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The influence of chloride on the moisture transport in mortar

Introduction

The corrosion of steel reinforcement caused by chloride penetration shortens the life-time of concrete structures and it is, therefore, desirable to understand this process. Marine structures in the splash and tidal zones are an example of concrete structures where a steel reinforcement can become corroded due to chloride penetration [1]. The corrosion of steel reinforcement, in these structures, begins with the wetting phase, where the concrete cover layer is saturated with seawater, which contains chloride, by capillary adsorption. When the water level drops down, the water evaporates at the surface leaving chloride behind [2]. During the next wetting phase, more seawater penetrates the concrete, with the already present chloride, the concentration of chloride rises. Repeating these cycles leads to a high chloride concentration and to corrosion of the steel reinforcement in concrete structures [3].

There is always an interaction between the moisture transport and the chloride. However, there are, to the authors' knowledge, no data available in the literature considering this interaction. The purpose of the present experiment is to investigate the influence of chloride in concrete on the moisture transport. This is carried out by comparing the moisture transport through specimens with chloride and specimens without chloride.

Specimen preparation

Mortar specimens with w/c of 0.5 are examined in this research. The cement used is CEM I 42.5 N. The choice of mortar over concrete is decided by the desired thickness of the specimens. The thickness of the specimens is limited by the desired duration of the experiment. This makes mortar a better material for this experiment.

Mortar specimens with a diameter of 100 mm are casted in PVC tubes. After 1 day the specimens are demoulded and cured for 28 days. Layers of 10 mm thickness are obtained from the cylindrical specimens. These layers are exposed to different chloride solutions to obtain mortar specimens with different chloride concentration. This process is explained next.

Chloride penetration

The mortar specimens are placed in various chloride solutions to provide them with a 0.5%, 1.0% and 2.0% chloride concentration of the mass of mortar. The chloride concentrations, C_t, 0.5%, 1.0% and 2.0%, of the mortal specimen mass is calculated as [4]

$$C_t = \frac{\phi \cdot C_{Cl} + C_{Cl_s} \cdot (1-\phi) \cdot \rho_{solid}}{\rho_c}, \tag{1}$$

where ϕ is the porosity of mortar, C_{Cl} the concentration of free chlorides, C_{Cls} the concentration of bound chlorides, ρ_{solid} the density of solid state of the mortar and ρ_c the density of the mortar.

It is assumed that bound chloride C_{Cls} is a function of C_{Cl} [4]:

$$C_{Cl_s} = K \cdot C_{Cl}{}^{n}, \tag{2}$$

where K is the chloride binding capacity and n the chloride binding intensity parameter.

In order to obtain a 0.5% chloride content of the mass of mortar specimen with a porosity of 20%, C_{Cl} is calculated from Eq. (1) for K = $0{,}53\text{x}10^{-3}$ $\text{dm}^{3n}/\text{g}^{n}$ [5] and n = 0.52 [5], so that C_{Cl} = 26.46 g/l. For 1.0%, C_{Cl} = 66.04 g/l and for 2.0 %, C_{Cl} = 155.72 g/l.

Calcium chloride solutions are used in this experiment to provide the specimens with chloride. To obtain 0.5% chloride, 54.87 g/l of the solution calcium chloride is used. For 1.0%, 136.94 g/l is used, and for 2.0%, 322.86 g/l is used.

The procedure of chloride penetrating in the mortar specimen starts by placing the mortar specimens in a desiccator. A pressure of 4 kPa is exerted on the specimens for three hours, to remove the air. This method is known by the name vacuum saturation. The salt solution is added to the mortar specimens in the desiccator after the first three hours. The pressure is left on for another hour. The specimens are left in the salt solution for 20 hours after that.

Chloride concentration profiles of three mortar specimens (one specimens from each salt solution: 0.5%, 1.0% and 2.0%) are measured in five positions in the specimens by Profile Grinder 1100 [6]. The profiles are shown in Figure 1.

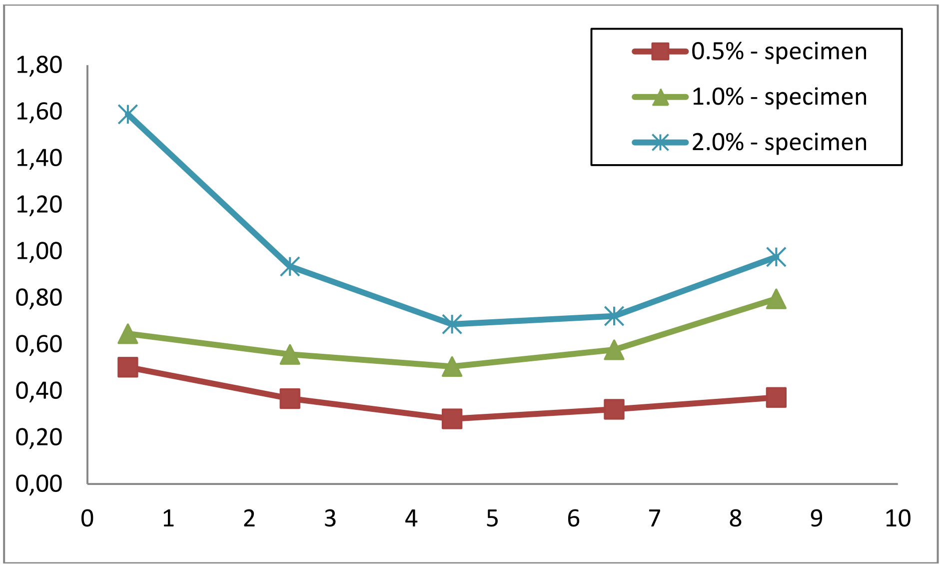

Figure 1: Chloride concentration profiles in mortar with calcium chloride solution

There is clear difference between the chloride content in the specimens of different groups. However, the concentration of chloride is lower than expected, especially in the middle of the specimen. This effect occurs due to the use of a specimen that is not completely dry in the beginning of the experiment. With dried specimens it is possible to obtain a constant chloride concentration. However, the drying procedure requires much attention, because drying causes micro cracks in the specimen, which must be avoided in this experiment. In this experiment, these types of chloride concentration profiles can still be used, because the purpose of the test is comparing the various chloride concentrations, which is clearly observable in these profiles.

Due to the negative effect of calcium chloride, as shown in Figure 2, that increases the volumetric shrinkage of concrete by 10% to 50% [7], mainly because of the higher degree of hydration, and changes in hydration products [8], the salt solution was changed to sodium chloride.

Figure 2: Damage of the mortar specimens in calcium chloride solution of 2%

The same procedure is carried out for the mortar with salt solution of sodium chloride. C_{Cl} is calculated one more from Eq. (1) for $K = 0.53x10^{-3}$ dm^{3n}/g^{n} [5] and n = 0.52 [5], so that $C_{Cl} = 24.82$ g/l. For 1.0%, $C_{Cl} = 61.32$ g/l, and for 2.0 %, $C_{Cl} = 143.43$ g/l.

To obtain 0.5% chloride, 40.92 g/l of the solution sodium chloride is used, for 1.0% 101.09 g/l is used and for 2.0% 236.44 g/l is used. The chloride concentration profiles of mortar in sodium chloride are shown in Figure 3.

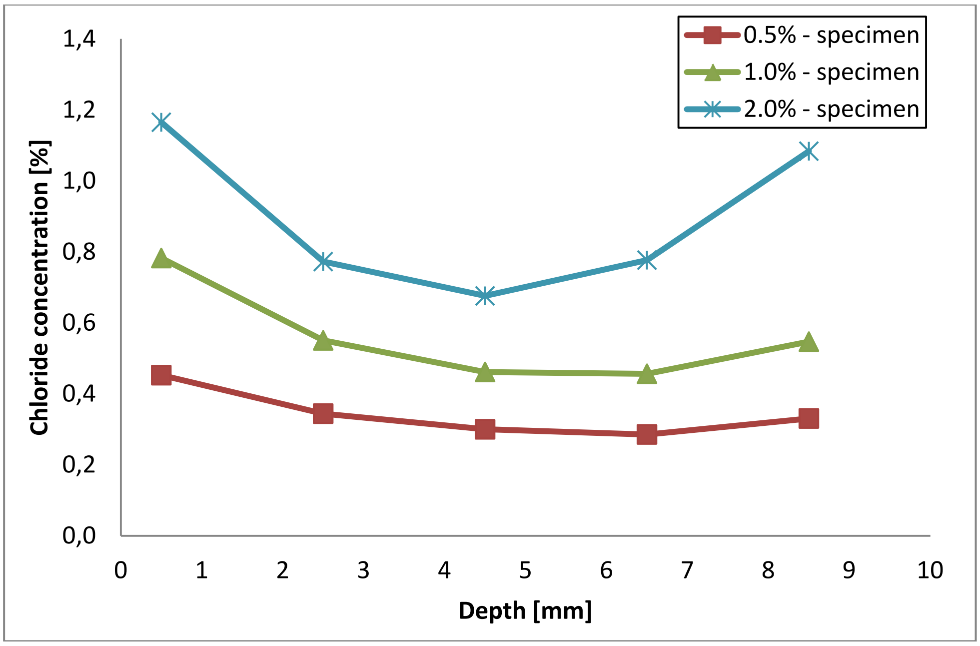

Figure 3: Chloride concentration profiles in mortar with sodium chloride solution

Due to the long duration of the experiment with mortar, sand-lime CS12, with a porosity of 32%, is also used in this experiment. By using sand-lime with this high porosity, results can be achieved much faster. Specimens with the same diameters are drilled from sand-lime bricks. Again, layers of 10 mm thickness are obtained from the cylindrical specimens. These layers are exposed to the same chloride solutions concentrations. It is expected that in these specimens the chloride concentration will be higher than in the mortar specimens, due to the higher porosity. The measurement of the chloride concentration in the sand-lime specimen is shown in Figure 4.

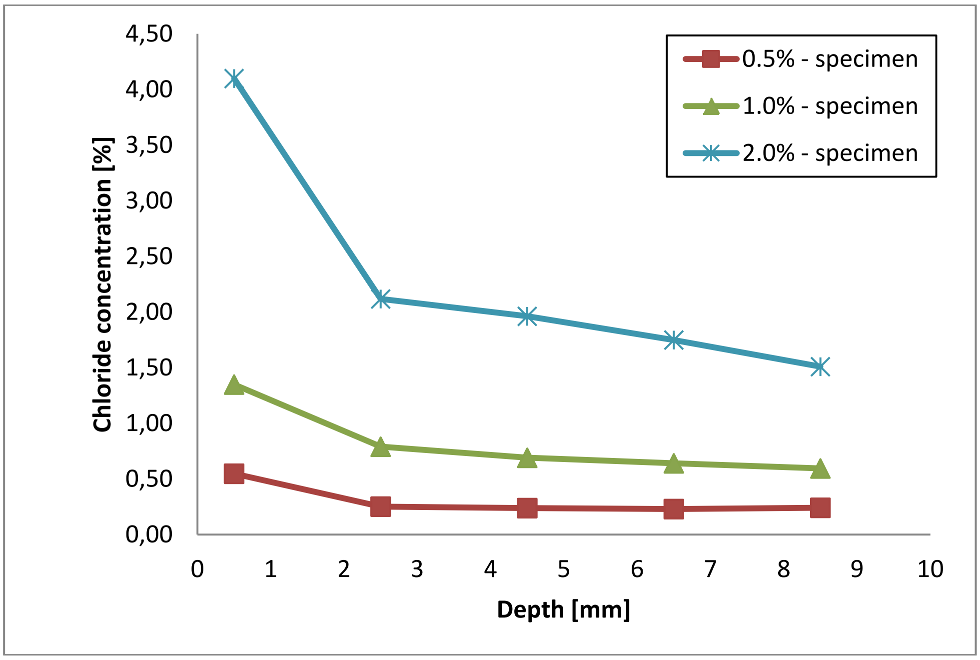

Figure 4: Chloride concentration profiles in sand-lime with sodium chloride solution

Experiment set-up and procedure

After penetrating the chloride into the specimens, the side plane of the specimens is sealed to acquire a one dimensional flux. Furthermore, the specimens are provided with a plastic ring, which serves as a fix in position as is shown in Figure 5.

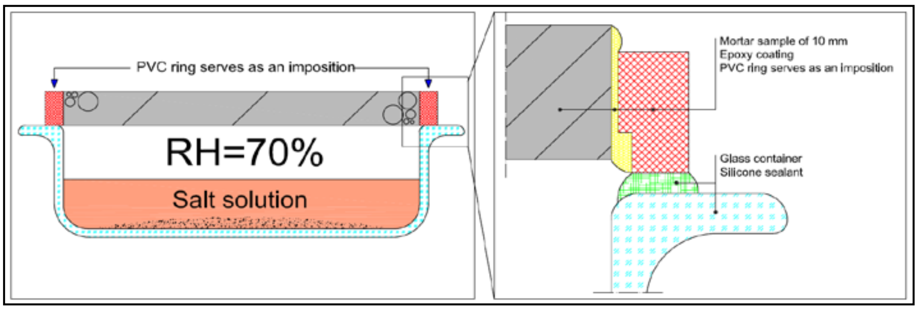

Figure 5: Glass container which is sealed at the top by the specimen

Glass containers with salt solutions are used to obtain a desired relative humidity. The glass container is sealed at the top by the specimen. The glass containers are placed in a large container, also with a certain relative humidity, which is lower than the relative humidity inside the glass container. The certain relative humidity is achieved by using oversaturated salt solutions. Table 1 shows the equilibrium relative humidity of the two used salt solutions for 15, 20 and 25 ^{o}C.

Table 1: Equilibrium relative humidity [9]

Temperature °C	Magnesium Nitrate	Sodium Chloride
15	55.87±0.27	75.61±0.18
20	54.38±0.23	75.47±0.14
25	52.89±0.22	75.29±0.12

The difference in relative humidity leads to a moisture flux from the inside to the outside through the mortar specimen, which means the mass of the specimen, will decrease during the experiment. The containers are weighed at least once a month to determine the mass loss. In the beginning, the mass decreases quickly because of evaporation of the water in the saturated specimen. After 26 hours, the specimen is in equilibrium with the surrounding relative humidity. The experimental scheme is shown in Figure 6.

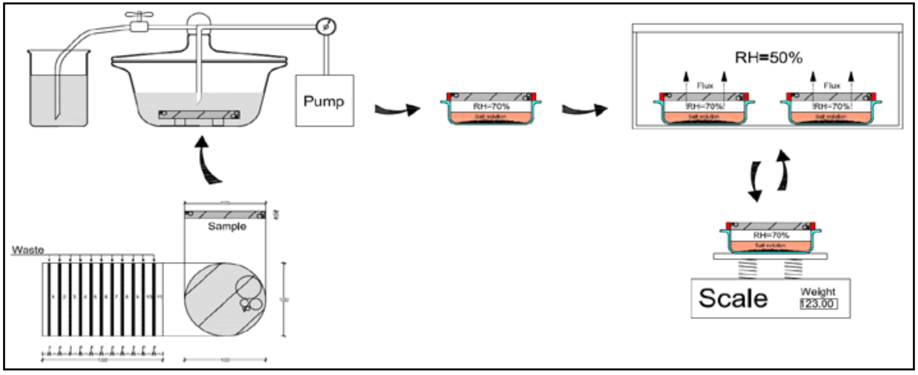

Figure 6: Schematic view of the experiment

Results and discussion

Before starting the experiment, the relative humidity inside the glass container and the relative humidity inside large container are investigated. The measurement in the glass containers are preformed for three days. The measured temperature is 21^{o}C and a relative humidity is 70%, which differ by 5% with the values in the literature [9]. The measurements are shown in Figure 7.

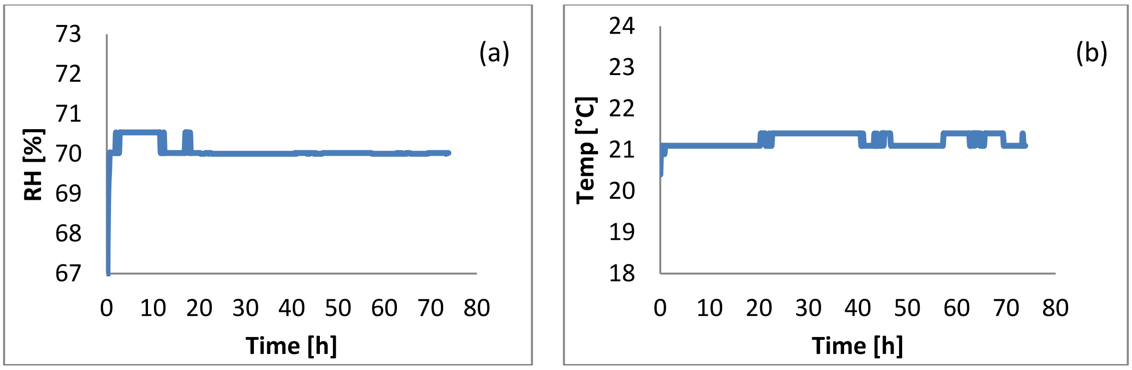

Figure 7: (a) Relative humidity measurements in the glass container; (b) temperature measurements in the glass container

The same measurements are performed for the large container, except the duration in this case is 27 days. The measured temperature is also 21^{o}C and a relative humidity is 55%, which differ by 1% with the values in the literature [9]. Figure 8 indicates these measurements.

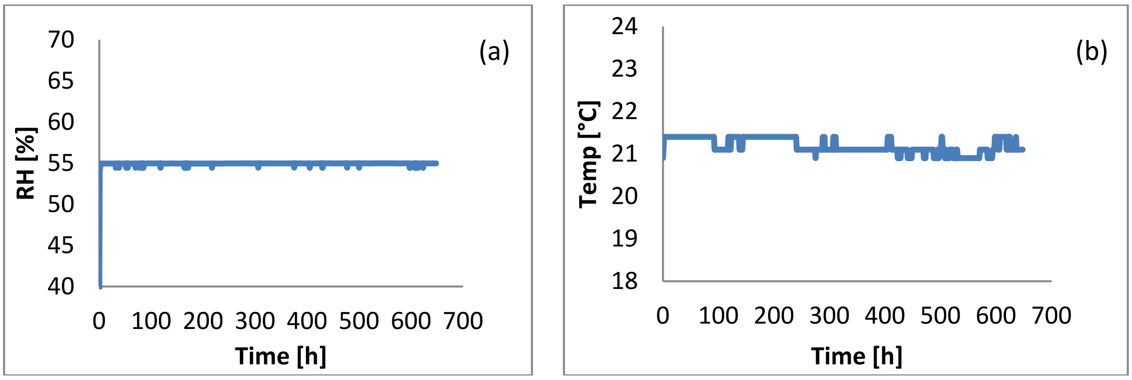

Figure 8: (a) Relative humidity measurements in the large container; (b) temperature measurements in the large container

Furthermore, the influence of opening the door of the large container is investigated as well, due to the influence on the relative humidity in the container. From these measurments, it can be concluded that the equilibrium state inside the container is reached in 2.5 hours after closing the door, as shown in Figure 9.

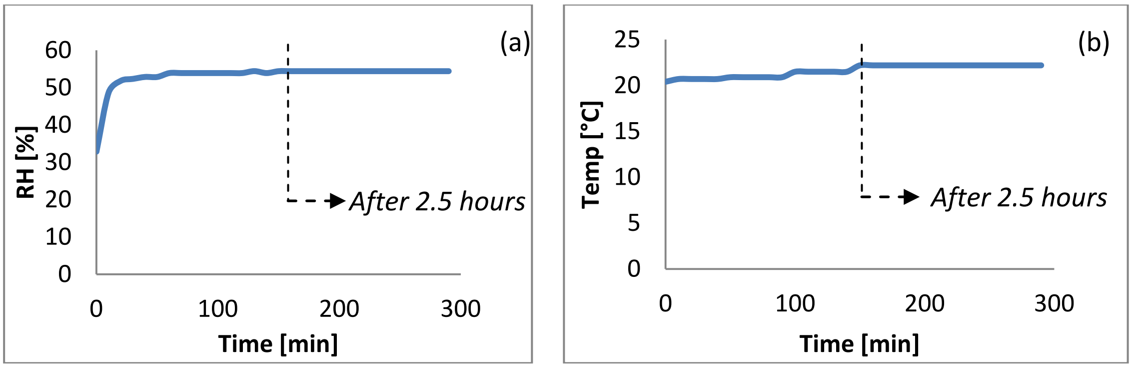

Figure 9: (a) Equilibrium relative humidity inside the large container reached in 2.5 hours; (b) Constant temperature inside the large container reached in 2.5 hours

So far the results for sand-lime are obtained. The moisture transport in the specimens with a higher chloride concentration is much lower than in the specimens without chloride, as shown in Figure 10.

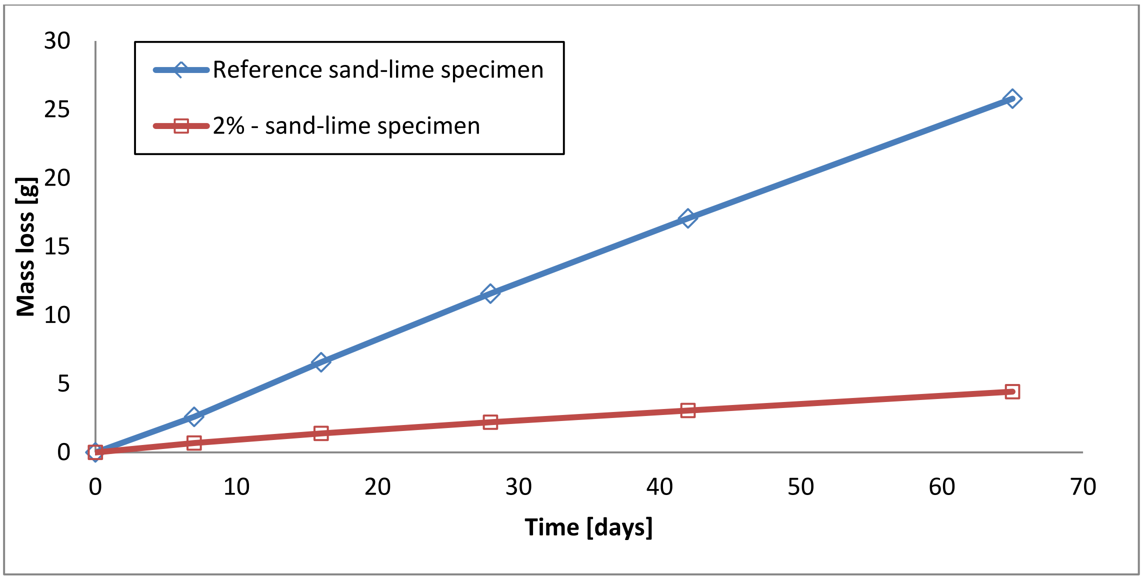

Figure 10: Mass loss of sand-lime specimens

Conclusion

The results of mass loss of sand-lime specimens provide compelling evidence that chloride has a large influence on moisture transport. The precipitating chloride salts block the pores in the sand-lime specimens, which leads to a slower transport of moisture. This process will be investigated further and compared to the results obtained on mortar specimens, in the authors' future work.

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