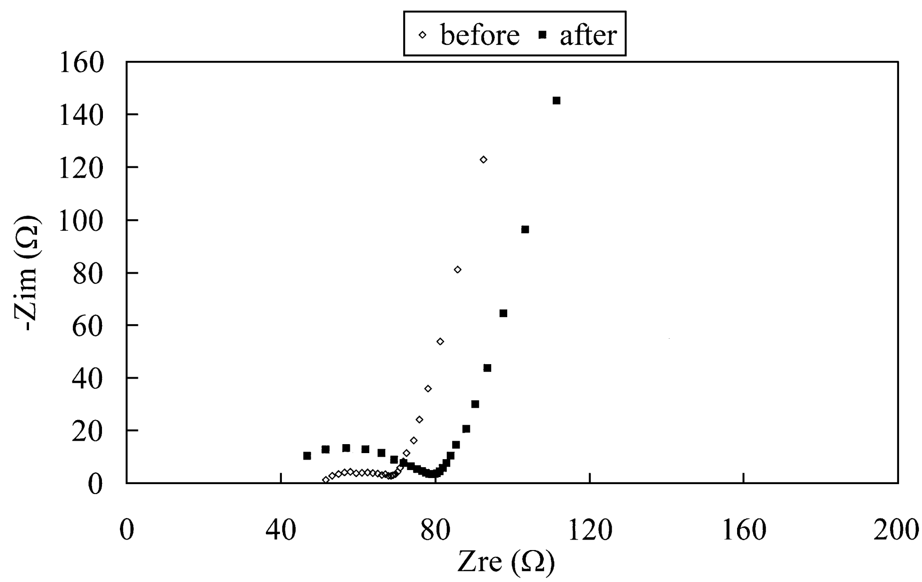

Fig. 5. AC impedance spectra of the mortar specimens coated with SBR latex before and after the chloride migration test.

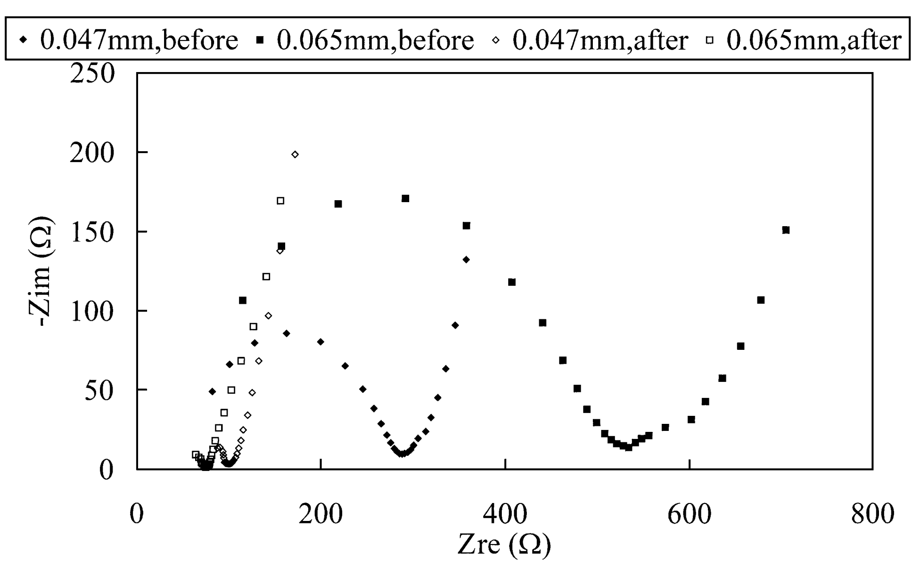

Fig. 6. AC impedance spectra of the mortar specimens coated with CPVC before and after the chloride diffusion test.

white corrosive product (mainly calcium sulfate) adhered to the surface of the polymer-modified mortar. They demonstrated a mechanical interaction between the polymer film and the salt that formed.

Because the SBR coating will be densified during the diffusion process, it can be concluded that the SBR latex coating is suitable for protection of chloride-contaminated concrete as long as the contamination does not induce corrosion of the steel bar.

The comparison of the impedance spectra of the CPVC-coated specimens before and after the chloride migration test is shown in Fig. 6. After the chloride migration test, the resistance of the CPVC coating (R_f) decreased acutely. This leads us to believe that the CPVC coating was damaged somewhat. Visual observation of the surface showed that the coating appeared to be good all the same, except that a small edge of the coating was spalled off. It may be concluded that the CPVC coating is not suitable for the protection of chloride-contaminated concrete because of the danger that the coating may be easily destroyed or spalled off.

4. Conclusion

The AC impedance spectra of the polymer-coated mortars showed a well-developed semicircle at the high-frequency range. This semicircle represents the character and the permeability of the coating. The greater the diameter of the semicircle, the lower the permeability of the coating. The comparison of the AC impedance spectra of the coated mortar specimens before and after the chloride migration test demonstrated that the SBR latex coating was suitable for protection of the chloride-contaminated concrete because the resistance of the SBR latex coating increased after chloride migration. The resistance of the CPVC solution coating decreased strongly, indicating that the CPVC solution was not able to provide adequate protection.

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