Caractérisation de la cinétique de diffusion hydrique de bois sans défauts de feuillus

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Context and objectives

Wood is an important material of construction since ancient times and it becomes more valued in recent year due to its renewability and carbon storage. Different from other inorganic building materials, wood is a hygroscopic material which is highly sensitive to the humidity of the environment and temperature (Hailwood and Horrobin, 1946), expressed in the equilibrium moisture content (EMC) and hygroscopic deformations. Moreover, changing of moisture content affects the mechanical properties (Wilfred & Kollmann, 1968). For the use as timber material, changing of moisture content would lead to mechano-sorptive creep under continuous loading in addition to viscoelastic expression which would cause additional deflection and possibly induce structural pathologies. The moisture content plays an important role on mechanical property of wood. So that the equilibrium process of moisture content is needed to be well established.

The relationship between relative humidity and moisture content is not linear and depending on the holding ways of bonding water. The sorption isotherm is the graph of this relationship under a constant temperature (Schmulsky & Jones, 2011). The definition of EMC is that the moisture content of wood is no gain and lose and assuming that the rate of moisture content changing rate is low enough (Glass et al., 2018). It can be calculated at a first attempt by the equation of relative humidity and temperature (eq. 1) (Ross, 2010).

$$EMC(\%) = \frac{1800}{W}\left[\frac{Kh}{1-Kh} + \frac{K_1Kh + 2K_1K_2K^2h^2}{1 + K_1Kh + K_1K_2K^2h^2}\right] \quad \text{(eq.1)}$$

In this equation, h is air relative humidity and W, K, K_1, K_2 are the parameters of temperature (T) in Celsius (°C) calculated by the below functions (Ross, 2010):

$$W = 349 + 1.29T + 0.0135T^2 \quad \text{(eq.2)}$$

$$K = 0.805 + 0.000736T - 0.00000273T^2 \quad \text{(eq.3)}$$

$$K_1 = 6.27 - 0.00938T - 0.000303T^2 \quad \text{(eq.4)}$$

$$K_2 = 1.91 + 0.0407T - 0.000293T^2 \quad \text{(eq.5)}$$

The relationship among moisture content, relative humidity and temperature has been studied for more than hundred years. However, it takes a period for wood to reach the EMC, the equilibrium of the moisture content is a kinetics behavior. The experiment on kinetics sorption has been carried out since the instrument improve these twenty years (Thybring et al., 2019). According to the result of Kohler (2006), the equilibrium process of mass by the time could be fitted by the Parallel Exponential Kinetics model (PEK-model). According to Morton and Hearle (1997) (as cite in Okubayashi et al., 2004), in PEK-model, the exchange of water vapor was separated into 2 mechanisms defined as fast and slow sorption sites, which can be related to different types of amorphous regions, external or internal fiber surface, and direct or indirect sorption. The direct sorption happens at the external surfaces and amorphous regions could be defined as fast sorption. On the other hand, the sorption behavior on to the inner surface and crystallites, which could be relatively slow, could be defined as slow sorption (Okubayashi et al., 2004). In following functions, number 1 stands for the fast process and 2 stands for the slow process. The PEK-model of weight is defined as (eq.6):

$$W_t = W_{eq1}\left(1 - e^{\frac{-t}{\tau_1}}\right) + W_{eq2}\left(1 - e^{\frac{-t}{\tau_2}}\right) \quad \text{(eq.6)}$$

W_t is the mass at any time, W_{eq} is the mass at equilibrium at time τ. The correlation factor R^2 value of the fitting result is more than 0.999. Since PEK model was published, it was widely used to describe the sorption kinetics behavior of the natural fiber materials. It can fit not only the relationship between the mass and time, but also the equilibrium process of moisture content MC(t). MC_1 and MC_2 are the MC value assume that the samples were place in a constant h until equilibrium state associated with the 2-independent process (Himmel & Mai, 2016; Kachrimanis et al., 2006). τ_1 and τ_2 are characteristic time, which assume that the MC would be constant at time τ (eq.7) (Hill et al., 2010; Guo et al., 2018; Thybring et al., 2019):

$$MC(t) = MC_0 + MC_1\left(1 - e^{\frac{-t}{\tau_1}}\right) + MC_2\left(1 - e^{\frac{-t}{\tau_2}}\right) \quad \text{(eq.7)}$$

Although the PEK model is perfectly fitted to the experiment data of sorption in many references, it has been questioned about the physical meaning of the model. In addition, there is not a clear definition of equilibrium during the dynamic sorption process (Glass et al., 2018; Thybring et al., 2019). It still needs further study on the dynamic sorption behavior including the models and the physical explanation in order to characterize the variety of different wood sorption behaviour.

Materials and Methods

In this study, two different kinds of wood species have been tested: European beech *(Fagus sylvatica*) and European oak (*Quercus petraea*). The size of the specimens was 150 mm in length among longitudinal direction, 12 mm in width among radial direction, and 2 mm in thickness among tangential direction. To have the regulated controled environment, the test was performed inside an auto-climate chamber Memmert HPP110 (Fig.1). The experiment temperature was set at 20 °C. The relative humidity (h) was set at 30% for 3 days, and raise up to 80% for 7 days, and back to 30% for 200 hours (Fig.2). The environment condition data was collected by the sensor per minute. The balance METTLER TOLEDO ME204 was put inside the chamber and keep the shade open to make sure the environment condition inside and outside the balance were the same. One specimen was put on the balance and the weight value was collect per second continuously. The other specimens were place in the chamber at the same time, and the size of the specimens were measured at the 3rd-day (20 °C, h=30%), the 10th-day (20 °C, h=80%), and the end of the test (20 °C, RH=30%), for collecting the size value under different environment condition.

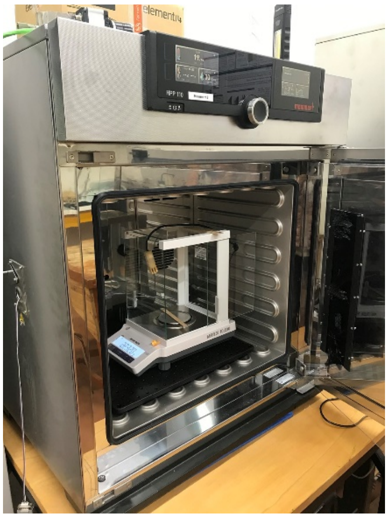

Fig. 1: Instruments setup.

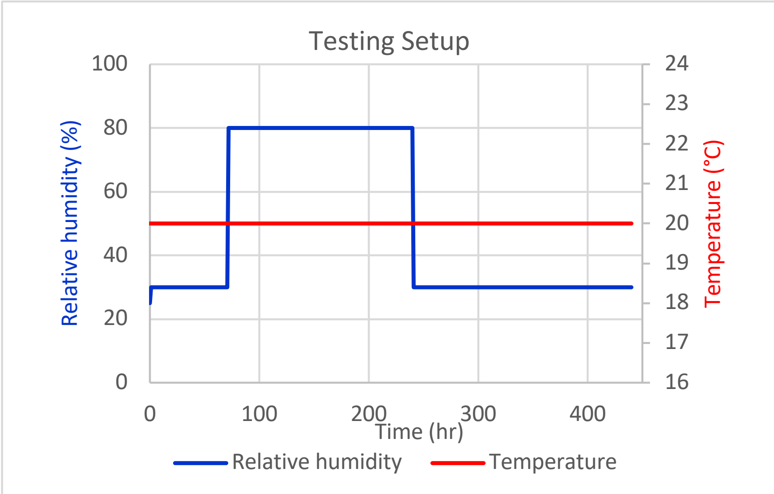

Fig. 2: Testing environment setup.

Results and Discussion

In this study, there are 6 different sorption curves would be concerned. The difference of the sorption curves among the specimens and wood species will be compared. Also, the testing result including both adsorption and desorption will be fitted by the PEK-model and the accuracy would be check. Through the PEK-model, the characteristic time τ would be defined as a reference time of MC of specimens reach the equilibrium situation. Therefore, the deference of testing result, fitting coefficient and τ between adsorption and desorption will be discussed, and how the hysteresis phenomenon affects the sorption process as well as the connection between the phenomenon and the model will be showed.

Conclusion

A comparison of data and fitting result between the experiments and references will be carried out in this study. The PEK-mode will be used to fit the testing result and find out the characteristic time value. In addition, the other possible models would be discussed and compared with PEK-model to find the possible explanation of the physical meaning of the PEK-model.

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