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# Electrochemical chloride extraction (ECE) from steel-reinforced concrete specimens contaminated by “artificial” sea-water

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## Abstract

Electrochemical chloride extraction (ECE) was studied in the laboratory using cylindrical concrete specimens containing chlorides from “artificial” sea-water. The ECE was carried out for 21 and 90 days, using current densities of about  $1 \text{ A/m}^2$  of steel surface. About 60% to 50% of the initial chloride was removed from the concrete on average. Around 1% chloride by mass of cement remained around the steel after treatment. No influence on the chloride removal efficiency was found from anolyte refreshment after treatment. The quantities of chloride removed correlated well with those observed in practice. Due to the negative polarity of steel in an ECE treatment,  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Ca}^{++}$  ions from the concrete pore solutions accumulate near the steel surface.  $\text{K}^+$  ions move towards the steel rebar more quickly than the other cations analyzed in this work. Although both the chloride content and the dissolution of the steel were reduced, the repassivation of steel rebar cannot be guaranteed.

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*Keywords:* Electrochemical chloride extraction; Steel-reinforced concrete; Repassivation

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## 1. Introduction

The degradation of steel-reinforced concrete structures due to exposure to chlorides either from de-icing salts or from marine environments is regarded as the principal cause of premature deterioration in such concrete [1]. This type of corrosion, called “pitting”, causes the formation of anodes at sites of breakdown of the passive film of oxide that would otherwise confer protection on steel in an oxygenated alkaline environment. These local anodes cause the formation of expansive corrosion products that induce cracks and then breakage of the concrete around the steel. Electrochemical chloride extraction (ECE) is a curative method for treating reinforced concrete about to suffer or already suffering from chloride-induced reinforcement corrosion. In this process, negatively charged chloride ions ( $\text{Cl}^-$ ) are carried away from the coating concrete by the application of a current between the steel, which acts as a cathode, and a temporary external anode placed on the concrete surface. This ECE treatment was investigated in several studies [2,3] in the 1970s. Very high current densities were used to allow short treatment periods. Cracking due to the high temperatures of the concrete, increases in permeability and loss bonding of the reinforcement were the major drawbacks. It was only at the beginning of the 1990s that reports of this method became more frequent [4–9]. This research focused primarily on the reduction in the chloride contents, but the aspects concerning the post-treatment behavior were not fully clarified. Thus, Elsener [5] and Polder [10], noted that the steel potential became more positive after application of ECE and affirmed a possible repassivation of the steel. But, using polarization resistance, Green et al. [11] and Marcotte et al. [12] also tested the ECE treatment on specimens of concrete and mortar manufactured with a NaCl addition at the time of mixing and found contradictory results. On the one hand, Green et al. [11] observed reductions in the corrosion rate of the steel, while Marcotte et al. [12] noted an increase in the corrosion rate and supposed a phenomenon of alkaline attack on the steel.

Concerning the physical state of the steel reinforcement before and after ECE treatment, Glass and Buenfeld [13] reported the formation of a  $\text{Ca}(\text{OH})_2$  layer on the steel surface. They concluded that increasing the chloride threshold level by generating such a layer may be the key to the success of ECE treatment, even if a significant quantity of chloride remains in the matrix concrete.

It should be noted that the majority of works were carried out on specimens in which the chloride contamination was achieved by the addition of NaCl solutions at the time of mixing.

Thus, there are still certain aspects which remain to be clarified, such as: does changing the anolyte used for the application of treatment have an influence on the technique’s effectiveness? Does the application of this technique really leads to a repassivation of steel reinforcement? Under which conditions of corrosion of steel reinforcement could this technique be effective? The purpose of this research work was to obtain experimental data, which not only would allow this technique to be better understood, but also could find the possible parameters which decrease its effectiveness. The ECE technique was applied to reinforced cylindrical concrete specimens first contaminated with an artificial sea-water solution (multi-ionic

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