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Influence of rapid changes of moisture content in concrete and temperature on corrosion rate of reinforcing steel

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Abstract

Electrochemical tests on corrosion rate of reinforcement were performed on six concrete specimens reinforced with a single bar equipped with temperature and concrete moisture sensors. The specimens were kept in a climatic and corrosion chamber where ambient temperature was changing discretely in a temperature range of 7°C ÷ 35°C, and similarly humid conditions were changing in a range of 30% ÷ 90%. The tests were also conducted on specimens immersed in water at 7°C and 35°C. Temperature and moisture content in concrete at the bar surface were monitored throughout the tests. The objective of this work was to analyse the influence of rapid changes in climatic conditions maintained for a few-day cycles, on corrosion rate of reinforcement in concrete. The tests demonstrated that the current corrosion process models for concrete reinforcement which assumed an immediate response of corrosion rate to a change in climatic conditions, was correct only for temperature.

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Keywords: concrete structures; reinforcing steel; reinforcement corrosion; polarization resistance method; LPR; electrochemical impedance spectroscopy; EIS; concrete temperature; moisture content in concrete; corrosion current density

1. Introduction

The development of corrosion processes of reinforcement in concrete structures is more and more often determined by the methods of continuous monitoring using advanced sensors. They are used to determine not only

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the rate of corrosion processes by electrochemical methods, but also to determine temperature, concrete resistivity, pH, concentrations of chloride ions (Broomfield et al. [1], Duffó and Farina [2], Yu and Caseres [3], Montemor et al. [4], McCartera and Vennesland [5]), and even oxygen concentration in concrete (Correia et al. [6]). Variation of corrosion rate, which is difficult to predict and mainly depends on the above factors, can be eliminated by continuous monitoring A problem on correct estimation of corrosion rate changes refers to structures that are not monitored as measurement data are collected only once. Then, it is necessary to model the course of corrosion process, which usually includes the empirical dependence of corrosion current density over a function of time as, according to Faraday's law, current intensity is proportional to the mass of iron ions moved from a crystalline grid of steel. The examples of such empirical relationships can be found, inter alia, in the papers by Gulikers [7], Morinaga [8], Liu and Weyers [9], Huet et al. [10], Pour-Ghaz et al. [11], Krykowski and Zybura [12]. They describe functions, in which current density was correlated mainly with temperature, concrete resistivity, and chloride concentration (assuming chloride-induced corrosion). Each model was based on an implicit assumption that a change of any of the above parameters would induce a rapid change in concentration of chlorides current density. Thus, such models do not include the effect of concrete heat capacity on temperature at the reinforcement surface and sunlight impact. Moreover, they neglect the impact of moisture content or freezing of concrete surface on its resistivity, which is then only conditioned by humidity.

The objective of this paper was to analyse the impact of rapid changes in thermal and humid conditions maintained for a few-day cycles, on corrosion rate of reinforcement in concrete test elements. Polarization measurements conducted by Linear Polarization Resistance and Electrochemical Impedance Spectroscopy techniques were used for evaluation purposes. The measurements were carried out in a continuous mode on concrete specimens with passive reinforcement and advanced corrosion. The tests were performed in tap water and a climatic and corrosion chamber at programmed changeable temperature and humidity.

2. Course of tests

The tests were conducted on six cylindrical specimens made of concrete class C20/25. Cement CEM I 42,5R (324 kg/m^3) and natural aggregate up to 16 mm (1931 kg/m^3) were used. Concrete with w/c ratio = 0.4 was prepared without any additives. Figs 1a and 1b illustrate a scheme and photo of the specimen element. Fragments of rebars *1*, whose protruding ends were protected against corrosion with epoxy resin and heat shrinkable plastic, were placed in cylinders. Moreover, a custom-made silver chloride electrode *2* and a rectangular stainless steel grid (or strip) *3* were embedded in concrete. Membrane of silver chloride electrode was placed at a distance of ca. 10 mm from the bar surface *1*, and the stainless steel grid (or strip) *3* was put parallel to the bar *1* at a distance of ca. 20 mm from it. The specimens also contained a temperature sensor *4* stabilized at a distance of ca. 10 mm from the rebar surface, and a concrete moisture sensor *5* composed of two parallel stainless steel bars with a diameter of 2 mm, at a distance of 16 mm from each other.

Before the tests began, three specimens were stored at dry air conditions for 5 months. Other three specimens with induced reinforcement corrosion were prepared much earlier. Then, in the climatic and corrosion chamber they were subject to electrochemical tests on corrosion rate for ca. 3 years. The course and analysis of the mentioned 3-year tests are described in the paper by Jaśniok and Jaśniok [13].

In the first stage of tests, the specimens were immersed in tap water of 35°C for 24 hours – Fig. 1d. Then, a series of electrochemical tests were performed followed by a change in water temperature to 7°C (by water replacement). Further two series of electrochemical tests were conducted an hour after temperature change. The assumed water temperature was maintained for two days, during which series of control tests were conducted. After that time, water temperature was again changed to 35°C, and similar electrochemical tests were performed – one series before the change and two series after it, and control series. When the measurements in water were completed, the specimens were stored under the conditions of reference constant temperature and humidity. The method of performing tests was not changed. Each time only one parameter was changed, that is, the air