Summary

The present doctoral thesis regards the solidification process of water confined in porous building materials. Careful attention is focused on the kinetics of the considered phase transition. The obtained results are valuable for the determination of the kinetic parameters describing phase changes of a liquid filling building materials utilized in cold regions. The drawn conclusions can lead to the prediction of the ice content and the rate of its propagation within the pore network, which is one of the main reason for jeopardizing the durability and stability of materials exposed to frost action and rapid temperature changes.

After the introductory section, which contains the formulated hypothesis, the theoretical background is provided. The part begins with the thorough characteristics of the porous materials, among which mesoporous ordered silica, as well as cement paste composed of the ordinary Portland cement, are considered. Additionally, a detailed comparison of experimental methods for microstructural analysis is provided. The next subsection concerns the theory behind thermodynamic equilibrium between solid and liquid states and includes the derivation of the Gibbs-Thompson formula and possible mechanisms of water solidification among others. Subsequently, the in-depth discussion about the kinetics of phase transition is provided. Finally, the existing hypothesis of porous materials deterioration induced by frost action and standard procedures leading to the estimation of such degradation are outlined. The theoretical section ends with a brief description of the thermal analysis and principles of differential scanning calorimetry.

The consecutive part considers the conducted experimental research and begins within a thorough description of the investigated materials and the applied techniques. Each performed experiment is described within a separate subsection. At the beginning, the kinetic analysis of pore water crystallization is conducted within materials of simple, unimodal pore size distribution, namely the mesoporous silica. This enables one to determine parameters of process rate function as well as to investigate the mechanism governing the analyzed phase transitions. The analogous investigation is carried out for cement paste composed of ordinary Portland cement, which then leads to a prediction of the kinetics of water crystallization within concrete. Thermal analysis is also applied to investigate the water freezing in partly saturated cement paste. To that end, samples of various water content are studied by means of differential scanning calorimetry. Such a procedure allows deducing about the structure of a pore system confined in the cementitious materials. Within the final experimental stage, the attention is focused on the influence of cooling rate on the stress-strain state in fully-saturated concrete. In the analysis, the system of electric resistance strain gauges is used. Additionally, one investigates how the kinetics of water crystallization affects strain arising in concrete.

The final section includes the drawn conclusions, together with the critical discussion concerning the formulated hypotheses. The results of the kinetic analysis indicate that the crystallization of water confined in pores of material is a process governed by homogenous nucleation at the initial state of the transition. Subsequently, along with the growth of ice crystals it develops into the heterogeneous one. It is also confirmed that the chemical composition strongly influences the thermodynamic properties of the liquid phase contained within the cement matrix, which implies that the Gibbs-Thompson formula should not be straightforwardly applied to analyze a pore size distribution of cement-based materials. In the final part, the thesis also includes the topics of prospective scientific activity, which the author is going to undertake.

The supplementary results are presented in three appendices. In the first one, the parameters of kinetic models determined within the conducted analysis are contained. The second appendix focuses on the thermodynamic properties of the solution filling the cement-based materials. In the third one, several experimental techniques of microstructural analysis are compared with regard to cement paste.