Physics of wood drying

Context

Wood has advantages in terms of innovative structures and environmental issues, but it is hygroscopic and its properties can be modified or even altered during its use. Indeed, climatic variations (relative humidity), or the presence of liquid water (infiltration), can lead to loss of mechanical performance of the wood, structural disorders and even destruction of the wood, via fungal attacks, when the species used does not have sufficient natural durability or if the conditions of water transfer (humidification-imbibition or drying) are poorly controlled. This sensitivity to humidity can slow down the use of wood in construction, even if the construction specificities (standards) are taken into account. Moreover, during the first transformation of wood (sawing), the reduction of energy expenses associated with the artificial drying of green wood (never dried) requires that it be optimized in relation to the species considered and its transfer properties. Water transfers (humidification-imbibition and drying) and water-wood interactions are still poorly understood, either because they are reproduced by models which do not allow the physics of the phenomena to be taken into account correctly, or because the description of the mechanisms at different scales is incomplete.

For several years, Navier laboratory has been carrying out original research on wood material, studying in particular: (i) water-wood interactions, in particular with so-called bound water [1-2], (ii) water transfers in the hygroscopic domain [3] or in the presence of liquid water [4-7]. All of this work is based on Navier laboratory 1H NMR and imaging tools and has made it possible to better understand and specify the physical mechanisms involved. In particular, we have shown (for the case of the longitudinal direction , according to the axis of the cells, main axis of the tree) that spontaneous imbibition in hardwood (poplar) is about a thousand times slower than that predicted by the standard model of absorption by capillarity (Washburn model) which is usually used to describe these phenomena [4]. From observations by MRI (Magnetic Resonance Imaging) and by microtomography-X (carried out at Synchrotron Soleil), we have proved that this phenomenon is linked to variations in the wettability of the internal wall of the vessels with their water content [5]. This work led to the conclusion that bound water "controls" the kinetics of imbibition. This mechanism has also been shown to be essential in the functioning of softwood imbibition [6]. In the case of wood drying, especially in the presence of so-called free liquid water (in the green state or re-soaked by rain or infiltration), the physics is also still very poorly understood. A better understanding of the physical phenomena associated with drying (mechanisms governing the process, drying speed, internal moisture distribution, etc.) will allow the development of relevant predictive models of the optimal conditions for drying wood before or during use.

Thesis objectives

We have recently initiated an original approach to drying wood (poplar) consisting in following (by MRI and NMR) both the distribution of free water and bound water along the direction of drying, and the evolutions of the free water at the scale of vessels and fibers within the sample (X-ray microtomography). This study concerning the drying in the longitudinal direction, led to the conclusion that the drying of wood can also be controlled by the transport of bound water to the free surface of the sample, and the absorption of free water as bound water in depth [7]. The objective of this thesis is therefore to fully develop the approach initiated on the drying of wood in the presence of liquid water, by applying it to the other directions of anisotropy of wood (radial, tangential) which are in practice the main ones, and to other types of wood (other hardwoods, and softwoods), and to provide

a general description of the physical mechanisms of wood drying in the different directions, allowing the speed of drying to be predicted as a function of external conditions and changes in moisture distribution over time, as well as the resulting deformations. By analogy with what has been possible to do for the drying of model porous materials [8] (drying regimes governed successively by capillary effects then vapor diffusion), such a simplified physical modeling objective seems achievable wood drying indeed seems to be governed by a few fundamental mechanisms, such as the diffusion of bound water and the diffusion of vapor, the competition of which leads to distinguish different regimes. For this thesis, the objective is, on the one hand, the distinction of drying regimes as a function of external conditions (air flow, humidity) and the wood sample thickness; and on the other hand, the description, for each regime, of the drying speed and of the water distribution over time. This approach will allow a rapid and relevant appreciation of the drying conditions, and their possible optimization, and could subsequently be taken into account in more complete numerical models.

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