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Investigation on *Monopetalanthus* behavior wood from Gabonese forest, during a natural moistening and drying phases

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Abstract: This work deals with the study of physico-mechanical behaviour of *Monopetalanthus* (Andoung) specie from Gabonese forest under natural moistening and drying phases. Wood which is generally used for the conception of footbridges in Gabon and therefore exposed to the weather conditions. Some pieces of this specie have been sized following its radial and tangential plane. In the first, the section of each specimen has been analysed by using a scanning electron microscope to have maps of the internal arrangement of cells of this specie according to RT and TL axis planes. Then physical tests (drying and moistening) have been done on specimens in a room where condition of temperature T (°C) and pressure P (mmHg) are considered constant. The principal parameters followed during the tests are: (i) the dimensions of the radiale plane (R, T)×(b, h) and (ii) the weight of each specimen studied. The results show a link between the variations of water in the specimen and its geometrical parameters. Specifically, a pronounced effect of drying and moistening on its dimensional variations before the Fiber Saturation Point (FSP). This work is the beginning of a series of studies conducted on several species endemic to the Gabonese forest and whose use in structures is proven. The goal is to provide a database of their intrinsic characteristics for better structural design.

Keywords: Natural drying; Natural moistening; Congo Basin Forest; Tropical Forest; Biobased material.

1. Introduction:

Presently, in the field of construction, the debates revolve around the need to offer materials capable of reducing the carbon impact, which is due in major cases, to the resurgence of the use of heavy materials such as steel and concrete (Nkene Mezui *et al.*, 2023). Having this perspective as scope, wood, and its derivatives, which have more advantageous operating, production, and recycling costs, appear as ideal palliatives for the fight of greenhouse reduction gases emissions (Pambou Nziengui *et al.*, 2019). Indeed, international policies on the fight against climate change define new frameworks whose objectives are to promote sustainable construction using so-called green materials (hemp concrete, straw, raw earth, cellulose wadding, wood, etc.) (Niyigena *et al.*, 2016; Yadav *et al.*, 2021).

That is one of the reasons why Gabon, whose forest cover is today estimated at more than 87 % of its territory, is implementing drastic policies for the regulation and management of timber exploitation in their forest. These policies are essentially based on the studies carried out at the scale of material on different wood species, endemic to its forest, and which are used in the field of construction (Odounga *et al.*, 2019; Manfoumbi Boussougou *et al.*, 2022). The objective is to have the necessary information on the type of species and their main characteristics founded within the Gabonese forest to better use them in structure. In rural areas, so-called "plank houses" are mostly built by the poorest class of the population due to the relatively low costs of materials that are accessible to everyone. Based on this observation, it is easy to understand that it is impossible to ban woodcutting in the forest, but it is necessary to regulate its exploitation. In Gabon, logging represents more than 60% of GDP (excluding hydrocarbons), with around 17,000 direct and indirect jobs in the private sector, making it a resource that the state cannot do without today.

The present paper focuses on some specific, physical tests, which occurred upon the *Monopetalanthus* (Gabonese wood commonly called *Andoung*), with the aim to understand its behavior in structure. First, the test tubes are sized to carry out microscopic studies to understand their internal structure. Then, other drying and moistening tests are carried out. The objective of these tests is to understand the effects of variations in the internal moisture of the wood on its dimensional variations in structure and to be able to propose mathematical models to better understand this behavior. Indeed, the Andoung wood is currently being used in Gabon for the construction and implementation of footbridges intended for pedestrians. Considering the equatorial environment in which these footbridges are structured, the wood, which is the main material, is faced with the very aggressive climate that characterizes this region. Hence the need to determine physical parameters affecting their mechanical behavior in structure during variations in humidity and temperature. This study will therefore ultimately be based on an experimental model proposed upstream based on the different tests carried out. A long-term scope is to propose some analytical model of the link which exists between the variations of its physical parameters and its mechanical behavior in structures.

2. Material and methods:

The material studied is wood samples of the *Monopetalanthus* species collected in the Gabonese forest, in the Congo Basin region and commonly called Andoung. The experimental setup is met for the study of wooden pieces with sizes of $20 \times 20 \times 30$ (b \times h \times L), all expressed in mm, during a drying phase of the probes. All the analyzed samples are machined along the fibers direction and the cross section is carried by the directions (R, T) and (T, L), as in Figure 1. The tests are carried out in a room where conditions of temperature ($^{\circ}\text{C}$), relative humidity (%) and pressure (mmHg) are considered constant and respectively equal to $22 \pm 2^{\circ}\text{C}$, $68 \pm 2\%$ and 760 mmHg. Then, some specimens are cut, following the cross sections carried by the (R, T) directions and the (T, L) directions as presented in the photo from Figure 1a. These cross sections are analyzed by a scanning electron microscope machine (results presented in Figure 1b). On this machine, several scans can be carried out at different levels of scales, to understand the disposition of the fibers and the cells vertical canals on the cross section of the specimen considered.

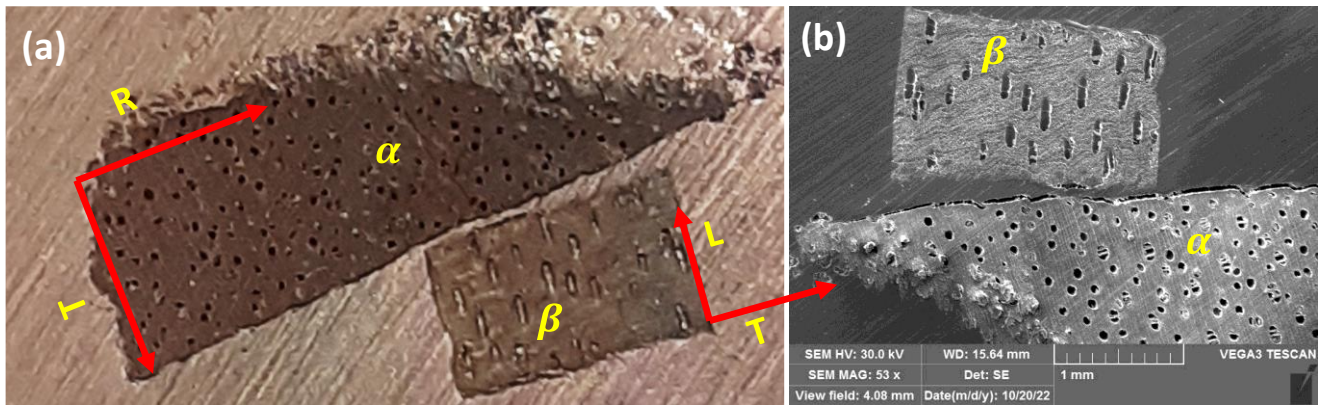


Figure 1: Examples of samples used by the scanning electron microscope tests: (a) pictures taken by the camera; (b) map taken by the electron microscope; α represents the transversal plan of the specimen, carried by (R, T) directions and β is the tangential plan, carried by (T, L) directions.

After the tests carried out using the scanning electron microscope on the different samples, humidity and drying tests are then performed on all the test tubes to highlight the impact of humidity variations on the shrinkage-swelling phenomenon of Andoung wood. The samples are previously machined (Figure 2a) and then immersed in a beaker (Figure 2b) until they are saturated (Figure 2c and 2d). The difference in watercolor observed in figures 2b, 2c, and 2d is due to the deposition of nutrient elements at the bottom of the beakers. Finally, the samples are removed from the water and all the dimensions, and the mass of the samples are measured during the shrinkage phase using respectively, a caliper and a balance.

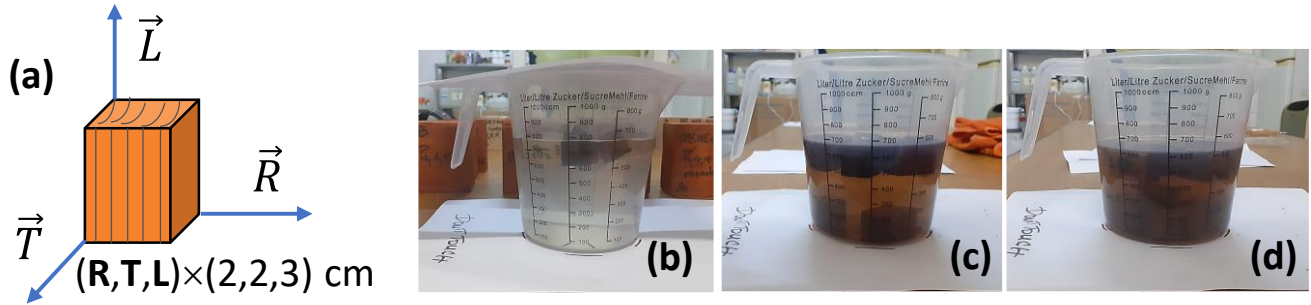


Figure 2: Main stages of sample moistening prior to drying: (a) typical tested sample; (b) first day of moistening; (c) 22nd day of moistening (beginning of sample saturation); (d) 27th day of moistening (all samples have leaked).

3. Results and discussions:

- Internal spatial structure of Andoung:

Figure 3 shows a zoom of the typical results of the internal structural analysis performed on an Andoung sample. We observe cavities present along the (R, T) and (T, L) planes. These cavities are vessels through which tree sap is conducted but also the places where free water lodges (Medzegue *et al.*, 2007; Zue Ondo *et al.*, 2021). These structural characteristics will help to better understand the phenomenon of shrinkage-swelling observed within the wood samples during the drying and wetting phases. The results of the study of these different cavities show that on average they have diameters of the order of $220.19 \pm 21.57 \mu\text{m}$.

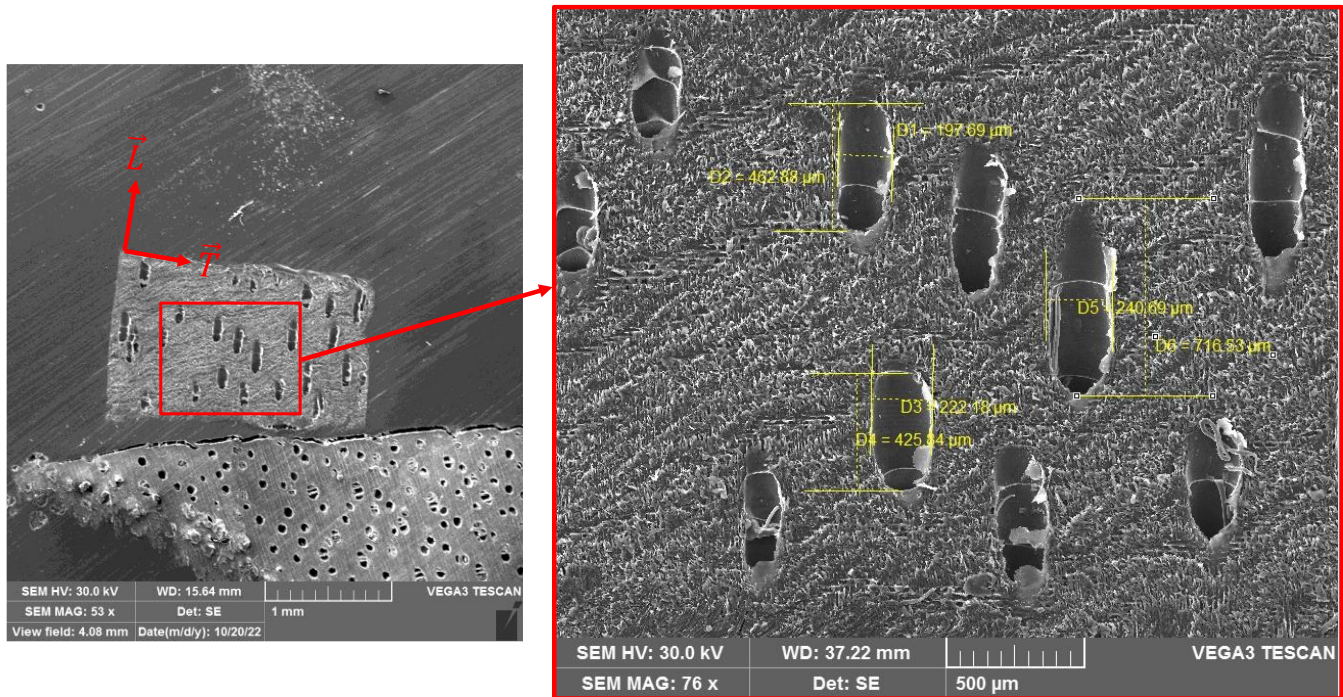


Figure 3: Close-up of the typical radial section of the Andoung species.

The literature (Pambou Nziengui *et al.*, 2019) shows that during the humidification phase, the wood gains moisture, and swells, which is why after a certain time (Figure 2b), the wooden test specimens sink to the bottom of the beaker. This phenomenon is defined as the saturation phase of the wood, which occurs when the internal moisture content of the wood is higher than the Fiber Saturation Point of the wood species being tested.

- Shrink-swell tests:

During the tests, the evolutions of three kind of parameters have been followed and measured on five (5) specimens of Andoung: the length (L) of the test specimen size following the fibers direction; the average of the thickness (e) carried by the directions (R, T); and the weight (m) of each specimen. The evolution of average thickness e(t) is given by the following equation:

$$e(t) = \frac{b + h}{2}(t) \quad (1)$$

Figure 4 shows the evolution of the relative average thickness $e_r(t)$ measured during the experimental campaign performed on the Andoung samples: Figure 4a shows the influence of moisture content on its evolution; and Figure 4b its evolution in the time during a drying phase.

Figure 4 shows that, the moisture content effects on the Andoung wood's dimensional variation are characterized by two steps: (1) a first step when the drying is slower ($\lambda_{(2)} \approx 2.3 \times 10^{-5} \text{ s}^{-1}$) and where the moisture content of the wood is below the *Point of Fiber Saturation* (here $PFS \approx 24\%$); (ii) a second step where the drying is faster ($\lambda_{(1)} \approx 4 \times 10^{-4} \text{ s}^{-1}$). Thus, one has shown on Figure 1 that the cross section of Andoung species shows porous cavities. According to the literature (Guitard and Amri, 1987) it is in these cavities that the free water of wood lodges. In fact, during the drying phase, this water evaporates hence the speed of dimensional variation observed (14 times higher) whereas below the *PFS*, water is difficultly evaporated because it is linked to the structure of wood.

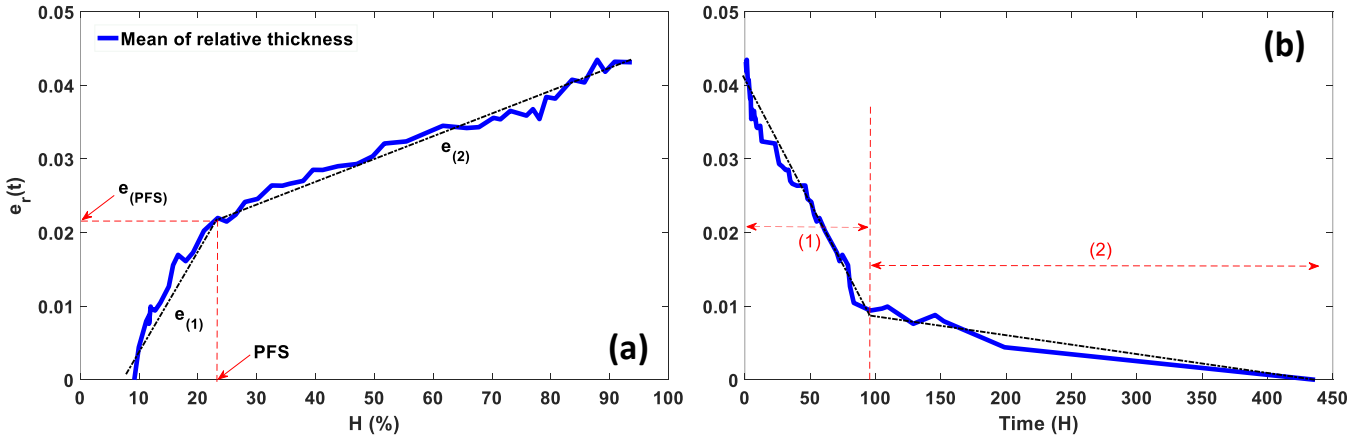


Figure 4: Typical evolution of Andoung wood's dimensional variations: (a) evolution during the moistening phase; (b) evolution during a drying phase.

Considering these informations and the results showed by Figure 4, the thickness could be expressed by the following expression:

$$e(t) = \alpha_{(<FSP)} H^+(t) + b_{(<FSP)} \quad (2)$$

Where $\alpha_{(<FSP)}$ is the swelling coefficient for a moisture content below the fiber saturation point, $H^+(t)$ is the internal moisture content of the specimen at time t , and $b_{(<FSP)}$ is a constant.

Table 1 presents the values of all coefficients in equation (2) during a humidification phase.

Table 1: Swelling coefficient of the Andoung species.

	H < FSP	H > FSP
α (%)	0.114	0.028
b (%)	1.4	3.66

The determined swelling coefficients reinforce the results found on the moisture absorption and shrinkage rate within the tested specimens. It is noticeable that during the humidification phase, swelling (or moisture absorption) is more significant than below the FSP, but above the FSP, the absorption is very slow or almost non-existent ($\alpha = 0.028$). By analogy, it can be concluded that during the shrinkage phase (drying), above the FSP, the shrinkage is more significant than below the FSP.

3. Conclusion and perspectives

One has shown that the physical mechanisms of moisture content variations, within wood, leads to a dimensional variation of this latter, phenomenon which can be problematic for a timber structure. Fortunately, this phenomenon is considered by Eurocode 5 (Eurocode 5, 2009) in its chapter devoted to the

service classes of wood in structure. But this normalization is not adapted for tropical species, because it's not considering all the intrinsic parameters of tropical species and their environmental conditions. Indeed, the results obtained in the context of this study show that the shrink-swell issues within tropical woods are aspects that deserve to be further investigated as the tropical environment is highly aggressive towards wooden structures. This demonstrates the need for standardization (national or regional) that considers all these aspects and considers the environment in which these structures are installed. Therefore, the next step of this research will be focused on the proposition of physico-mechanical analytical model of this tropical species during a drying or moistening phase. These models will allow us to limit our total dependence on experimental studies whose equipment can be very expensive for certain laboratories.

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