



Electrochemical chloride removal in reinforced concrete structures: Improvement of effectiveness by simultaneous migration of silicate ion



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HIGHLIGHTS

- A technique for rehabilitating chloride contaminated concrete was applied.
- The initiation time of corrosion for steel was prolonged by this technique.

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ABSTRACT

For rehabilitating the chloride contaminated concrete structure to extend its service life, an electrochemical chloride extraction (ECE) treatment with simultaneous migration of silicate ion was proposed. The electrochemical technique is capable of alienating the chloride ions from the reinforcement and simultaneous injecting SiO_3^{2-} into the mortar to interact with $\text{Ca}(\text{OH})_2$, resulting in mortar desalination and densification. By a comparative experiment, the chloride extraction efficiency and corrosion properties of steel reinforcement in sodium chloride solution after the electrochemical treatment were investigated by chloride potentiometric titration, corrosion potential (E_{corr}) and corrosion current density (I_{corr}) determined by electrochemical impedance spectroscopy (EIS). The microstructure of mortar after the electrochemical treatment was observed using mercury intrusion porosimetry (MIP), scanning electron microscopy (SEM), differential thermo-gravimetric analysis (DTG) and X-ray diffraction (XRD). About 40–55% of initial chloride was removed from the mortar using a current density of 2 A/m^2 . The electrochemical treatment can effectively prolong the initiation time of secondary corrosion for the steel reinforcement, due to the mortar densification by electro-migration of silicate ion.

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1. Introduction

Steel-reinforced concrete is the most widely used structural material, owing to its low cost, ease of construction and versatility. Chloride is the main factor causing reinforcement corrosion, which leads to the service-life reduction of reinforced concrete exposed to chloride-laden environment [1,2]. Nowadays electrochemical chloride extraction (ECE) treatment is becoming a common technique for repairing reinforced structures, and the ECE treatment involves the application of an electric field for chlorides removal from contaminated reinforced concrete [3–6]. Compared with other conventional technologies, it has many advantages, such as high efficiency and little influence on the environment and surroundings.

Even though the ECE treatment has many advantages, the corrosion of reinforcement in the reinforced concrete after this treatment still happens [7]. Due to the porous nature of concrete, the chloride ions will inevitably diffuse into the porous concrete when the reinforced concrete structure is still exposed to a chloride-contaminated environment [8]. In addition, the ECE treatment cannot completely remove the chloride ions from the concrete (30–75% of the total chloride can be removed), and the rate of chloride removal depends on the amount of chloride present, depth and arrangement of reinforcement and permeability [9–11]. Accordingly, a small amount of chloride ions from the environment can make chloride ions in the concrete exceed chloride threshold value, resulting in the corrosion of reinforcement for the second time. In order to solve this problem, the ingress of chloride ions into the concrete structure is required to be resisted. Some techniques reported in literatures can be applied [12–18]. For example, surface coating treatment has also been extensively used to reduce ingress of chloride ion [12,13]. Impregnation of

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Table 1
Oxide composition of cement (% w/w).

Oxide	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	SO ₃	Ignition loss
% w/w	22.97	9.28	59.68	3.10	1.03	1.73	1.23	0.98

fillers (such as sodium silicate) in concrete under pressure makes concrete denser through physical and chemical reaction of fillers [14]. Application of capillary crystalline waterproofing agents can block the pore of concrete through crystallization reaction [15]. The electro-kinetic treatment has been used to drive nano-SiO₂ particles into the pores of concrete for reduction of permeability through secondary hydration reaction with SiO₂ [16–18].

In previous literature, the electrochemical-migration of silicate ion treatment, during which the SiO₃²⁻ ions are driven into the continuously connected pores of mortar under the external applied electric field and react with Ca²⁺ ions in the mortar pore fluid to produce the calcium silicate hydrate (C-S-H) gel, can make the mortar compact [19]. The electrolytic solution of SiO₃²⁻ ions is easily to be prepared and it has a good stability, when compared to nano-SiO₂. Based on these, an electrochemical chloride extraction (ECE) treatment with simultaneous migration of silicate ion was proposed. During the ECE treatment with simultaneous migration of silicate ion, the chloride ions in reinforcement concrete structure can be removed. Due to the reinforcement concrete densification during the ECE treatment, the chlorides ions in external environment can be prevented from diffusing into the concrete. Under the condition of reinforced concrete still exposed to chloride-laden environment after the electrochemical treatment, the corrosion initial time of reinforcement in concrete will be delayed.

This paper aims to evaluate the extracted chloride amounts of ECE treatment with simultaneous migration of silicate ion and corrosion properties of steel reinforcement in sodium chloride solution after this electrochemical treatment by corrosion potential (E_{corr}) and corrosion current density (I_{corr}) determined by electrochemical impedance spectroscopy (EIS) with a comparative experiment. The efficiency of the treatment was confirmed by the visual inspection of the rebar. The microstructure of mortar

after this electrochemical treatment was observed using mercury intrusion porosimetry (MIP), scanning electron microscopy (SEM), differential thermo-gravimetric analysis (DTG) and X-ray diffraction (XRD).

2. Experiment

2.1. Materials and specimen preparation

The cement used in our work was No. 42.5 ordinary Portland cement (OPC) made in China. Its oxide composition is listed in Table 1. The fine aggregate was river sand with a fineness modulus of 2.1. Tap water was used in mortars, and distilled water was utilized to prepare various electrolytic solutions for the subsequent electrochemical treatment.

The mortar samples with the size of 4 cm × 4 cm × 16 cm were fabricated with one rebar (1-cm-diameter, 10-cm-long) embedded in each specimen. NaCl was added to the mixing water (2 wt% Cl⁻ by mass of cement). Water/cement ratio of 0.45, 0.55 and sand/cement ratio of 2.5 have been employed. After one day of casting in plastic molds, all the mortar were de-molded, then cured in a 95% humidity chamber at 20 ± 2 °C for 27 days.

2.2. Electrochemical treatment

A rectangular electrolytic tank (24 cm × 16 cm × 6 cm) made from plexiglass was separated into two identical compartments by placing the as-fabricated mortar in the middle of tank, of which the width side was paralleled to the length one of the mortar. In order to ensure that the two compartments are not connected, the as-fabricated mortar was sealed by epoxy resin at the edges, Titanium meshes were served as the anode and cathode. In addition, the rebar connected to the negative pole of the power supply for preventing the rebar from corroding. Electrolytic solutions of saturated calcium hydroxide and sodium silicate with the concentrations of 0.05 mol/L were added into anodic and cathodic compartments, respectively. The sealing treatment was applied to prevent the solutions in the compartments from

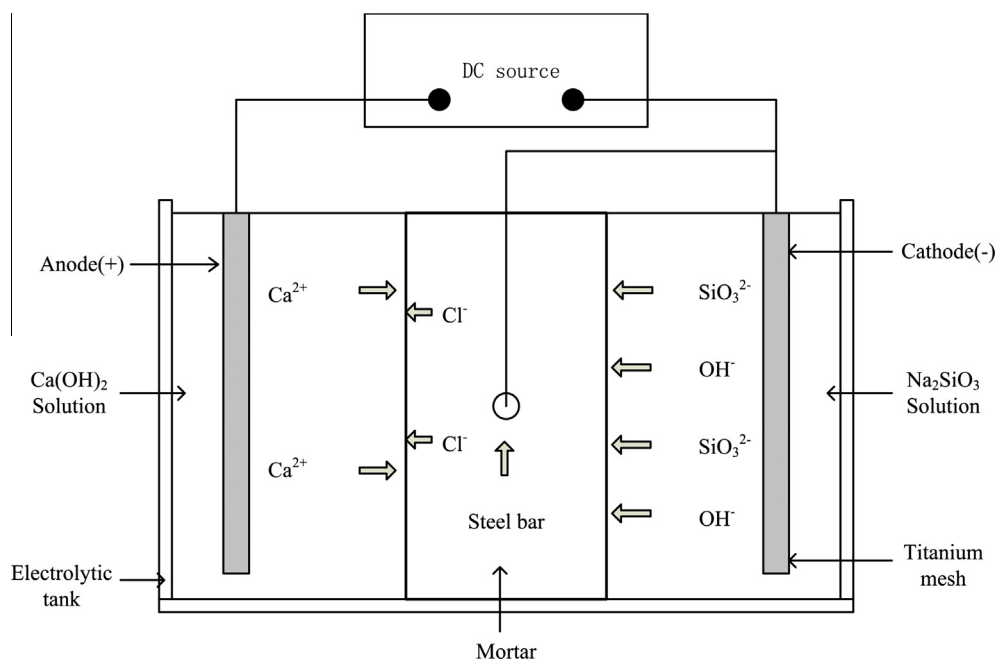


Fig. 1. Detailed experimental configuration for the electrochemical treatment.

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