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EFFECT OF DOUGLAS GENETICS ON ITS HYGROSCOPIC BEHAVIOR: OPTIMIZATION OF SAMPLES DIMENSIONS FOR EXPERIMENTAL TESTS

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Abstract

This study present an original approach of wood durability by proposing a coupling between different genetic families of Douglas and the structures durability using as 'marker', the hygroscopic behavior of materials. This approach appears as a statistical study which has the ambition to highlight some markers linked with a low diffusion coefficient and of low equilibrium moisture.

This paper present a preliminary study that concerns the development of a numerical tool for performing a finite elements modeling of moisture transfers in the wood material. The purpose of modeling is to simulate the experimental tests that characterize the diffusion processes in controlled humidity and temperature. The hygroexpansion behavior will also be studied.

The aim of this paper is to optimize dimensions of samples with time necessary to obtain the equilibuim hygroscopic for each climatic condition defined.

Key words: *wood; durability; hygroscopic; genetic; diffusion; equilibrium moisture; finite element modeling.*

INTRODUCTION

Although wood is a building material that can meet the current environmental challenges by its low consumption of energy and its ability to store carbon dioxide, its use is still limited today for durability reasons. Beyond the aspect durability reasons, some species such as Mélèze or Douglas have natural durability against biological attacks. However, the use of these species in structural applications such as, for example, structures, Fig. 1, needs to increase the level of this durability in order to limit the systematic use of preservation treatment often aggressive to the environment.

Fig. 1.
Merle bridge in Corrèze-France

Wood is a hygroscopic material. Indeed, it has the ability to absorb water in the air and then release it when the air becomes drier. The use of this material in the construction must meet a multitude of constraints related to durability, due to the fact of its variable and complex nature with humidity conditions of the environment. For durability of the material, care must be taken to preserve wood from an extension of a high moisture content for which the biological growth are activated beyond 20%, even of dryness, because of eventual cracks. Today, limit the impact of moisture is a major axis of scientific research. Several families of solutions are developed. The first is the architectural solutions that consist to protect exposed elements, e.g., structures roof or aprons overhangs or protective inserts metal profiles to cover the most moisture-sensitive elements of structures. The second family includes preventive and / or curative physicochemical treatments (stain, paint, heat treatments, etc.), and with more or less significant environmental impacts. The approach that we propose in this work is based on the hygroscopic properties of Douglas material.

As part of the chair 'Ressources Forestières & Usages du Bois' set up by the University of Limoges, we present an original approach of durability by proposing a cross between biology and mechanical behavior of wood, and more precisely a coupling between different genetic families of Douglas and structure durability using as 'marker', the hygroscopic behavior of the material. Indeed, the coupling between diffusion properties and sorption isotherms provides moisture inertia characteristics limiting, both, the moisture peak and the penetration of the hydric front in the massive elements of structure.

The aim of this work is devoted to a statistical study of the hygroscopic behavior of different genotypes of Douglas. The selection is based both on a reduction of the components of the diffusion tensor D_w and the equilibrium moisture content W_e, for different climatic environments. Today, four genotypes are under consideration. This statistical study has the ambition to highlight some markers linked with a low diffusion coefficient and of low equilibrium moisture.

HYGROSCOPIC BEHAVIOR: THE ADSORPTION AND DESORPTION ISOTHERMS

By definition, wood is a hydrophilic material because it has certain affinities with water. In fact, a sample of wood placed under defined climatic conditions (temperature and humidity) sees its mass scale to stabilize at an equilibrium value. Therefore, a moisture exchange phenomena has been produced between the external environment and the piece of wood by mechanisms called diffusion until equilibrium called "equilibrium moisture". This state of equilibrium is described by experimental curves called sorption isotherms that express the sorption equilibrium moisture status of the wood from ambient humidity conditions at a constant temperature. The adsorption and desorption isotherms curves do not coincide, Fig. 2; they form a hysteresis area likely caused by incomplete rehydration sorption sites (Bou Said 2003).

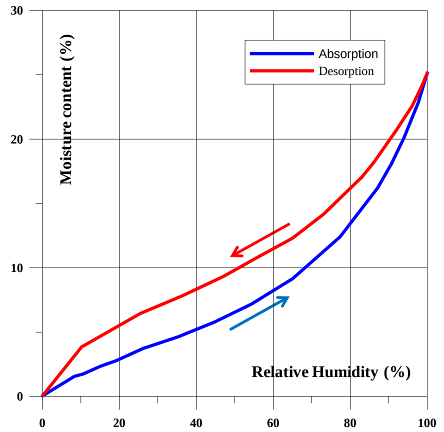

Fig. 2.
Example of sorption isotherms (Merakeb 2006)

The sorption isotherms in the wood can be defined through several mathematical models (Model B.E.T & G.A.B, Brunauer et al. 1938), Dent model (Dent 1977), Hailwood-Horrobin (Hailwood 1946). These models allow connecting the water content with the temperature (T) and the relative humidity (RH) of the environment. However Merakeb's model (Merakeb 2006) is based on a thermodynamic approach to the equilibrium of water phase. Water, in liquid state, is characterized by an equilibrium vapor pressure called saturation vapor pressure and a latent heat of vaporization. The two differ only with temperature (Merakeb 2006). Theoretically, Bruhat (Bruhat 1968) binds these two properties by the following formula of Clapeyron:

$$L = \frac{RT^2}{MP_S} \cdot \frac{dP_S}{dT} = \frac{RT^2}{M} \cdot \frac{dLnP_S}{dT} \quad (1)$$

By analogy to liquid water, Merakeb interprets moisture equilibrium as a thermodynamic property of the hygroscopic water in the woods, except that heat of sorption depends on moisture conditions of the material. Thus, it is characterized by its vapor pressure dryer according to the equation:

$$L' = \frac{RT^2}{MP_v} \cdot \frac{dP_v}{dT} = \frac{RT^2}{M} \cdot \frac{dLnP_v}{dT} \quad (2)$$

With L' is is the latent heat of vaporization of the hygroscopic water and P_v is the vapor pressure dryer. The difference between the heats of vaporization of liquid and hygroscopic water gives the molar enthalpy ΔH_s which is the heat of sorption. using the principle of thermodynamic of phases equilibrium by equalizing chemical potentials of the vapor and hygroscopic water, Merakeb obtained a logarithmic relationship between the moisture content W and relative humidity h that weighted by an exponential function of humidity symbolizing a non-linearity of process (Manfoumbi 2012, Merakeb 2006).

$$\ln\left(\frac{w}{w_s}\right) = \rho \cdot \ln(h) \cdot e^{a \cdot h} \quad (3)$$

ρ is a thermodynamic parameter and a calibration constant that depend of drying or humidification phases. w_s represent the moisture storage capacity of the material when air are satured.

DIFFUSION PROCESS

The diffusion process mainly relies on the use of the Fick's second law for defining moisture conditions in the material and its evolution over time. Two phenomena thus become competitive; namely the massive diffusion and surface water exchange. The massive difussion is expressed by the following relationship (Perre & Degiovanni 1990, Dubois et al. 2013):

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$$\frac{\partial w}{\partial t} = \nabla \cdot \underline{\underline{D}}_w(w)\nabla w \tag{4}$$

w means the moisture content defined as, for a given volume, the ratio of the mass of water contained in the sample on its dry mass:

$$w = \frac{m_{H_2O}}{m_{dry}} \tag{5}$$

$\underline{\underline{D}}_w$ means the diffusion tensor. In the main landmark of orthotropy, this tensor is diagonal with three distinct values giving an anisotropic nature of the diffusion process, and the non linearity is introduced as (Droin et al. 1989):

$$\overline{\overline{D_W}} = \begin{bmatrix} D_w^L & 0 & 0 \\ 0 & D_w^R & 0 \\ 0 & 0 & D_w^T \end{bmatrix} \tag{6}$$

$$D_w^{\alpha}(w) = D_0^{\alpha}.e^{(k_{\alpha}.w)}, \quad \alpha \in \{L, \quad R, \quad T\}$$

D_0^{α} is the diffusion coefficient in the anhydrous state of the material and k is a parameter of non linearity. Superficial water exchanges are managed by writing, in terms of boundary conditions of Fick's law (Simpson & Liu 1991, Simpson 1993, Simpson & Liu 1997). We get:

$$-\underline{\underline{D}}_w \cdot \vec{\nabla} w \cdot \vec{n} = \left(w_W - w_{eq}\right) \cdot S_w \tag{7}$$

Where S_w is the surface exchange coefficient.

w_W means the water content in the raw wood fiber very close to the exchange area. w_w represents the equivalent moisture to replace surface air by a fictitious layer of wood. The determination of the moisture equivalent uses the concept of sorption isotherms for measuring the equilibrium moisture content of a sample placed in a climatic environment in which the temperature and relative humidity is imposed.

HYGROEXPANSION

The gaint or departure of hygroscopic water leads to phenomena of shrinkage and deformation. Shrinkage and swelling are proportional to the decrease or increase of the moisture content of the wood. This phenomenon is very orthotropic. If we consider that the support characterized by shrinkage and swelling properties and elasticity properties which do not depend on the humidity, the law of mechanical behavior can then be written as (Randriambololona 2003, Husson 2009):

$$\underline{\underline{\varepsilon}}(t) = \underline{\underline{C}} \cdot \underline{\underline{\sigma}} + \int_0^t \underline{\underline{\alpha}} \cdot \frac{\partial w}{\partial t} \cdot dt \tag{8}$$

$\underline{\underline{C}}$ means the complaisance orthotropic tensor composed of the elastic properties of wood material in all three directions orthotropy. In this same reference, $\underline{\underline{\alpha}}$ designates the diagonal tensor of shrinkage and swelling characterized by high orthotropy as:

$$\underline{\underline{\alpha}}_{(\vec{L},\vec{R},\vec{T})} = \begin{bmatrix} \alpha_L & 0 & 0 \\ 0 & \alpha_R & 0 \\ 0 & 0 & \alpha_T \end{bmatrix} \tag{9}$$

α_L, α_R et α_T designate the swelling shrinkage coefficients in the longitudinal, radial and tangential

RESULTS AND DISCUSSION

The first part of this thesis was dedicated to optimize the dimensions of the samples with time necessary to obtain the equilibrium hygroscopic for each climatic condition defined. Thus, the modeling has been implemented in a finite element code (Castem), wherein the different behaviors mentioned above are integrated.

The purpose of modeling is to simulate the experimental tests that characterize the transient diffusion processes in controlled humidity and temperature (Weres et al. 2009, Olek et al. 2011). Therefore, it is important that it (diffusion processes) is simulated in the case of wetting (adsorption) and drying (desorption). The modeling will be conducted in the three Main directions: longitudinal, radial and tangential. To impose the diffusion on the considered direction, it is considered sealed all non concerned faces Fig. 3.

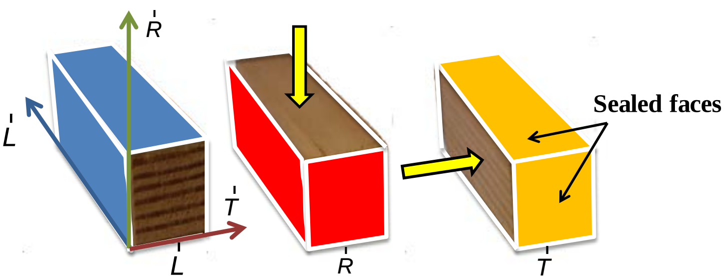

Fig. 3.
Conditioning of samples

To take into account the anisotropy of the wood effects, it is modeled in 3 dimensions using massive elements. To be as representative of reality, the finite element model takes into account the orientation of growth rings via a cylindrical orthotropic coordinates system centered at a virtual pith of our samples. Thus, for any point M of the support, we consider a local coordinates system, composed of the longitudinal direction $\vec{L}$ (parallel to the heart), the radial direction $\vec{R}$ (collinear with growth rings) and the tangential direction $\vec{T}$ (tangent to the growth rings) Fig. 4.

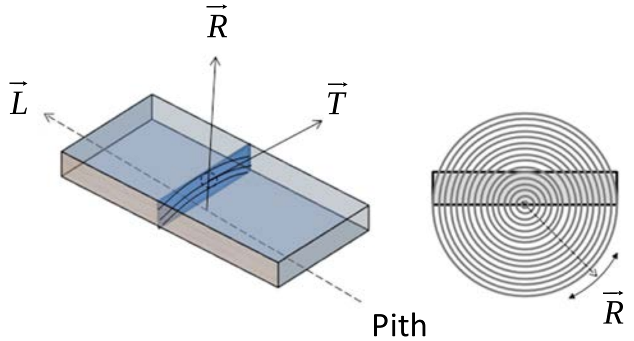

Fig. 4.
Local cylindrical orthotropic coordinates system

In order to optimize the sample dimensions, several configurations in term of hygrometric conditions and geometries were analyzed. In the present paper, two cases will be presented. For the first case, we opted for a geometry used in the research of MANFOUMBI (15 x 15 x 15mm^3, Manfoumbi 2012). For this case the temperature is fixed at 20°C and the relative humidity varies between 10 to 100% with an increment of 10%. The second configuration was selected after several numerical simulations. The final choice (20 x 15 x 10mm^3) is a compromise between, the diffusion rate and the time of the experimentation which must not be too long. Also, the hygroscopic equilibrium must to be achieved simultaneous in the three directions (L, R, T). During wetting phase, the relative humidity varied from 20% to 100% with increments of 20%. For the drying process, the relative humidity varied from 100% to 20% using the same increment. This relative humidity was translated to moisture contents through the sorption isotherms, and imposed thereafter on the edges of the samples.

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Fig. 5 shows the evolution of the moisture content for the first sample. Analysis of this evolution reveals a too long experimentation time about 270 days at the drying phase. The results show also that the hygroscopic equilibrium is not reached in the radial direction.

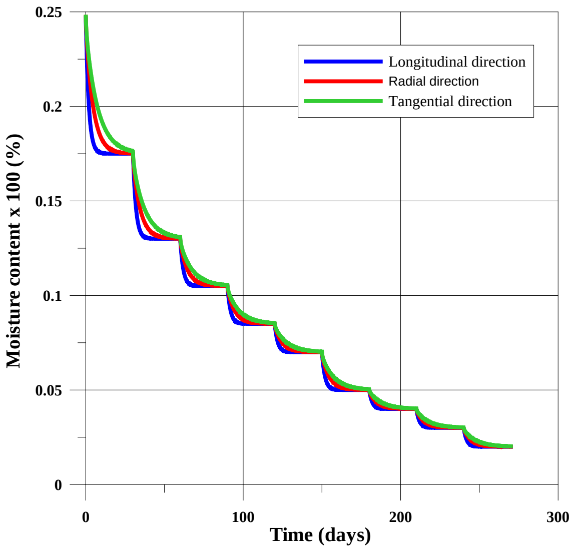


Fig. 5.
Diffusion kinetics for the first configuration (desorption)

Figs. 7a and 8a shows the evolution of moisture content for the second case. For this configuration, the hygroscopic equilibrium was achieved simultaneously in all three directions during the absorption and desorption phases.

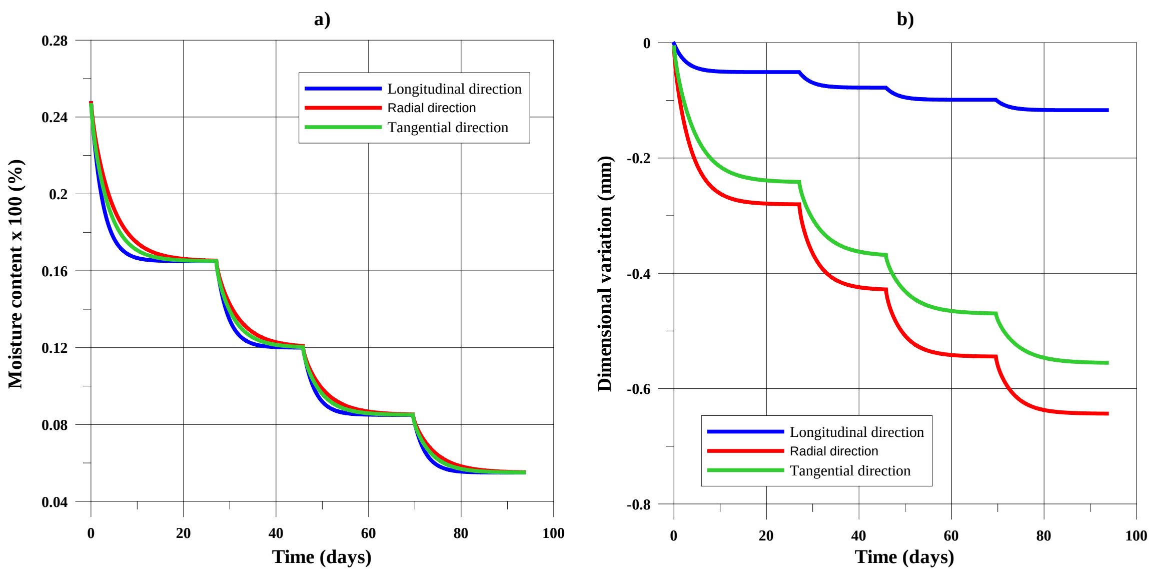
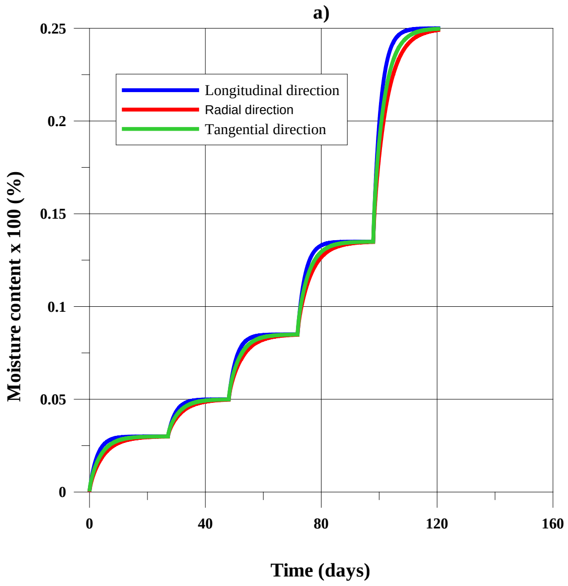


Fig. 6.
Desorption process: a) Diffusion kinetics; b) Dimensional variation



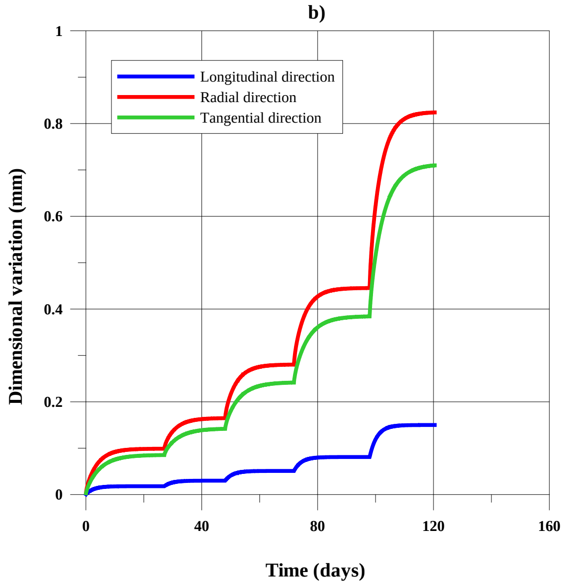


Fig. 7.
Absorption process: a) Diffusion kinetics; b) Dimensional variation

The hygroexpansion behavior was also studied. The dimensional changes were evaluated in order to provide the necessary tools to take measurements during the experiment. The dimensional variations of the sample during the drying and wetting phases are plotted in Fig. 7b.

CONCLUSION

This project concerns the development of a numerical tool for performing a finite element modeling of moisture transfers in the wood material. This model integrates the hygroscopic behavior in terms of diffusion processes and hygroexpansion behavior. The performed simulations allowed us to choose the dimensions of samples in order to launch thereafter the experimental series to characterize the hydric parameters of our four genotypes in terms of diffusion processes and the equilibrium moisture. The choice of dimensions results from a compromise between the experimental time and the obtaining of the equilibrium moisture, and also the dimensional variation that should not be too low in order to be able to quantify them. Today, having validate the dimensions of the specimens according to the directions of diffusion processus, we can proceed to the next step, that consist to initiate experimental testing and build our database, linking the genetic and hygroscopic properties in order to define a durability criterion.

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