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Corrosion rate of ordinary and high-performance concrete subjected to chloride attack by AC impedance spectroscopy

Mohamed Ismail *, Masayasu Ohtsu

Graduate School of Science and Technology, Kumamoto University, Kumamoto 860-8555, Japan

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Abstract

Corrosion of reinforcing steel in concrete is studied by using AC impedance. Subjected to different conditions and chloride concentrations, a laboratory study was conducted to estimate the corrosion rate of reinforcing steel embedded in ordinary Portland concrete (OPC) and high-performance concrete (HPC).

One hundred and four OPC and HPC concrete cylinders embedded with a single reinforcing steel bar were exposed to sodium chloride solution with 0%, 1%, 3% and 5% concentrations. Specimens were also subjected to pre-conditioning and drying-wetting cycles.

The AC Impedance technique (IS) was used to determine the corrosion rate of the reinforced concrete cylinders. In order to interpret the AC impedance spectra, several electrical equivalent circuits were employed.

This investigation aims to compare IS with commonly used corrosion assessment techniques, such as Tafel plot (TP) and linear Polarization (LP).

Results confirm that data obtained from AC impedance can be used to calculate the corrosion rate of reinforcing steel. A reasonable agreement with the results of TP and LP techniques is demonstrated. It is found that the corrosion rates obtained by AC impedance technique are lower than TP by 5–20%, while results of LP are 20–30% higher than those of TP.

Keywords: Corrosion rate; High-performance concrete; AC impedance spectroscopy; Tafel plot; Linear polarization

1. Introduction

Corrosion of reinforcing steel in concrete has become a major problem world-wide, especially for such structures as bridges, parking decks, tunnels, offshore structures and other buildings exposed to aggressive environments due to seawater or de-icing salts. As a result, the repair costs nowadays constitute a major part of the current spending on infrastructure [1]. Quality control, maintenance and planning for the restoration of these structures need non-destructive inspections and monitoring techniques that detect the corrosion at an early stage. For measurement of the corrosion rate of reinforcing steel in concrete, electrochemical techniques are available. Most of them rely on measuring the polarization resistance of steel. The polarization resistance can be measured by means of direct current measurements, impedance spectra, and transient techniques [2]. The measurement of AC impedance spectroscopy provides information on the electrical resistivity, the dielectrical properties of the concrete cover, the corrosion rate and the mechanism of reaction at the steel/concrete interface. This technique is effectively used in the laboratory to study the corrosion of reinforcing steel in concrete. Experimental investigations [3] have shown a close relationship between the

* Corresponding author. Tel.: +81 96 342 3066x503; fax: +81 96 342 3507.
E-mail address: ismail@civil.kumamoto-u.ac.jp (M. Ismail).

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corrosion rate determined by weight loss and those calculated from AC impedance measurement. This paper aims to study the effect of concrete type, pre-conditioning, chloride concentration, drying and wetting cycles, and drying temperature on the corrosion of steel reinforcement by using the AC impedance technique. Since the correlation among Tafel plot (TP), linear polarization (LP) and AC impedance has not yet been covered in detail in publications, a comparison of these three techniques is carried out by employing identical specimens.

2. Equivalent electrical circuit

To interpret AC impedance spectra, an equivalent circuit is commonly applied via electrical fitting. Due to the complexity of the reinforced concrete system, several models have been tested to obtain the best fit and to calculate the corrosion current [4–6].

It is generally accepted that a physical model of the steel/concrete interface consists of a layer of iron oxides and hydroxides in the form of a film in the passive stage and an interfacial film adjoined to the concrete matrix [5–7]. In order to describe such stages of corrosion as active and passive corrosion processes involving diffusion control, passive film formation and macro-cell corrosion, many equivalent circuits have been proposed [6,8–10]. Four types of equivalent electrical circuit (EEC) of A, B, C and D are used in this work. EEC A in Fig. 1 shows the steel/concrete interface, consisting of the resistance R_s of the electrolyte in the concrete pores and a series of impedances related to the steel/concrete interface. Impedance Z_1 corresponds to products formed in cement paste (close to the steel surface), resulting from its reaction with steel. This impedance is composed of resistance R_f, which corresponds to the ionic resistance of the film of corrosion products formed on the metal surface, and capacitance C_f. Impedance Z_2 represents the contribution of the residual corrosion process at the iron interface, where resistance R_{ct} is linked to the surface reaction, and double layer capacitance C_{dl} and diffusion impedance W. The latter account for the dependency of the impedance on the frequency. In EEC B, along with the resistance R_s of the electrolyte, impedance Z_1 is composed of two capacitances and resistances, which corresponds to the ionic resistance of the film of corrosion products formed on the metal surface. Impedance Z_2 is composed of resistance R_{ct} that is linked to the surface reaction, double layer capacitance C_{dl} and diffusion impedance W. EEC C consists of resistance R_s of the electrolyte in the concrete pores and impedance Z, which is composed of a capacitance and a resistance, which corresponds to the ionic resistance of the film of corrosion products formed on the metal surface. EEC D consists of resistance R_s, impedance Z_1 and impedance Z_2. The former impedance is composed of a capacitance and a resistance, which corresponds to the ionic resistance of the film of corrosion products formed on the metal surface. The latter is composed of resistance R_{ct} that is linked to the surface reaction, dispersion capacitance C_{dl} and diffusion impedance W. When the corrosion current of reinforcing steel in concrete is determined using the AC impedance technique, the charge transfer resistance, R_{ct}

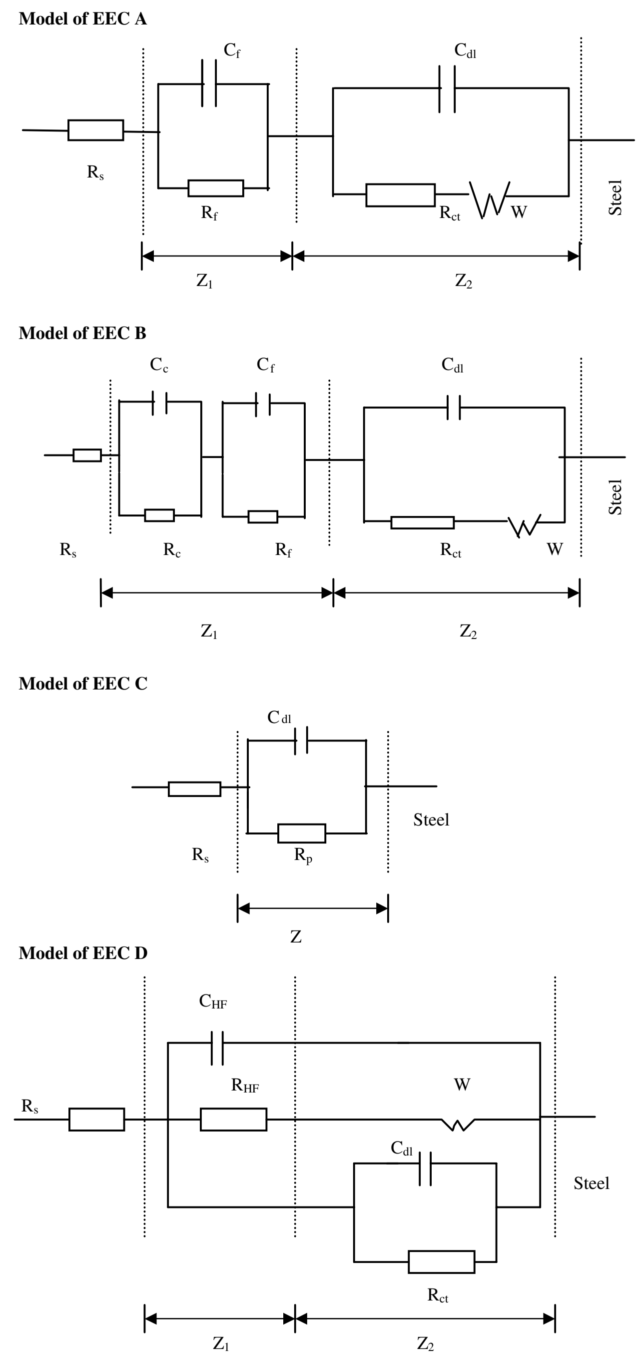

Fig. 1. Equivalent electrical circuits used in the fitting process of AC impedance.