Quantitative analysis of liquid water uptake in softwoods by thermal neutron radiography

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1 Introduction

Wood is a porous material with orthotropic cellular structure. Liquid water uptake in longitudinal direction (parallel to the fibers) is much faster than in the tangential and radial directions. At the growth ring scale, water uptake is found to be faster in latewood compared to earlywood [1]. A main reason for the difference in liquid water uptake behavior within a growth ring is the varying size of the cell lumen, e.g. for spruce, from larger earlywood cells of 100 µm X 50 µm to very small latewood cells of a few microns for a width of 30 µm. An added complexity comes from the fact that water adsorption by the porous cell walls results in a swelling, thus a change of dimensions of the earlywood and latewood layers during the experiment. A neutron imaging experiment is performed to provide insights of the water uptake behavior at the growth ring scale and datasets for validation of modeling uptake in wood species of different liquid permeabilities, e.g. spruce, pine and fir. Because of the high sensitivity of neutrons to hydrogen, neutron imaging (NI) is an efficient way to visually and quantitatively evaluate the water uptake process of a porous material [2]. We measured the time resolved distribution of moisture content during liquid water uptake in softwood using the NEUTRA beamline (thermal neutron radiography facilities) at the Swiss Spallation Neutron Source) of the Paul Scherrer Institute in Villigen, Switzerland. The spatial resolution of the detector is 100 microns. The detector has a 128-grey scale, which yield in high accuracy in detecting moisture content variation.

2 Experimental setup and image analysis

Three 1.5 x 1.5 x 0.5 cm samples of three different softwood species (spruce, fir and pine), in longitudinal, tangential and radial directions (27 in total), were quarter-sawn resulting in the growth ring features to be visible in the images. The sample sides parallel to liquid uptake direction were coated with epoxy. A custom-made setup consisted in a sample holder and a water container supported on an elevator. After imaging the dry samples, the water container was moved up until the base of the sample came in contact with the free water surface, see Figure 1a. NIs were taken at 60 seconds intervals for 30 to 120 minutes depending on the samples. Figure 1 b and c shows NI of a dry sample and the same sample with clearly visible swelling after tangential water uptake. In some experiments, we added the acquisition of X-ray radiography between each neutron image acquisition, to acquire better spatial resolution of the swelling deformation. In a first step of data analysis, the change of moisture content due to liquid uptake versus time is calculated using a series of neutron images. As neutron attenuation is directly related to the presence of hydrogen, the NI for the whole sample is processed, using correlations developed for this beamline, to provide an equivalent water mass thickness. The difference of water mass thickness between the dry and wet states, divided by samples thickness of water and wood density yields the moisture content of the samples.

3 Preliminary results and discussion

The analysis of the whole dataset is still on-going. Figure 2 shows results on a spruce sample undergoing water uptake in longitudinal direction. Figure 2 a) presents the moisture uptake versus square root of time. Although capillary uptake of isotropic porous materials is known to be proportional to square root of infiltration time, this is not the case for wood as confirmed with the neutron results.

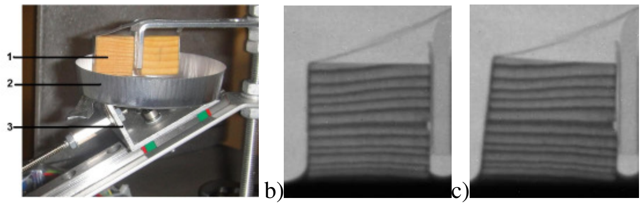

Figure 1 – (a) Experimental setup inside the NEUTRA station; 1. installed samples on the stand, 2. water container, 3.elevator, (b) Neutron image of dry spruce before water uptake test, (c) same sample after uptake in tangential direction.

One reason could be that the rapid capillary uptake in the cell lumen and the slower water adsorption in the cell wall occur at two different time scales. Analysis of radiographic images can also show the difference between the earlywood and latewood layers. Figure 2 b) shows the time dependent profiles of relative neutron signal in spruce, across the horizontal line, thus perpendicular to the water uptake direction. The maxima relate to latewood and the minima to earlywood. For this sample, the change in neutron signal is 50% more important in latewood than in earlywood. Noteworthy are the shifts of the minima and maxima positions due to the swelling of wood resulting from water uptake. Further work will be combining analysis of swelling with moisture uptake

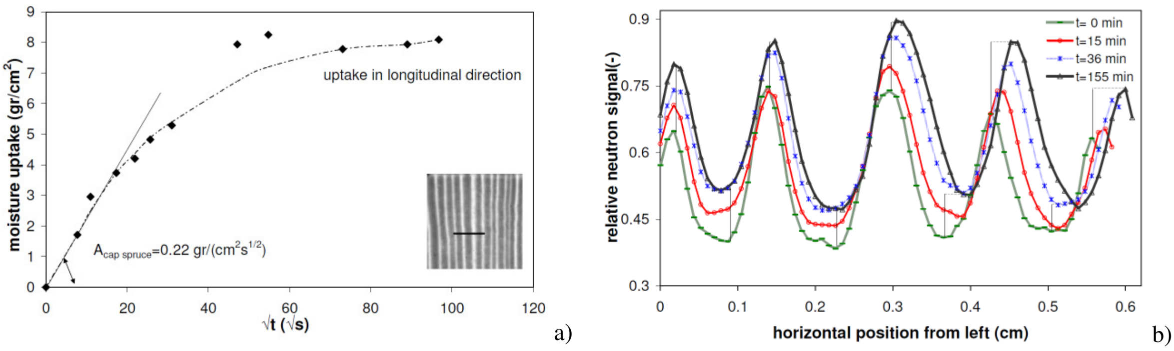

Figure 2 Results for spruce in longitudinal direction a) moisture uptake versus square root of time, b) time dependent profiles of relative neutron signal. Inset: processed NI of sample with line indicating source of data shown in b.

Figure 3 presents results of the water uptake of a fir sample in tangential direction. Figure 3 a) indicates a slower process for this sample compared to the previous one. Figure 3 b) shows time dependent profiles of the relative neutron signal across the vertical line at the bottom of the fir sample. We observe the rapid change in moisture uptake profile between initial state and the first result at 8 minutes, occurring in the earlywood of the first growth ring. The subsequent changes are much slower to occur and are concentrated in the latewood region of the first growth ring.

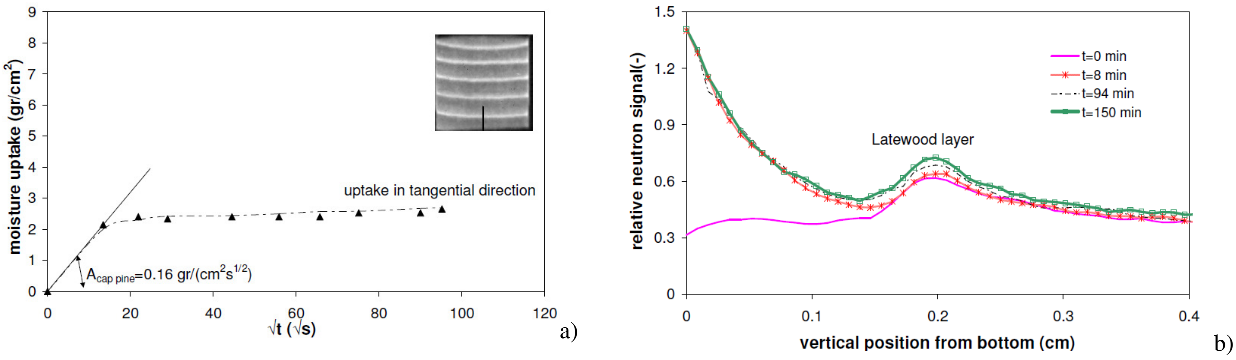

Figure 3. Results for fir in tangential direction a) moisture uptake versus square root of time, b) time dependent profiles of relative neutron signal. Inset: processed NI of sample with line indicating source of data shown in b.

NI is used to quantify differences in water uptake in wood depending on directions and growth ring features. Further analysis is on-going to produce data required to validate a multiscale model of coupled moisture and swelling behavior of wood.

References

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