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Influence of the applied voltage on the Rapid Chloride Migration (RCM) test

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ABSTRACT

This study addresses the influence of the applied voltage (electrical field) on the value of the chloride migration coefficient, as determined with the Rapid Chloride Migration (RCM) test, and on other properties of cement based mortars. It is shown that in the investigated ranges of applied voltages, the chloride migration coefficients, computed from two different chloride transport models, are relatively constant. However, other properties of mortars are changing due to the application of the electrical field. It is shown that the resistance of the test samples increases during the migration test (therefore the DC current during the test decreases). Moreover, the mass of the samples increases and this increase is found to be proportional to the chloride penetration depth. The pH of the catholyte solution (10% NaCl water solution) increases significantly during the migration test, thus the test conditions change as the OH^- to Cl^- proportion changes. Furthermore, the measured values of the polarization of the electrodes confirm the value of 2 V, assumed in the guidelines for the RCM test. Also, a dark coloration is observed on samples split after the test, prior to spraying with the colorimetric chlorides indicator. This coloration is attributed to a liquid-saturation of the samples only in the colored region and not in the entire volume of the sample, as is assumed after performing the vacuum-saturation prior to the migration tests.

1. Introduction

In the case of deteriorated concrete elements/structures being in frequent contact with a chloride bearing environment (e.g. de-icing salts or seawater), the chloride initiated corrosion of the reinforcing steel is the main reason of the deteriorations in the majority of cases. Therefore, a proper design of the concrete cover (the layer of concrete covering the steel), considering its quantity (thickness) and quality (permeability to chlorides), is very important from the point of view of service life and maintenance work. In order to quantify the chloride ingress speed in concrete, the chloride diffusion/migration coefficient is used, because the diffusion controls the ingress of chlorides. There are various laboratory test methods for determining the chloride diffusion/migration coefficient. In the past mainly the 'natural' diffusion test methods were used, in which concrete samples are exposed to a chloride solution for a long period, so the chlorides are penetrating the samples due to the concentration gradient. However, recently the application of electrically accelerated test methods has significantly increased due to their short testing period and simplicity. The Rapid Chloride Migration (RCM) test, described in the guideline NT Build 492 [1], is one of the accelerated test methods, which is nowadays very often used. The output of this test method—the chloride migration coefficient D_{RCM}—has been incorporated into the DuraCrete model [2] for the service life design of concrete structures. However, as demonstrated in Spiesz et al. [3], the D_{RCM}, computed according to the 'traditional' RCM model [1,4], has to be treated carefully because of oversimplifications of this theoretical model, which are reflected by the deviation of the chloride concentration profiles measured after the RCM test from the theoretical profiles. As shown in the improved RCM model [3], when taking into account the non-linear chloride binding isotherm and the non-equilibrium conditions between the free- and bound-chlorides (due to the short duration of the RCM test, which usually amounts to only 24 h), the transport of chlorides in concrete by migration can be predicted more accurately than given by the 'traditional' model.

Other important aspects regarding the chloride migration in concrete are the test conditions and their influence on the results of the test. According to the guideline for the RCM test [1], the value of the voltage applied during the test is adjustable, and depends upon the value of the initial current, which is measured at the DC voltage of 30 V. Based on the value of this current, which basically reflects the permeability of concrete (its permeability is related with its conductivity and therefore with the measured current), the value of the voltage applied during the RCM test and the duration of the test are adjusted, following Table 1 [1]. This action is performed in order to obtain a sufficient chloride penetration depth for concretes with low permeability, for which the initial voltage of 30 V would result in a too shallow chloride penetration depth, and to prevent the chloride breakthrough for concretes with high permeability (i.e. the chloride penetration depth obtained after the test should be within certain limits regardless of the permeability of concrete). As demonstrated in [4] and shown in

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Table 1
Applied voltage (U) and duration (t) of the RCM test, based on the initial current (I_{30}) measured at 30 V [1].

I_{30} [mA]	U [V]	t [h]
<5	60	96
$5 \le I_{30} \le 10$	60	48
$10 \le I_{30} \le 15$	60	24
$15 \le I_{30} \le 20$	50	24
$20 \le I_{30} \le 30$	40	24
$30 \le I_{30} \le 40$	35	24
$40 \le I_{30} \le 60$	30	24
$60 \le I_{30} \le 90$	25	24
$90 \le I_{30} \le 120$	20	24
$120 \le I_{30} \le 180$	15	24
$180 \le I_{30} \le 360$	10	24
≥360	10	6

Fig. 1 [4], a minimum penetration depth of about 10 mm is required in order to minimize the error (maximize the precision) of the chloride migration coefficient. As also demonstrated in [5], the resolution of the migration coefficient highly depends on the penetration depth of chlorides and is increasing when the penetration depth increases. The adjustable voltage and test duration imply that the testing conditions during the RCM test are not always the same. However, different test conditions may influence the test results. In the research of Stanish [6,7] it has been demonstrated that the chloride penetration depth is a linear function of the applied voltage and the duration of the RCM test. However, the migration coefficient was not investigated in that research, as the author believed that the RCM model developed by Tang [4] and the migration coefficients computed based on that model are doubtful. Therefore, the aim of this study is to evaluate whether the voltage applied during the RCM test is influencing the value of the chloride migration coefficient calculated based on two methods: the 'traditional' RCM model [1,4] and the RCM model presented recently by Spiesz et al. [3]. Additionally, other measurements (such as mass, electrical resistance, DC current, etc.) are performed in order to demonstrate whether the applied voltage has any influence on the properties of the test samples, the electrolytes and the polarization potential of the electrodes.

2. Materials and methods

2.1. Materials and mixture design

A mortar was used in this study to investigate the influence of the applied voltage on the RCM test, because mortars do not contain coarse aggregates which are impermeable to chlorides and therefore often disrupt the chloride penetration front. Fig. 2 shows the differences between chloride penetration fronts that can usually be observed after the RCM test on concretes and mortars. A uniform chloride penetration front (Fig. 2b) will help to reduce discrepancies in measurements of the chloride penetration depths and the total chloride concentration profiles.

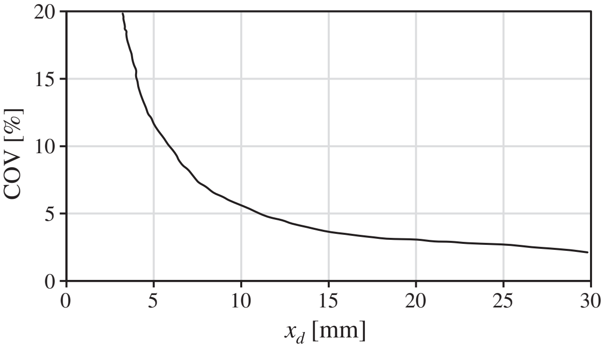

Fig. 1. Coefficient of variation (COV) introduced to the value of D_{RCM} by measurement of the chloride penetration depth x_d ($U = 30$ V, $L = 0.05$ m, $T = 298$ K, $t = 24$ h, $c_0 = 2$ mol/dm^3 and the accuracy of x_d measurement of ±0.5 mm) [4].

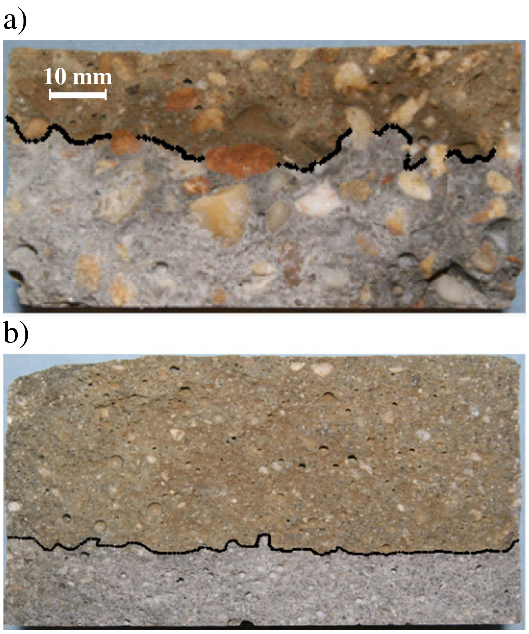

Fig. 2. Typical chloride penetration fronts after the RCM test observed on: a) concrete and b) mortar.

As mentioned earlier, NT Build 492 [1] recommends applying a voltage in the range of 10–60 V, depending on the value of the initial current, recorded when a voltage of 30 V is applied. Therefore, in order to compare the chloride migration coefficients obtained for different voltages, the mortar used in this study is intended to have 'average' permeability according to NT Build 492. Here, the 'average' permeability represents such a permeability of mortar, for which according to Table 1 [1] the initial current at voltage of 30 V should be in the middle range of the given initial currents (20–60 mA), so that the same mortar recipes tested at $U = 30$–40 V could also be tested using higher and lower voltages, without a risk of chloride breakthrough or very shallow chloride penetration depth, respectively.

In order to find a mortar of 'average' permeability, in preliminary experiments a few mortars of different quality (and permeability), obtained by varying the content of cement and the water–cement ratio, were cast in 150 mm cubes. The mortars were composed of Portland cement CEM I 52.5 N, sand 0–2 mm, water and polycarboxylate-based superplasticizer. One day after casting, the cubes were demolded and then cured in water until the age of 27 days, when the cylindrical cores were extracted from the cubes by drilling, cut and saturated with limewater under vacuum conditions. At the age of 28 days the samples were placed in the migration test set-up and the initial current at the external voltage of 30 V was measured, so that the RCM test conditions for these mortars could be specified following Table 1. Based on these trials, the mortar mixture shown in Table 2 was selected for further testing and subsequently a new set of nine cubes (150 mm size) was cast,

Table 2
Composition of the employed mortar mixture.

Material	Volume [dm^3]	Mass [kg/m^3]
CEM I 52.5 N	249.4	785.6
Sand 0–2 mm	521.5	1382.1
Superplasticizer (SP)	7.1	7.86
Water (including water from SP)	206.9	206.9
Air	20	–
Total	1000	2377.4