Prepared for submission to Cement and Concrete Research

Effect of leaching on the composition of hydration phases during chloride exposure of mortar

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Electronic Supplementary Data

Estimation of the impact of changes in porosity due to leaching on the total chloride content

Leaching causes the dissolution of portlandite, and potentially other hydration phases, in the outer sections of the exposed mortar specimens and consequently increases the porosity in these sections. This additional porosity might be filled with the chloride-containing exposure solution and might therefore increase the total chloride content determined by potentiometric titration in the leached sections.

The differences in the maximum total chloride content between the specimens exposed to the NaCl solution and the NaCl+KOH solution for 180 days is about 0.7 wt% of chloride per dried mortar (Figure 5).

First, we wanted to have a rough estimate of the amount of free chloride in the mortar unaffected by leaching. We assumed that the cement used binds approx. 20 g water per 100 g cement after about half a year of hydration (see Figure 4). We then deducted the water bound by the cement from the mixing water in the mortar (see Table 2) and assumed the remaining water to be free water, which is about 128 kg free water/m^3 mortar[1]. If, for the sake of simplicity, we do not consider shrinkage, the volume of free water would represent the porosity in the mortar after half a year of hydration.

If we fill this porosity with the NaCl solution, we reach a chloride content of 2.34 kg Cl/m^3 mortar[2]. Dividing by the dry density (2184 kg/m^3 mortar[3]), we obtain the wt% of chloride per

[1] Water bound by cement: 0.20·561.6 kg cement/m^3 mortar (see Table 2) = 112 kg bound water/m^3 mortar
Mixing water in the mortar: 241 kg mixing water/m^3 mortar (see Table 2)
Free water in mortar: 241 – 112 = 128 kg free water/m^3 mortar
[2] Cl concentration in solution: 3% NaCl · M(Cl)/M(NaCl) = 3% · 35.5 g/mol / 58.4 g/mol = 1.82% Cl

mass of mortar dried at 105 °C, i.e., 0.11 wt% Cl per dried mortar. This means that the free chloride content is only slightly more than 10% by wt. of the total chloride content and cannot explain the large difference in total chloride content determined experimentally for the two exposure conditions.

Next, we therefore calculated how much the leaching of portlandite would increase the pore volume and thereby the free chloride content in the mortar. The portlandite content in the mortar is approx. 1 wt% dry mortar (see Figure 7), which corresponds to a volume of approx. 0.446 mL per 100 g dry mortar or 9.7 L/m^3 dry mortar[4], using the molar mass of 74 g/mol and molar volume of 33 mL/g for portlandite. If this volume is filled with exposure solution, it would contribute 0.177 kg chloride/m^3 mortar or 0.008 wt% chloride per portlandite-leached mortar[5]. The increase in porosity, due to portlandite leaching and a consequent increase in free chlorides content of 0.008 wt% dry mortar, cannot therefore explain the 0.7 wt% of chloride per dry mortar difference between the NaCl and NaCl+KOH exposed mortars.

If we look at a hypothetical extreme case, where leaching washes out all cement paste from the mortar, the entire cement paste volume of 432 L/m^3 mortar[6] will be dissolved. If this volume is filled with the exposure solution, this would contribute to 7.87 kg chloride/m^3 mortar or 0.52 wt% chloride per fully leached-out mortar[7]. This gets us closer to the 0.7 wt% difference in total chloride content between the specimens exposed to the NaCl solution and the NaCl+KOH solution after 180 days, but we have still not reached it. So, even such an extreme increase in porosity, due to the leaching of the entire cement paste, cannot explain the difference in the total chloride content between NaCl and NaCl+KOH exposed mortar.

Cl content in the pores per volume mortar: 1.82 kg Cl/100 kg free water · 128 kg free water/m^3 mortar = 2.34 kg Cl/m^3 mortar

Cl content in the pores per mass mortar: (2.34 kg Cl/m^3 mortar) / (2184 kg mortar/m^3 mortar) = 0.11 wt% Cl/ dry mortar

[3] Dry density mortar: (112 kg bound water + 561.6 kg cement + 1510 kg sand)/m^3 mortar = 2184 kg/m^3 mortar

[4] Volume of portlandite/100 g dry mortar: 1 g portlandite/100 g dry mortar · 74 g/mol · 33 mL/mol = 0.446 mL/100 g dry mortar

Volume of portlandite/m^3 dry mortar: (0.446·10^{-3} L/1·10^{-1} kg) · (2184 kg mortar/m^3 mortar) = 9.7 L/m^3 dry mortar

[5] Cl content in leached portlandite volume per volume mortar: 1.82 kg Cl/100 kg free water · 9.7 kg free water/m^3 mortar = 0.177 kg Cl/m^3 mortar

Cl content in the leached portlandite volume per dry mortar mass: (0.177 kg Cl/m^3 mortar) / (0.99 · 2184 kg/m^3 mortar) = 0.008 wt% Cl/ portlandite-leached mortar.

[6] cement density = 2.93 kg/L; water density = 1 kg/L; volume of cement paste in 1 m^3 mortar: (562 kg cement / 2.93 kg/L) + (241 kg water / 1 kg/L) = 432 L/m^3 mortar = 432 kg/m^3

[7] Cl content in leached paste volume per volume mortar: 1.82 kg Cl/100 kg free water · 432 kg free water/m^3 mortar = 7.87 kg Cl/m^3 mortar; Cl content in the leached paste volume per mass leached-out mortar: (7.87 kg Cl/m^3 mortar) / (1510 kg sand* /m^3 mortar) = 0.52 wt% Cl/ fully leached-out mortar.

* We assume that only the sand is left in the fully leached-out mortar.