Hydrophobe III -
3rd International Conference on Surface Technology with Water Repellent Agents,
Aedificatio Publishers, 79–90 (2001)

Monitoring the Durability of Hydrophobic Treatment at Existing Concrete Structures

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Abstract

Research to evaluate the effectiveness and durability of hydrophobic treatments are carried out at ibac.The paper describes studies where the measurement of the electrolytic resistivity of concrete has been used to assess any moisture ingress through the hydrophobized concrete surface. For this purpose, an embedded multiring-electrode (MRE) has been used to measure the resistivity at different depths. This sensor, developed at ibac, is composed of several stainless steel rings separated by plastic rings and allows to determine the electrolytic resistance between each pair of neighbouring stainless steel rings by impedance measurements. The sensors are installed by embedding into the fresh concrete or by mounting them into hardened poured concrete with a special mortar. The test specimens were produced with different concrete mixes and, after at least two-year storage, were treated with a hydrophobic cream. This was applied in three different amounts to evalutate the effectiveness of the varying amounts of introduced active agent on the concrete surface. The concrete specimens were then weathered artificially in the VENUS simulation chamber. The effectiveness of the hydrophobic coatings was tested by applying different water pressure to the surface and evaluating the water migration into the concrete with the installed sensors. It is shown that the post-installation of sensors furnishes adequate results. In addition, the obtained results show that the tested hydrophobic treatment, applied to normal concrete in the recommend dosage, is effective for pressures of about 1.05-m water-column height.

1 Introduction

1.1 Electrolytic resistance of concrete

The electrolytic resistance of concrete is a function of its manufacturing characteristics (e.g. type of cement, water/cement ratio, additives, age) and the environmental conditions such as carbonation, salinity and temperature. The influence of the latter can be discounted by means the Arrhenius equation. But the main influence on the electrolytic resistivity is provided by concrete moisture.

Raising concrete moisture from dry to water-saturated may change resistivity up to four orders of magnitude. Predictions about the electrolytic resistivity of treated concrete constructions with respect to water migration and drying behaviour have already been made [4,6].

1.2 Measurement of the electrolytic resistance

For the measurement of the specific electrolytic resistance of concrete at different depths a sensor, called a multiring-electrode (MRE) was developed at ibac. The schematic build-up of this electrode is shown in figure 1. For further information on MRE see [3,4].

1.3 Post-installation of the multiring sensor

At existing structures or test specimens post-installation of the MRE allows to follow changes in moisture in areas below the surface of the concrete. The electrolytic conductance between the electrode and the concrete is achieved by a 2-mm thick connecting mortar. After hardening of the connecting mortar it takes time to equilibrate with the moisture of the existing concrete. To determine the best method for post-installation of sensors research into the development of an appropriate conneting mortar formulation and its installation was carried out.

The research focused on developing a special mortar that had to fulfill special requirements such as ease of application and fast moisture equilibration with the surrounding concrete. For this purpose the connecting mortar should not show creep or capillary suction and have small water permeability. Furthermore, the installation conditions, such as pouring of the mortar and the wetting-time of the existing concrete were optimized. The developed mortar fulfils the mentioned demands. Figure 2 shows schematically the post-installation of the Multiring-electrode.

2 Experimental

2.1 Monitoring the efficiency of hydrophobic treatment

The research aims can be divided into those dealing with the testing procedure and those for the evaluation of hydrophobic coating effectiveness.

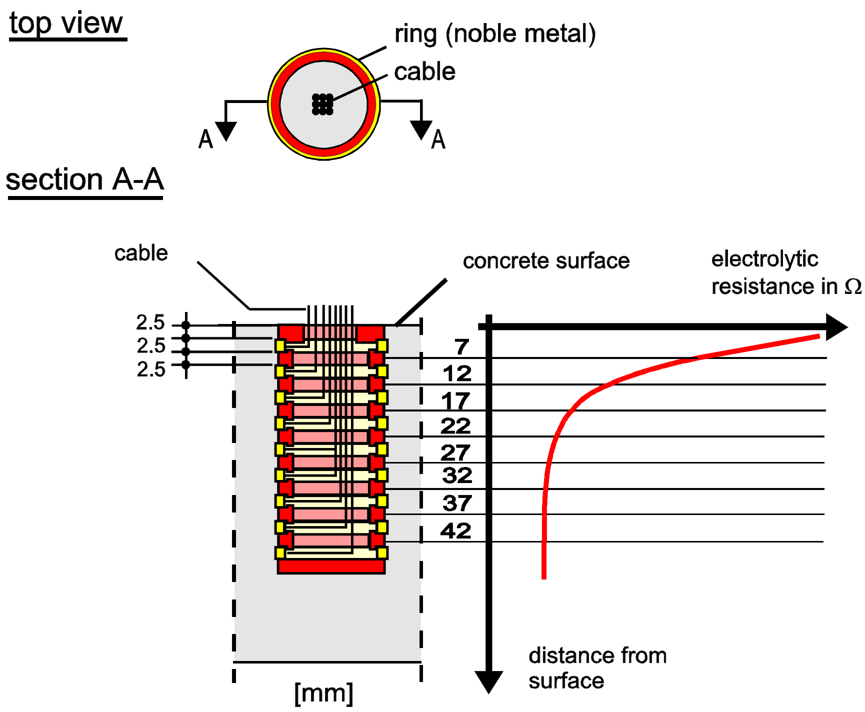


Figure 1: Schematic drawing of the Muliring-electrode

Aims of the testing procedure:

- Verification of the effectiveness of the hydrophobic treatment using the Multiring-electrode
- Optimisation of the post-installation of the elctrode
- Application of the artificial weathering VENUS

The evaluation of hydrophobic coating effectiveness was carried out:

- on new hydrophobic cream treatments
- through application of different amounts of the hydrophobic treatment
- by increasing the moisture impact

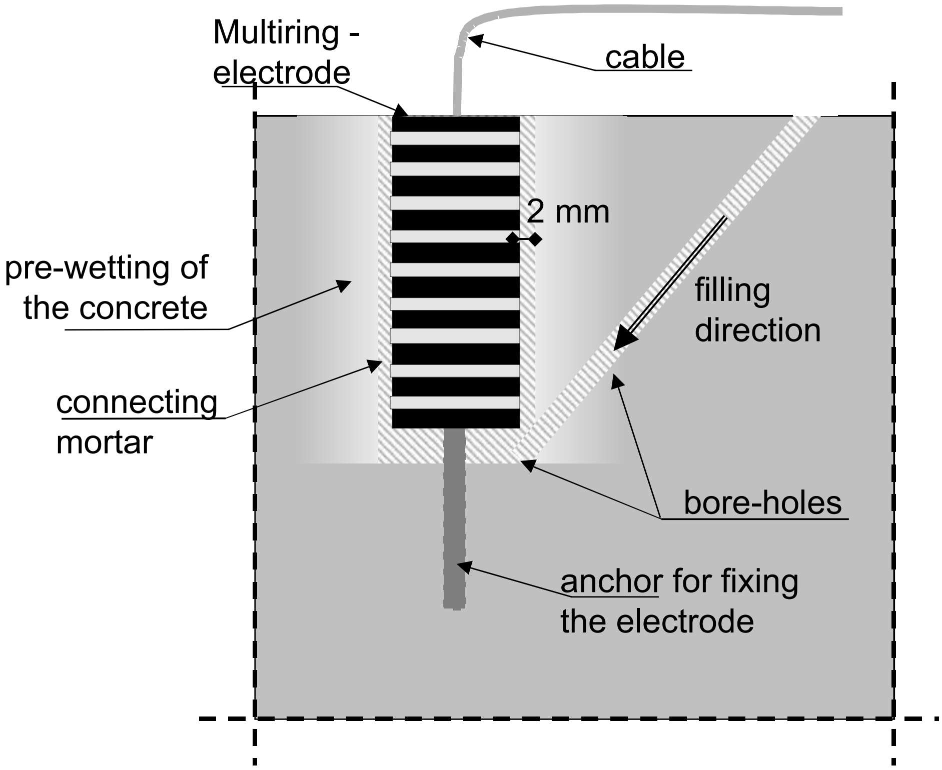


Figure 2: Schematic illustration of the post-installation of the electrode

2.2 Test matrix

The test matrix presented in fig. 3 was used. The test specimens used (C45 and C15) were produced in the years 1997 and 1998 for different research projects and were stored for at least 2 years at 23°C/50% RH (C15) and 20°C/65% RH (C45). The C45 test specimens were already produced with a MRE embedded in the fresh concrete in the center of the cube. An additional electrode was eventually post-installed in the hardened concrete for this research. The C15 specimens were only fitted with post-installed electrodes. Figure 4 shows a test specimen C45 with both MRE as well as the temperature sensors used to eliminate the temperature influence.

The specimens were sealed on the sides and bottom with an epoxy resin and treated with different amounts of the hydrophobic cream on the top. Eventually, the specimen were exposed to different artificial weathering test-loops described below.

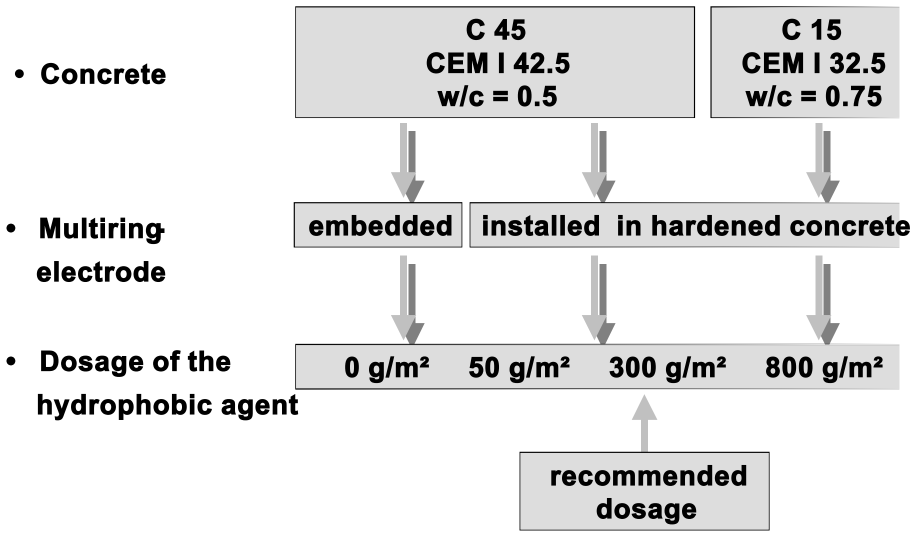


Figure 3: Test matrix

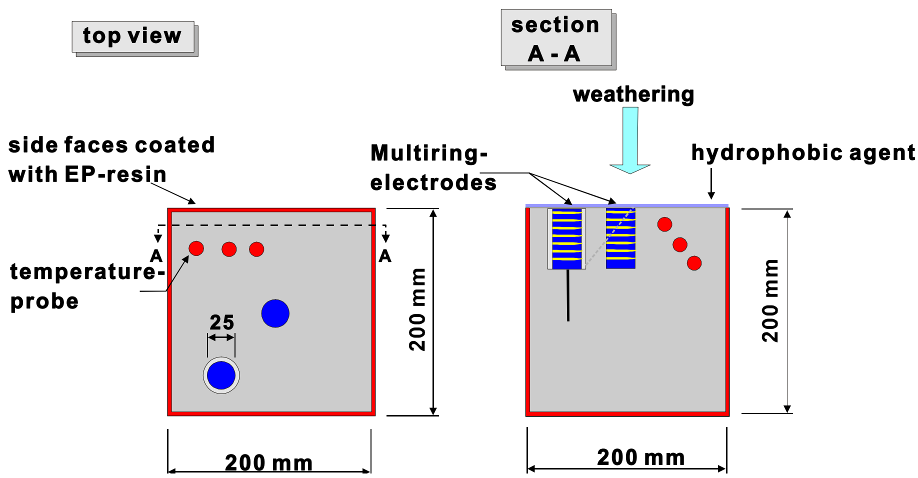


Figure 4: C45 specimen with the originally installed MRE in the center, the supplementary post-installed MRE and the temperature sensors.

2.3 Hydrophobic agents

The hydrophobic agent used in these tests is a cream formulation based on an octyl triethoxy silane. It has a thixotropic, creamy consistency which allows an easy application on vertical surfaces and ceilings. The active component is 80% of the formulation, the rest contains mainly water and on a smaller amount of emulsifiers. The very high content of the active ingredient leads to a large penetration depths, even with application of a small volume of the cream. The introduced silane hydrolyses with the water in the concrete releasing alcohol and subsequently condensing into a polymeric network which forms a thin layer in the pores of the concrete. While water vapour penetration and diffusion in the concrete are not affected, water intrusion is effectively inhibited.

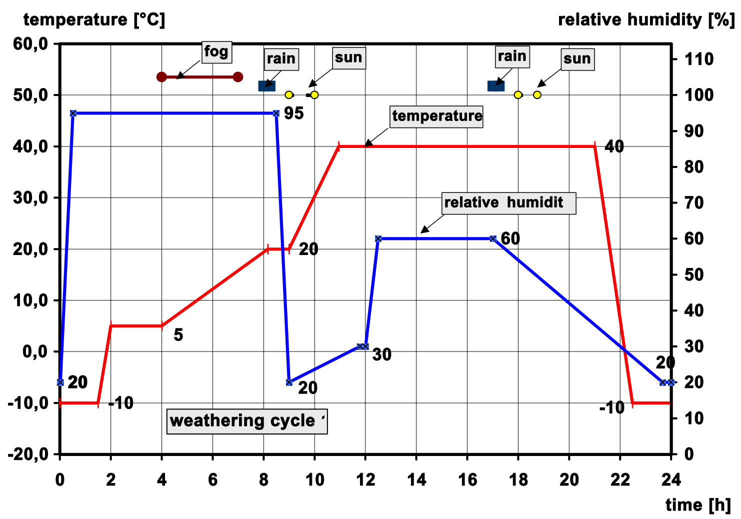
2.4 Test loops

phase A:	mounting of electrodes, coating	(dur.: 28 · 24 h)
phase B.	3-times weathering program 1 (see also fig. 6a)	(dur.: 3 · 24 h)
phase C:	2-times weathering program 2 (see also fig. 6b)	(dur.: 2 · 24 h)
phase D:	20 °C / 65 % r.h.	(dur.: 24 h)
phase E:	rain (slowly rising from 15 min up to 23 h)	(dur.: 7 · 24 h)
phase F:	20 °C / 50 % r.h.	(dur.: 24 h)
phase G:	water impact	(dur.: 8 · 24 h)
phase F:	20 °C / 50 % r.h.	(dur.: 3 · 24 h)
phase I:	pressure water impact (0 ... 1.05 m water column)	(dur.: 8 · 24 h)
phase J:	20 °C / 50 % r.h.	(dur.: 10 · 24 h)

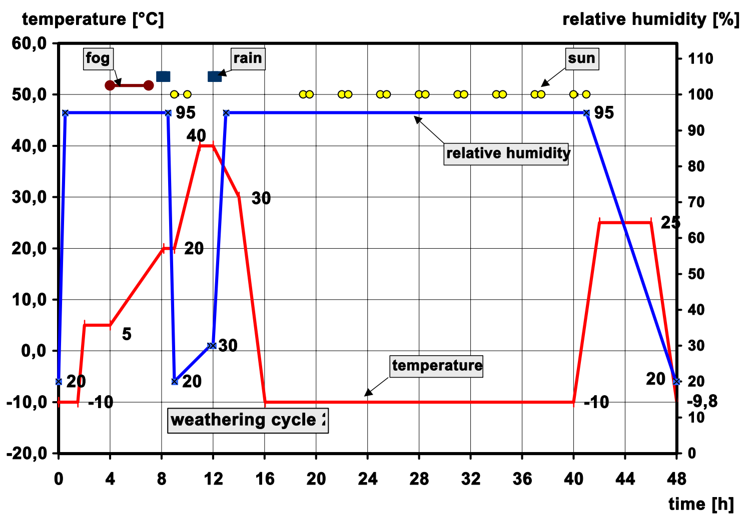
2.5 The "VENUS" environmental simulation chamber

The overwhelming majority of scientific publications on the weathering resistance of natural stone demonstrate the complex, interactive effects of numerous influencing factors and resultant corrosion processes. Single-parameter laboratory tests provide only imprecise simulations of the processes which take place in nature and generally fail to supply any results which can be used for further material optimisation measures.

Furthermore, accelerated weathering tests may lead to gross misjudgements if excessive stress levels are applied such as may initiate processes which do not occur in natural weathering. Apart from the implementation of multiple parameters for the influencing factors, a key requirement in developing the VENUS environmental simulation chamber was compliance with the limits found in natural weathering variables such as maximums, minimums, ramps, combinations. A degree of acce-



a)



b)

Figure 5: Parameters of the weathering programs 1 [(a), duration 24 h] and 2 [(b), duration 48 h] VENUS

leration was to be attained by means of weathering cycles in which elements known to have little influence on the promotion of corrosion processes were masked out. The possibility of generating reproducible damage corresponding to natural condi-

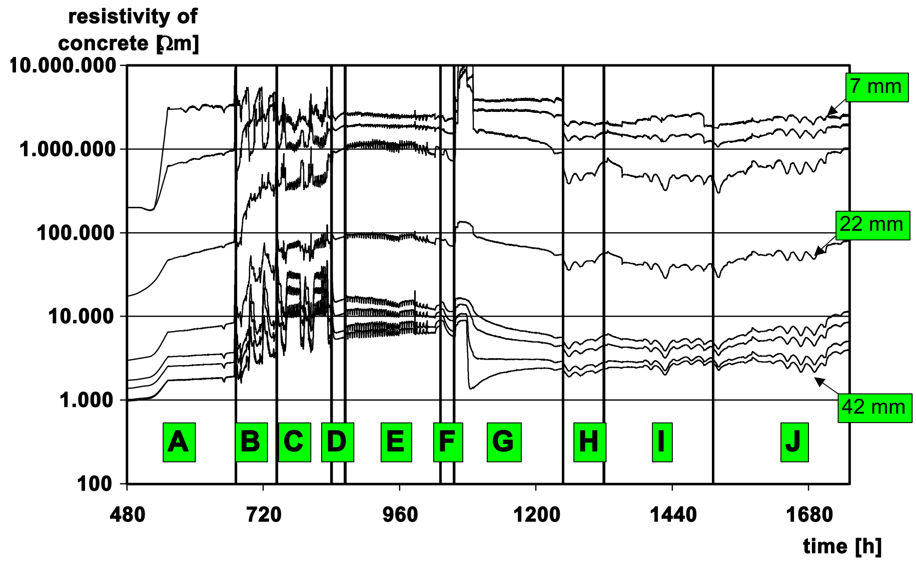


Figure 6: Resistivity curves of specimen C45 with Multiring-electrode installed in hardened concrete and an application of 300 g/m² of hydrophobic cream. Numbers in the boxes indicate distance from the surface.

tions was seen as the advantage of laboratory simulation, rather than the acceleration aspect.

The VENUS chamber enables the controlled exposure of specimens to weathering elements such as solar radiation, rain, freeze-thaw cycles, temperature changes, humidity changes and gaseous pollutants (SO_2, CO_2, NO_x). Condensation processes inside capillary pores of different materials can also be controlled. Two different cycles covering the above mentioned elements were developed in interdisciplinary co-operation (Figure 5a/b).

The cycles represent weather elements of an average year in central Europe which, though extreme, nevertheless correspond to the naturally occurring characteristics in terms of all minimums, maximums and ramp gradients.

3 Results

3.1 Measurement of Resistivity

The electrolytic resistivities was recorded continuously at 5-min intervals. Also recorded were the temperatures in the test specimens as well as all climate values in the "VENUS" chamber during the weathering cycles 1 and 2 (phase B and C).

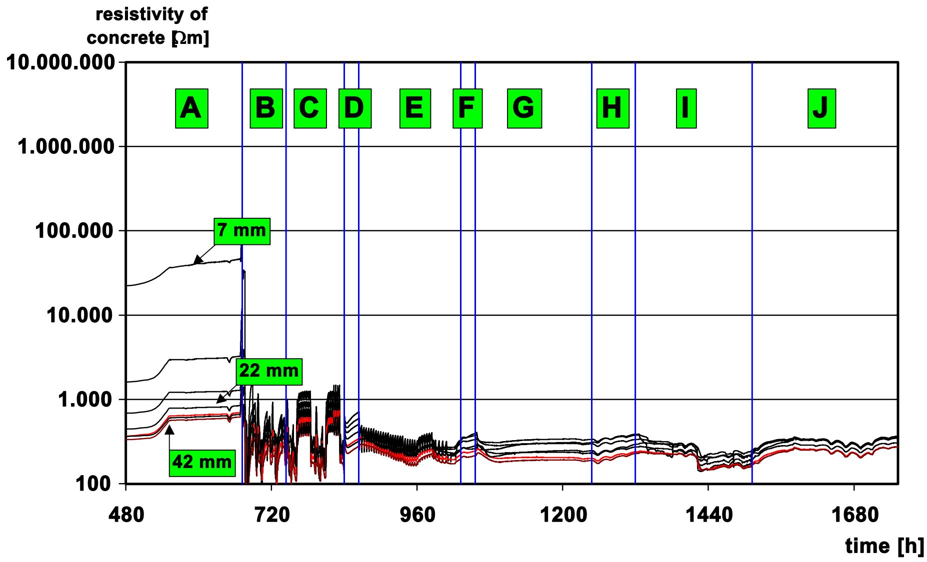


Figure 7: Specimen C45 without hydrophobic treatment cream and Multiring-electrode-post-installed in hardened concrete

Fig.6 shows as an example the curves of resistance as function of time during the indicated exposure conditions (phase A-J) for the specimen C45 with the Multiring-electrode installed in hardened concrete and an application of 300 g/m² of the hydrophobic cream. The influence of the temperature on the resistivity values is eliminated by calculation.

Fig. 6 shows the clear profile of humidity during weathering where the area by the concrete surface is dry due to the hydrophobization treatment while the interior has a higher moisture content. In comparison, the resistivity curves of specimen C45 without hydrophobic treatment but with Multiring-electrode installed in hardened concrete are presented in Fig. 7.

The specimen without hydrophobic treatment already shows decreasing electrolytic resistivities at the beginning of the weathering cycles (phase B) which indicates a complete water saturated concrete.

An example where the hydrophobic treatment looses its efficiency under water pressure is shown in Fig. 8. This gives the resistivity curves of specimen C15 with an application of 800 g/m² hydrophobic cream. During weathering cycles 1 and 2, no decrease in restivity is observed, however, it can be seen during exposure phase G (water exposure). With the impact of water pressure (phase I) the resistivity decreases further until the concrete is nearly saturated with water. The higher resis-

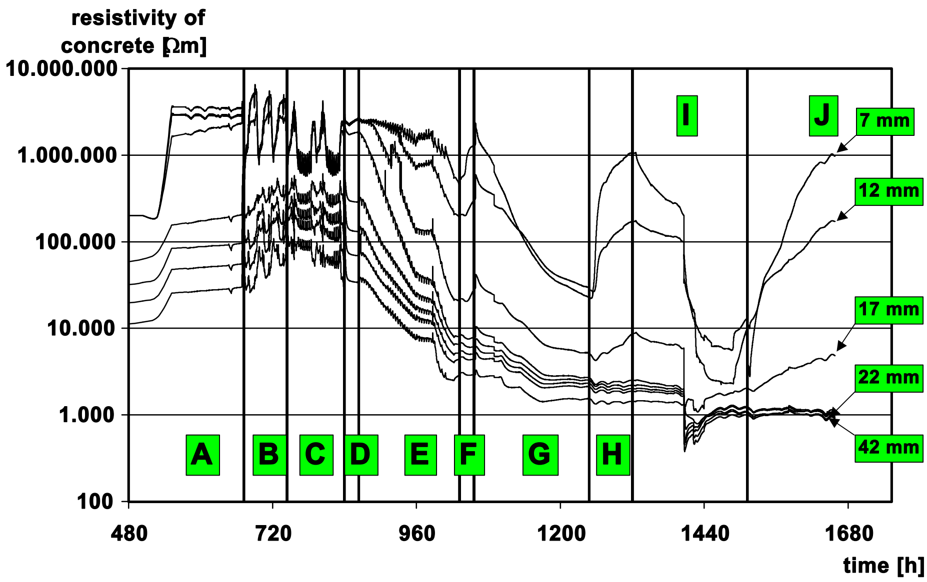


Figure 8: Specimen C15 with an MRE post-installed in hardened concrete and application of 800 g/m² hydrophobic cream.

tivity at the points near the surface can be attributed to the hydrophobic treatment (penetration depth is 22-mm) which reaches the MRE. It can also be seen that even with application of a high amount of hydrophobic cream the resistivities increase in phase J (drying the specimens at 20 C and 65% RH.) due to the continuous drying of the specimen.

3.2 Efficiency of the hydrophobic treatment

In Table 1 the moisture profiles after different stress conditions are presented. While untreated test specimen already remain water saturated under weathering cycles 1 and 2, the water migration was delayed with rising dosage of the cream and rising quality of the concrete. With concrete C45 and a dosage of over 300 g/m² cream water migration was prevented even under a water pressure of 105 cm.

3.3 Measurement instrumentation

The results regarding the used measurement equipment can be summarised as follows:

- the MRE detects with sufficient sensitivity changes in the moisture contents of concrete;

<table>
<tr><th rowspan="2">concrete</th><th rowspan="2">application of hydrophobic cream</th><th colspan="2">weathering cycle</th><th rowspan="2">rain phase</th><th rowspan="2">water exposure</th><th rowspan="2">water exposure (exerting pressure)</th></tr>
<tr><th>1</th><th>2</th></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td rowspan="4">C15</td><td>0 g/m²</td><td colspan="5">concrete: water saturated</td></tr>
<tr><td>50 g/m²</td><td>concrete: dry</td><td colspan="3">increasing humidit</td><td>water saturated</td></tr>
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<tr><td>800 g/m²</td><td colspan="3">concrete: dry</td><td></td><td>water saturated</td></tr>
<tr><td rowspan="4">C45</td><td>0 g/m²</td><td colspan="5">concrete water saturated</td></tr>
<tr><td>50 g/m²</td><td colspan="3">concrete: dry</td><td colspan="2">water saturated</td></tr>
<tr><td>300 g/m²</td><td colspan="5">concrete: dry</td></tr>
<tr><td>800 g/m²</td><td colspan="5">concrete: dry</td></tr>
<tr><td></td><td></td><td colspan="3">required efficiency of th hydrophobic cream</td><td colspan="2">increased efficiency</td></tr>
</table>

Table 1: Evaluation of the resistivity curves with regards to concrete humidity after different exposure conditions

- the post-installed sensors also detect changes in the electrolytic resistance of concrete;
- The temperature influence of the resistances can be nearly eliminated by using the Arrhenius equation.

Thus the durability and the effectiveness of hydrophobic coatings can be evaluated by using the multiring-electrode.

4 Conclusions and Outlook

The presented results show that the Multiring-electrode is suitable to evaluate the effectiveness of different hydrophobic treatments against water ingress. The MRE also performs well when it is post-installed in hardened concrete.

Furthermore, different parameters such as carbonation and freezing depths can be determined by using the MRE sensor. The effectiveness of the new hydrophobic treatments in cream formulations could be assessed for different exposure conditions and even under water pressure.

In the future, constructions such as bridges, tunnels and watergates could be equipped with the MRE sensor. In combination with a datalogger and a modem connection, on-line monitoring of these constructions would be possible allowing to monitor water penetration into the concrete.

5 References

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