A new material description for plant tissues under frost exposure

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ABSTRACT

Plant tissues have developed several strategies to cope with multiple cycles of freezing and thawing events. Some of these strategies are of physiological nature, others arise from structural properties. Since plant tissues are formed by ordered arrangements of single cells, they can be regarded as porous materials. As plants, common construction materials also exhibit a porous structure. However, repeated cycles of freezing and thawing of the pore water frequently leads to ageing processes and damage in construction materials due to its associated volume change, while plants withstand such conditions. With this in mind, the present contribution aims to assess the strategies of frost-resistant plant tissues, and to basically transfer their properties to construction materials.

A key mechanism for frost resistance is the dehydration of the cell body, as freezing within the cells threatens the structural integrity and even the ability of a plant to survive. Another important mechanism is the flow management capability, which is mainly determined by structural properties of the plants. Thus, the water leaves the cell body and flows within the vascular bundles towards locations where freezing is not critical [1].

For the description of frost-resistant plant tissues, a multicomponent and multiphasic model is introduced within the framework of the Theory of Porous Media (TPM) [2]. According to [3], plant tissues are described by considering four constituents. The model proceeds from a thermoelastic solid skeleton, which is formed by the cells containing initially trapped water. Within the pore space, two mobile fluids are present, namely, materially compressible air and materially incompressible water, where the latter can be subjected to a phase transition and turns into ice, which is then kinematically coupled to the solid skeleton.

The above mentioned mechanisms can be described in case of the cell dehydration by a production term in the mass balance of the solid skeleton, where the water is with decreasing temperature no longer trapped within the cell body. The flow management capability can be included by spatially varying anisotropic permeability conditions. Freezing processes of the pore water are characterised by a density jump at the interface. This interface is conceptionally treated as a singular surface, at which mass transfer can be formulated with the help of jump conditions according to [4]. Furthermore, the freezing of the pore water leads to the necessity to consider the so-called compaction point in the material description, accounting for the case when there is no pore space present anymore. Selected numerical examples illustrate these effects.

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