Electrochimica Acta 202 (2016) 269–276

Contents lists available at ScienceDirect

Electrochimica Acta

journal homepage: www.elsevier.com/locate/electacta

Thermogalvanic Currents in Steel Reinforced Concrete

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ARTICLE INFO

Article history:
Received 27 August 2015
Received in revised form 20 November 2015
Accepted 27 November 2015
Available online 30 November 2015

Keywords:
galvanic coupling
temperature gradients
steel reinforcements
corrosion in concrete

ABSTRACT

The thermogalvanic currents between nominally identical segments in a reinforced concrete beam were investigated. Temperature gradients induce galvanic currents that exhibit a 30 °C critical point. The character of the hot electrode side changes from anodic to cathodic when the temperature rises above that pivot point. Parallel tests performed in solution using carbon steel-stainless steel galvanic couples also revealed that 30 °C is a critical temperature. In NaOH solution the carbon steel behaves cathodically with respect to stainless steel but only for $T < 30\,^{\circ}C$. In $Ca(OH)_2$ solution containing chlorides the carbon steel consistently behaves anodically while the degree of thermogalvanic current exhibits a pronounced temperature dependence.

1. Introduction

According to a classical definition [1], a thermogalvanic cell is formed when two similar half-cells share an electrolytic contact and each cell is held at a different temperature. The galvanic current resulting from the difference in electrode potentials enhances the corrosion rate at the anode while protecting the cathodic side [2,3].

In the particular case of steel in concrete, galvanic current usually represents less than 50% of the total corrosion current of the anode when galvanic effects are associated with changes in electrolyte composition, as the presence of chlorides [3,4] or carbonation [5–8]. Galvanic current should represent even less when the electrical contact occurs between dissimilar rebars such as carbon steel and stainless steel couple, because of the lower oxygen reduction rate on stainless steel [9–12].

Civil infrastructures (such us bridges, viaducts, buildings) contain a large number of structural elements usually submitted to temperature gradients, the simplest example being those that arise from varying degrees of sun exposure. However, the thermogalvanic effects of such temperature gradients are scarcely treated in the literature. Some reports state that in the case of passive electrodes, that are readily polarised, the thermogalvanic current is usually small; however, when local depassivation occurs, the current increases and can approach the total corrosion current [13] and can reach penetration rates of 10 mm year^{-1} [14]. It has also been found that no direct correspondence exists between temperature gradients and open circuit potential (OCP) or galvanic currents, the latter two factors appearing to be independent of the corrosion rate [15].

The lack of literature consensus on the importance of thermogalvanic effects on steel reinforcements in concrete derives in part from the fact that available studies have focused solely on electrochemistry and have not examined the structural and chemical changes that temperature induces at the steel-concrete interface. In pursuing an understanding of such changes, the present communication exploits previous findings [16,17] on the importance of temperature on the electrochemical properties of the steel-concrete interface. The rebar' passive layer, based on magnetite [18], becomes richer in Fe^{3+} as temperature increases [17], a relatively fast process [19]. The increased concentration of Fe^{3+} in the passive layer increases the corrosion potential due to the Fe^{3+}/Fe^{2+} cathodic reaction [20,21] that occurs simultaneously with oxygen reduction. The solubility of $Ca(OH)_2$ also decreases as temperature increases [16], which leads to a decrease in pH at the metal–concrete interface and possible subsequent breakdown of the passive layer.

We examined the effect of temperature gradients on macro-galvanic behaviour within the same structure using segmented carbon steel rebars. Owing to the increasing importance of the carbon steel/stainless steel couple in new and repaired structures, this system was also studied in alkaline solution.

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http://dx.doi.org/10.1016/j.electacta.2015.11.138
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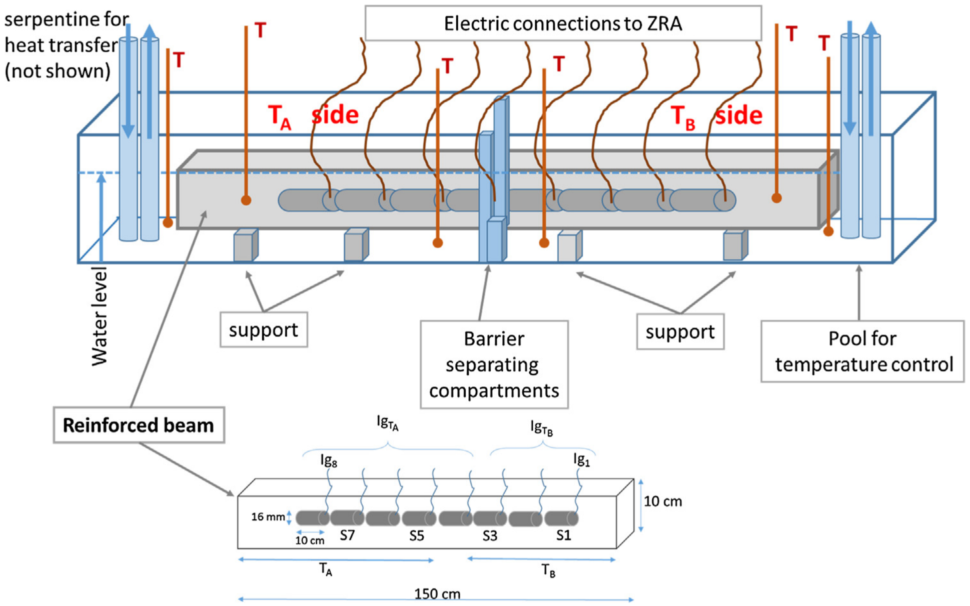

Fig. 1. Schematic representation of the distribution of the rebar segments in the beam and placement of the beam in the thermostatic bath. Details of the wiring arrangement for the measurement of thermogalvanic currents, Ig, in the 1.5 m length beam are also given. Dark orange rounded arrows marked with T indicate the points were temperature was measured.

2. Experimental

2.1. Electrochemical equipment

Galvanic currents were recorded using a potentiostat with multi-zero resistance ammeter from ACM Instruments®, UK. Temperatures were controlled with two model RE 207 Lauda® low-temperature thermostats. Temperatures in the electrochemical cells and at the rebar' level (by drilling a dedicated hole) were recorded using Pt-100 sensors and an Agilent model 34972A data logger.

When required, electrochemical impedance in 4-electrode mode was performed using a potentiostat/galvanostat model PGSTAT302N from Metrohm-Autolab B.V., NL.

2.2. Reinforced beam

A reinforced mortal beam (150 cm in length with a 10 cm^2 cross section) was prepared according to the Spanish Structural Concrete Code (EHE-08) under designation HA-30/F/20/IIa-0 that comprises B-500 S carbon steel ribbed bars, and 300 kg m^{-3} Portland cement at a maximum of 0.55 w/c ratio.

Eight segments of rebar (each containing insulated ends and an electric connection for external short-circuiting) were embedded in the beam. This type of segmented rebars was already employed in studies of galvanic corrosion [3,4,22]. The eight segments embedded were 10 cm in length and 16 mm in diameter, and centred and at 5.4 cm from the bottom of the beam, opposite to the output of the electric connections. The exposed surface of each segment was 50 cm^2.

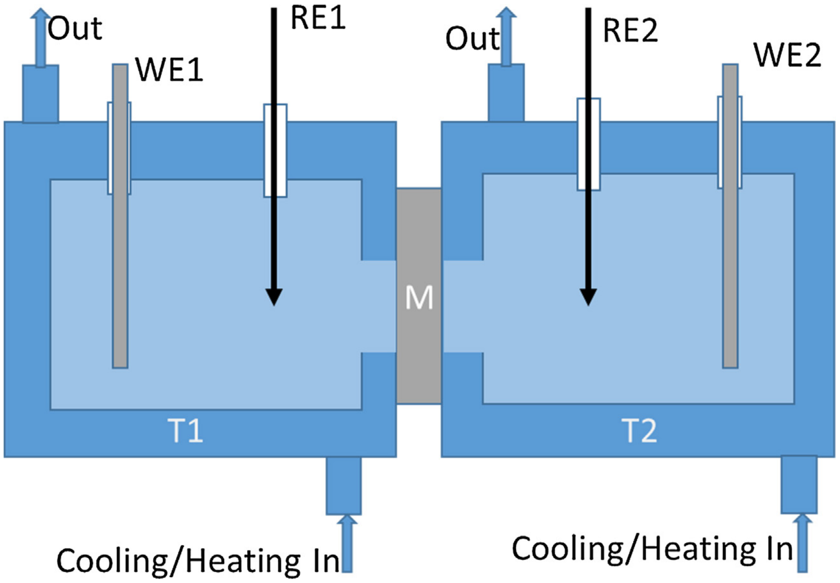

Fig. 2. Representation of the experimental setup used for thermogalvanic tests in alkaline solution. The compartments set at temperatures T1 and T2 are separated by a cement paste membrane M.