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Comparison of Chloride Diffusion Coefficient Evaluation Based on Electrochemical Methods

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Abstract

The paper focuses on the evaluation of chloride ion diffusion coefficient of selected concrete mixture. The diffusion coefficient is computed using Nersnt-Einstein relationship between electrical material properties and ionic diffusion. There are two procedures of interest. First method called rapid chloride penetration test (ASTM C1202) is based on measurements of electrical charge passed through concrete sample. Second method is based on measurements of electrical resistivity. The resulting diffusion coefficients obtained by both methods are compared.

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1. Introduction

The durability of civil engineering structures is often affected by chloride ingress induced corrosion of steel reinforcement in concrete. Thus study of the material parameters that influence the durability of reinforced concrete are of high interest. Parameter that significantly influences the chloride ingress into concrete is diffusion coefficient and frequently serves as an input into the durability analysis (see e.g. [1], [2], [3]).

Diffusion coefficient can be obtained nowadays with the help of the electrochemical procedures in order to reduce the labor cost and time constraint of chloride penetration tests. Those penetration test procedures require exposure of samples to chloride solution for several weeks, analysis of chloride profile using drilling or grinding, chemical analysis

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of chloride content in the sample profile with subsequent computation of steady-state diffusion coefficient. See e.g. AASHTO T259 [4] or NT Build 443 [5] for details.

The electrochemical procedures are significantly faster. The accelerated chloride penetration tests (RCPT, AASHTO T277 [6], ASTM C1202 [7]) require couple of days while preparation of samples is still labor intensive. The diffusion coefficient value may be computed due to correlation between electrical properties and diffusion coefficient of concrete (see e.g. [8], [9], [10], [11], and [12]). Even though there are differences in actual value of diffusion coefficient based on the procedure of recalculation. The difference in results does not affect comparison of performance of selected mixtures if one of diffusion computation methods is selected. However it needs to be noted that the difference in computations between procedures ([8], [9], [10], [11], and [12]) may affect the penetration speed of chlorides in numerical models. Thus if selected values of diffusion coefficient from literature sources, one needs to be careful in order to obtain diffusion coefficients prepared and computed under the same conditions. Even though diffusion coefficient computed based on the measurement of electrochemical properties of concrete is suitable as measure of quality of concrete.

There is also other method for evaluation of concrete against the penetration of aggressive agents based on the flow of electrical current – measurement of an electrical resistivity ρ (AASTHTO TP-95 [13], [14], [15]). The determination of the concrete electrical resistivity or conductivity parameter takes minutes. Duration of such a test is extremely fast in comparison with chloride penetration tests [4], [5] or even RCPT test [6], [7]. The drawback of the electrical resistivity measurement using Wenner probe is rather large variation of measurements comparing to RCPT. This drawback may be mitigated by measurements of inverse parameter to resistivity via conductivity meter or suitable test setup [15], [16]. If the conductivity or resistivity reading are proportionally corrected to sample size of the RCPT test [6], [7] than the results of both methods may be comparable. Comparable are both the measurements of electrical resistivity (or passed charge) as well as the diffusion coefficient.

The resistivity measurements of concrete is being introduced especially to Central Europe quite recently [17], [18]. Thus there is lack of research dealing with the comparison of electrical resistivity measurements with rapid chloride penetration measurements that is used in order to qualify the quality of concrete.

2. Research significance

Aim of the research is to compare two approaches for determination of electrochemical procedures for the determination of concrete ability to resist aggressive agents namely chloride ingress. The results from Rapid Chloride Penetration Test procedure (RCPT [6], [7]) are compared with the electrical resistivity measurements [9]. Subsequently the resulting values are expressed as electrical resistivity and diffusion coefficient in order to compare them.

If the results of electrical resistivity measurements become comparable with results of RCPT test than resistivity method might be applied to grade the concrete faster and with less labor work involved comparing to RCPT test.

3. Methodology

The computation of the diffusion is based on the procedure given in [11] where the volumetric resistivity ρ_{BR} is calculated based on electrochemical procedures. For porous materials such as concrete the diffusion coefficient formulation is selected according to Nernst-Einstein. The equation (1) is given bellow (Lu, [11], [15]):

$$D = \frac{RT}{Z^2F^2}\frac{t_i}{\gamma_i C_i \rho_{BR}}, \tag{1}$$

where are D diffusion coefficient [m^2/s], R universal gas constant [J/K.mol], T absolute temperature [K], Z valence of ions [-], F Faradays constant [C/mol], t_i transport number of chloride ions [-], γ_i activity coefficient of chloride ions [-], C_i concentration of chloride ions [mol/m^3], ρ_{BR} volumetric resistivity [Ωm].

Molar concentration of chloride ions C_i for a water solution can be determined as follows: