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ASSESSMENT OF THE HYGRO-MECHANICAL RESPONSE OF POROUS MATERIALS BY MULTI-PHYSICS MODELLING

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1 INTRODUCTION

Recently poromechanical approaches are coupled to damage-plasticity models to take into account the moisture influence on damage and fracture processes[1-5]. The penetration of fluids through cracks is usually modeled by an increased permeability in a certain zone, using empirical laws based on average crack widths. Drawback of a continuum model is that a crack strain over a band governs the damage process rather than a crack width. In this way the continuum model does not take into account the peculiar features of cracks with varying width and connectivity, which may highly influence the resulting permeability[6-10]. Apart from that, when trying to model the steep moisture fronts in the fracture one is confronted with numerical instabilities, caused by the difference in magnitude between permeability of fracture and matrix[10].

To overcome these problems a combination of two discrete models for simulating discrete cracking and liquid flow in fractures is presented. The discrete model for the damage process is a partition-of-unity (PU) crack model[11], where cracks are modeled as displacement continuities, which can run freely through the finite element mesh. To simulate moisture transport in the fracture, a 1D moving front model for liquid flow in a fracture is combined with a finite element model that solves the unsaturated liquid flow in the uncracked matrix [12]. These discrete models are coupled to a poromechanical continuum model, describing the moisture influence on the mechanical behavior and the transport in the uncracked porous matrix. To exemplify the potential of the proposed model, we show two different test cases showing the strong coupling between moisture and damaging processes.

2 COUPLED MODEL

In this section the main features of the coupled PU-crack model for hygro-mechanical loading are summarized. An extensive description of the model can be found in Roels et al.[13].

The hygro-mechanical response is obtained by alternately solving the mechanical and the hygric problem for each time step. Both problems are non-linear and require an iterative solution. For the mechanical problem, the non-linearity is mainly caused by the presence of cracks; for the hygric problem, it is due to the high degree of non-linearity of the material properties.

Cracking is modeled using a discrete approach: strong (displacement) discontinuities are embedded in finite elements. In this formulation, the cracks are not restricted to the element boundaries; instead, they can freely run through the finite element mesh[14-16]. For the propagation of a discontinuity, a mode I stress criterion is evaluated in the element in front of the crack tip: if the maximal principal stress exceeds the tensile stress of the material, a new discontinuity is initiated perpendicular to the maximal principal stress direction.

Cracks act as preferential pathways for the distribution of moisture in the material. A 1-D discrete fracture flow model is adopted to predict the water flow in the rough-walled fracture with variable aperture. The system is solved using a moving front technique[17] and the capillary pressures corresponding to the calculated liquid pressure field in the crack are imposed as boundary condition along the matrix-fracture interface.

The moisture distribution in the matrix is solved using a continuum approach, based on the conservation of mass and Darcy's mass transfer equation[18]. Since the hygric material properties (moisture capacity and permeability) are function of the unknown capillary pressures, a solution can only be obtained by iteration.

The capillary pressures in the material matrix generate additional internal stresses of which the magnitude can be estimated based on the elastic effective stress concept[2]. The mechanical response in the next time step is evaluated based on the mechanical loading during that time step on the one hand and the hygric stresses and mechanical properties, both dependent on the capillary pressures calculated during the previous time step on the other hand.

A general scheme of the coupled model is given in Figure 1.

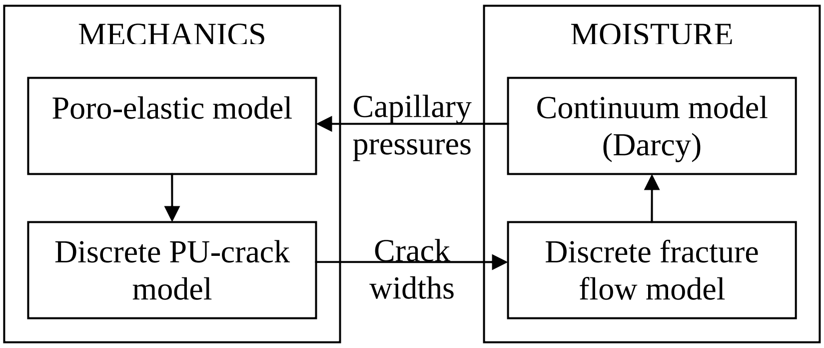

Figure 1: Coupled model for simulating unsaturated moisture transport and fracture development in quasi-brittle porous materials.

3 NUMERICAL EXAMPLES

3.1 Swelling and bending due to free uptake

As a first problem the mechanical response of a dry beam (p_c=5 10^9 Pa) submitted to a free uptake experiment is analyzed. During the uptake experiment the position of the waterfront gradually approaches the top side of the sample. The height of the waterfront evolves linearly with square root of time. During the process the beam will bend out due to the non-uniform moisture saturation distribution over the height. The evolution of the vertical displacement in the middle of top and bottom plane of the beam is plotted as a function of square root of time in figure 2. The bending increases to reach a maximum value after approximately 302 seconds, the moment the waterfront reaches half the height of the beam. Afterwards the displacement diminishes again. Due to the swelling of the beam with increasing saturation a gradually shift appears between top and bottom curve during the process.

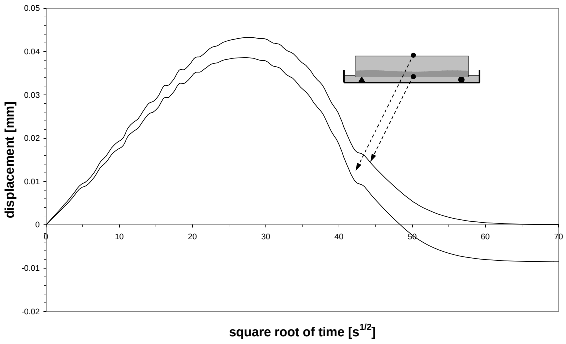

Figure 2: mechanical response of an initially dry beam submitted to a free uptake experiment.

3.2 Cracking due to free water uptake during three point bending test

In a second simulation a dry beam (p_c=5 10^9 Pa) is first loaded to approximately half of the maximal loading. From then on, the beam is exposed to a water contact at the bottom side while the mechanical loading process continues. Figure 3 compares the simulated load versus displacement curve with the response curves of the dry material and of the capillary saturated material. In a first step a decrease of the loading due to a decrease of the stiffness in the wetted part can be observed. When afterwards the force starts to increase again, soon the decrease of the strength in the wetted zone initiates the damage process leading to failure far below maximum loading.

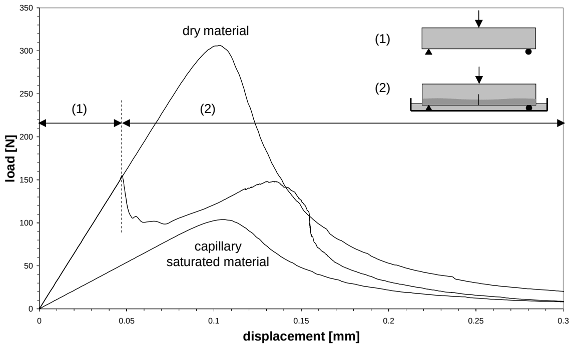

Figure 3: coupled mechanical / hygric loading during bending tests.

4 CONCLUSIONS

A finite element model for the analysis of moisture effects on damage processes in porous building materials has been presented. The model is a combination of two discrete models: a partition-of-unity crack model to simulate crack propagation due to poromechanical loading and a front tracking method embedded in a continuum model to simulate moisture transfer in discrete fractured media. Numerical examples of combined mechanical and moisture loading illustrated the possibilities of the proposed model. The numerical examples showed the important effect of wetting on dimensional stability, crack opening evolution and cracking behavior.

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