PROCEEDINGS OF SWBSS 2021

Fifth International Conference on SALT WEATHERING OF BUILDINGS AND STONE SCULPTURES

22-24 September 2021
Delft, the Netherlands

EDITED BY
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TU Delft OPEN

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PMSOLVER: DEVELOPMENT OF A GENERIC FEM CODE FOR HEAT, MOISTURE, AND SALT TRANSFER AND DEFORMATION IN POROUS MATERIALS

Masaru Abuku[1*], **and Koichi Ishii**[2]

KEYWORDS

Finite element method, poromechanics, salt crystallization, seepage flow

ABSTRACT

A numerical simulation can be useful for studying salt weathering problems when all the required input data are available. Thus far, several numerical models (e.g. [1]) have been developed by researchers for this purpose, in addition to the efforts of measuring physical and chemical data of porous materials, ions, and salt crystals. When a numerical simulation is applied to different real-world objects, such as a building wall and stone cultural property, one has often to deal with complex geometries comprising various material and boundary conditions. To render a salt weathering prediction feasible, we have developed a generic finite element method (FEM) code, namely: PMSolver. This code analyzes non-steady heat, moisture, and salt transfer in porous materials, while examining the deformation of materials due to changes in temperature, salt solution content, and salt crystal content (Figure 1). Further, this code is equipped with a GUI that works on a pre- and postprocessor Femap, and incorporates the input data of geometries, material properties, and initial and boundary conditions into the solver. Furthermore, the transport and crystallization/dissolution of a mixture, which is obtained by dissolving two different salts in water, are included while maintaining electrical neutrality. The code includes the data on sodium chloride and sulfate [1-3]. Note that PMSolver can neither yet consider a phase change between different salt crystals nor additional driving forces for moisture and ion transfer such as osmosis. During the mechanical analysis, the pore liquid pressure, crystallization pressure, and thermal stress are considered, in addition to the stress obtained from a static mechanical analysis. The code can also consider different boundary conditions such as wind-driven rain with ions, sea spray, atmospheric salt deposition, and seepage water.

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Two case studies were conducted to demonstrate examples of the effective use of the PMSolver. In the first case study (case 1), the two-dimensional water level and salt concentration distributions and seepage water in a bedrock, which is not initially contaminated by salt, is simulated, where the water level of sodium chloride solution of 1 mole/kg at a boundary increases at 1 m/day. In the second case study (case 2), vapor absorption and evaporation at a surface of a one-dimensional 5 cm wall of tuff, in which the initial saturation of a salt solution containing Na^+ (4.0 mole/kg), Cl^- (3.0 mole/kg), and SO_4^{2-} (0.5 mole/kg) is uniformly 0.5 (-), has been simulated to determine the amount of salt crystals of NaCl (halite) and Na_2SO_4 (thenardite) that would precipitate at different times and locations. The tuff surface was assumed to be exposed to a rainfall of 1 mm/h for the first 1 hour but dried after that at a temperature of 15 °C and a relative humidity of 80 %. Examples of simulation results of the two case studies are given in Figure 2.

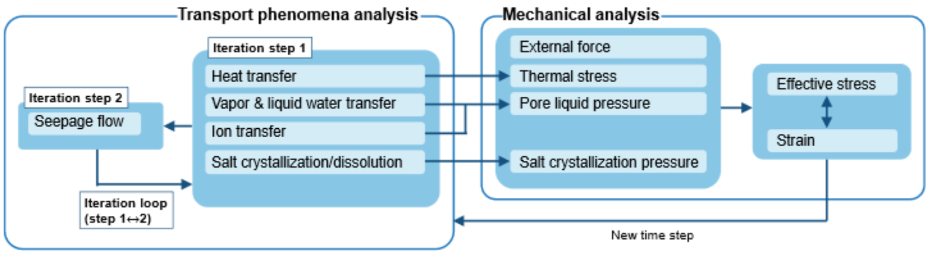

Figure 1: Calculation procedure of PMSolver.

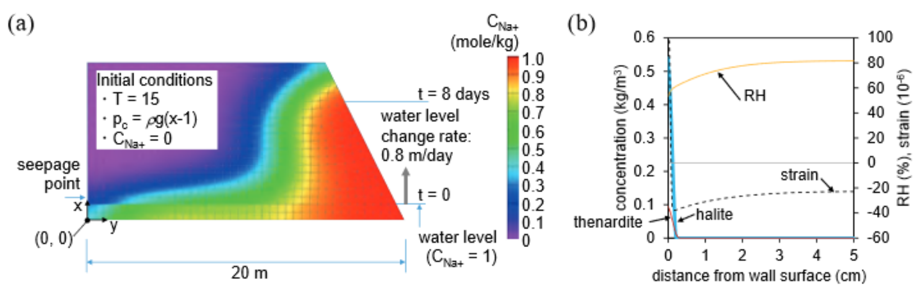

Figure 2: Examples of simulation results. (a) Na^+ concentration (C_{Na+}) of case 1 (t = 8 days) and (b) relative humidity (RH), salt concentration and strain of case 2 (t = 24 hours). T: temperature (°C), p_c: capillary pressure (Pa), and ρ: density (kg/m^3).

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