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A comprehensive model for transient moisture transport in wood below the fiber saturation point: Physical background, implementation and experimental validation

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ABSTRACT

During the last three decades the macroscopic formulation of moisture transport in wood below the fiber saturation point has motivated many research efforts. From experiments the difference in steady-state and transient transport processes is well known, but it could not be explained in a fully physically motivated manner. In this article, we aim at enhancing the current understanding and improving the mathematical description of the moisture transport process in wood. For this purpose, we first present the microstructure of wood and then describe the physical background of steady-state and transient transport processes in wood, based on which we finally derive a suitable mathematical model. For a correct macroscopic description of transient transport processes, three coupled differential equations have to be solved in parallel, which is done using the finite element method. A comparison of model predictions for the sorption behavior of wood specimens with corresponding experimentally derived values yields very promising results and confirms the suitability of the assumptions underlying the model.

1. Introduction

Wood is currently facing a boom in the construction sector and is increasingly used, both for common building and for special civil engineering purposes. To meet the resulting high demands on wood in design and dimensioning, accurate knowledge of the material and its properties is necessary. Thereby wood–water relations are of great importance, due to the pronounced influence of moisture and moisture changes on mechanical properties as well as on dimensional changes. However, the formulation of an accurate model for moisture transport in wood is a difficult task, which has motivated a lot of research effort. This is reflected by extensive literature on this subject, also including different modeling approaches. Moisture transport in wood is a diffusion process [1]. Steady-state processes can be suitably described by Fick's first law of diffusion with bound water concentration as driving force [2–5]. For transient processes, it is known from experiments [3,6,7] that a single-Fickian modeling approach leads to peculiarities like thickness dependent diffusion coefficients and other so-called "Non-Fickian-effects". To overcome these problems, many more advanced modeling strategies were developed [8–12]. The weakness of most of these models is their need for back-calculated material parameters without a clear physical meaning. Moreover, all of them lack a thorough validation based on independent experiments. Suitable explanations for the observed phenomena can be derived from the hierarchical microstructure of wood, spanning across several length scales. Thus it is investigated first.

2. Microstructure of wood

Wood is a cellular material with an anatomy [13,2] as illustrated in Fig. 1. The wood cells (tracheids) are hollow tubes oriented in the stem direction (longitudinal direction L). In softwood, the cell diameters range typically from 20 to 50 μm. In hardwood, an additional cell type with a diameter up to 500 μm exists (vessels), which forms a pipe-like structure. Both softwood and hardwood contain wood rays, which are responsible for the water transport in the radial direction of the wood stem. Most of the wood cells are interconnected by pits, which are small holes in the cell wall with a central membrane. In the living tree, the pits are open for flow of liquid water, while during drying most of these pits get aspirated

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