Investigation on the effectiveness of the repair method 8.3 "Corrosion protection by increasing the electrical resistivity" in chloride-containing concrete

Part 3: The influence on corrosion of chloride-contaminated concretes under protective coatings

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Abstract

With the implementation of the repair method "increasing the electrical resistivity by coating" (MR 8.3), no direct repassivation of the reinforcing steel is initially intended. The success of the repair is rather linked to the change of the corrosion-relevant parameters over time. These include an increase in the concrete resistivity due to dehydration and gradual decrease in corrosion currents and driving voltages on the reinforcing steel. Within the scope of a research project funded by the German Research Foundation (DFG), application limits for the repair principle W-Cl could be defined. The chloride content present in the concrete at the rebar is the significant limiting factor for the application. While the corrosion activity even with moderately dehydrated specimens under diffusion-retarding coatings at chloride contents of 1 wt% Cl⁻/c is in the range of the passive current density, this cannot be generally determined for chloride contents of 2 wt% Cl⁻/c. The type of coating has a decisive influence on the dehydration of the concrete. For example, less dense concretes under a permeable coating (acrylic dispersion/OS 4) can dry out to such an extent that the passive current density is reached. With semipermeable coatings and the presence of high chloride contents of 2 wt% Cl⁻/c, the repair principle W-Cl does not lead to success according to the available test results.

KEYWORDS

chloride, concrete resistivity, corrosion, durability, repair
The third part of the publication on the repair principle W-Cl according to RL-SIB\textsuperscript{[1]} or Method 8.3 according to DIN EN 1504-9\textsuperscript{[2]} deals with the investigations carried out within the framework of a German Research Foundation (DFG) project on the limits of the application of the repair principle to investigate the dehydration of chloride-containing concretes under protective coatings and their effect on relevant corrosion parameters. The investigations were carried out in cooperation with the Technical University of Kaiserslautern, Institute of Construction Material Technology, by Prof. Dr. Ing. Wolfgang Breit and Dipl. Ing. Ayhan Celebi.

1 | INVESTIGATIVE METHODOLOGY FOR DETERMINING THE RELEVANT PARAMETERS FOR MR 8.3/W-Cl

Within the framework of the research project, those parameters were analyzed which was of significant importance for the effectiveness of the repair principle W-Cl\textsuperscript{[3,4]}

• Moisture content of chloride-contaminated concretes
• Temporal development of the electrical resistivity of coated, chloride-contaminated concretes
• Temporal development of corrosion in coated, chloride-contaminated concretes.

The concrete compositions specified in Table 1 were selected for investigations. This was intended to realistically represent the range of concrete qualities of the existing buildings. The cement used was an ordinary portland cement CEM I 42.5 N and a blast furnace cement CEM III/A 42 N.

The investigation on the corrosion activity of the steel and the drying behavior of the concrete after the application of surface protection systems was carried out on multifunctional specimens. The electrolyte resistances were measured with a depth-graded arrangement of stainless-steel electrodes. The vertical spacing of the electrodes was set to 2 mm. The corrosion activity was determined for each sample on two steel anodes ($A = 0.6 \text{ cm}^2$). As there is a risk of manganese-dioxide-based reference electrodes drying out in very dry concretes, a mixed metal oxide-activated titanium strip (Ti-MMO) was installed as a quasi-reference electrode (QRE), which was repeatedly calibrated over time against an externally coupled Ag/AgCl reference electrode. The structure of a multifunctional specimen is shown in Figure 1.

| TABLE 1 | Investigated concrete compositions |
|----------|-----------------------------------|
| Cement type | Cement content (kg) | w/c ratio | Chloride$^a$ (wt%/c) |
| CEM I 42.5 N (OPC) | 300 | 0.50 | 0 | 1 | 2 |
| CEM III/A 42.5 N (BFC) | 300 | 0.60 | 0 | 1 | 2 |

Abbreviations: BFC, blast furnace cement; OPC, ordinary portland cement.

$^a$Added into the mixing water of the concrete.

The sorption isotherm and the resulting resistivity were determined on flat prisms measuring 150 mm $\times$ 100 mm $\times$ 25 mm. The electrolyte resistance of the test specimens was determined with the aid of Ti-MMO strips embedded in concrete at the front edges.

2 | ADSORPTION AND DESORPTION ISOTHERM

The successful application of MR 8.3 and W-Cl requires that the chloride-containing concrete dries out in the existing environmental conditions, thus reducing the electrolytic conductivity of the concrete. Salts have a hygroscopic effect. As is noted in the literature, the equilibrium moisture content in porous building materials with high salt contamination can increase significantly at certain relative humidities (RHs).\textsuperscript{[5-8]} To what extent this also applies to moderately chloride-contaminated concretes, however, has hardly been investigated so far. In this context, the sorption isotherms of the concrete listed in Table 1 were prepared in accordance with DIN EN ISO 12571\textsuperscript{[9]} for five RHs each, which in the authors’ view, are relevant in practice, see Table 2.

Figure 2 shows as an example the results of the respective equilibrium moisture contents achieved through
desorption of the concrete CEM I, w/c = 0.5 and −2 wt% Cl"⁻/c.

A comparison of the chloride-containing concrete with the chloride-free concrete shows no significant differences in either desorption or adsorption (cf. Figure 3). The chloride-containing concrete tends to have a slightly higher equilibrium moisture content.

Interestingly, the NaCl content of concrete hardly influences its sorption isotherm at the examined, practical air humidity levels. An expected abrupt increase in water content, as described for NaCl for example in DIN EN ISO 12571 for a range around 75% RH could not be observed for the NaCl content investigated here. According to these results, it can be assumed that the drying out of moderately chloride-contaminated (NaCl) concretes should proceed similarly over time as the drying out of chloride-free concretes of the same concrete composition. The clear hysteresis between adsorption and desorption (Figure 3) indicates that the readsorption of moisture from the air takes place at a significantly reduced rate and that the concrete keeps dryer in the equilibrium moisture while adsorption than while desorption.

The electrolyte resistivity according to references [3,10–13] is—in addition to the anodic polarization resistance—an important parameter in the assessment of reinforcement corrosion and is therefore of particular importance for the W-Cl repair principle. Reference [14,15] indicates a threshold value of 1 kΩm, above which the risk of corrosion decreases—nevertheless, corrosion current densities up to 1 µA/cm² can still occur. Only resistivities in a value of 10 kΩm or higher lead to very low corrosion rates, which are in the range of the passive current density (0.1 µA/cm²).

In the course of the conducted investigations, the following electrolytic resistivities, shown in Figure 4, resulted for the concretes listed in Table 1 at an age of 28 days after moisture exposure at 98% RH. A comparison

### Table 2

| No. | Appliance                | Relative humidity (%) |
|-----|--------------------------|-----------------------|
| 1   | Climate chamber          | 55                    |
| 2   | Climate chamber          | 65                    |
| 3   | NaCl/climate chamber     | 75                    |
| 4   | KCl/climate chamber      | 85                    |
| 5   | Climate chamber          | 95                    |

**Figure 2** Results of desorption measurements on specimens with CEM I, w/c = 0.5 and Cl"⁻ 2 wt% Cl"⁻/c

**Figure 3** Exemplary representation of the sorption isotherm of samples with CEM I, w/c = 0.5 at 0 wt% Cl"⁻/c and 2 wt% Cl"⁻/c

**Figure 4** Electrolyte resistivities of concrete mixtures according to Table 1 after 28 days storage in 98% relative humidity (RH) (gray: literature results from Osterminski[16] for water storage)
of these results with the results for water exposure from Osterminksi\[16\] shows the influence of exposure on the concrete resistivity.

When applying the repair principle W-Cl, the chloride-contaminated concretes should dry out until a sufficiently high resistivity is achieved to reduce the corrosion current densities to a harmless level. As described above, a reduced risk of corrosion can be expected from a threshold value of 1 kΩ m for resistivity.\[15\] At the uncoated flat concrete prisms, in addition to the desorption isotherms, the resistivities were also recorded, so that the correlation between the water content occurring during the drying of the concrete and the concrete resistivities could be determined. Figure 5 shows that a water content below 2 wt% is required to exceed the threshold value of 1 kΩ m when using a CEM I concrete. If a CEM III concrete is used, water content below 3 wt% should be targeted to reduce the risk of corrosion.

By applying a surface protection system (coating), the chloride-contaminated reinforced concrete components are protected from further chloride penetration and renewed direct exposure to water. Each coating inhibits the permeation of water vapor, so the concrete underneath can only dry out slowly. The size of the water vapor diffusion coefficient (or the diffusion-equivalent air layer thickness) of the coating determines the passage of water vapor and thus also how much the drying out is retarded. Here, acrylic dispersion coatings (coating system OS 4 according to Deutscher Ausschuss für Stahlbeton)\[1\]) are considered to be more permeable and while crack-bridging coatings with a polyurethane floating layer (e.g., OS 11 coatings) are more water vapor diffusion retarding.

In the course of the investigations, coatings were selected which exhibit a broad spectrum with regard to the diffusion-equivalent air layer thickness, see Table 3. The application of the coatings on the test specimens was carried out according to the manufacturer’s specifications. Only the inherent moisture content of the test specimens was between 5.0 and 6.0 wt% much higher than usual at the time of coating. However, this was necessary for determining the drying behavior of coated concrete by means of experiments. During the coating process, no negative effects such as blistering formation could be detected.

After 3 months of conditioning at 98% RH and subsequent application of the coating, the laterally sealed test specimens were exposed to a defined laboratory climate of an average of 55% RH and 21 ± 1°C for about twelve months. In parallel, uncoated reference test specimens were stored at 55% RH and 98% RH for the entire period. The electrolytic resistances were measured at regular intervals on the electrode conductors by means of an impedance measurement at 1,000 Hz. The concrete resistivity determined on electrode pairs with an average depth of about 10 mm is presented below.

The measured resistances in Ω are converted into resistivity with the use of a geometry constant established for the test arrangement according to the following equation (e.g., from Brem\[12\] and Reichling\[17\]).

\[
\rho = R_{\text{absolute}} \times Z,
\]

### Table 3

| System | OS-class | Diffusion-equivalent air layer thickness Sd (H2O) (m) |
|--------|---------|------------------------------------------------------|
| Acrylic dispersion | 4 | 0.12 |
| Epoxy resin | 8 | 80 |
| PU | a | 180 b |

aFloating layer of a crack-bridging coating (OS 10/OS 11a).
bCharacteristic values estimated from literature.
where \( R_{\text{absolute}} \) is the absolute electrolytic resistance (\( \Omega \)), \( Z \) is geometry factor (m), and \( \rho \) is electrolytic resistivity (\( \Omega \)m).

The geometric constant of the electrode conductors was determined both by means of a finite-element calculation using the COMSOL Multiphysics® program and by accompanying tests. For the electrode ladder, it is assessed to be about 5 mm.

The time-dependent development of the electrolytic resistivity over the investigation period is shown in Figure 6 as an example for a concrete CEM I, w/c = 0.50 in dependency of the used coating systems. In the diagram, the range of 1,000 \( \Omega \)m was marked, which is often given in the literature reference [14], as the lower threshold value of a detectable influence on the corrosion current density.

As expected, the results in Figure 6 show almost constant concrete resistivities over time for the test specimens without coating when stored in a humid climate (98% RH). On the other hand, the concrete resistivities of the test specimens without coating when stored in dry conditions increase continuously by a factor of about 40 compared with the initial resistance during the first ten months, ultimately reaching about 1,500 \( \Omega \)m. The concrete resistivities of the coated test specimens in dry storage are between those of the uncoated test specimens in dry storage on the one side and those of the uncoated test specimens in moist storage on the other side as the exposure time increases. The test specimens with a permeable OS 4 coating show concrete resistivities which, at the end of the investigation period, approach those of the uncoated test specimens in dry storage. In contrast, the resistivities of the test specimens with EP (OS 8) coating and the PU floating layer remain at a low level over the entire duration of the study. As expected, a significant drying out cannot be determined for such rather vapor impermeable coatings.

Figure 7 shows the results of the time-dependent development of the electrical resistivities for all examined parameters (concrete compositions, chloride contents) at the beginning of the exposure in the laboratory climate (90 days) and at the end of the investigation period. The influence of the cement type on the electrical resistivities of the reference test specimens in wet exposure can easily be seen. Especially for CEM III concretes the increase of the electrical resistivities over the exposure period due to the delayed latent hydraulic reaction can be seen. During dry storage (exposure at 55% RH), the uncoated test specimens (reference concretes) and the specimens with the permeable coatings reach values above 1 k\( \Omega \)m after 1 year.

In the case of the more impermeable coatings/floating layers, such a high degree of drying cannot be observed in any concrete tested or with any chloride contamination. Although the increase in concrete resistivities, starting from the beginning of dry exposure, is in a range from factor 3 to 5, the maximum resistivities remain for a CEM III concrete, w/c = 0.5, \( \text{Cl}^- \) 1 wt%/c with 550 \( \Omega \)m but clearly below 1.000 \( \Omega \)m.

Over the investigation period, no concrete resistivity of \( \geq 10 \Omega \)m could be determined on any of the test samples examined. This limit value is recommended to ensure corrosion current densities that are in the range of the passive current densities.[3,12,13]

### 4 | TEMPORAL DEVELOPMENT OF THE POTENTIALS

The insertion of a Ti-MMO strip in the test specimens allows the determination of further corrosion-relevant parameters. Thus, the Ti-MMO strip is used as a QRE in accordance with references [18] and [19] to measure the

![FIGURE 7 Temporal development of concrete resistivities at the beginning of exposure in the laboratory climate (90 days) and at the end of the investigation period in dependence of the applied coating/climate. RH, relative humidity](image-url)
free corrosion potentials ("rest potential") of the anodes embedded in chloride-containing concrete. The stability of the QRE was regularly checked over the measuring period by means of externally coupled silver/silver chloride (Ag/AgCl) reference electrodes. In addition, the Ti-MMO strips can be used as cathodes for corrosion current measurement, which is described in detail later.

The temporal development of the free corrosion potentials (cf. Figure 8) in relation to the standard hydrogen electrode shows a tendency towards positive potentials for all coated and uncoated test samples when stored at 55% RH. Only the potential voltages of the reference samples stored at 98% RH remain at a stable negative value. The samples with the impermeable coatings show only slightly more negative potential voltages than the samples with the permeable coating or the uncoated samples in a dry climate.

The temporal development of the free corrosion potentials of all test specimens in dry storage in positive direction is initially surprising, since the concrete resistivities of the test specimens with impermeable coatings increase only moderately over time (and—as explained below—the corrosion currents decrease only moderately). Thus, even a slight decrease in the water content at the anode seems to lead to a significant increase in the free corrosion potential. This finding is of great relevance in practice: In corrosion monitoring, the sole focus on the free corrosion potentials (e.g., by installing reference electrodes) can lead to a clear misinterpretation of the actual corrosion dynamics (corrosion currents or electrical resistivities).

5 | TEMPORAL DEVELOPMENT OF CORROSION CURRENTS

The temporal increase in the free corrosion potentials of the anodes of the test specimens in dry exposure is theoretically accompanied by a decrease in the driving voltage between anode and cathode, which would lead to a reduction in corrosion currents. To qualitatively record the time-dependent development of the corrosion activity of the installed steel anodes, the anodes were temporarily short-circuited with the Ti-MMO strips as cathode. The cell current was recorded in a zero resistance ammeter measurement with a potentiostat (Gamry Reference 600).

The measured quantity is the macrocell corrosion current between the specifically designed anode (steel in chloride-containing concrete) and a Ti-MMO cathode (anode/cathode ratio, 3:100). The part of the corrosion current that forms on the cell acting as the anode due to cathodic surface areas (microcorrosion) is not measurable (a research project—WIPANO-Project "KoMICS" Corrosion monitoring during repair of chloride-deteriorated reinforced concrete structures, FKZ 03TNH025—is currently being carried out at Munich University of Applied Sciences in cooperation with Technical University of Munich and the German Federal Institute for Materials Research and Testing (BAM) and others to investigate the microcorrosion while applying W-Cl). As a result, the measured current is only a cell current, which may only be one part of the actual corrosion current. However, the term corrosion current will be used in the following to simplify matters. To convert the corrosion current densities from the corrosion currents (cell currents), the anodes were partially removed after completion of the test series and the area of the corrosion pits was measured under an incident light microscope. The corrosion current densities were then based on the measured anode surfaces. The element currents are measured at a defined point in time after a temporary short circuit of anode and cathode (transient corrosion current measurement). With this measuring method, the free corrosion potential of the anode can be determined in addition to the corrosion current. Since the corrosion current usually drops significantly after the short circuit is established, it is essential for the evaluation of the results that the measurements are carried out at the same time after the short circuit is established. Here, a uniform time point for measuring the corrosion current at 120 s was chosen for all tests. This point in time led to an extensive convergence against a (stationary) corrosion current, whereas in the case of measurements that do not fully converge, the corrosion current is overestimated on the safe side.

Figure 9 shows the development of the corrosion current densities exemplary for the sample series CEM I, w/c = 0.5, 2 wt% Cl⁻/c. According to RILEM,\(^{[20]}\) corrosion current densities of 0.1 µA/cm² are to be interpreted as negligible with regard to the service life of the reinforcement. This threshold is defined subsequently for the purpose of evaluation as "passive current density."
Analogous to the electrolytic resistivities (Figure 6), the results in Figure 9 show almost constant corrosion current densities over time for the test specimens without coating when stored in a humid environment (98% RH). On the other hand, the corrosion current densities of the test specimens without coating when stored in dry conditions decrease continuously over the first nine months, by a factor of 200 compared with the corrosion current densities when stored in humid conditions, to finally below 0.1 µA/cm². Likewise analogous to the concrete resistivity, the corrosion current densities of the coated test specimens are between the reference test specimens stored in a wet or dry environment. The corrosion current densities of the test specimens with a more permeable OS 4 coating come close to those of the uncoated test specimens in dry storage at the end of the investigation period. In contrast, the corrosion current densities of the test specimens with an OS 8 coating or PU floating layer last remain at approximately 10–20 µA/cm² and are thus 100–200 times higher than the passive current densities.

Figure 10 shows the results of the corrosion current densities at the beginning of the exposure to laboratory climate (90 days) and at the end of the investigation period for all examined parameters (concrete types, chloride contents). Again, it is shown that in the reference test specimens made of CEM III concrete in damp storage, a late cement reaction leads to a decrease in the corrosion currents. In contrast, the corrosion currents of the uncoated test specimens made of CEM III/A, w/c = 0.50 and Cl⁻ 2 wt%/c remain above the passive current densities even after approximately 12 months of dry storage.

With the corrosion currents of the coated test specimens after approximately 12 months of dry storage, the significance of the chloride content of the concretes is striking: With chloride contents of 1 wt% Cl⁻/c, corrosion current densities of maximum 0.5 µA/cm² can be observed regardless of the coating type (according to RILEM[20] of little importance for the service life of the reinforcement), the corrosion current densities are predominantly in the range of the passive current density. In contrast, with chloride contents of 2 wt% Cl⁻/c, the corrosion current densities of the test specimens with diffusion-blocking coatings/floating layers after 12 months of dry storage are in some cases well above

FIGURE 9 Development of the corrosion current densities over the investigation period exemplary for CEM I, w/c = 0.50, 2 wt % Cl⁻/c depending on the applied coating/climate. RH, relative humidity

FIGURE 10 Development of corrosion current densities at the beginning of exposure in laboratory climate (90 days) and at the end of the investigation period as a function of the applied coating/climate. RH, relative humidity
1 µA/cm² (according to RILEM\cite{20} of great importance for the service life). Interestingly, in the case of CEM III concretes with high chloride contents (2 wt% Cl<sup>-</sup>/c), the corrosion current densities of the test specimens with the permeable OS 4 coating remain far above the passive current densities in the period under investigation—even above 1 µA/cm².

If subsequently the measured concrete resistivities are correlated with the corrosion current densities (all test specimens with 2 wt% Cl<sup>-</sup>/c) at the end of the investigation period in each case, the dependence shown in Figure 11 results. The results of references \cite{12,21,22} have been added to our own results. Above the corrosion current-resistance ratio determined by reference \cite{12} it can be assumed that the electrolyte controls the corrosion kinetics ("resistance control"), whereas pairs of values below the relationship are driven anodically controlled. The results at high water contents show that the scattering is considerable, but the values are scattered around the correlation given by Brem.\cite{12} At high resistivities above 1,000 Ωm (combined with low water contents), anodic control becomes dominant in most of the test specimens examined: the value pairs are well below the Brem correlation. However, the example of the test specimen CEM III, w/c = 0.6 also shows that an evaluation of the corrosion kinetics by determining the electrical resistivity is not appropriate: The test specimen with an OS 4 coating has a current density of 5.1 µA/cm² at an electrical resistivity of 2.1 kΩm, while the test specimen without coating has a current density of 0.07 µA/cm² below the passive current density at an electrical resistivity of 2.3 kΩm. It must, therefore, be suggested that proof of the success of the W-Cl repair principle is not provided by determining the concrete resistivity, but by measuring the corrosion current density.

6 | CONCLUSION

Within the scope of a DFG research project concerning the application limits of the repair principle W-Cl, the drying behavior of coated test specimens was investigated. From the results obtained, fundamental insights into the repair principle W-Cl can be gained.

6.1 | Sorption isotherm

The adsorption and desorption isotherms of the chloride-containing concrete investigated (up to 2 wt% Cl<sup>-</sup>/c) differ only marginally from those of chloride-free concretes. Overall, the pronounced hysteresis of the sorption isotherm shows that the equilibrium moisture content of drying systems is significantly higher than the moisture content of humidified systems. In practice, this means that the ambient conditions must have very low air humidity for concretes to dry out. However, once they have dried out and the ingress of water is prevented by a coating, there is hardly any increase in water content when stored in higher air humidity. At ambient moisture of 55% RH, the uncoated test specimens examined exhibit a pronounced drying behavior of the concrete even at chloride contents of up to 2 wt% Cl<sup>-</sup>/c.

6.2 | Drying out under coatings

On the basis of the measured electrolyte resistances, it can be determined that test specimen with permeable OS 4 coating dry out more slowly but after approximately 12 months of dry storage reach concrete resistivities in the area of the uncoated specimens (>1 kΩm).
In contrary, test specimens with a more impermeable OS 8 coating or PU floating layer show, as expected, a strongly inhibited drying out. The resistivities remain below those of the uncoated samples by a factor of 4–10.

In practice, this means that very low air humidity levels in the environment are required to ensure that concretes dry out and that coating system which is as open to diffusion as possible is to be used. In the course of the investigations, an OS 4 coating proved to be suitable with regard to the drying behavior.

6.3 Practical relevance of electrolyte resistance measurement as a method of corrosion monitoring

It could be shown that the measured corrosion activity of samples with high water content correlates with the electrical resistivity. However, at low water content, as desired with the W-Cl principle, the electrical resistivity is not a suitable parameter for evaluating the corrosion kinetics. For high chloride contents, a threshold value of the concrete resistivity of 1 kΩm is not on the safe side. Consequently, further measurements of corrosion parameters are required in addition to the resistance measurement.

6.4 Practical relevance of potential measurements as a method of corrosion monitoring

The results of the measurements of the free corrosion potentials ("rest potentials") show that these increase significantly for test specimens in dry storage even if the test specimens are only slightly dried out under impermeable coatings.

In this case, a warning must be issued against attempting to conclude the effectiveness of the W-Cl repair principle only on the basis of measurements of the free corrosion potential. This can lead to significant misjudgments.

6.5 Corrosion current densities under coatings

It could be shown that the chloride content of the concrete is the decisive parameter for the success of the W-Cl repair principle. At chloride contents of 1 wt%/c, maximum corrosion current densities of 0.5 µA/cm² (according to RILEM of little importance for the service life of the reinforcement) could be determined after 12 months of dry storage, even with rather impermeable coating systems. The corrosion current densities were even below the passive current densities at this chloride contamination. At the same time, however, since the electrolyte resistances under the impermeable coatings were still low (Figure 7), it appears that the corrosion kinetics are controlled anodically ("repassivation of the pitting").

At a chloride load of 2 wt%/c, a clearly different picture emerges: Here, even an uncoated test specimen with CEM III/A, w/c = 0.5 remains above the passive current density (up to 0.3 µA/cm²) after 12 months of dry storage. In the other concretes examined, the passive current densities are just below those of the uncoated test specimens. The corrosion current densities of the coated test specimens with a chloride content of 2 wt% Cl⁻/c remain far above the passive current densities even after 12 months of dry storage, while those of the test specimens with a diffusion-inhibiting OS 8 coating and PU floating layer even remain in the range of 5–20 µA/m². In the case of the test specimens with a permeable coating, the corrosion current density which occurs at chloride contents of 2 wt% Cl⁻/c depends largely on the type of cement: In test specimens with CEM III/A the corrosion current densities remain above 1 µA/cm² (and thus according to RILEM as service life-limiting), in those with CEM I, w/c = 0.50 in the range of the passive current density of 0.1 µA/cm².

6.6 Practical relevance of corrosion current measurements

6.6.1 Chloride content

The chloride content present in the concrete is a decisive criterion for the use and success of the W-Cl repair principle. Here, the investigations carried out show that at chloride contents of Cl⁻ 1 wt%/c, even moderate drying, as can occur under diffusion-blocking coatings, is sufficient to reduce the corrosion activity to passive current densities. At a chloride content of 2 wt%/c, a reduction of the corrosion activity to passive current densities cannot be assumed.

6.6.2 Density of the concrete

At high chloride contents, dense CEM III concretes, w/c = 0.50, lead to corrosion current densities above the passive current densities even after long dry storage and without coating, whereas less dense concretes (CEM I, w/c = 0.50 or CEM III, w/c = 0.60) are to be considered as passive at these boundary conditions.
6.6.3 | Permeable coatings

The application of even a permeable OS 4 coating on dense concretes (CEM III/A, w/c = 0.50) with high chloride contents slows down drying to such an extent that damaging corrosion current densities above 1 µA/cm² remain. In contrast, the less dense concretes mentioned above can also dry out under a permeable OS 4 coating to such an extent that the passive current density is approximately reached.

6.6.4 | Impermeable coatings

At high chloride contents, the repair principle W-Cl does not lead to success when using impermeable coatings according to the available test results.

6.6.5 | Monitoring

The results of the investigation show that the success of a repair according to the W-Cl principle can be most appropriately proven by measuring the corrosion currents. When determining the concrete resistivities without measuring the corrosion current densities, no reliable statement can be made about the remaining corrosion activity. Measuring the free corrosion potentials is unsuitable for evaluating the effectiveness of the repair principle.

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