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Electrochemical chloride extraction: Efficiency and impact on concrete containing 1% of NaCl

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HIGHLIGHTS

- Concrete with higher w/c ratio has a tendency of having a higher efficiency for removal of chlorides.
- In concretes with lower w/c ratio, the thickness of the reinforcement cover has a great influence on the corrosion potential.
- Total porosity increases by more than 30% as a result of applying the chloride extraction.
- Percentage growth of porosity due to chlorides extraction depends on the w/c ratio.
- Concrete water absorption increased 13% and 12% for concrete with w/c ratios of 0.43 and 0.59, respectively.

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ABSTRACT

This paper aims to evaluate the efficiency of the electrochemical chloride extraction technique and its impact in concrete contaminated with 1% of chloride by monitoring chloride content, specific porosity, water absorption and corrosion potential, verifying the influence of variables reinforcement cover (1.0 and 3.0 cm) and water/cement ratio (0.43 and 0.59). Results show that the concrete needs additional protection after chlorides extraction in order to prevent recontamination, since the porosity of the concrete increases with the application of the electrochemical chloride extraction. Average pore diameter increased 78% and 42% for concretes with w/c of 0.59 and 0.43, allowing the ingress of aggressive agents.

1. Introduction

The corrosion reinforcement, caused by the presence of chloride ions, is a major cause of the degradation of reinforced concrete structures [1–3]. The presence of chloride ions in the concrete structure affects the steel passivity layer and, in the presence of water and oxygen, corrosion occurs. Prevention is still the cheapest measure to fight this deterioration mechanism, however once the structure is contaminated it is necessary to repair it in order to avoid additional future spending. A traditional repair technique involves the removal of the affected area replacing the weakened reinforcement and inserting a new repair material [4]. Alternatively, there is the Electrochemical Chloride Extraction method (ECE). This method consists in removing part of the chloride ions, which are contaminating the structure, without the need of removing the concrete [5]. Compared to traditional techniques it has advantages such as little effect on the environment along with high efficiency [6].

The chlorides extraction technique consists of applying an electric field between the reinforcement inside the concrete and an electrode constituted by a metal mesh fixed externally to the surface of the material. With the application of electric current negatively, charged ions such as chloride ions, are attracted to the anode placed on the external surface of the concrete. Also, cations (Na^+) migrate to the reinforcement and there is production of hydroxyl ions (OH^-) on the reinforcement surface, as a consequence of cathodic reactions [6,7]. Fig. 1 shows a schematic diagram of the chloride extraction technique.

The electrochemical extraction of chlorides and the electric potential difference between the anode and the cathode cause the following reactions:

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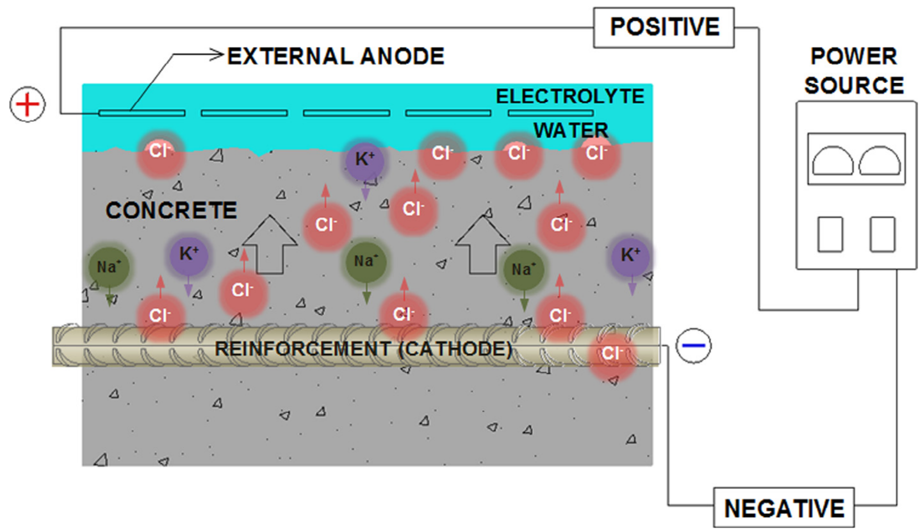

Fig. 1. Schematic design of chloride extraction technique (Adapted from [8]).

$$2OH^- = \frac{1}{2}O_2 + H_2O + 2e^-$$

$$2H_2O = O_2 + 4H^+ + 4e^-$$

$$2Cl^- = Cl_2 + 2e^-$$

At the same time, hydroxyl ions are produced around the reinforcement by electrolysis.

$$\frac{1}{2}O_2 + H_2O + 2e^- = 2OH^-$$

$$2H_2O + 2e^- = H_2 + 2OH^-$$

For the technical operation, the presence of an electrolyte allowing the ion migration process is fundamental. The most commonly solutions used as external electrolytes are saturated calcium hydroxide, sodium hydroxide and treated water. From those solutions, water is the most widely used. According to Polder [9] and Elsener, Angst [10], its widespread use is due to the absence of salts, therefore chloride ions move more easily in the concrete and are effortlessly extracted.

Regarding current intensity, the usual values are between 1 A/m^2 and 5 A/m^2. Despite this, the majority of the studies focused on densities until 1 A/m^2 [11–13]. These authors believe that higher intensities can generate cracking in the concrete as a function of the chloride extraction velocity. In this sense, Elsener, Angst [12] and Broomfield [14] determine that the current intensity should not exceed 2 A/m^2.

The application period of the technique varies between 6 and 10 weeks, period in which a significant reduction of chloride concentration is attributed to values below 0.40% of total chlorides, considered to be a critical value [15–18]. If the content of chloride ions is reduced below the critical threshold, increased hydroxyls production on the surface of the reinforcement and the simultaneous reduction of the ions chloride content create enabling favorable environment for the reinforcement repassivation [7]. According to results from Orellan and Escadeillas [19], chloride content after treatment was reduced by around 40% within 7 weeks and, at the same time, significant amounts of alkali ions were observed around the steel. Efficiency percentages can reach up to 70% according to experimental works [5,20,21].

Siegwart et al. [11], Liu and Shi [22], and Yeih; Chang and Hung [23] performed the treatment during 6 weeks, obtaining satisfactory results. Abdelaziz et al. [24] evaluated intervals of 2, 4 and 8 weeks, with best efficiency found at 8 weeks. The author points out, however, that the reduction rate of chloride content decreases along the weeks. Regarding this aspect, Elsener and Angst [12] found that periods of rest may increase the efficiency of the technique. The authors attribute this behavior to the fact that in the first step the free chloride ions were removed, while the ions combined with compounds of the hydrated paste dissolve more slowly. According to Andrade [4], the rest period is justified since the alkalization produced during extraction induces a decrease in the migration flux of chloride ions.

Huang et al. [25] emphasize the importance of studying the progresses of electrochemical chloride extraction due to the possible effect on the microstructure and performance of the material. The application of the chloride extraction technique can have consequences on the porosity of the concrete, on the activation of alkali-aggregate reactions, on the reduction of the steel-concrete adhesion and on steel embrittlement.

According to Siegwart et al. [11], the extraction of chlorides alters the size and quantity of pores in the concrete, with effects on their resistance and permeability. Chlorides can be combined with hydrated cement compounds in order to form chloroaluminate and chloro ferrite hydrates, contributing to changes in porosity [20,26]. The main effect is reducing the number of macropores and increasing the number of micropores [20].

An increase in OH^- concentration in the interstitial dissolution around the steel bar has a positive effect in terms of protection against corrosion. However, if a concrete contains reactive aggregate particles this can catalyze reactions like alkali-aggregate. Bennett et al. [28] performed tests on concrete containing reactive aggregates and verified increase in material expansion. Orellan, Escadeillas, Arliguie [19] verified formations of sodium rich phases in the region near the steel reinforcement. However, the authors state that these compounds were only verified under accelerated conditions, and it is not possible to assert that the increase in hydroxyl ions content can be considered as a catalyst of the reactivity with the aggregate.

The objective of this paper is to evaluate the efficiency of the electrochemical chlorides extraction technique and its effect in concrete, by monitoring chloride content and corrosion potential, checking the influence of variables reinforcement concrete cover and water/cement ratio. The measurement of absorption and concrete porosity, through porosimetry tests by mercury intrusion and