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Assessment of the unsaturated water transport properties of an old concrete: Determination of the pore-interaction factor

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ABSTRACT

In this study all the data needed to describe water transport (drying) within an existing concrete structure were characterized using a simple drying experiment. The properties (desorption isotherm, porosity and the unsaturated water transport properties namely, diffusivity and permeability) were evaluated by post-processing the weight loss data. Once obtained, the permeability evolution was used to check the validity of the Mualem–van Genuchten equations. It appeared that the default pore-interaction factor value proposed by Mualem ($p = +0.5$) is just a rough estimate: the values obtained in this study were all negative. Comparing these values to the literature, the pore-interaction factor seems to be correlated to the van Genuchten's exponent m.

1. Introduction

Water plays a very important role in the durability of concrete structures. For example, the well-known results of Tuutti [36] show that for a carbonated concrete the corrosion current is maximal for a Relative Humidity (RH) of about 95% and then drastically decreases with RH. In fact water significantly impacts reinforced concrete durability through many different ways:

- the concrete mechanical properties and delayed deformations (drying shrinkage, creep) are greatly influenced by water content which may lead to cracking;
- the transfer properties are greatly influenced by the moisture content;
- for pathologies involving in solution chemical reactions (such as carbonation or reinforcement corrosion), water is the reaction medium; the less free water, the less the probability of occurrence of the involved chemical reactions.

The durability assessment of concrete structures in relation to their environment thus requires an accurate description of the water transfer all along their service life. This is commonly achieved in a simplified way using a single equation which accounts for liquid water transport driven by pressure gradients only. The other motions (diffusion and gaseous permeation) are neglected. This was proven to be true for low-permeability cementitious materials [25,34,35]. The water mass flow can be described using the well known Darcy's law extended to unsaturated flow [29]:

$$\underline{j}_w = -\rho K \frac{k_r}{\eta} \underline{grad}(P), \tag{1}$$

where P is the liquid water pressure (Pa); η and ρ are the water viscosity (Pa s) and density (kg/m^3); K is the intrinsic permeability to water (m^2), it characterizes the resistance of the saturated concrete to water flow under a pressure gradient; and k_r is the relative permeability to water (without unit), it ranges between 0 (dry state) and 1 (saturated state) and describes the influence of water content on the porous network percolation.

The equation of continuity (water mass conservation) writes:

$$\frac{\partial}{\partial t}(\rho \phi S) = -div\left(-\underline{j}_w\right), \tag{2}$$

where S is the saturation index (fraction of the pore volume occupied by water, without unit), it ranges between 0 (dry state) and 1 (saturated state) and ϕ is the concrete porosity (without unit).

In isothermal conditions, assuming that water is incompressible and that a derivable relation between concrete saturation S and water pressure P exists (this relation is known as the capillary curve), one can obtain two simple equations depending on the choice of the unknown variable (water pressure P or saturation S) [25,10]:

$$\phi \left(\frac{\partial S}{\partial P}\right) \frac{\partial P}{\partial t} = div\left[K \frac{k_r}{\eta} grad(P)\right], \tag{3}$$

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