COMSOL® Implementation of a Porous Media Model for Simulating Pressure Development in Heated Concrete

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Abstract

When concrete is subjected to high temperature, capillary water evaporates and chemically bound water is released due to dehydration. This results in an increase of pore pressure, which is believed to be one of the mechanisms leading to spalling. Spalling of concrete is of high concern for the fire safety of concrete structures.

Several models for simulating the high-temperature behavior of concrete have been published in the literature. Most of these models are based on the theory of heat and mass transfer in porous media and have been implemented in specialized finite element codes [1, 2]. We consider a model similar to [1] and show how easily it can be implemented in COMSOL® using the Weak Form interface. Mass conservation laws are specified directly in terms of mass densities and mass fluxes, while the dependent variables are pressures. Defining the mass densities and mass fluxes in terms of pressures and pressure gradients is all what is needed as input. COMSOL then takes care of substituting these definitions and the required derivatives. Energy conservation is treated in a similar way. This high-level problem definition is contrasted with conventional implementations, where all the definitions and their derivatives have to be substituted manually. This is a cumbersome and error-prone process leading to long and complex equations.

Despite this high-level problem definition, implementing such a model is not trivial. Most of the material properties are pressure and temperature dependent and described by analytical expressions fitted to experimental data. These empirical laws are only valid in a certain pressure or temperature range. However, any error in the weak form, or in the boundary or initial conditions can lead to variables which are out of the valid range and produce invalid numerical operations ("non-integral power of negative number" or "complex number encountered"). Such errors are difficult to debug, in particular if they occur at the very beginning of the simulation and no results are available yet. We discuss some strategies for coping with such problems.

Simulations of an experiment from the literature [3] are presented. In this experiment, a concrete plate of 120 mm thickness is heated from above by a radiant heater. The specimen contains combined temperature and pressure sensors located at different depths as shown in Figure 1. Numerical results are compared with experimental results for the temperature and gas pressure evolution in Figures 2 and 3, respectively.

As shown in Figure 4, COMSOL results compare well with our implementation in Cast3M [4], which also uses a high-level implementation but lacks the automatic evaluation of derivatives. For equal spatial discretization and equal time steps, computational times are comparable for the two softwares.

Reference

[1] D. Gawin et al., Modelling of Hygro-Thermal Behaviour and Damage of Concrete at Temperature above the Critical Point of Water, Int. J. Numer. Anal. Meth. Geomech., Vol. 26, p. 537 (2002)
[2] S. Dal Pont et al., Modeling Concrete under Severe Conditions as a Multiphase Material, Nuclear Engineering and Design, Vol. 241, p. 562 (2011)
[3] P. Kalifa et al., Spalling and pore pressure in HPC at high temperatures, Cement and Concrete Research Vol. 30, p. 1915 (2000)
[4] Cast3M, Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA), www-cast3m.cea.fr

Figures used in the abstract

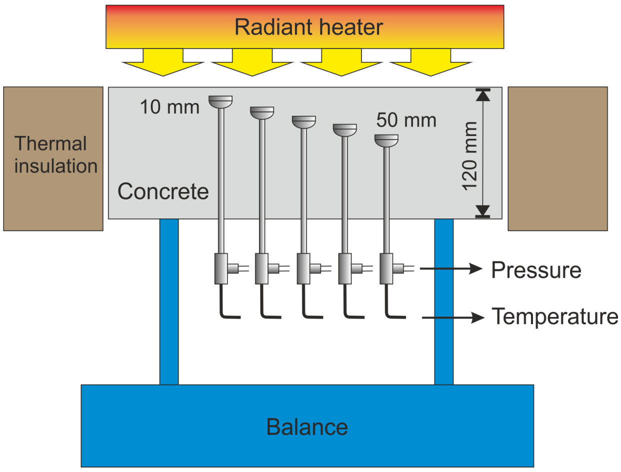

Figure 1: Experimental setup [3].

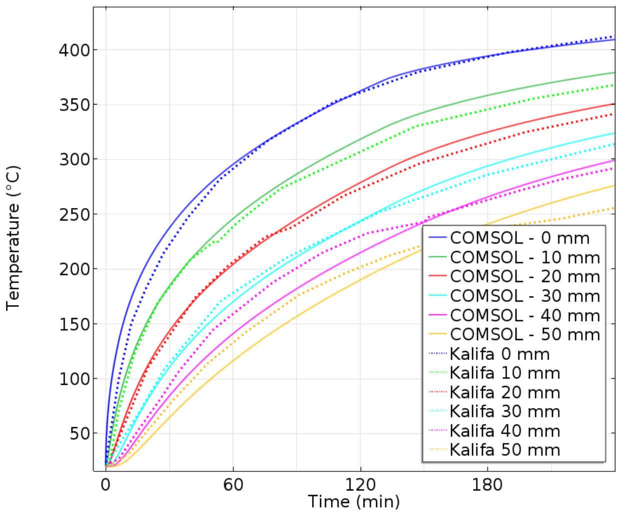

Figure 2: Temperature evolution, comparison with experiment [3].

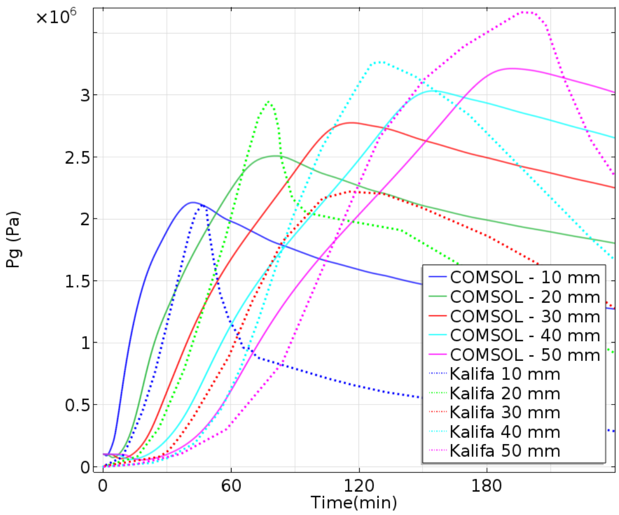

Figure 3: Gas pressure evolution, comparison with experiment [3].

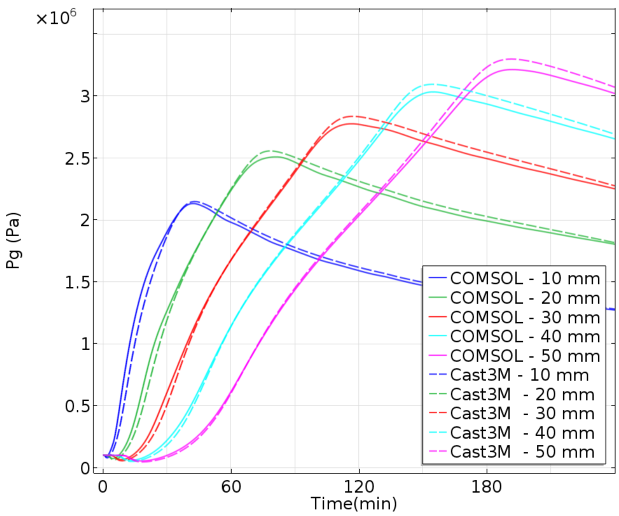

Figure 4: Gas pressure evolution, comparison with Cast3M.