Modelling Freeze-Thaw Behavior of Cementitious Materials

S. Zadran[1*], J. Ožbolt[1], S. Gambarelli[1]

[1] Institute of Testing Materials (MPA), Faculty of Civil Engineering, University of Stuttgart, Pfaffenwaldring 4, 70560 Stuttgart, Germany, Zadran.Sekander@mpa.uni-stuttgart.de

Frost damage is one of the most important factors affecting the durability of cementitious materials in regions with cold climates. Over the years, many theories have been proposed to explain this complex phenomenon. Frost induced damage can be categorized as internal cracking and surface scaling. Damage due to internal cracking leads to lower material stiffness modulus, drop in tensile strength and increase in porosity and permeability. Surface scaling, which is most commonly associated with the presence of solutes, results in material surface loss at a solute concentration of roughly 3%.

The freezing behavior of cement-based materials under fully saturated condition has been experimentally investigated by a number of researchers. Experimental test results reported by Zeng et al. [1] showed that the ice saturation degree is influenced by both porosity and pore connectivity. Additionally, the test findings by Zeng et al. [1] demonstrate that as the number of freeze-thaw cycles increases, concrete's compressive strength, flexural strength and splitting tensile strength decrease.

Several models have been developed over the years to predict the thermo-mechanical behavior of porous building materials such as cement paste subjected to frost action. Powers introduced the famous hydraulic pressure and osmotic pressure theories, which constructed the basic theory of frost damage [2]. A mathematical model based on the pore size distribution and desorption and absorption isotherms for concrete below and above 0°C was established by Bažant et al. [3]. Despite the proposed models by several researchers, freezing process in porous media, such as concrete, still remains a very complex topic. The process involves interaction between heat transfer and moisture, phase change and deformation.

The main goal of the present study is to numerically investigate the freeze-thaw behavior of two different cement pastes saturated with variable chloride concentrations. With this purpose, the 3D coupled hygro-thermo-mechanical (HTM) model [4], implemented in the in-house FE code MASA [5] is employed. The mechanical part of the model is based on the microplane theory [6]. The coupling between the mechanical (loading) and non-mechanical processes (freeze-thaw processes) is ensured by using the staggered solution procedure.

The model is first validated using a numerical and experimental study available in the literature [1]. It is shown that the model can well capture the freeze deformation during the initial cooling phase. Moreover, as a function of porosity and pore size distribution, the same as the experimental tests, the numerical results show initial contraction followed by expansion when the temperature drops below the freezing point of the pore solution. The validated model is then used to study the effect of the liquid water permeability and elastic modulus of the hardened cement paste on the freeze-thaw behavior of the material.

References

[1] Q. Zeng, T. Fen-Chong, K. Li, Freezing behavior of cement pastes saturated with NaCl solution, Construction and Building Materials, 59 (2014) 99–110.

[2] T.C. Powers, A working hypothesis for further studies of frost resistance of concrete, J. Am. Concr. Inst., 41 (1945) 245–272.

[3] Z.P. Bažant, J.-C. Chern, A.M. Rosenberg, J.M. Gaidis, Mathematical model for freeze-thaw durability of concrete, J. Am. Ceram. Soc. 71 (1988) 776–783.

[4] J. Ožbolt, F. Oršanić, J. Balabanić, G. Kušter, M., Modeling damage in concrete caused by corrosion of reinforcement: coupled 3D FE model, Int. J. Fract., 178, (2012) 233-244.

[5] J. Ožbolt, MASA-"Macroscopic Space Analysis", Internal Report, Institute für Werkstoffe im Bauwesen, Universität Stuttgart, Germany. (1998).

[6] J. Ožbolt, Y. Li, I. Kožar, Microplane model for concrete with relaxed kinematic constraint, International Journal of Solids and Structures, 38 (2001) 2683-2711.