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Evaluation of the Rapid Chloride Migration (RCM) test

Introduction

In view of problems with chloride-induced corrosion of reinforcing steel, there is a need for quantified information on chloride transport properties of concrete. A reliable prediction model of chloride ingress into the concrete cover is considered as the key point for an assessment of the behaviour of concrete exposed to sea water or de-icing salts.

Several laboratory testing methods have been developed to quantify the transport properties in concrete and between these a distinction between long-term and short-term methods can be made. However, the long-term methods are usually not preferred from the practical point of view because they are laborious, time consuming and costly.

To overcome these disadvantages an accelerated test - the Rapid Chloride Migration test (RCM) with the associated resulting D_{RCM} (chloride-ion migration coefficient) has been developed among others by Tang /1/. NT Build 492 /2/ and BAW-Merkblatt /3/ describe how to perform the test.

During the European DuraCrete project, the chloride ion migration coefficient (D_{RCM}) has been introduced in the service life model of concrete. Such an application (besides the simplicity and rapidity of the method) caused a very wide spread of the RCM test through laboratories. Nowadays the test is becoming a standard in Europe. The number of laboratories participating in the inter-laboratory Round-Robin test (mostly from the Netherlands) increased from 12 (2006) to almost 30 (2009). Nevertheless, the test could still be improved, because the test procedures contain some ambiguities and incorrect assumptions.

In this paper two improvements of the RCM test are proposed. The first one concerns the exact determination of the electrochemical phenomenon of the polarization of the electrodes, which appears during the RCM testing. The effect is taken into account in the NT Build 492 /2/ test procedures (assumes 2V) and neglected in the BAW-Merkblatt /3/. Knowing the value of the polarization potential it is possible to calculate the D_{RCM} coefficient in a more accurate way. The results of the polarization measurements, presented in this paper, are showing that in the case of stainless-steel (SS) electrodes, the value of polarization can vary from 1.8V to 2.2V. The polarization effect of titanium electrodes is also investigated, as titanium could be a more suitable material for the electrodes.

The second improvement concerns the test procedure. According the available RCM test procedures, it is required to test samples from the inner layers of concrete elements – the outer layer always has to be cut off. This action is performed to avoid the testing of already chloride-contaminated concrete and to reduce the influence of concrete surface effects on the test results. However, as shown in this paper, due to differences in curing conditions, the properties of inner and outer layers of concrete are also different. To assess the real resistance of concrete against chloride ions intrusion, it is necessary to test the outer layers, so the layer which in reality is exposed to the chloride source. This can be done only if it is sure that concrete is not contaminated with chlorides prior to testing. The results also show a variation of D_{RCM} values for concrete cast from the

same batch, but cured under laboratory and real industrial conditions. It is important from the designing point of view – properties of the big scale (“real quality”) concrete are often much worse in comparison to laboratory small scale (“potential quality”).

Effect of the polarization of electrodes

The value of the electric field over the concrete specimen is required for calculating the chloride ions migration coefficient (D_{RCM}). However, due to the polarization effect of the electrodes, the potential applied by the power source is not equal to the potential difference over the concrete specimen. The effect is only included in the NT Build 492 procedure /2/ (BAW-Merkblatt /3/ does not take it into account) and assumed 2V. Nevertheless, the value of this polarization can vary, depending on the value of the current flowing in the circuit, so on the quality of concrete.

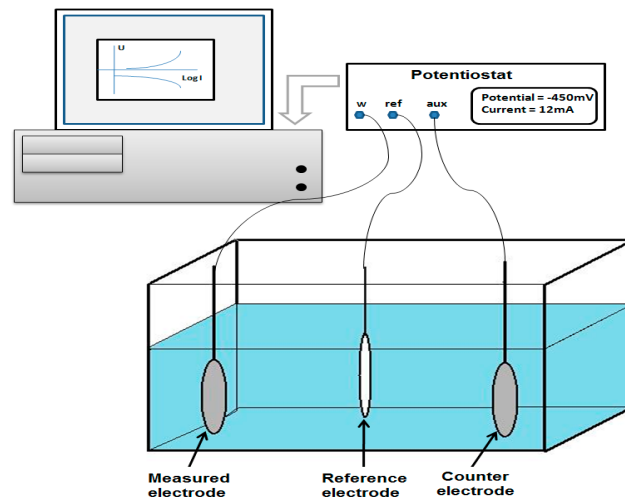


Figure A. Setup for measurement of polarization curves

To measure the polarization potential of electrodes, the setup shown in Figure A was constructed. The potentiodynamic measurements of current were performed for stainless-steel electrodes (SS) and for mixed-metal-oxides coated titanium (MMO-Ti) electrodes. The scan rate yielded a value of ± 0.056 mV/s. Ag|AgCl and MMO-Ti electrodes were used as standard reference electrode and counter electrode, respectively. The measurements were performed in a 0.2N KOH + 10% NaCl water solution (anolyte) and a 0.2N KOH water solution (catholyte). The results are presented in Figures B and C.

The results obtained on the SS and MMO-Ti electrodes show the polarization effect over a wide range of DC currents flowing in the circuit (10^{-8} A \div 0.3A). Nevertheless, during the RCM testing, the value of current usually remains within the range of 10 \div 100 mA (bold sections of curves in Figure B and Figure C). To estimate the total polarization potential, the absolute values of the polarization potentials of both electrodes, relevant to the current flowing in the circuit, should be read out from the presented figures and summed up. For the SS electrodes, in a range of current of 10 \div 100 mA, the total polarization effect can vary from 1.8V up to 2.2V.

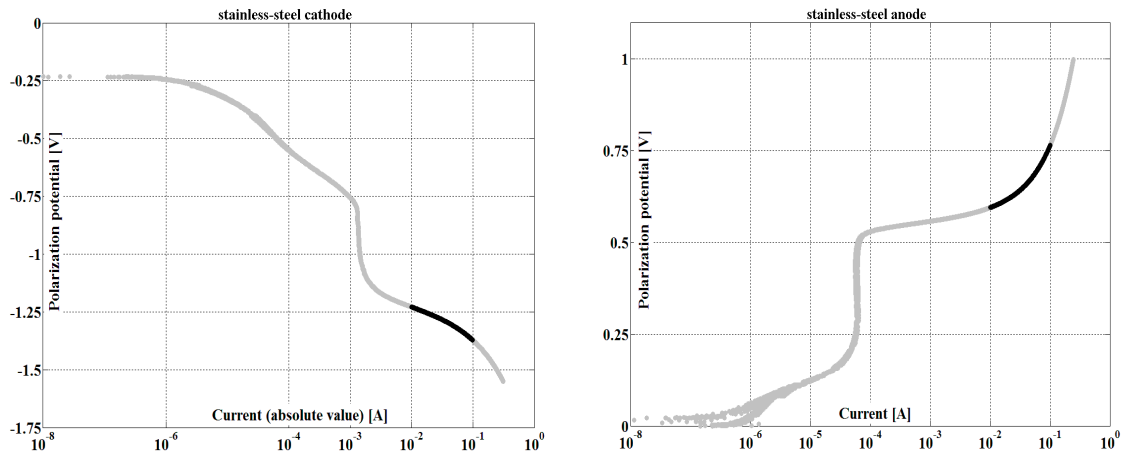


Figure B. Polarization curves for the stainless-steel electrodes

If the value of current exceeds 100 mA, the polarization effect could be considerably higher. The assumption of a 2V polarization adopted in /2/ seems to be correct, while it is close enough to the real polarization value in the investigated current range. It is also clear that in /3/ a calculation error is introduced because the polarization effect is not included. For an application of 30V external voltage, the error may reach 7% for 100mA since the potential difference over the concrete specimen yields 27.85V instead of 30V. Knowing the exact polarization value, it is also possible to insert it directly into the final D_{RCM} calculation, so that the final test result is more accurate.

The polarization effect of the MMO-Ti electrodes is shown in Figure C. These electrodes are made of titanium and coated with mixed precious active metal oxides. The special coating prolongs the life of the electrodes and provides excellent corrosion resistance.

The polarization effect of the MMO-Ti electrodes in comparison to the SS electrodes is lower and yields 1.5÷1.8V. Due to the lower polarization potential and higher corrosion resistance, the MMO-Ti electrodes can successfully replace the SS electrodes. Also, applying the Ti-MMO electrodes in the test setup described in /3/ could reduce the introduced error by decreasing the overestimation of the potential difference over a concrete specimen.

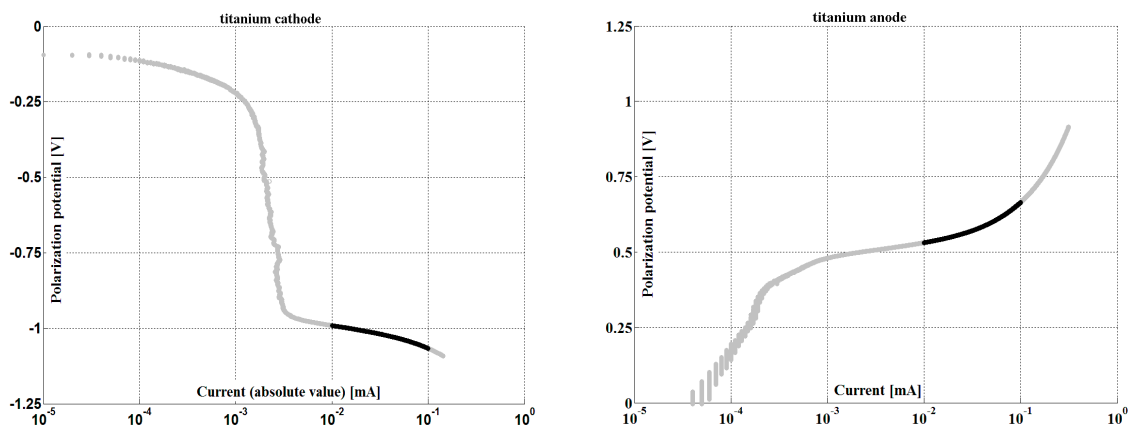


Figure C. Polarization curves for mixed-metal-oxides coated titanium electrodes

Influence of curing of concrete on the chloride ions migration coefficient (D_{RCM})

The available RCM test procedures prescribe the testing of concrete from inner layers of structures or testing cubes. It is required to avoid the surface effects (bleeding, wall effect) or prior chloride contamination. However, some properties of inner and outer layers of concrete are different due to the differences in their microstructure. This fact implies that the resistance against intrusion of chloride ions is different for the different parts of concrete. In the case of concrete prepared and cured under laboratory conditions (relative humidity = 100%, temperature $\approx 22^{\circ}\text{C}$), these differences can be minimized. Nevertheless, in reality, in the case of concrete structures, the outer layer –the layer which is directly exposed to a chloride source – is the real barrier against harmful substances. In practice it means that an inappropriate part of concrete is tested for the chloride ions migration (D_{RCM}) – not the outer one which could be in contact with the chloride source but the inner one /4,5/. It can lead to an overestimation of the quality of concrete and finally to an overestimation in predicting the service life of structure.

The following experiment was performed to show the differences in quality of concrete cured under laboratory and real construction-site conditions. Four concrete mixes were prepared – two having a potentially good quality (low w/c ratio) and 2 with a potentially poor quality (high w/c). Concrete mix proportions are presented in Figure D.

Symbol	Cement [kg/m ³]	Water [kg]	Sand 0-2 mm [kg/m ³]	Sand 0-4 mm [kg/m ³]	Gravel 4-16 mm [kg/m ³]	w/c	Density [kg/m ³]
C1	Cem I 52.5R, 360	137	0	837	1132	0.38	2466
C2	Cem III/B, 42.5N, 360	137	0	828	1120	0.38	2445
C3	Cem I 52.5R, 360	216	72	679	1015	0.6	2342
C4	Cem III/B, 42.5N, 360	216	0	742	1003	0.6	2321

Figure D. Concrete mix proportions

Concrete cubes (15cm x 15 cm) and a test wall (1m x 1m x 30 cm) were cast from each batch. The cubes were stored in water (22 °C), while the test panels were kept outside. To represent the real construction-site curing, one side of each test wall was demoulded after 1 day from casting and left freely for the weather exposure (wind, rain, changes in temperature – poor curing) and the opposite side of walls were covered by a plastic foil and demoulded after 7 days from casting (to represent better curing).

Cores were drilled out of each cube and a test panel after 26 days from casting. After 28 days from casting the RCM testing started (following the NT Build 492 manual /2/). The tests were performed on the inner layers of concrete cured in laboratory (to represent potential quality) and on the outer layers of concrete cured on the construction-site (to represent the real quality). The results are presented in Figure E.

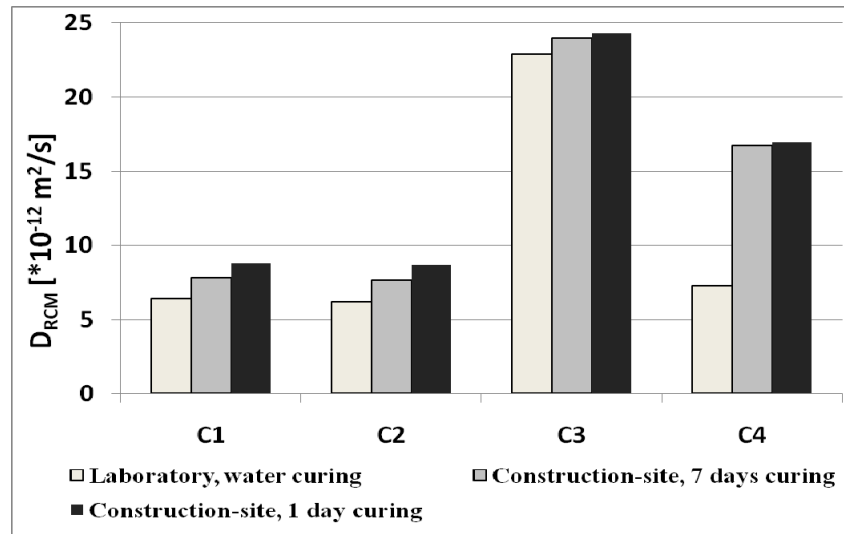


Figure E. Influence of curing of concrete on the migration coefficient (D_{RCM})

The results show the influence of the curing of concrete on its resistance against chloride ions intrusion. It is clear that the concrete cured in water has the lowest values of chloride ions migration coefficient. Furthermore, the influence of the curing of the construction-site test panel is also noticeable – the side cured for only 1 day shows the weakest resistance against chlorides intrusion. In practice it means that concrete prepared under laboratory conditions will resist better against chlorides in comparison to the same concrete, but prepared and cured in a common industrial way. From the designing point of view, it should be considered as necessary not only to rely on the RCM results obtained on concrete prepared/cured in laboratory scale, but also to test samples from real structures. The above presented results show, that the RCM test procedure should be modified to test the outer layer of concrete instead of the inner one. However, it is only possible in the case of concrete elements which were not exposed to chlorides. The presence of chlorides on the concrete surface can be easily checked by spraying silver nitrate over the surface. If chlorides are present, the depth of contamination should be determined, and the contaminated layer should be removed prior to testing.

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