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NMR imaging study and multi-Fickian numerical simulation of moisture transfer in Norway spruce samples

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ABSTRACT

Wood has potential as a renewable material for a large variety of applications that often call for improved properties such as dimensional stability, moisture insensitivity, and durability. Moisture migration in wood is a particularly important factor in determining the cost-effective service life of wooden construction. Within the present research, proton NMR imaging was applied for recording the moisture spatial distribution of various samples of Norway Spruce. Moisture distribution along the radial, tangential and longitudinal directions in wood was monitored at different times upon three consecutive changes of relative humidity: (1) from 65% to 94%; (2) from 94% to 33%; (3) from 33% to 65%. Uncoated samples and specimens treated with different types of surface coatings were studied.

The experiments were numerically simulated by using the multi-Fickian model. The model describes the moisture transport process in wood which is characterized by three phenomena: (a) bound water diffusion, (b) water vapor diffusion and (c) coupling between the two phases through sorption. The model is implemented into the Abaqus FEM code. The numerical results are found to be in agreement with the experimental data.

1. Introduction

Wood is a porous, hierarchically structured composite with a complex chemistry. It has a potential as a renewable material for a large variety of applications which often call for improved properties such as dimensional stability, moisture insensitivity, and durability. The distribution and dynamics of adsorbed water is a particularly important area [1]. The sorption/desorption of moisture leads to swelling and shrinkage phenomena and moisture concentration gradients can cause cracking or dimensional instability [2].

The commonly used methodology for measuring moisture content in wood is to determine by weight the total uptake of moisture or to estimate a more local moisture content by resistive methods, i.e. using metal rods placed in drilled holes in the wood [3]. These methods are not suitable for measuring local moisture variations, i.e. on a sub-millimeter scale. Owing to their non-invasive nature, spatial selectivity, and quantitative response, nuclear magnetic resonance (NMR) imaging (often referred to as magnetic resonance imaging, MRI) [4] has recently become the premier method for investigating moisture distribution in wood [5,6]. The steady state moisture contents and kinetic of moisture migration in wood species under different conditions have been investigated [7–13]. With a properly designed setup, NMR provides a response directly proportional to the amount of contributing nuclei, e.g. protons in the water. The spatial resolution of the order of tens of micrometers can be achieved in a one-dimensional image [12,14]. Experiments have typically been performed in green wood, where the high moisture content (typically far above fiber saturation point) results in favorable NMR parameters, such as long spin relaxation times, which make MRI experiments convenient to perform. There are far fewer studies where wood dried to equilibrium with ambient air humidity has been investigated [12,14]. This is part of the present study.

Another important objective of this paper is the numerical simulation of the performed experiments. In literature several models for moisture transfer can be found. Luikov's model considers the effect of varying temperature and the hydro-thermal problem is

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