Impact of leaching on chloride ingress profiles in concrete

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Electronic Supplementary Material

Online source 1: Service life prediction

In this study, we used the service life prediction model for reinforced concrete structures subjected to chloride-induced corrosion described in Chapter 3.2 in *fib* Bulletin 34 [1], which assumes uncracked concrete. Annex B2 in *fib* Bulletin 34 provides an approach for estimating the critical chloride content C_{crit} [wt%/sample dried at 105 °C] at the reinforcement (Equation 1) and for quantifying the parameters required for the service life calculations. The service life here is defined as the time it takes for the chlorides to reach the critical chloride concentration at the steel reinforcement. The approach is based on the error function solution (erf) of Fick's second law of diffusion (Equation 1).

The parameters that require to be quantified in Annex B2 in *fib* Bulletin 34 [1] and applied to Equation 1 are as follows: x is the depth [mm] from the exposed surface, Δx the depth [mm] of the convection zone, a represents the thickness [mm] of the concrete cover, t the time [years], $C(x, t)$ the chloride content [wt%/sample dried at 105 °C] at depth x and time t, C_{crit} is the critical chloride content [ditto] in the concrete, C_0 is the initial chloride content [ditto], $C_{S,\Delta x}$ is the chloride content [ditto] at a depth Δx, and $D_{app,C}$ is the apparent diffusion coefficient [mm^2/year] of the concrete.

$$C_{crit} = C(x = a, t) = C_0 + (C_{S,\Delta x} - C_0) \cdot \left[1 - erf\,\frac{a - \Delta x}{2\sqrt{D_{app,C} \cdot t}}\right] \qquad (1)$$

In our calculations, C_0 was determined by the background chloride content, i.e. the last point in the chloride profiles (approx. 0.02 wt%/sample dried at 105 °C). Since our study concerns submerged conditions, there is no convection zone, so Δx is set at 0 mm [1]. As a consequence,

$C_{S,\Delta x}$ is equal to the surface chloride content C_s. The only parameters that remain to be determined are the apparent diffusion coefficient, $D_{app,C}$, and the surface concentration, C_s.

According to *fib* Bulletin 34 [1], the D_{app} can be determined based on accelerated laboratory testing, also known as rapid chloride migration (RCM) testing. This was not done in this case, but *fib* Bulletin 34 [1] also proposes that D_{app} and C_s can be estimated from chloride profiles from existing structures where the concrete has been exposed for several months. In this study, D_{app} and C_s were estimated by fitting Equation 1 by the least mean square method to the total chloride profiles obtained from the mortar and concrete samples after 180 days of exposure (see Figure 4 in the main article related to this online source).

Figure 1 shows the chloride profiles with the fitted curves for the specimens exposed 180 days. Table ***1*** gives the apparent diffusion coefficient D_{app} and surface chloride content C_s was calculated by fitting the curves for all mortar specimens. The first points in the profiles were not discarded because the profiles have few datapoints and because there is no convection zone in submerged conditions.

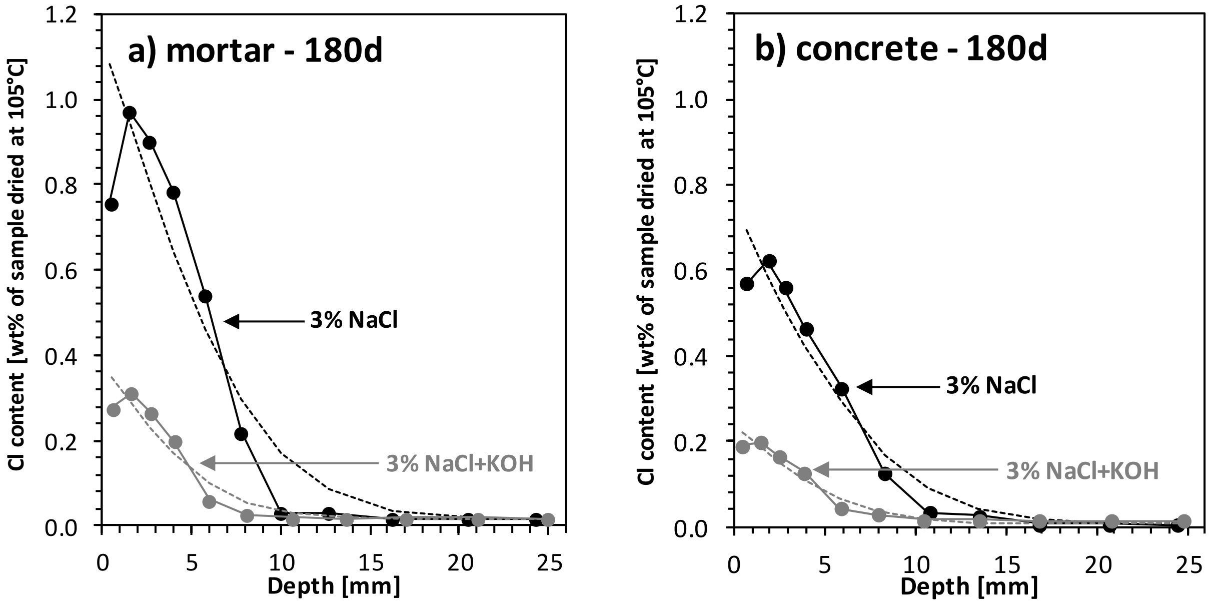

Figure 1 Fitted curves (dashed lines) together with the chloride profiles obtained from titration (solid lines) of a) mortar specimens and b) concrete specimens, which were exposed to NaCl (black) and NaCl+KOH (grey) for 180 days

Table 1 D_{app}, C_0 and C_s, and the predicted service life for the concrete and mortar specimens exposed to NaCl or NaCl+KOH for 180 days

Specimens exposed for 180 days	D_{app} [10^{-12} m²/s] ([mm²/year])	C_0 [wt%/conc]	C_s [wt%/conc]	Service life [years]
Mortar NaCl	1.46 (46.0)	0.018	1.143	11
Mortar NaCl+KOH	0.76 (24.0)	0.018	0.383	63
Concrete NaCl	1.46 (46.0)	0.007	0.750	11
Concrete NaCl+KOH	0.75 (23.7)	0.015	0.237	58

To estimate the service life of a structure prepared with the mortars and concretes investigated in this study in accordance with the *fib* Bulletin 34 model [1], we need to assume a concrete cover, a, and a critical chloride content, C_{crit}. As suggested by *fib* Bulletin 34 [1], we used a C_{crit} equal to 0.6 wt%/g cement (yielding a critical chloride content of 0.15 wt%/g mortar dried at 105 °C and of 0.09 wt%/g concrete dried at 105 °C) as a lower boundary value for the critical chloride content. The cover depth, a, was determined in accordance with Eurocode 2 Section 4 [2], where a nominal cover depth of 50 mm is prescribed for exposure class XS2 (permanently submerged structures exposed to chlorides from seawater). This nominal cover depth consists of a minimum requirement regarding durability $c_{min,dur}$ of 40 mm plus a variation Δc_{dev} of 10 mm.

D_{app} is considered to be time-dependent, so by acquiring chloride profiles at different exposure times, one can gain information on the time dependency of $D_{app,C}$. However, in the absence of such information, we used the D_{app}, as well as the C_s, given in Table ***1***. The service life was calculated as the time it takes for the chlorides to reach the critical chloride content C_{Crit} at the reinforcement steel using Equation 1 and the above-named parameters. The results of the service life predictions are also given in Table ***1***.

References

[1] International Federation for Structural concrete (fib), fib Bulletin 34: Model Code for Service Life Design: Model code prepared by Task group 5.6, fib, Lausanne, 2006.

[2] EN 1992, Eurocode 2: Design of concrete structures. CEN, European Committee for Standardization, Brussels, 2004.