Swelling and drying of non-treated and treated spruce wood during and after exposure to liquid water

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Aims

Non treated wood is known to exhibit pronounced anisotropic swelling upon exposure to moisture. Furthermore, moist wood is much more susceptible to degradation by various pests such as fungi. Moisture uptake into wood can occur both from the gas phase and from liquid water. Liquid water transport into wood is especially problematic as capillary flow can effectively lead large quantities of water deep into the wood, and can results in much higher values that achieved with water vapor adsorption This, in turn, leads to long drying times and like that long times during which the wood is susceptible to biodegradation. Furthermore, fast local water uptake may lead to macroscopic deformation of the wood and in the worst case to mechanical damage to the wooden structures.
Protection of wooden surfaces occasionally exposed to liquid water is therefore an important technical challenge. In the past, waterproof coatings were used in this context. Such coatings are effective as long as they are intact. However, any moisture ingress through even small damages will have difficulties to escape again from the wood leading to longer moisture exposure than without the protective cover. More recently, hydrophobic treatments of the wood have become more popular which aim at excluding liquid water from the wood while keeping the vapour phase transport properties for wood almost unchanged. In such a structure, liquid water won’t be transported by capillary suction any more while moisture exchange via gas phase diffusion is still possible. Various hydrophobic treatments to wood are available such as impregnation with liquid oil or with wax dispersions. The aim of the present study was to visualize dimensional changes and the distribution of liquid water inside the wooden structures both during immersion into liquid water and during subsequent drying, Samples were prepared according to a protocol similar to that used in a recently conducted MRI study [2].

Method

All studies were conducted on a Bruker-Skyscan 1172 equipped with a 10 W X-ray generator with a maximum acceleration voltage of 100 kV (Hamamatsu, Hamamatsu Japan) and an 11 MPixel X-ray camera (Ximea, Münster, Germany). For all experiments, unfiltered 40 keV radiation was used. Series of usually 30 scans were conducted with a 1K data matrix. Typical scan times were in the range of 15 min for images with a voxel size of 23.8 µm. Single mages with higher resolution were performed with larger data matrices before and after the serial measurements.
The samples were cubes with 1 cm side length cut with one side aligned with tree growth rings (and thus with the axial and tangential directions of the wood, see figure 1). In order to study both water uptake and drying without changing the position of the sample, the samples (equilibrated with lab air of 50% RH at 23 °C) were glued to the bottom of a 2.2 cm diameter cylindrical PE vial by means of a cone of modelling wax. A first scan was conducted for the cube inside the empty tube. Then the cylindrical vial was filled with water until the cube was

fully immersed into the water and a first series of images was recorded to study water intrusion into the cube.

After several hours of water uptake, the water was removed as good as possible by suction into rolled pieces of paper towel. After that, the vials were left open and drying of the wood into the ventilated scanning chamber (29°C) was observed by means of another series of scans.

The recorded µCT data sets were rotated in the Data Viewer software (Bruker Skyscan, Antwerp) to align the axes of the cube with the axes of the data set.

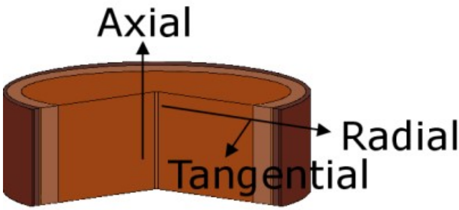


Figure 1 Terminology of the different directions in wood. Figure from [1]

Results

In figure 2, a crosshair views from the beginning and the end of the immersion series for native wood are given.

Several observations can be made from the images presented in figure 2:

- Water uptake occurs mainly along the axial direction of the wood which is oriented parallel to the y-direction in the sagittal sections given in the lower right field of the crosshair views. When comparing the coronal sections from the centre of the cube (upper left field in the crosshair views), a substantial increase in X-ray absorption can be even seen in this innermost slice of the wooden cube. The water uptake occurs mainly by capillary suctions in some but not all of the wood fibers oriented along this axis.
- Almost no dimensional change occurs in the wood along this direction. By contrast, the strongest dimensional change can be seen along the tangential axis (which is positioned parallel to the x-direction in the coronal sections). Some swelling occurs also along the radial direction (parallel to y-axis in the coronal section).

The macroscopic findings are in accordance to the expectations from experience with moisture uptake in wood. The fact that not all fibers contribute to water transport in the same way is macroscopically not as easy to observe but rather obvious from the images.

In figure 3, a comparison of the crosshair views directly after removal of the water and about 8 hours later is given. The strongly X-ray absorbing structure at the bottom of the images in figure 3 A is liquid water which was not fully removed in the suction process for water removal. This water is removed due to drying after about 2,5 h. Nevertheless, drying of the wood is not yet complete after 8 h. This can be seen from the incomplete shrinkage to the cube's original dimension as well as from the presence of remaining moisture inside the wood structure.

As the intrusion of moisture is dominated by fast long-range transport by capillary processes while drying occurs mainly via diffusion of moisture in vapour state, it is not really surprising that drying is considerably slower than moisture uptake during immersion.

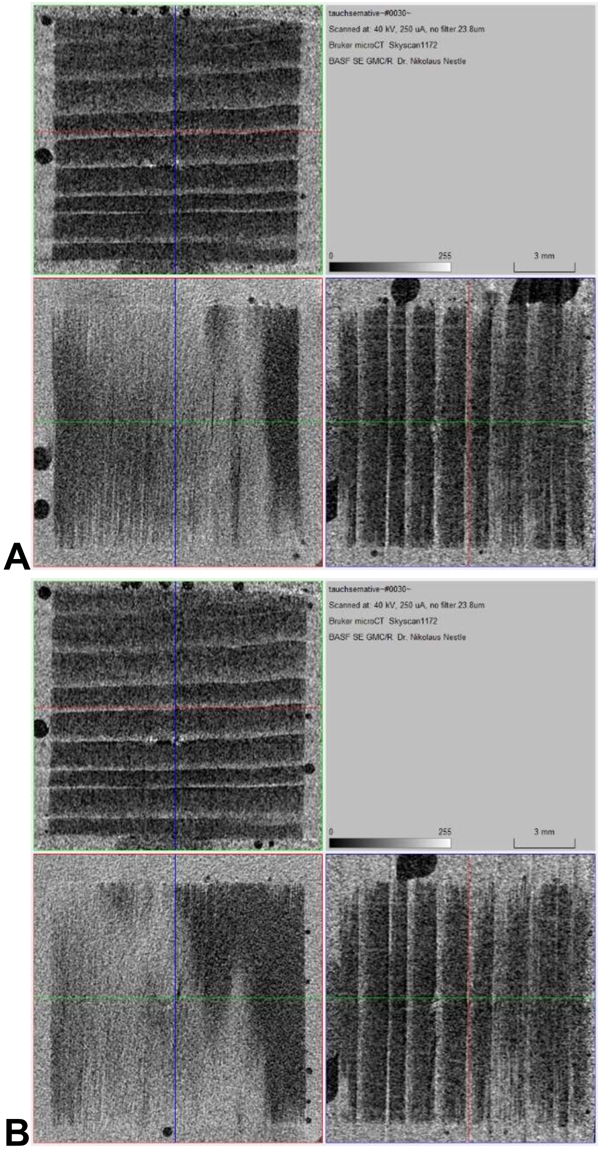


Figure 2 Crosshair views for native spruce wood (A) directly after immersion and (B) 8 h later

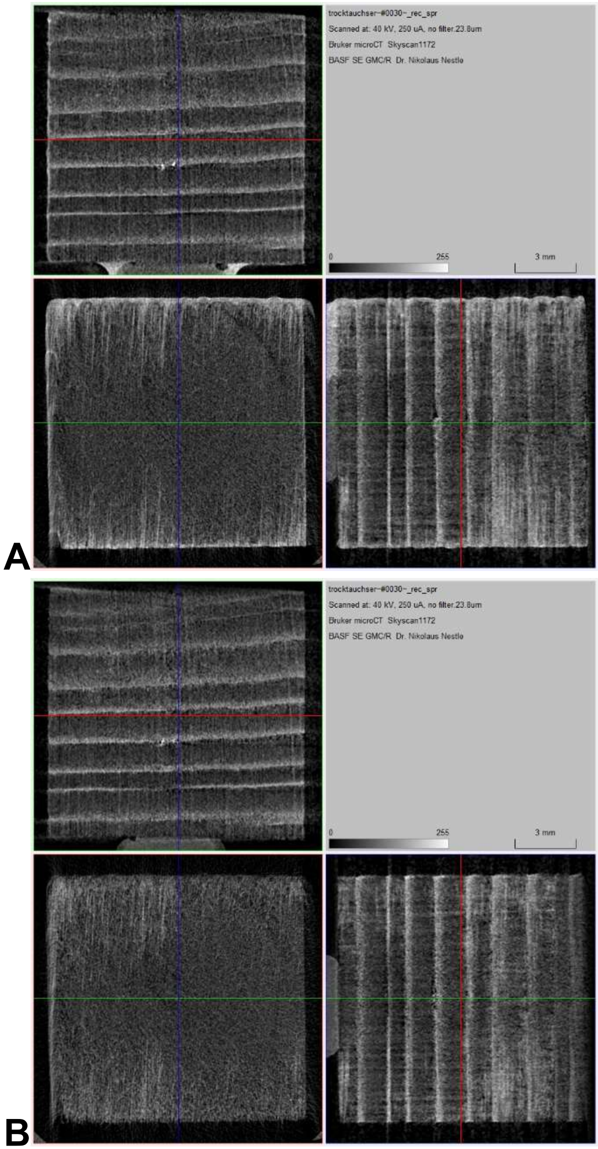


Figure 3 Crosshair views for native spruce wood (A) directly after removal of the water and (B) 8 h later

In figure 4, a wood specimen treated with a wax dispersion is shown right after immersion into water and 8 h later. In contrast to the experiments with native spruce wood, almost not water uptake and also no significant dimensional change are observed for this specimen.

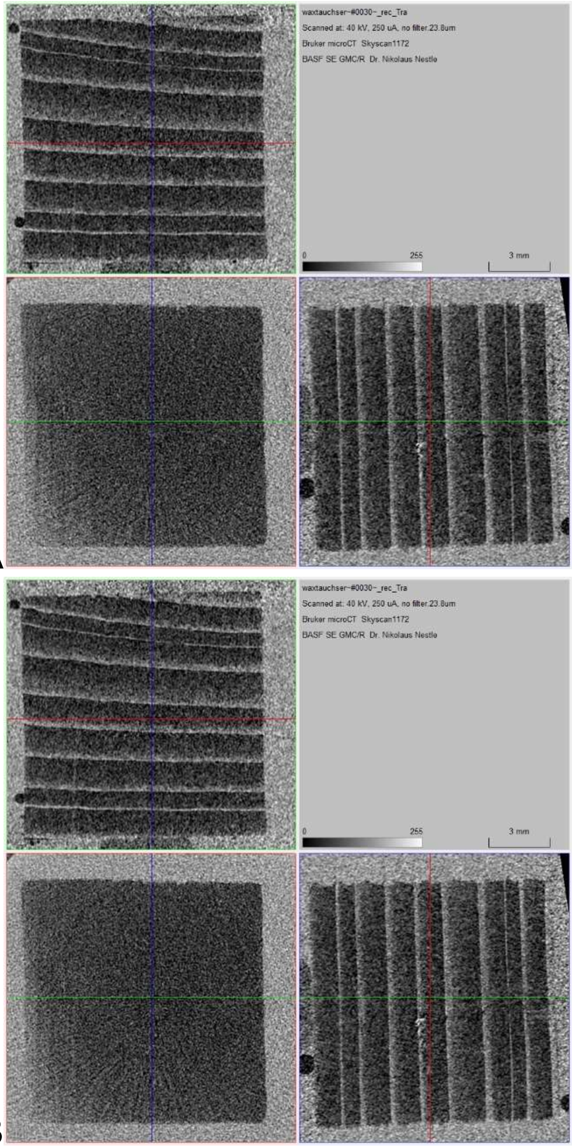
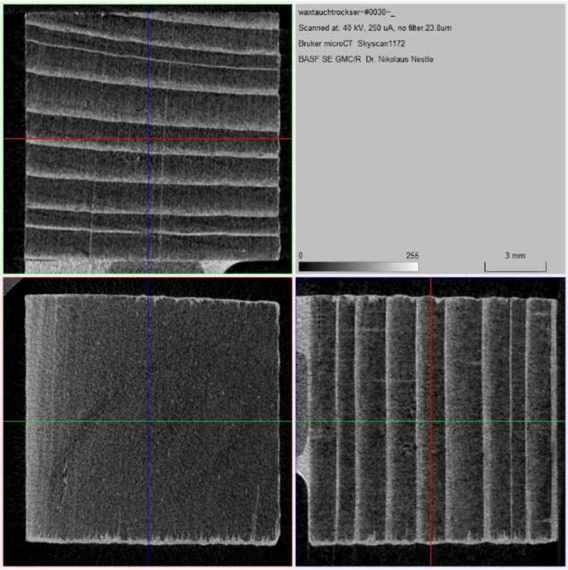
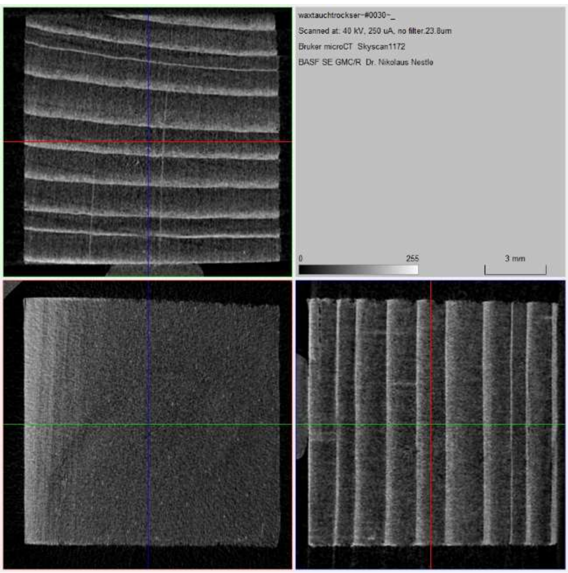


Figure 4 Crosshair views for spruce wood treated with wax dispersion (A) directly after immersion and (B) 8 h later

In figure 5, the corresponding images obtained after water removal in the drying phase are given. Again, no dimensional changes are visible. Furthermore, the presence of a mainly superficial moisture layer with a few individual wood fibers where some moisture saturation extends partially into the sample can be seen directly after water removal. After 8 hours of drying, this superficial moisture is completely gone. As expected, no dimensional changes are observed during drying either.



A



B

Figure 5 Crosshair views for spruce wood treated with wax dispersion (A) directly after water removal and (B) 8 h later

Conclusion

X-ray micro-CT is an excellent tool to follow the distribution of moisture in wood specimens during water immersion and subsequent drying. The spatial resolution achievable in time series of µCT scans is sufficiently good to gain insights into processes at the level of individual wood fibres.

For untreated wood, considerable water uptake along the fibre direction is observed while almost no water transport along other directions could be seen. By contrast, considerable moisture-induced dimensional changes are observed especially in tangential direction. Drying into air of about 30% RH at 29°C occurs much slower than water ingress.

References:

1. From section “wood structure 2” on http://www.materials.unsw.edu.au/tutorials
   U. Mikac, I. Serša, M. Žlahtič Zupanc, M. Humar, M. Merela, P. Oven "Application of MR microscopy for research in wood science" submitted to Microporous and Mesoporous Materials