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Abstract

This paper aims to investigate the influence of temperature on the bending strength and modulus of elasticity of the tropical wood species: *Pterocarpus soyauxii* and *Triplochiton scleroxylon*. A probabilistic analysis of the fracture behavior of these two species is also conducted, utilizing a two-parameter Weibull distribution to assess the effect of temperature. Bending properties were measured for temperature ranges from 25°C to 100°C using four-point static bending tests. The findings reveal that temperature significantly impacts moisture content, bending strength, and longitudinal modulus of elasticity. Bending strength decreases linearly from 44 to 32 MPa for *triplochiton scleroxylon* and from 91 to 65 MPa for *pterocarpus soyauxii*. The modulus of elasticity shows random variation with temperature; it increases between 25°C and 45°C then decreases between 45°C and 100°C. The Weibull modulus varies between 9.2 and 15.6 for *triplochiton scleroxylon*, and *pterocarpus soyauxii* presents lower values which are between 3.4 and 6.1. In general, for both species, the Weibull modulus evolves very randomly with temperature. These results give engineers an overall understanding of the thermomechanical behavior of tropical wood species.
Keywords: Wood, *pterocarpus soyauxii*, *triplochiton scleroxylon*, thermo-elasticity, Weibull distribution

Introduction

Wood is a biologically-based building material derived from perennial plants, specifically trees. Compared to conventional construction materials (like concrete and steel), wood offers a diverse range of possibilities for architectural expression (Nsouandele et al. 2010, ido et al. 2010). In the past decade, the emphasis on sustainable development and environmental respect has driven a shift towards using biological and renewable materials, with wood being a primary choice (Fothe et al. 2019). The global forest cover, in Africa and particularly in Cameroon, is well-documented with approximately 1.5 billion of cubic meters for more than 100 species of wood (Odounga et al. 2018, Manfoumbi et al. 2022, Kouefouet et al. 2024). As a renewable resource, wood stands out due to its exceptional mechanical, physical, and thermal properties. However, the optimal use of wood requires a thorough understanding of its physical and mechanical properties, particularly its behavior under various types of loading typically encountered in structures. Many wooden structures are situated in environments where temperature and humidity levels fluctuate. As wood is a hygroscopic material, these fluctuations impact its mechanical behavior and can lead to premature failure of the entire structure (Engonga et al. 2021). Designing timber structures without considering the influence of temperature and humidity on wood's properties would be unwise, as it could hasten the failure of structural elements. Given this situation, scientists have focused on characterizing the physical and mechanical properties of various wood species, with significant research dedicated to understanding how environmental conditions affect this biomaterial's behavior (Turgut et al. 2013, Joffre et al. 2014, Vega et al. 2022). Over the past decade, numerous tropical species from different regions of the African continent have been extensively studied.

(Michel et al. 2020) investigated the physical and mechanical properties of the tropical wood species Wengé (*Millettia laurentii)*. Specimens extracted from tree trunks in the South Cameroon forest were subjected to a four-point bending test under constant temperature and humidity conditions. This testing allowed them to determine key characteristics of the wood, such as density, hygroscopicity, and Young's modulus. Their study concluded that Wengé wood is characterized by dimensional stability and mechanical properties adapted for civil engineering constructions, but the effect of temperature is neglected.

(Guillaume Blaise et al. 2020) studied the viscoelastic behavior of tropical wood species Sapelli *(Entandrophragma cylindricum)* and Movingui *(Distemonanthus benthamianus)*. Their objective was to understand the behavior of these woods under mechanical loading at varying temperatures and the study shows that the stiffness of the wood decreases as the temperature increases. (Guillaume Blaise et al. 2023) also conducted studies on these tropical species from Cameroonian forests. They investigated the influence of temperature on Young's modulus and found that this mechanical property increases at temperatures below 40°C and decreases as the temperature rises above this threshold in both mechanical compression and four-point bending tests. These results show that the elastic behavior of wood has a high heterogeneity nature making it behavior difficult to predict. It is therefore important to propose solutions that allow for a better understanding of this type of behavior, similar to the models used in the literature, but which have not been applied to these wood species by the authors. (Mwondo et al. 2017, Mwondo et al. 2020, Mwondo et al. 2021) conducted studies to show the influence of water content on flexural strength and thermal conductivity of these species, demonstrating a negative correlation between water content and these mechanical properties in characteristic tensile and four-point bending tests. To complete and validate these results, species collected from forest reserves in Nigeria (Jamala et al. 2013), Ghana (Okoh et al. 2014, Dadzie et al. 2016), and Congo (Nyobe et al. 2021), when studied using identical protocols, yielded results consistent with existing standards in the field.

Ayous (*Triplochiton scleroxylon*) and Padouk (*Pterocarpus soyauxii*), have already been the focus of physical, mechanical, and thermal characterization studies. (Biekop et al. 2022) conducted investigations to determine the modulus of elasticity and the breaking stress of Ayous wood from the Abong-Mbang locality in Eastern Cameroon. Their study is limited to determining these properties without addressing the causes of the variability observed in the obtained values and also while temperature affect these elastic properties. Similar studies were conducted by (Gennari et al. 2021, Gennari et al. 2022) on species from the Southern Cameroonian Forest. In addition to determining the breaking stress in compression and bending, the authors demonstrated that thermal treatment of the samples had a random probabilistic effect on these mechanical properties; once again, this aspect was not modelled, and the question of the influence of temperature on mechanical properties was not addressed. In their study on Ayous, (Mvondo et al. 2021) show that the bending strength is affected by moisture and variability in the values of mechanical and physical parameters is noted. The description and modelling of this variability would allow for a better understanding of the overall behavior of the wood. (Nouemsi et al. 2020) studied the physical properties of Padouk and Ayous wood from the Central Cameroonian Forest and observed thermal stability depending on the density of the wood species.

The previous studies did not address aspects related to thermo-elastic behaviour; our main goal is therefore to study the thermo-elastic properties of these species, as well as to describe the elastic variability in order to develop a behavior model specific to these materials. This article focuses on the influence of temperature on the physical and mechanical properties of Padouk and Ayous species from the Gambe locality in the central region of Cameroon, followed by a probabilistic analysis of their thermo-elastic behavior. The article is structured as follows: after this introduction, we present the wood species used and their preparation for testing, followed by the experimental protocols and methods for determining material properties. We also introduce the mathematical models used to predict some of these properties. The final part of the article presents the results obtained, compares them with existing literature, and concludes with prospects for future research.

Materials and Samples preparation

Materials

This study utilized two tropical wood species: Padouk (*Pterocarpus soyauxii*) and Ayous (*Triplochiton scleroxylon*). Both species were sourced from the tropical forest in the Gambe locality of Central Cameroon. Padouk, a member of the *Fabaceae* family, thrives in the forests of Central and West Africa (Thies et Beligné 2017). It typically reaches heights of 40 to 50 meters with a diameter of up to 150 centimeters, distinguished by its fine, scaly grey bark (see Figure 1). This species holds significant commercial value and is highly sought after for applications such as constructing water-contact bridges, shipbuilding, and hydraulic engineering (Corleto et al. 2020). Ayous, scientifically known as *Triplochiton scleroxylon*, is a member of the *Malvaceae* family, characterized by its light yellow to creamy white coloration (Figure 2). It typically features a straight trunk, albeit rarely cylindrical, reaching heights up to 30 meters with an average of 50 meters, and a diameter around 2 meters. This lightweight and soft wood is renowned for its use in interior joinery and plywood manufacturing (Nguedjio et al. 2024).

a.

b.

Figure 1. *Pterocarpus soyouxii*: a. Trunk; b. Section in the Longitudinal-Radial plane.

Samples preparation

The specimens were prepared in two primary stages: collection of wood samples and drying. Originating from the rural Gambe forest, all specimens were sourced from the same tree trunk, primarily from the heartwood (Figure 3). Following the (AFNOR French Standard) NF B 51-008, specimens were cut for the four-point bending test with a square cross-section of 20 mm × 20 mm and a length of 360 mm. Additional specimens, 20 mm in length with a cross-section of 20 mm × 20 mm, were prepared for moisture content determination. Each species underwent duplicate sets of specimens, with each set including specimens of 360 mm and 20 mm lengths, sharing identical initial structures and cutting consecutively. These samples were then stored in an open-air conditioning room for a duration of three weeks, under ambient conditions of approximately 24°C ± 2°C temperature and 65% ± 5% relative humidity and tested directly without further specific drying. After this period, the samples were weighed to ensure constant mass, indicating their readiness for the subsequent tests.

a.

b.

Figure 2. *Triplochiton scleroxylon*: a. Trunk; b. Section in the Longitudinal-Radial plane.

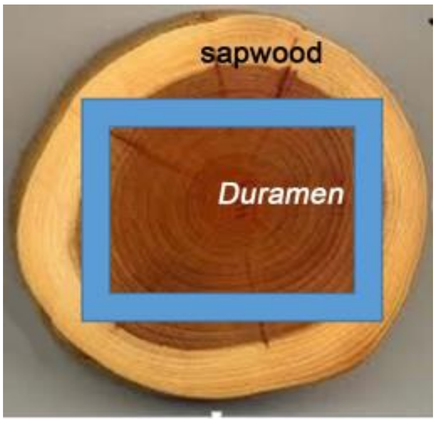


Figure 3. Zone of extraction of specimen.

Methods

Determination of moisture content

The focus of this part is the physical property of moisture content. To measure this, 20 control specimens measuring 20 mm × 20 mm × 20 mm were prepared at each temperature level and for each species, following the guidelines of (AFNOR French Standard) NF B 51-004. The tests were conducted across various temperature levels for each species, aimed at investigating how temperature influences the moisture content of the selected woods.

The specimens are first weighed and then placed in a thermal oven initially set at 25°C. To determine the moisture content at specific temperatures, the samples are placed in the oven until each target temperature is reached. Afterward, the specimens are taken out, weighed, and the average mass is calculated. This process is repeated for temperatures ranging from 25°C to 100°C, with the maximum oven temperature set at 103°C. The specimens are maintained at 103°C until their mass stabilizes (denoted as m_0). The moisture content (H) is calculated using Equation (1) (Mvondo et al. 2021). It is important to note that the balance and thermal chamber are positioned close to each other to minimize heat loss during weighing:

$$H = \frac{m_T - m_0}{m_0} \quad (1)$$

where H (%) is the moisture content of the specimen, m_T the mass of the test piece at temperature T and m_0 the mass of the test piece in the anhydrous state.

Mechanical properties

Bending strength

In this study, bending strength is determined by a static four-point bending test using the machine shown in Figure 5 and the principle of this test is shown in Figure 4 (following the AFNOR French standard NF BS 408). According to (AFNOR French Standard) NF B 51-016, the tests involve placing a specimen on two simple supports and subjecting it to two loading points concentrated at these supports, each applied at an equal distance from them. In this test, specimens measuring 360 mm x 20 mm x 20 mm were prepared according to (AFNOR French Standard) NF B 51-008 for each selected species. These test specimens were utilized across all eleven temperature levels, employing the same thermal regulation principles described earlier for moisture content determination. As depicted in Figure 5, the ram of the hydraulic press is controlled by a lever that regulates both the direction and speed of movement. In our case, the 3mm\min loading speed of the cylinder on the bending machine pattern remained constant). Upon contact with the pattern, the ram exerts pressure per unit area on the specimen. The stress is determined based on the pressure value indicated by the pressure gauge, using the relationship described in Equation (2) (Mvondo et al. 2021):

$$\sigma_R = \frac{3Pd}{bh^2} \tag{2}$$

where P (N) represents the total applied load, d (mm) the lever arm defined as the distance between outer and inner loading points, b (mm) the width of the specimen, and h (mm) the specimen's height.

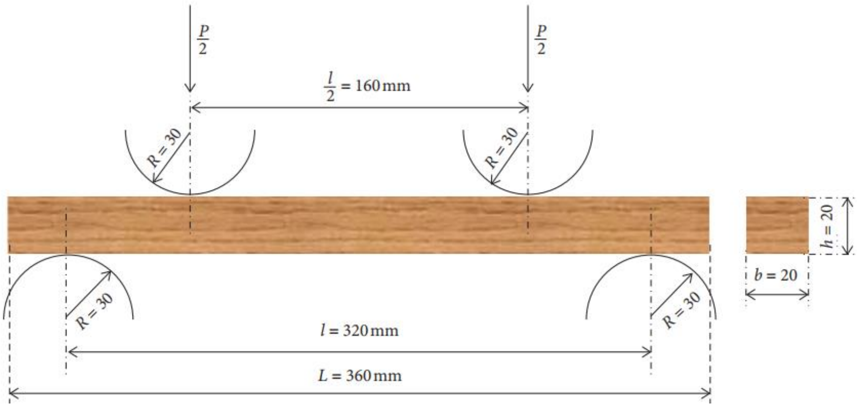


Figure 4. Four-point static bending test (Foadieng et al. 2021).

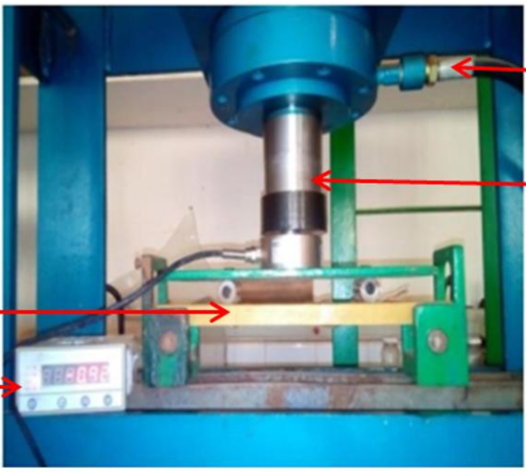


Figure 5. Machine for determining breaking stress.

Longitudinal elastic modulus

The static four-point bending test is repeated to determine the modulus of elasticity in the longitudinal direction parallel to the wood fibers, using the equipment depicted in Figure 7. A temperature-controlled chamber maintains a constant temperature within the test specimen chamber. Initially, specimens measuring 360 mm x 20 mm x 20 mm are prepared according to (AFNOR French Standard) NF B 51-008, and strain gauges (Figure 6b) are affixed. The strain gauges used, from Measurements Group Inc., have a gauge factor $K_j = 2 \pm 0.1\%$, and resistance $R = 120 \pm 0.3\%$ (Figure 6a). For each species, 15 specimens were tested at temperature levels of 25°C, 30°C, 35°C, 40°C, 45°C, 50°C, 60°C, 70°C, 80°C, 90°C and 100°C, respectively. At room temperature T_0, the specimen is positioned between the supports of the bending machine. The entire setup (machine and test specimen) is enclosed within the temperature-controlled chamber, with the controller set to stabilize the chamber at the desired temperature. Two minutes after temperature stabilization, known masses of identical values are sequentially placed on the plate (Figure 7). An ET616 extensometer from Deltalab (Figure 7) is connected to the specimen to record deformations ε with an accuracy of 1 micrometer per meter. For each temperature level, the above procedure is repeated for several specimens of the species under study, and the tests are conducted across all temperature levels considered in this study. While deformation is measured indirectly by electronic instrumentation, stress is derived from beam theory in materials science for bending, as described by the following relationship (Guillaume Blaise et al. 2023):

$$\sigma = \frac{3g(L-l)}{2h^3}m \tag{3}$$

where L(mm) is the length of the specimen, l(mm) the distance between the internal supports, h(mm) the height of the specimen, m is the total mass of the steel blocks in Kg and g is gravity in N/Kg.

a. b.

Figure 6. a. Strain gauge; b. Samples carrying two gauges.

Mathematical modelling

Wood strength and stiffness are influenced by temperature and moisture content, particularly below the fiber saturation point (Mvondo et al. 2017). The impact of temperature on the modulus of elasticity and yield stress is commonly modelled using polynomial functions with empirical coefficients (Gao et al. 2014). (Pulngern et al. 2016) utilized the following general form of Equation (4):

$$E = K_0 + K_1 T + K_2 T^2 + \cdots + K_n T^n \ , \quad (4)$$

where K_n (for i = 0 to n) are empirical coefficients. This model will be employed to fit experimental data for the modulus of elasticity as a function of temperature. The adjustment will utilize Python's lmfit algorithm, which employs the method of least squares.

Figure 7. Experimental protocol for determining Young's modulus as a function of temperature (Foadieng et al. 2021).

Weibull Probabilistic model

Wood is recognized as a composite material characterized by multiple levels of heterogeneity across various scales, including distributed and localized defects of varying sizes. These inherent heterogeneities manifest as spatial variations in the material's physical and mechanical properties, which have been experimentally verified (Redjel 2013). This composite nature significantly influences the mechanical and physical parameters related to the damage and failure of wooden structures. Microstructural defects that initiate cracks in wood typically exhibit random distribution, imparting a stochastic nature to failure phenomena (Redjel 2017). Therefore, combining deterministic models dedicated to modeling damage and fracture with statistical and probabilistic approaches is essential. Such approaches better estimate the relative impacts of various variability on the reliability of construction materials (Saoud et al. 2018).

In this study, a probabilistic Weibull analysis is employed to predict the microstructural origins of damage and fracture in the Ayous and Padouk timber species under investigation. The two-parameter Weibull distribution used is widely recognized in the literature for describing the failure probability of tropical woods (Roy et al. 2011, Maache et al. 2018). The probability density function of the two-parameter Weibull statistical model is defined by Equation (5) (Djeghader et redjel 2019). Integrating this probability density yields the cumulative distribution function used as the predictive function for material failure, as described in Equation (6) (Barbosa et al. 2018):

$$f(x) = \frac{m}{a}\left(\frac{x}{a}\right)^{m-1} e^{-\left(\frac{x}{a}\right)^{m}} \tag{5}$$

$$F(x) = 1 - e^{-\left(\frac{x}{a}\right)^{m}} \tag{6}$$

where m is the Weibull modulus, a is the shape parameter of the distribution, and x is the independent variable. The Weibull modulus m, also referred to as the Weibull parameter, characterizes both the variability in defect sizes and the level of dispersion. This parameter is derived by linearizing Equation (6) as shown in Equation (7) (Maache et al. 2017, Iwuoha et al. 2021):

$$\ln\big(-ln\big(1 - F(x)\big)\big) = m(\ln(x) - \ln(a)) \tag{7}$$

The graphical representation of the function $\ln\big(-ln\big(1 - F(x)\big)\big)$ as a function of $\ln(x)$ is a straight line, with m as the slope (Naresh et al. 2017).

By bringing back Equations (5), (6) and (7) to the probabilistic analysis carried out in this paper, the probability of rupture or the axial stiffness rate P_r is then defined as a function of the rank of the sample i and the size of the sample N. Here, x and a will be respectively the experimental and normalization amplitudes, and more precisely the stress σ or the modulus of elasticity E depending on the case. The probability of failure P_r, which satisfactorily plays the role of distribution function F(x) (Youbi et al. 2023), is given by Equation (8) (Kana et al. 2024) below:

$$P_r = \frac{i}{N+1} \tag{8}$$

For each species, 15 specimens were tested at various temperature levels, allowing for comparisons between the two species, and the influence of temperature on this distribution was examined.

In addition to the Weibull modulus m, the coefficient of variation C has been also evaluated, whose expression as a function of the parameter m is calculated by the following formula (Talla et al. 2018):

$$C = \frac{\sqrt{\Gamma\left(1+\frac{2}{m}\right) - \left(\Gamma\left(1+\frac{1}{m}\right)\right)^2}}{\Gamma\left(1+\frac{1}{m}\right)} \tag{9}$$

where $\Gamma(z) = \int_0^{+\infty} t^{z-1} e^{-t} dt$ is the Gamma function (Chen 2024).

It's worth noting that several studies have aimed to establish a correlation between Weibull modulus m and the coefficient of variation C. Models proposed by Brokenbrow (Broutman et al. 1967) and Macmillan (Redjel et Achouri 2014) for composite materials have been used, with their mathematical formulations given by Equations. (10) and (11), respectively. These models are employed to describe the relationship between the Weibull modulus m and the coefficient of variation C:

$$m = \frac{1.27 - 0.56C}{C} \tag{10}$$

$$m = \frac{1.2}{C} \tag{11}$$

Results and Discussion

Influence of temperature on moisture content

Before conducting the various tests, it was crucial to control the moisture content of the test specimens to comply with the standards applied in our experiments. Results from tests on the control specimens indicated a moisture content of 12.9% $\pm$1.4 for Padouk and 9.4 % $\pm$ 2.5 for Ayous for samples initially conditioned in an ambient environment of 24°C ± 2°C temperature and 65% ± 5% relative humidity. These values are relatively difficult to compare to the reference value of 12%, especially for Ayous, and could be attributed to the microstructural constitution of the samples used. Moisture content as a function of temperature has also been measured. Figure 8 shows the evolution of moisture content as a function of temperature for Padouk and Ayous. As temperature increases, moisture content decreases, reflecting the loss of water from the wood due to heat exposure. This result was first reported by researchers studying tropical wood species (Miguiri et al. 2020, Manga Bengono et al. 2023) and later validated by studies on temperate species (Pang 2002, Aytin et al. 2015, Hsieh et Chang 2018). Notably, water desorption is more pronounced in Ayous than in Padouk.

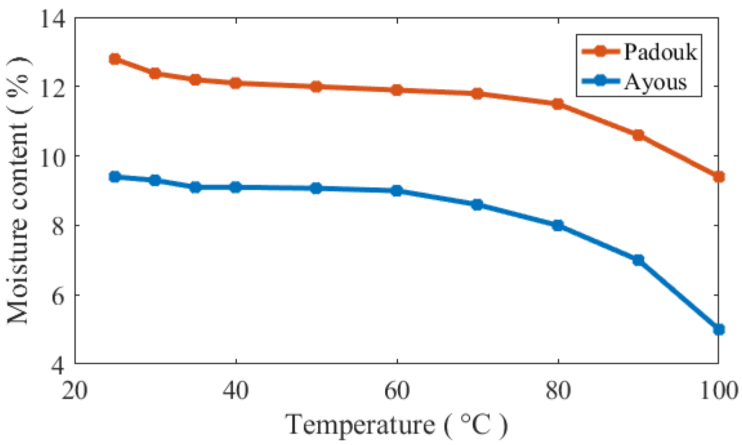


Figure 8. Influence of temperature on moisture content.

Influence of temperature on MOR

Bending strength (MOR) is a crucial characteristic of wood material. Knowing its value helps to identify the elastic range, where deformations are reversible. Technicians must know the elastic limit of a material to determine the maximum load it can withstand without permanent deformation. Understanding MOR values in relation to temperature would enable engineers to design more durable materials. Tables 1 and 2 below present the MOR results for Padouk and Ayous, respectively and where it can be observed that the MOR decreases when the temperature increases. This trend aligns with the general effect of temperature on the elastic properties of wood (Bodig et Jayne 1982). The underlying reason for this behavior is that increasing temperature induces changes in energy and permanent structural reorganization within the wood (Bodig et Jayne 1982). This effect can be more pronounced if the wood has defects like cracks or splits caused by variations in moisture content (De la Cruz Sanchez 2006). Numerous studies on different wood species support these findings (Tsoumis 1991, Tajvidi et Mizaei 2009, Zhou et al. 2012, Hernandez et al. 2013, Hidayat et al. 2013, Hernandez et al. 2014). In this study, it is important to note that temperature has a more significant impact on the MOR of Ayous compared to Padouk. This is because Ayous is a lighter and less dense wood, making its polymer bonds more susceptible to temperature changes.

Table I. Bending strength (MPa) of Padouk as a function of temperature.

Temperature	25°C	30°C	35°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Mean	91.37	89.38	87.29	85.40	82.30	77.62	74.50	69.32	67.34	65.24
Std	1.71	1.57	1.35	1.22	1.23	1.68	1.37	1.36	1.34	1.49

Table II. Bending strength (MPa) of Ayous as a function of temperature.

Temperature	25°C	30°C	35°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Mean	44.44	43.55	42.82	41.65	40.72	38.52	37.44	35.65	34.43	32.58
Std	1.30	1.57	1.52	1.50	1.49	1.59	1.84	1.60	1.42	1.48

Influence of temperature on MOE

The longitudinal modulus of elasticity, also known as Young's modulus (MOE), is one of the most critical mechanical properties of wood. It measures the material's stiffness. In this study, the longitudinal MOE of Ayous and Padouk has been evaluted using four-point bending tests. This modulus is determined experimentally by assessing the slope of the stress-strain curve within the elastic domain, which is represented by a straight line (Naylor et al. 2012, Kuo et Wang 2019, Fajdiga et al. 2019, Huang et al. 2020). Figures 9 and 10 present the results obtained for both species at each of the temperature levels considered in this work.

An analysis of the slopes of these lines found that the MOE of Ayous is between 5000 MPa and 7000 MPa, and that of Padouk between 8500 MPa and 13000 MPa. This indicates that Padouk is significantly stronger and stiffer than Ayous, a conclusion also supported by other researchers (Fan et Ndikontar 2014, Saha Tchinda 2015, Gennari et al. 2022, Eyinga Biwole et al. 2022).

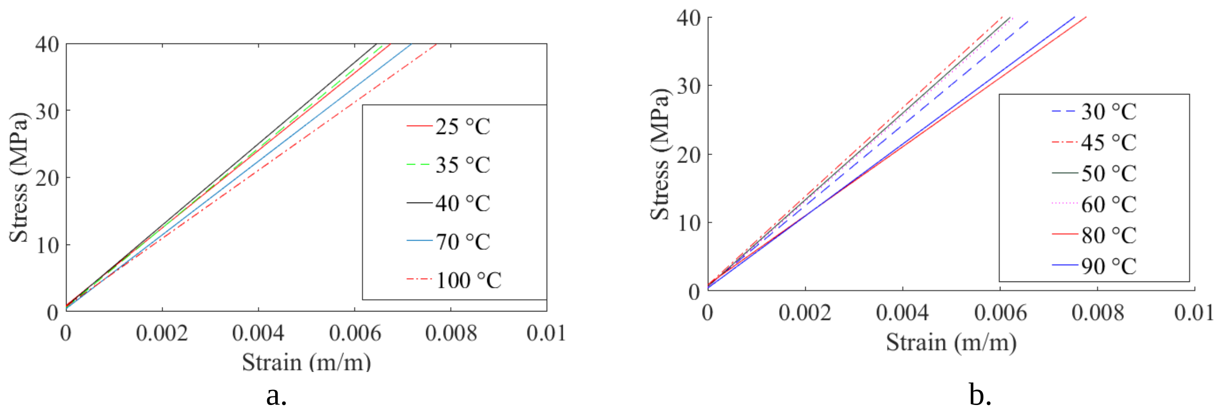
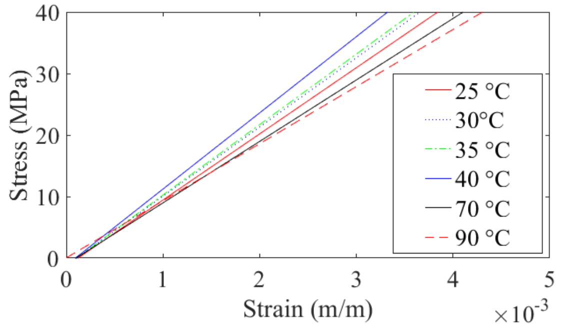
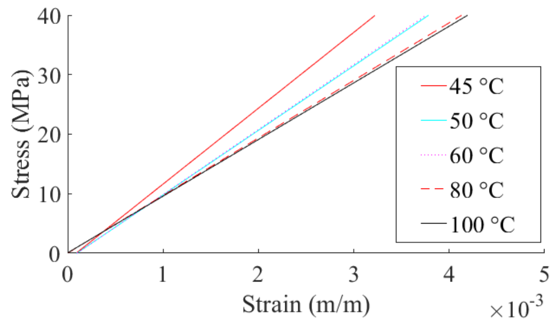


Figure 9. Determination of the Ayous MOE.

From the stress-strain curves, it is evident that temperature has a considerable effect on the wood's MOE. Understanding how the elastic modulus of wood varies with temperature is essential for predicting its mechanical behavior under different thermal conditions. The curves in Figure 11 illustrate the influence of temperature on the MOE of Ayous and Padouk. These figures show that MOE varies somewhat randomly with temperature. Generally, the MOE is highest between 35°C and 40°C and lowest between 90°C and 100°C for both Padouk and Ayous. Figure 12 indicates that the MOE of Ayous increases from 5780 MPa to 6474 MPa as temperatures rise from 25°C to 45°C, then decreases from 6400 MPa to 5079 MPa as temperatures further increase to 100°C. For Padouk, the MOE increases from 10753 MPa to 12750 MPa between 25°C and 45°C, then decreases to 9283 MPa between 45°C and 100°C. Similar to MOR, the effect of temperature on MOE can be attributed to the internal microscopic structural reorganization of wood due to thermal gradients. The trends observed in this study align with those reported by (Moraes et al. 2004) for *Pinus sylvestris L* and by (Llana et al. 2014) for *Scots Pine* wood, with the exception that the samples were taken from the same tree trunk, which may account for the random elastic behavior observed with varying temperatures. (Guillaume Blaise et al. 2023) observed a similar random elastic behavior in tropical wood species, with an increase in MOE between 22°C and 40°C, followed by a decrease beyond 40°C.



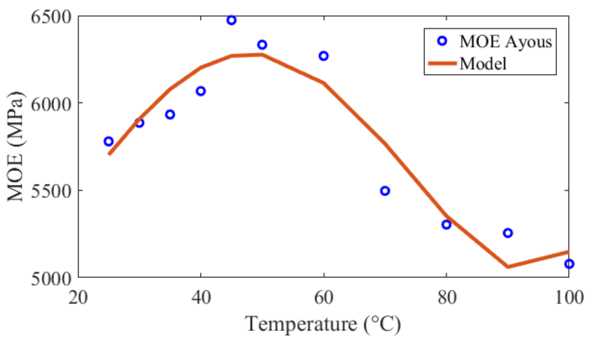
a.

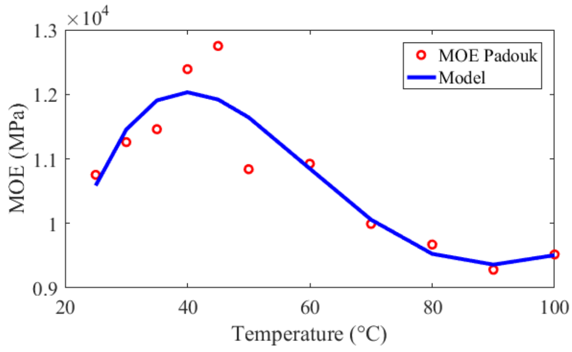


b.

Figure 10. Determination of the Padouk MOE.

The mathematical model in Equation (4) was used to fit the evolution of MOE as a function of temperature. The curves in Figure 11 illustrate the results of these adjustments. The optimal coefficients of the polynomial are presented in Table 3. The values in this table show considerable variability, making it challenging to establish a clear relationship between these coefficients and the thermomechanical characteristics of the wood material. Therefore, this mathematical model is far from being a reliable predictive tool, and further research is needed to improve its accuracy.





a. b.

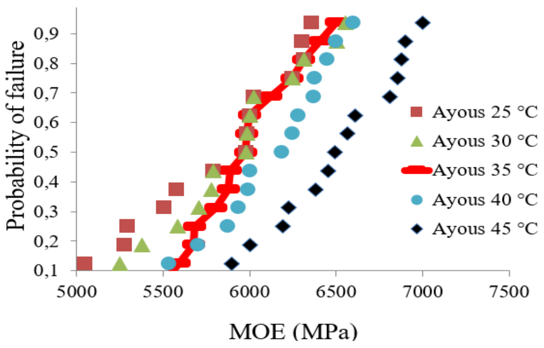
Figure 11. Influence of temperature on MOE: a. Ayous; b. Padouk.

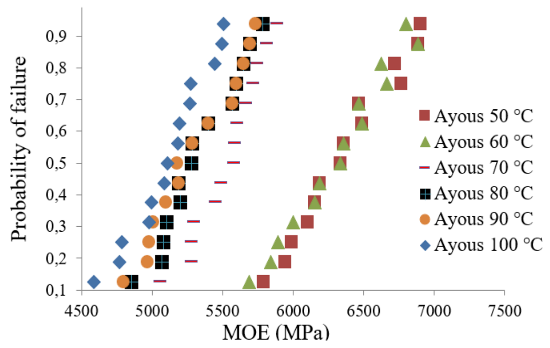
Table III. Optimal coefficients of the mathematical model fitting the MOE.

Specimens	K_0	K_1	K_2	K_3
Ayous	4.906	-0.0043	0.0026	-0.0001
Padouk	-3.995	1.054	-0.0237	0.0002

Weibull probabilistic analysis

Figures 12 and 13 show the probability of failure for each of the two species. The curves obtained at each temperature level are sigmoidal, reflecting the Weibull distributions of the MOEs measured in four-point bending. The graphical representation of the linear probability equation for determining the Weibull modulus and the normalized MOE (denoted by a in Equation (7)) is illustrated in Figures 14 and 15. There is a dispersion of experimental points around the linear regression line of the probability equation observed for both Ayous and Padouk. The various values of the Weibull modulus as a function of temperature are listed in Tables 4 and 5, demonstrating that the fracture and the elastic variability of orthotropic materials like wood can be described by a two-parameter Weibull distribution (Redjel 2017). The disparities between the experimental points and the regression line can be attributed to microscopic defects within the internal structure of the tested samples. This disparity is even more pronounced for Ayous, likely due to the variability observed in moisture content measurements. According to (Redjel 2017), the size of these defects impacts the wood's strength and can initiate failure, contributing to the dispersion around the regression line. The Weibull modulus, indicating dispersion, ranges from 9.2057 to 15.621 for Ayous and from 3.409 to 6.1503 for Padouk. The fracture rate for Ayous aligns with the findings of (Talla et al. 2018). The lower range of Weibull modulus values for Padouk reflects a highly variable distribution of defects across samples, leading to the wide dispersion in experimental MOE measurements (Roy et al. 2011, Redjel 2017, Brito et al. 2023).



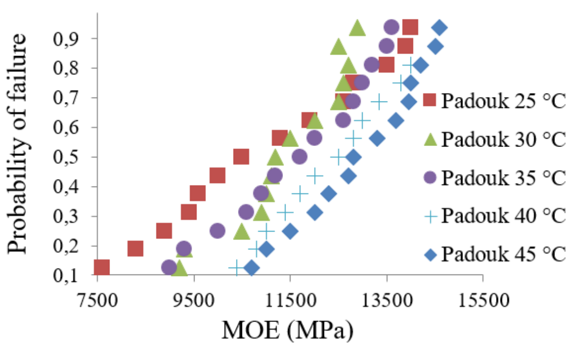


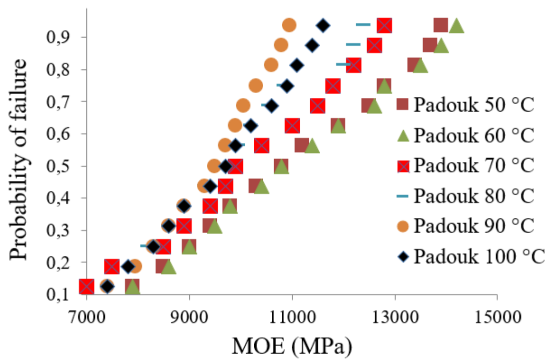
a. b.

Figure 13. Probability of failure of Padouk.

The higher Weibull modulus for Ayous compared to Padouk indicates less variability in dispersion among Ayous samples. For both species, the Weibull modulus is below 20, a reference value in the literature indicating variable dispersion across samples. These results clearly demonstrate that the fracture phenomenon in wood is random and can be effectively described by a two-parameter Weibull probabilistic model.

The evolution of the Weibull modulus m as a function of temperature (Figure 16) has also been plotted. The experimental points were fitted with a periodic moving-average function of order 2. Similar to the MOE, the distribution of m with respect to temperature appears random. Figure 17 shows the evolution of the Weibull modulus m as a function of the coefficient of variation C. The Brokenbrow and Macmillan fitting models were used to describe this evolution for the two species, Ayous and Padouk. The fit curves indicate that both mathematical models generally match the experimental data well. However, the Macmillan model struggles with certain experimental points, whereas the Brokenbrow model captures these data more accurately. The superior performance of the Brokenbrow model is due to a corrective factor introduced by Brokenbrow, which allows for a more precise description of the evolution of the Weibull modulus as a function of the coefficient of variation for Ayous and Padouk wood species. This result is consistent with findings by (Achouri et al. 2015, Achouri et al. 2022) in their work on composite materials.





a. b.

Figure 13. Probability of failure of Padouk.

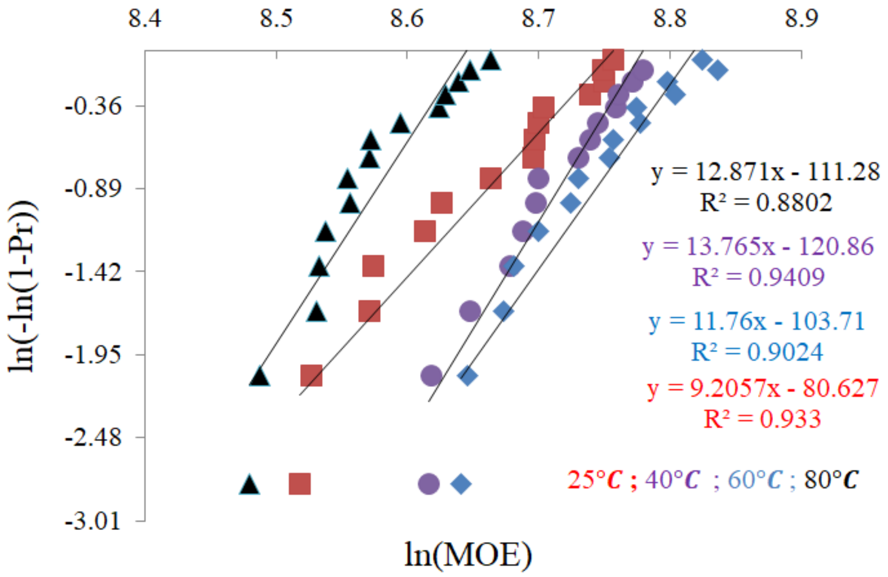


Figure 14. Determination of Weibull modulus of Ayous.

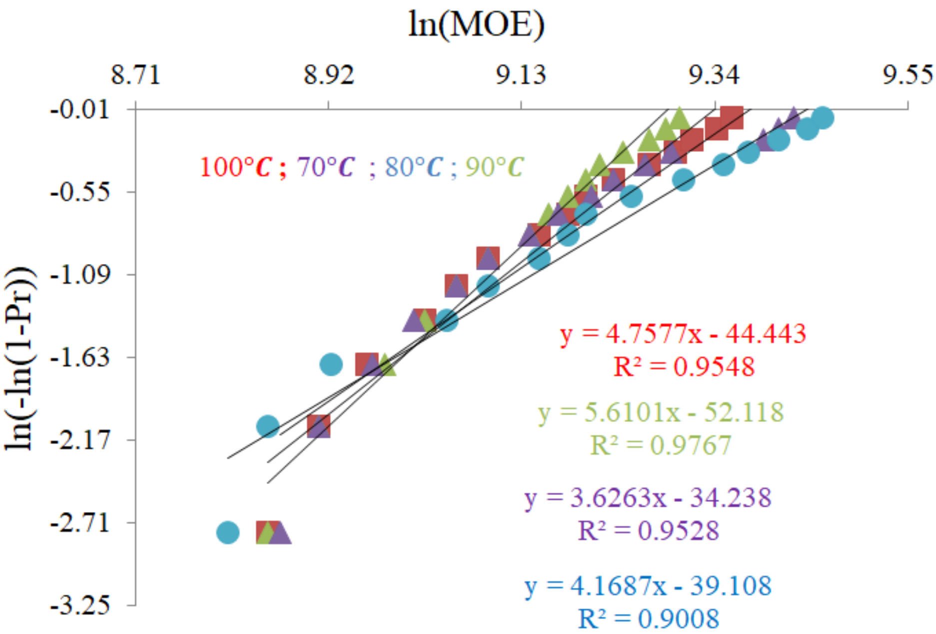
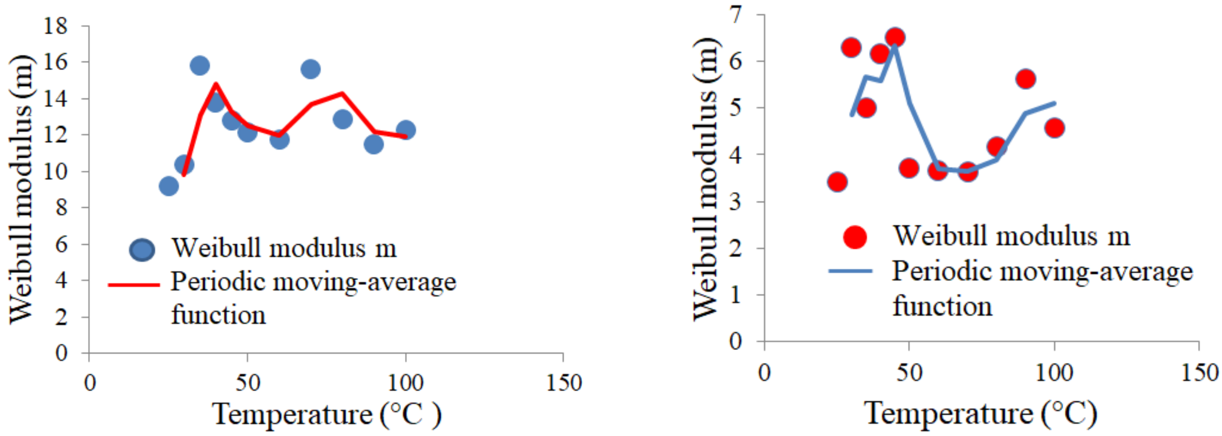
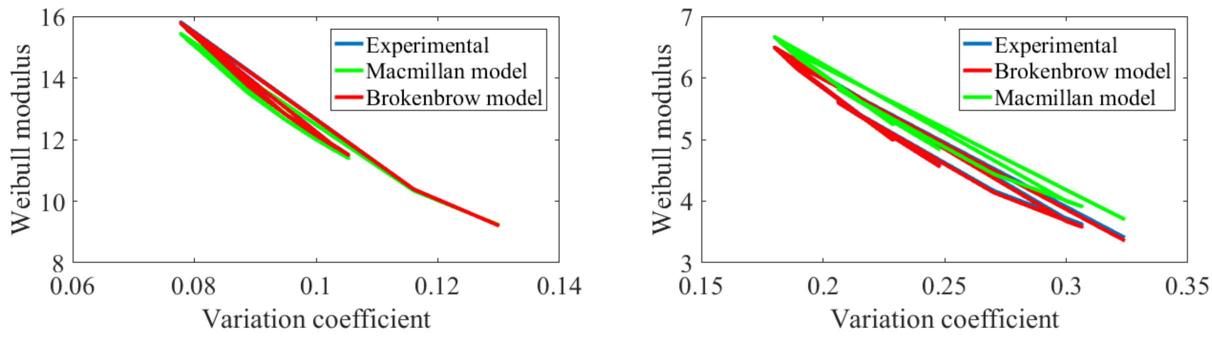


Figure 15. Determination of Weibull modulus of Padouk.



a. b.

Figure 16. Evolution of the Weibull modulus as a function of temperature.



a. b.

Figure 17. Analysis of the evolution of the Weibull modulus as a function of the coefficient of variation: a. Ayous; b. Padouk.

Table IV. Weibull parameters of Ayous.

Temperature (°C)	25	30	35	40	45	50	60	70	80	90	100
m	9.2	10.3	15.8	13.7	12.7	12.1	11.7	15.6	12.8	11.5	12.3
MOE_0 (MPa)	219.1	247.5	376.2	328.5	280.1	291.8	281.9	368.1	302.4	270.3	287.7
R^2	0.91	0.87	0.95	0.93	0.87	0.90	0.95	0.88	0.89	0.95	0.93
C	0.11	0.07	0.08	0.09	0.09	0.10	0.07	0.09	0.10	0.09	0.13

Table V. Weibull parameters of Padouk.

Temperature (°C)	25	30	35	40	45	50	60	70	80	90	100
M	3.4	6.2	5.0	6.1	6.5	3.7	3.6	3.6	4.1	5.6	4.5
MOE_0 (MPa)	88.2	161.3	129.5	159.9	169.4	96.0	95.0	93.0	106.3	141.6	120.8
R^2	0.94	0.93	0.96	0.94	0.97	0.93	0.92	0.95	0.95	0.90	0.95
C	0.18	0.22	0.18	0.18	0.3	0.3	0.3	0.27	0.2	0.24	0.32

Conclusion

This study investigates the thermo-elastic properties, including bending strength and longitudinal modulus, of Ayous (*Triplochiton scleroxylon*) and Padouk (*Pterocarpus soyauxii*) wood species through experimental tests conducted in static four-point bending. The investigation of the fracture phenomenon yielded several findings. Firstly, regarding bending strength, it was observed that between 25°C and 45°C, Ayous and Padouk require significant loads to fracture, with decreasing fracture loads observed above 45°C. Comparing the bending strength of Ayous and Padouk, Padouk exhibits greater resistance, demonstrating higher bending strength at equivalent temperatures. Secondly, experiments showed that the elastic modulus of both Padouk and Ayous increases between 25°C and 45°C, indicating increased rigidity and resistance to deformation under load. Conversely, above 45°C, the elastic modulus decreases. Lastly, the two-parameter Weibull distribution effectively describes the random nature of wood fracture. It was observed that Ayous has a higher Weibull modulus than Padouk, suggesting greater dispersion of microscopic fracture indicators in Ayous. However, both species exhibit Weibull moduli below 20, indicating variability in sample dispersion. Temperature exerted a significant influence on these probabilistic parameters, contributing to their random characteristics. A highly variable behavior was observed overall with temperature changes, given that the tested samples came from the same tree trunk and showed significant disparities in moisture content measurements. Future studies should increase sampling variation and investigate the effects of sample density and moisture content levels.

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