APPLICATION OF MULTIPHASE POROUS MEDIA MECHANICS FOR ASSESSMENT OF BUILDING MATERIALS DURABILITY

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1. Modeling durability of building materials

Durability of building materials is of great practical importance. It may be analysed by means mechanics of multiphase porous media, non-equilibrium thermodynamics and damage mechanics. A general approach [1] to modelling various degradation processes in partially saturated porous building materials, due to combined action of variable chemical, hygro-thermal and mechanical loads, is presented. Kinetics of physico-chemical processes, like: salt crystallization/dissolution [2], calcium leaching [3], alkali silica reaction (ASR) [4], and water freezing/thawing [5], is described with evolution equations in order to take into account variable hygro-thermal conditions. The mathematical model consists of the mass-, energy- and momentum balances, the evolution equations describing chemical reactions/processes, as well as the constitutive and physical relations. The model state variables are capillary pressure, p^c, gas pressure, p^p, temperature, T, displacement vector, $\mathbf{u}$, and, if necessary, chemical species concentration, $c_{chem.}$ The internal variables of the model are mechanical damage parameter, d, chemical damage, V, and chemical process extent, Γ_{ch} . The most important mutual couplings between the chemical, hygral, thermal and deterioration processes are considered and discussed, both from the viewpoint of physicochemical mechanisms and mathematical modelling.

2. Kinetic model of chemical- and deterioration processes

Following linear non-equilibrium thermodynamics, the rate of chemical process, $\dot{\Gamma}_{ch}$ (e.g. salt crystallization – dissolution, calcium leaching, ASR progress, water freezing – ice thawing), is expressed in terms of the process affinity A_{ch} (i.e. the difference between chemical potentials of the actual state and equilibrium one) and the process constant k, which is dependent on the process characteristic time τ_{ch} and temperature T,

$$\dot{\Gamma}_{ch} = k \cdot A_{ch} . \tag{1}$$

Specific form of relationship (1) for a considered process is given in [2] for salt crystallization – dissolution, in [3] for non-isothermal calcium leaching, in [4] for alkali silica reaction, and in [5] for water freezing – thawing. Material deterioration may be directly dependent on the progress of chemical process, e.g. chemical damage for calcium leaching [3], or caused by material cracking due to expanding strains, e.g. for ASR [4], or crystallization pressure exerted on the skeleton, e.g. for water freezing [5] or salt crystallization [6]. The latter process is modelled by means of the delayed damage model, where the rate of mechanical damage, $\dot{d}$, is directly considered, as presented and discussed in [5, 6].

3. Numerical solution

The weak form of the model governing equations is obtained with Galerkin's method, and state variables are discretized in space by means finite element method and in time domain using implicit finite difference scheme, resulting in the following equation set [1],

$$\mathbf{C}_{i,j}\left(\mathbf{X}_j^{n+1}\right)\frac{\mathbf{X}_j^{n+1}-\mathbf{X}_j^{n}}{\Delta t}+\mathbf{K}_{i,j}\left(\mathbf{X}_j^{n+1}\right)\mathbf{X}_j^{n+1}-\mathbf{f}\left(\mathbf{X}_j^{n+1}\right)=\mathbf{0}, \tag{2}$$

where $\mathbf{X}_j^{n+1}$ is the vector of nodal values of state variables at time step $n+1$, $\mathbf{C}_{i,j}\left(\mathbf{X}_j^{n+1}\right)$ and $\mathbf{K}_{i,j}\left(\mathbf{X}_j^{n+1}\right)$ are the coupling matrices, and $\mathbf{f}\left(\mathbf{X}_j^{n+1}\right)$ is the vector considering BCs and source terms, ($i,j= g, c, T, u_x, u_y$). The nonlinear equation set (2) is solved by means of a monolithic Newton-Raphson type iterative procedure [1]. At each iteration the discretized form of kinetic equation (1) is solved in all the Gauss points.

4. Application examples

Four examples of the model application for analysing transient chemo-hygro-thermo-mechanical processes in porous building materials are presented and discussed. The first example concerns the salt crystallization during drying of a wall made of concrete and ceramic brick, causing degradation of surface layer due to development of crystallization pressure. The second one deals with calcium leaching from a concrete structure due to chemical attack of pure water, exposed to gradients of temperature and pressure. The third one describes cracking of concrete element, caused by development of expanding products of ASR. The fourth example concerns freezing – thawing of a wet concrete wall in variable hygro-thermal conditions.

Some exemplary results of numerical simulations concerning moisture content, ASR progress and shape deformation in a retaining wall exposed for 2 years to external air with variable temperature and relative humidity from one side, and the other side and its footing being in direct contact with the ground, are presented in Fig. 1. The results showing calcium content distribution in a concrete column exposed to 20-years action of pure water having temperature of 25°C or 60°C, are presented in Fig. 2.

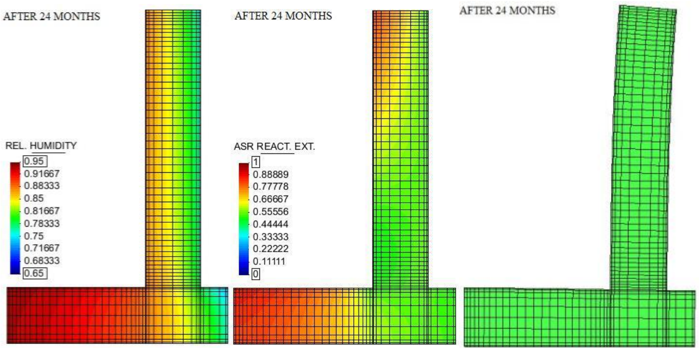

Figure 1: Results of simulations for a retaining concrete wall exposed to ASR for 24 months: relative humidity, reaction extent and deformed configuration (shown with factor 25x)

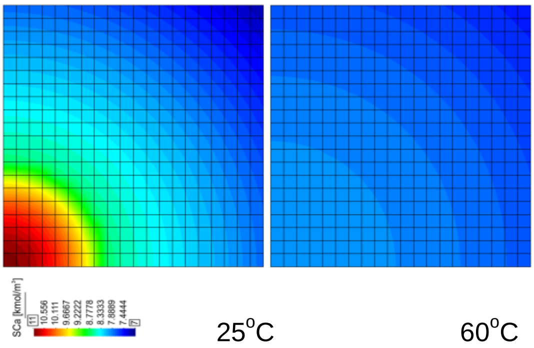

Figure 2: Calcium content in a concrete column exposed to calcium leaching for 20 years in pure water at temperature of 25°C and 60°C.

5. References

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