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RESEARCH ARTICLE

EFFECT OF LOADING TIME ON THE LINEAR VISCOELASTIC PARAMETERS OF BORASSUS AETHIOPUM MART

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Abstract

In the construction sector, wood proves to be an ecologically advantageous material. Its production requires less energy compared to other materials, making it highly beneficial for the environment. It is a natural material whose level of stress and loading duration can significantly influence its physical and mechanical characteristics. For a proper understanding of the instantaneous and delayed behavior of wood, it is essential to subject it to tests under various types of loading, especially in the short and long term. This study focuses on the delayed behavior of Borassus wood, conducting creep tests on suitable samples to analyze the effects of loading duration on its viscoelastic parameters. The creep test was carried out by uniformly subjecting the samples to two-point bending, with a load corresponding to 20% of the breaking load, for a period of 15 hours. The instantaneous deflection was recorded a few seconds after loading, then other deflections were recorded every 30 minutes until the end of the test. Based on the geometry of a deformed beam, the general expression of the longitudinal strain was established, allowing all strains to be calculated as a function of the recorded deflections. The linear viscoelastic parameters of Borassus were determined using the nonlinear least squares method for each observed loading time. Analysis of the results shows that the loading duration does not influence the dynamic viscosity modulus, whereas the elasticity modulus varies decreasingly from the shortest to the longest loading duration. The use of a power function made it possible to establish a relationship between the dynamic elasticity modulus and loading time, which could be used as a means of extrapolation for deformations.

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Introduction:-

Wood is among the materials that can be used in structures. It stands out as a particular natural resource since it is not only renewable, but its production does not require a large amount of energy, thus not propagating carbon dioxide into the atmosphere. Therefore, wood is an ecological material that has been used in the construction of large structures of various natures. Nowadays, it continues to be the subject of several studies in an effort to be exploited more judiciously, given that it is a material highly sensitive to the type and duration of loading to which it may be subjected. It is therefore imperative to know the reactions of wood towards each of the loading cases, namely short, medium, or long-term loading. It is thus necessary to conduct tests on the material, which in this case is Borassus wood, in order to get an idea about the trend of deformations over time. Previous studies have shown that the deferred behavior of wood falls within the viscoelastic domain. Therefore, creep tests by bending were carried out on samples of borassus wood with the aim of identifying in the first instance its linear viscoelastic parameters, namely the dynamic elasticity modulus and the dynamic viscosity constant, and then to analyze the effects of loading duration on said determined parameters. The study has opted for the creep test since it is the most commonly used for studying the deferred behavior of wood, given the ease in the procedure with a non-complex device, as well as the consistency of relations between deflections, deformations, and the geometric characteristics of the sample.

To highlight the viscoelasticity of wood through a creep test, the degree of solicitation of the specimen must remain low under constant loading. The determination of the linearity domain of wood has been the subject of several studies that have led to convergent results. These are studies conducted by Kingston and Clarke[1], Nakai and Grossman [2], andMukudai[3], as reported by Montero[4], through which it appears that linear viscoelasticity of wood is verified for a loading rate less than 40% of the breaking load.

In 1986, Foudjet[5]also studied the linearity of the viscoelastic behavior of wood through creep tests on four tropical species (Azobé, Tali, Sapelli, and Movingui) with a humidity rate of 12%. According to his studies, it turns out that linearity is proven for loading stresses lower than 35% of the breaking strength.

According to Randriambololona[6], the limit of linearity of the viscoelastic behavior of wood is related to the type of stress and is between 10% and 20% of ultimate tensile strength for a compression test, and it is between 20% and 30% of the maximum tensile strength for the creep test in bending or traction.

In his work in 2006, Placet[7]also emphasized that temperature, humidity, and duration of load, related to the polymeric nature of wood constituents, have a significant influence on its viscoelastic behavior. He thus revealed that the behavior of a viscoelastic material at a higher temperature for short loading times is equivalent to that of the same material at a lower temperature, but for longer loading durations. This is the principle of time-temperature equivalence or also the principle of hourly temperature superposition.

In Montero's paper[8], it appears that when the water content is below the fiber saturation point, it influences the viscoelastic behavior at two levels: the evolution of kinetics and the mechanosorptive effect due to the viscosity of the wood that depends on its water content but is also very sensitive to changes in water content. Thus, the viscoelastic compliance is seven times higher for wet creep (humidity of 22%) than for dry creep (humidity of 0.5%).

Regarding the phenomenon of mechanosorption, the first works were published in 1960 by Armstrong and Kingstonemphasizing the influence of the variation of wood's humidity on its deferred behavior. During bending tests, they compare the creep of wood samples kept at constant humidity to that which can dry during the test. The results of these tests show that the creep of these samples is at least twice as high as those kept at constant humidity. A year later, Armstrong and Christensen[9], detailing the previous studies, indicated that this increase depends on the rate of sorption and not on the humidity of the loaded sample. These results on mechanosorption have paved the way for other studies, notably those by Randriambololona[6]devoted to modeling the deferred behavior of wood in a variable environment.

The mechanical behavior of wood is most often modeled by the viscoelastic model. The viscoelastic model is by far the most used to model the mechanical behavior of wood. In fact, linear viscoelastic behavior is generally represented by building a model consisting of an assembly of springs and dampers. It is therefore an analog and symbolic model represented by a combination of more or less complex series and parallel springs and dampers[5,7].

In the works of Haque et al.[10], devoted to comparing the relevance of these different models with an empirical model based on the equation of the empirical Bailer-Norton model, it was found that the Kelvin model seems to be the best suited to interpolate the experimental curves[11,12]. Thus, several authors have adopted the Kelvin model, or more precisely the series connection of n Kelvin elements, to restore the viscoelastic behavior of wood during a creep test. However, the identification of problems quickly becomes insoluble as at least as many coefficients as elements introduced must be determined, which may be impractical, especially in practice, since these parameters depend strongly on humidity and temperature. In this context, Foudjet[5]presented a rheological model with a maximum of two (2) Kelvin-Voigt elements connected in series, which was largely sufficient to represent the linear viscoelastic behavior of wood.

Other studies conducted on the linear viscoelastic behavior of polymers have shown that the creep compliance J(t) is only a function of time and not the magnitude of stress and strains[13–15], and the deformation (stress) depends on the applied stress[15,16].

Considering the results obtained by these previous works, the studies published by Michozounnou et al.[17]were devoted to the identification of linear viscoelastic parameters of Borassus Aethiopum Mart at a humidity of 12% and maintained constant, under a constant applied load throughout the test period.

The aim of this study is to determine the mechanism to take into account to consider the effect of loading duration on the design of a wooden structure in the linear viscoelastic zone, and not just in the elastic zone, as has been done until now. More specifically, it is a matter of studying the influence of loading duration on the linear viscoelastic parameters, with the humidity of the wood and the applied load maintained constant throughout the creep test. The study also aims to model the behavior of each parameter as a function of the loading duration, in order to extrapolate the creep or deformation values, identify a model to predict the mechanical failure of a structural element, and develop an appropriate method to extrapolate the longitudinal deformation values.

To achieve these objectives, the parameter identification approach described in Michozounnou et al.[18]wasused.

Materials and Methods:-

The test specimens designed for the creep tests were taken from the outer crown of the Borassus logs in the longitudinal direction. Thus, nine (09) specimens were made in accordance with the configuration presented in Figure 1, in order to carry out the test.

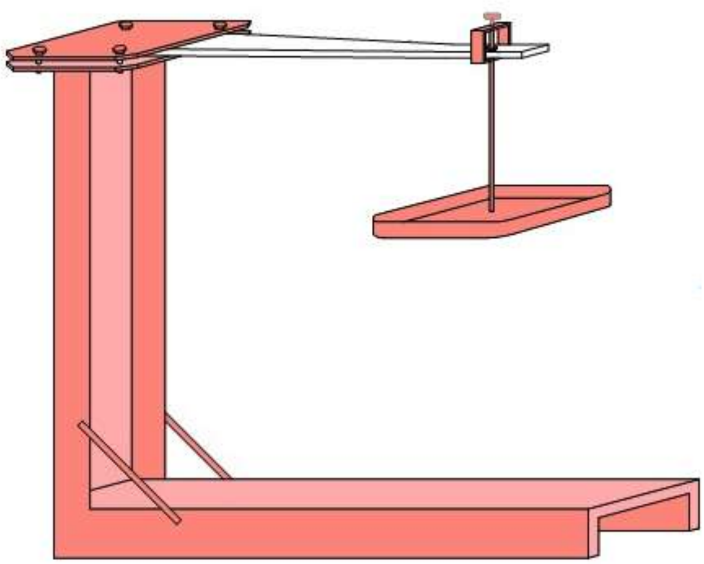

Fig. 1:- Configuration of the specimens.

The cut samples have the shape of a beam subjected in all its sections. The experimental specimens were dried to 12% moisture in a modern dryer, adhering to the normal conditions of temperature, pressure, and drying. They were then carefully wrapped in aluminum foil to keep their water content under control.

The bending creep test consisted of subjecting the sample to a two-point bending test. The samples are embedded at one end, and 20% of the breaking load in bending, or 18.90 MPa, was applied to the other end. This load is applied at 300 mm from the other end of the beam, as illustrated in Figure 2.

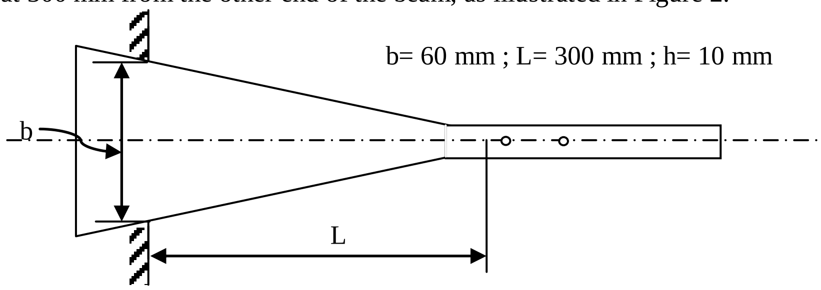

Fig. 2:- Experimental device for bending creep test.

The creep tests were carried out over a total duration of 15 hours. Deflections were measured using a comparator with an accuracy of 1/100 mm every 30 minutes at mid-span of the beam, after measuring the instantaneous deflection. The data were processed considering 14 periods: (0-2 h), (0-3 h), (0-4 h), (0-5 h), (0-6 h), (0-7 h), (0-8 h) (0-9 h), (0-10 h), (0-11 h), (0-12 h), (0-13 h), (0-14 h) et (0-15 h). Each period represents an observation window.

The samples were weighed at the beginning and the end of the creep test. The temperature is kept constant during handling. The recorded deflections were converted into longitudinal strain using the following formula:

$$\varepsilon = 4h \frac{f}{f^2+L^2} \frac{\sigma_{ut}\sigma_{uc}}{(\sigma_{ut}+\sigma_{uc})^2} \quad (1)$$

Where:

σ_{uc}: ultimate compressive stress(MPa) ; f : Beam deflection (mm)

σ_{ut}: ultimatetensile stress (MPa) ; L: Beam span (mm)

h: Beam height (mm)

These strains were used to calculate the creep compliance, J(t), using the formula derived from Foudjet[5]:

$$J(t) = \frac{\varepsilon}{\sigma_0} \quad (2)$$

Where:

$\varepsilon$is the strain calculated using equation (1),

$\sigma_0$corresponds to the test load.

The compliance to creep J(t) is the sum of the instantaneous creep compliance J(τ) and the linear viscoelastic creep compliance J(t>τ) with τ, the time at which the instantaneous strain is read (τ = 15 seconds).

The mathematical expression for creep compliance is in the form [5,19,20]:

$$J(t) = \frac{\varepsilon(t)}{\sigma_0} = \frac{1}{E_0} + \frac{1}{E}\left(1 - \exp\left(-\frac{E}{\eta}t\right)\right) \quad (3)$$

Equation 4 is derived from the Zener rheological model. This model is the series combination of a spring characterizing the instantaneous deformation and the Kelvin-Voigt model representing the wood's inherent creep in the linear viscoelastic domain.

In this expression, E_0 represents Hooke's modulus of elasticity; E stands for the dynamic elasticity modulus of the spring, and η is the dynamic viscosity modulus of the damper. For identification, the following equations are used:

$$J(t) = \frac{1}{E_0} \quad (4)$$

Et

$$J(t) = \frac{1}{E}\left(1 - \exp\left(-\frac{E}{\eta}t\right)\right), \quad \text{avec} \; t > \tau \quad (5)$$

For each observation window, the optimal values of 'E' and 'η' of the expression for creep compliance in the linear viscoelastic field, as described by equation (5), are determined by adjusting them using the nonlinear least squares method, as described in Michozounnou et al[18]. The specific creep compliance is calculated using equation (2), taking into account the delayed deformation.

For a better analysis of data in a purely linear viscoelastic field, a change of basis is made when the origin is located at (0, 0) and the starting point of the experience is now at (-τ; -j(τ)) new coordinate system. This change allows considering the period of reading the instantaneous deformation characterizing the purely elastic range.

The mathematical model for predicting the evolution of the dynamic elasticity modulus as a function of loading duration was established using the least squares method, and the fitting equation deduced from the experimental curves can be expressed as follows [18,20,21]:

$E(t) = at^b \text{Witha} > 0 \,; b < 0 \text{ and} t > 0$ (6)

$E(t) = ae^{bt} \text{Witha} > 0; b < 0 \text{ and} t > 0$ (7)

The quality of each fit will be characterized by the determination coefficient and the normality of the residues[22]. Then, using the determination coefficient, the study will determine the optimal observation window.

In order to highlight the species, Borassus, which has better linear viscoelastic parameters, an analysis of its linear viscoelastic compliance curve was performed.

The tests were carried out on a male species from the Republic of Benin, the Borassus Aethiopum Mart, coming from the Pahou-Ahozon gallery forest in southern Benin. The Borassus was cut down, sawn, and reduced to planks; then, after these various stages, the obtained palm planks were dried at the ATC wood company in Allada at a moisture content of 12%. Finally, the plant material was transported to the Coulibaly Technical High School's wood workshop in Cotonou, where it was machined into standardized specimens.

Results and Discussions:-

Relevant Evaluation of Wood Behavior in a Creep Bending Test

The characterization of various mechanical behaviors of wood is conducted through creep and relaxation tests. The optimal values of “E” and “η” along with the corresponding coefficient of determination (R^2), which indicates the reliability of the simulated model, are presented in Table 1.

Table 1 reveals that the coefficient of determination (R^2) of linear viscoelastic models decreases with increasing loading duration, reaching a minimum value of 89.9% for a 15-hour duration. Beyond this duration, no significant deformation is observed. This variation of the determination coefficient is due to the behavior of different parameters in the linear viscoelastic model of the Kelvin-Voigt rheological model. Thus, the results indicate that the analysis of the linear viscoelastic behavior of wood to characterize its creep is effectively performed by adopting the Kelvin-Voigt rheological model.

Table 1:- Determination of linear viscoelastic parameters "E" and "η"

Loading Duration (hours)	**Data**		
	E (MPa)	**η (MPa.s)**	**Coefficient of determination R^2**
2	1.531E+05	5.700E+06	97.97%
3	1.439E+05	5.700E+06	97.74%
4	1.387E+05	5.700E+06	97.49%
5	1.351E+05	5.700E+06	97.54%
6	1.322E+05	5.700E+06	97.53%
7	1.300E+05	5.700E+06	97.46%
8	1.282E+05	5.700E+06	97.29%
9	1.264E+05	5.700E+06	96.97%
10	1.249E+05	5.700E+06	96.42%
11	1.237E+05	5.700E+06	95.55%
12	1.225E+05	5.700E+06	94.20%
13	1.214E+05	5.700E+06	92.32%
14	1.204E+05	5.700E+06	90.46%

15	1.200E+05	5.700E+06	89.90%

Table 2:- Values of standardized residuals (di) by loading duration.

Ordre	**Durées de chargement**													
	2 h	**3 h**	**4 h**	**5 h**	**6 h**	**7 h**	**8 h**	**9 h**	**10 h**	**11 h**	**12 h**	**13 h**	**14 h**	**15 h**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	-4.372	-3.475	-3.053	-2.878	-2.821	-2.804	-2.803	-2.79	-2.758	-2.705	-2.621	-2.5	-2.373	-2.311
3	-0.819	-0.651	-0.572	-0.539	-0.529	-0.526	-0.525	-0.523	-0.517	-0.507	-0.491	-0.469	-0.445	-0.433
4	1.497	1.19	1.045	0.986	0.966	0.96	0.96	0.955	0.944	0.926	0.897	0.856	0.813	0.791
5	2.444	1.943	1.707	1.609	1.577	1.568	1.567	1.56	1.542	1.513	1.465	1.398	1.327	1.292
6		2.235	1.963	1.851	1.814	1.804	1.803	1.795	1.774	1.74	1.686	1.608	1.526	1.486
7		2.304	2.024	1.908	1.87	1.859	1.858	1.85	1.829	1.793	1.738	1.658	1.573	1.532
8			1.89	1.782	1.746	1.736	1.735	1.727	1.708	1.675	1.623	1.548	1.469	1.431
9			1.681	1.585	1.553	1.544	1.543	1.536	1.519	1.489	1.443	1.377	1.307	1.273
10				1.368	1.34	1.332	1.332	1.326	1.311	1.285	1.245	1.188	1.128	1.098
11				1.114	1.092	1.085	1.085	1.08	1.067	1.047	1.014	0.968	0.918	0.894
12					0.841	0.836	0.835	0.832	0.822	0.806	0.781	0.745	0.707	0.689
13					0.63	0.627	0.626	0.623	0.616	0.604	0.586	0.559	0.53	0.516
14						0.474	0.474	0.472	0.467	0.458	0.443	0.423	0.401	0.391
15						0.319	0.319	0.318	0.314	0.308	0.298	0.285	0.27	0.263
16							0.153	0.152	0.15	0.147	0.143	0.136	0.129	0.126
17							0.055	0.055	0.054	0.053	0.052	0.049	0.047	0.046
18								-0.268	-0.265	-0.26	-0.252	-0.241	-0.228	-0.222
19								-0.425	-0.42	-0.412	-0.399	-0.381	-0.361	-0.352
20									-0.42	-0.412	-0.399	-0.381	-0.361	-0.352
21									-0.681	-0.668	-0.647	-0.618	-0.586	-0.571
22										-0.706	-0.684	-0.653	-0.62	-0.604

23										-0.754	-0.731	-0.697	-0.662	-0.644
24											-0.804	-0.767	-0.728	-0.709
25											-1.304	-0.986	-0.936	-0.912
26												-1.082	-1.027	-1.001
27												-1.161	-1.102	-1.073
28													-1.161	-1.13
29													-1.194	-1.163
30														-1.203

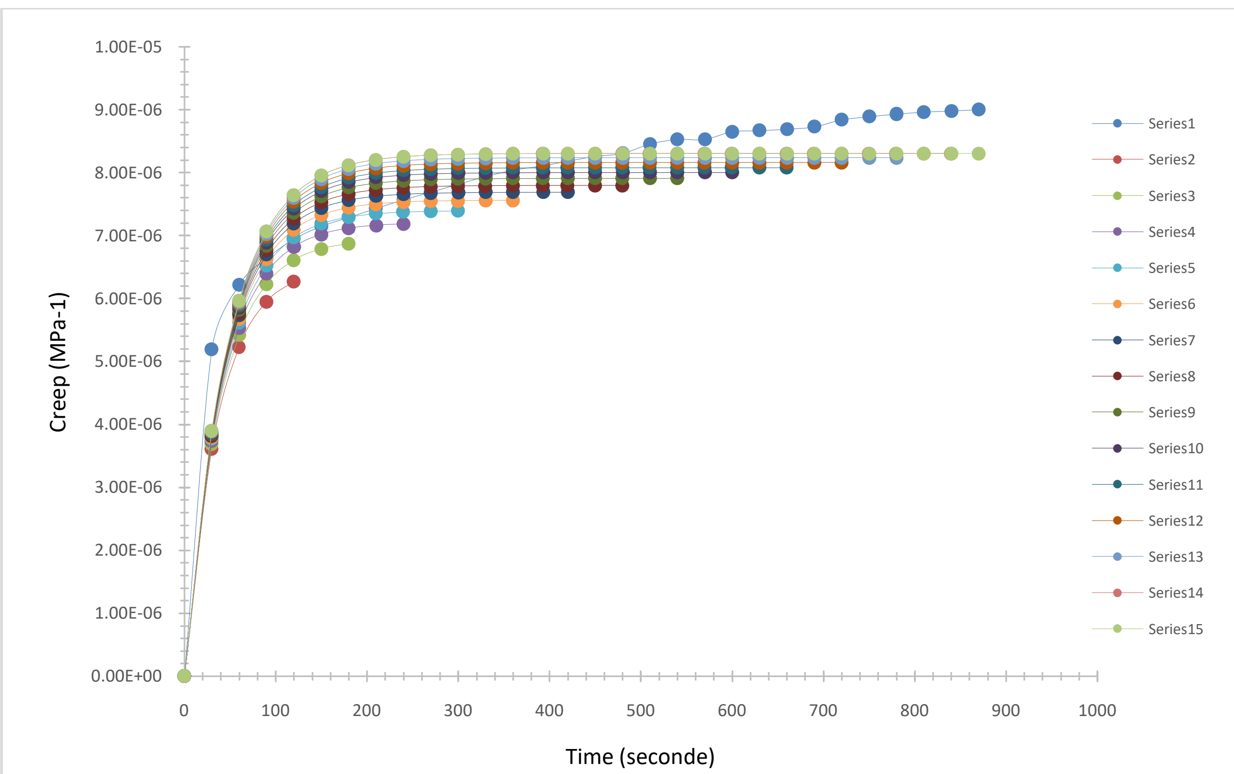

Fig. 3:- Curves of different models and experimental values.

Figure 3 shows the curves of different models and experimental values.

Stability of the Dynamic Viscosity Modulus

According to the data presented in Table 1, the dynamic viscosity modulus of Borassus Aethiopum Mart appears constant across all examined loading durations. These results agree with the notion that the viscosity of a material reflects the internal frictions produced during the movement of atoms at the microscopic scale[23]. The constancy of this phenomenon can be attributed to the fact that the temperature was kept constant during the experimentation, thereby eliminating any potential disturbance in the behavior of atomic constituents.

Correlation Between Loading Duration and Dynamic Elasticity Modulus

The dynamic elasticity modulus exhibits a systematic decrease as the loading duration increases, as illustrated in Figure 4. These observations are consistent with the findings by Gardelle[24], who demonstrated that wood material is sensitive to loading duration. Under constant load, the rigidity of the wood decreases over time, resulting in increased deformation. This loss of strength, attributed to the elastic behavior of wood, is accompanied by a reduction of stress within the material. This trend is analogous to what is observed with certain polymers, whose mechanical properties are influenced not only by the duration of the load but also by temperature[4,11].The decrease in the dynamic elasticity modulus can be attributed to the movements of macromolecules making up the wood. These movements induce a viscous behavior, one of the consequences being increased sensitivity of mechanical properties to the duration and speed of load application. For example, a more extended application time may result in more significant deformation and, therefore, a reduced elasticity modulus[25].

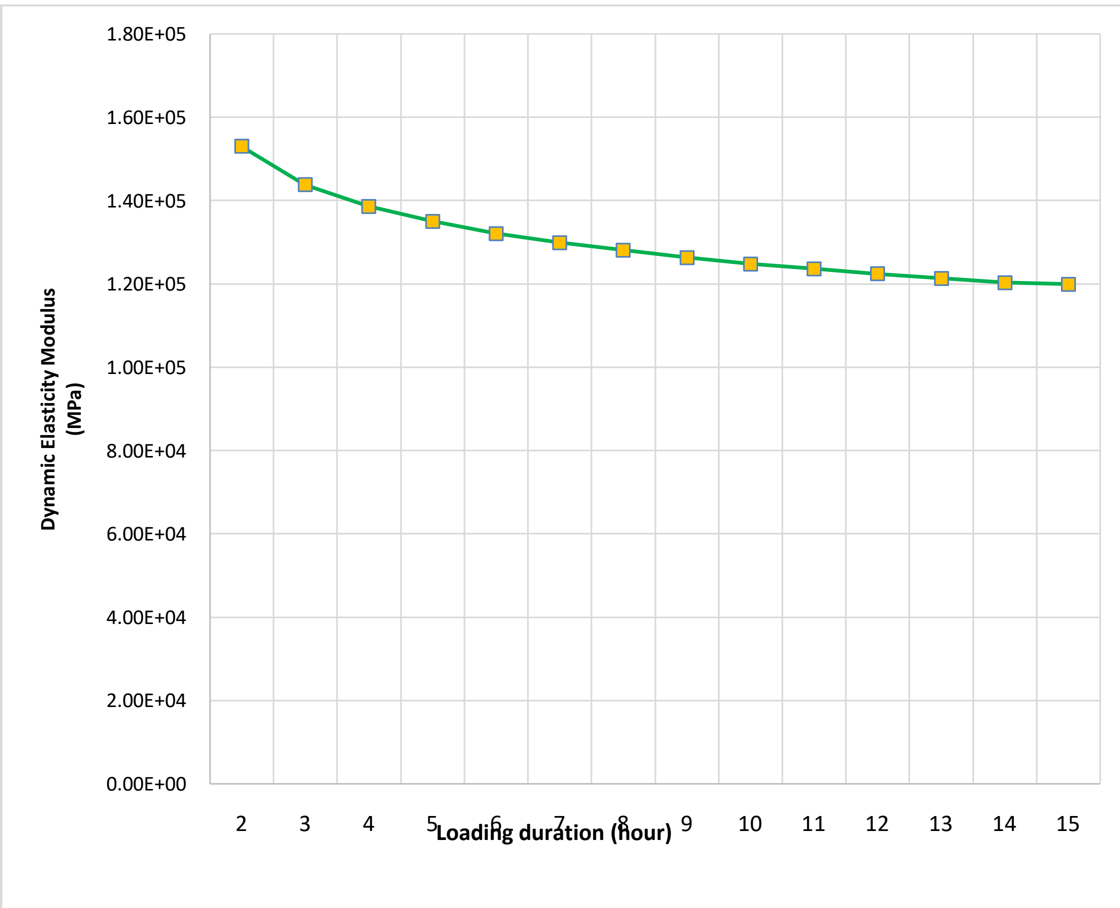

Fig. 4:- Evolution of the dynamic elasticity modulus as a function of loading duration.

Modeling the Correlation Between Loading Duration and Dynamic Elasticity Modulus

The values of the coefficients “a” and “b” of each function are indicated in Table 3.

Table 3:- Values of coefficients of the models.

Model	**Coefficient**	
Power function	a	145689

$E(t) = at^b$	b	-0.07
Exponential function	a	153126
$E(t) = ae^{bt}$	b	-0.016

Figure 5 shows the experimental curve and the modeled curves.

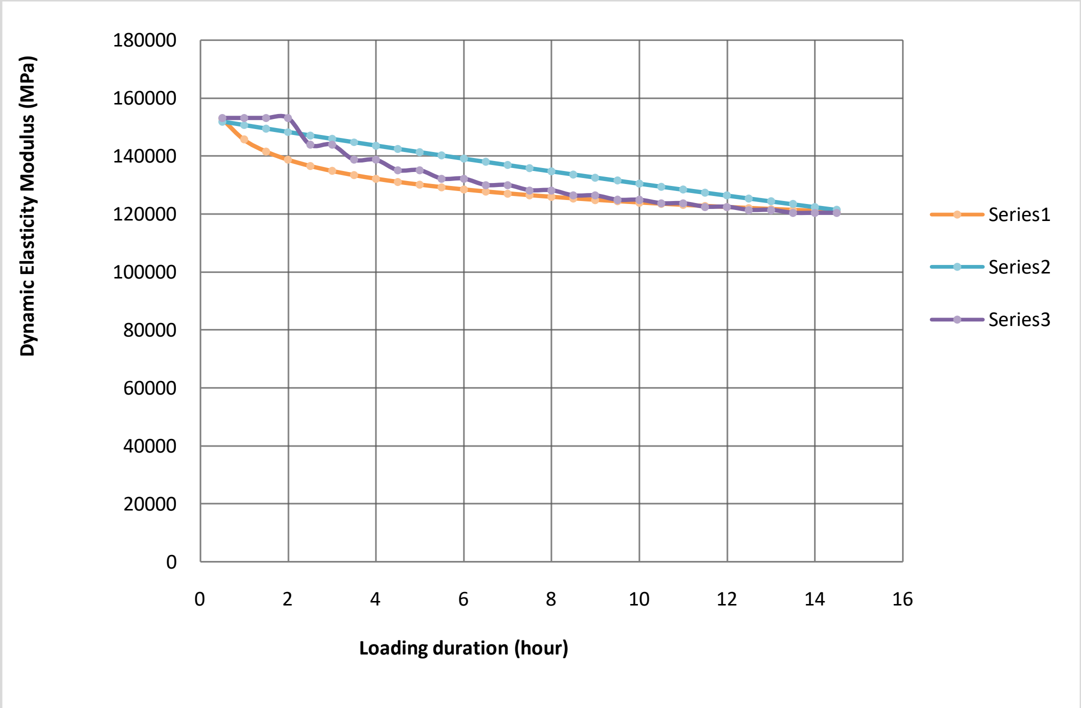

Fig. 5:- Curves of the dynamic elasticity modulus as a function of loading duration.

The coefficient of determination is calculated from equation (8) as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} ei^2}{\sum_{i=1}^{n} di^2} (8)$$

The different coefficient of determination values for each model are presented in Table 4.

Table 4:- Coefficient of determination for the models.

Model	**Coefficient of determination**
Power function	89.81%
Exponentialfunction	89.64%

Next, the results show that at least 85% of the observation values are explained regardless of the model used. Tables 5 and 6, which provide details on the calculations, indicate that 97% of the standardized residuals$d_i = \frac{e_i}{\sqrt{\hat{\sigma}^2}}$fall within the range [−2, +2]. This proportion is significantly higher than the recommended value (95%)[20], confirming that the residuals are normally distributed.

Table 5:- Details of model fit calculation, exponential model case.

y_{exp}	Y_{cal}	$e_i = y_{exp} - Y_{cal}$	e_i^2	$d = Y_{cal} - \bar{y}_{exp}$	d^2	d_i
0.000E+00	0.000E+00	0.000E+00	0.000E+00	-7.756E-06	6.015E-11	0.000
5.191E-06	3.889E-06	-1.302E-06	1.695E-12	-3.867E-06	1.495E-11	-2.305
6.219E-06	5.942E-06	-2.770E-07	7.671E-14	-1.814E-06	3.292E-12	-0.490
6.639E-06	7.025E-06	3.860E-07	1.490E-13	-7.309E-07	5.343E-13	0.683
6.946E-06	7.597E-06	6.504E-07	4.231E-13	-1.592E-07	2.533E-14	1.151
7.150E-06	7.899E-06	7.486E-07	5.603E-13	1.426E-07	2.034E-14	1.325
7.290E-06	8.058E-06	7.675E-07	5.890E-13	3.019E-07	9.114E-14	1.358
7.435E-06	8.142E-06	7.067E-07	4.994E-13	3.860E-07	1.490E-13	1.251
7.570E-06	8.186E-06	6.159E-07	3.794E-13	4.303E-07	1.852E-13	1.090

7.693E-06	8.210E-06	5.171E-07	2.674E-13	4.537E-07	2.059E-13	0.915
7.819E-06	8.222E-06	4.026E-07	1.621E-13	4.661E-07	2.172E-13	0.713
7.941E-06	8.229E-06	2.874E-07	8.260E-14	4.726E-07	2.234E-13	0.509
8.041E-06	8.232E-06	1.909E-07	3.645E-14	4.761E-07	2.266E-13	0.338
8.113E-06	8.234E-06	1.208E-07	1.459E-14	4.780E-07	2.285E-13	0.214
8.185E-06	8.235E-06	4.943E-08	2.443E-15	4.788E-07	2.293E-13	0.087
8.262E-06	8.235E-06	-2.721E-08	7.403E-16	4.793E-07	2.298E-13	-0.048
8.308E-06	8.236E-06	-7.202E-08	5.186E-15	4.796E-07	2.300E-13	-0.127
8.457E-06	8.236E-06	-2.215E-07	4.905E-14	4.798E-07	2.302E-13	-0.392
8.530E-06	8.236E-06	-2.938E-07	8.632E-14	4.798E-07	2.302E-13	-0.520
8.530E-06	8.236E-06	-2.938E-07	8.629E-14	4.799E-07	2.303E-13	-0.520
8.652E-06	8.236E-06	-4.159E-07	1.730E-13	4.799E-07	2.303E-13	-0.736
8.670E-06	8.236E-06	-4.341E-07	1.885E-13	4.799E-07	2.303E-13	-0.768
8.693E-06	8.236E-06	-4.568E-07	2.087E-13	4.799E-07	2.303E-13	-0.809
8.729E-06	8.236E-06	-4.928E-07	2.428E-13	4.799E-07	2.303E-13	-0.872
8.842E-06	8.236E-06	-6.059E-07	3.671E-13	4.799E-07	2.303E-13	-1.072
8.891E-06	8.236E-06	-6.556E-07	4.298E-13	4.799E-07	2.303E-13	-1.160
8.932E-06	8.236E-06	-6.961E-07	4.846E-13	4.799E-07	2.303E-13	-1.232
8.964E-06	8.236E-06	-7.279E-07	5.299E-13	4.799E-07	2.303E-13	-1.289
8.982E-06	8.236E-06	-7.459E-07	5.564E-13	4.799E-07	2.303E-13	-1.320
9.004E-06	8.236E-06	-7.686E-07	5.907E-13	4.799E-07	2.303E-13	-1.360

Where,
y_{exp}: creep value obtained experimentally;
Y_{cal}: creep value calculated using the model;
$\bar{y}_{exp}$: means of sample observations
$d_i = \frac{e_i}{\sqrt{\hat{\sigma}^2}}$: standardized residual;
$\hat{\sigma}^2$: variance

Table 6:- Details of model fit calculation, power model case.

y_{exp}	Y_{cal}	$e_i = y_{exp} - Y_{cal}$	e_i^2	$d = Y_{cal} - \bar{y}_{exp}$	d^2	d_i
0.000E+00	0.000E+00	0.000E+00	0.000E+00	-7.756E-06	6.015E-11	0.000E+00
5.191E-06	3.895E-06	-1.296E-06	1.681E-12	-3.861E-06	1.491E-11	-2.315
6.219E-06	5.957E-06	-2.620E-07	6.865E-14	-1.799E-06	3.238E-12	-0.468
6.639E-06	7.048E-06	4.094E-07	1.676E-13	-7.075E-07	5.006E-13	0.731
6.946E-06	7.626E-06	6.801E-07	4.626E-13	-1.295E-07	1.676E-14	1.214
7.150E-06	7.933E-06	7.826E-07	6.124E-13	1.766E-07	3.119E-14	1.397
7.290E-06	8.095E-06	8.042E-07	6.468E-13	3.387E-07	1.147E-13	1.436
7.435E-06	8.180E-06	7.452E-07	5.554E-13	4.245E-07	1.802E-13	1.331
7.570E-06	8.226E-06	6.555E-07	4.297E-13	4.699E-07	2.208E-13	1.170
7.693E-06	8.250E-06	5.573E-07	3.106E-13	4.939E-07	2.440E-13	0.995
7.819E-06	8.263E-06	4.432E-07	1.964E-13	5.067E-07	2.567E-13	0.791
7.941E-06	8.269E-06	3.282E-07	1.077E-13	5.134E-07	2.636E-13	0.586
8.041E-06	8.273E-06	2.319E-07	5.376E-14	5.170E-07	2.673E-13	0.414
8.113E-06	8.275E-06	1.618E-07	2.618E-14	5.190E-07	2.694E-13	0.289
8.185E-06	8.276E-06	9.047E-08	8.185E-15	5.199E-07	2.703E-13	0.162
8.262E-06	8.276E-06	1.386E-08	1.920E-16	5.204E-07	2.708E-13	0.025
8.308E-06	8.277E-06	-3.094E-08	9.571E-16	5.207E-07	2.711E-13	-0.055
8.457E-06	8.277E-06	-1.804E-07	3.254E-14	5.208E-07	2.713E-13	-0.322
8.530E-06	8.277E-06	-2.527E-07	6.386E-14	5.209E-07	2.714E-13	-0.451
8.530E-06	8.277E-06	-2.527E-07	6.384E-14	5.210E-07	2.714E-13	-0.451
8.652E-06	8.277E-06	-3.748E-07	1.405E-13	5.210E-07	2.714E-13	-0.669
8.670E-06	8.277E-06	-3.930E-07	1.545E-13	5.210E-07	2.714E-13	-0.702
8.693E-06	8.277E-06	-4.157E-07	1.728E-13	5.210E-07	2.714E-13	-0.742

8.729E-06	8.277E-06	-4.517E-07	2.040E-13	5.210E-07	2.714E-13	-0.806
8.842E-06	8.277E-06	-5.648E-07	3.190E-13	5.210E-07	2.714E-13	-1.008
8.891E-06	8.277E-06	-6.145E-07	3.776E-13	5.210E-07	2.714E-13	-1.097
8.932E-06	8.277E-06	-6.550E-07	4.291E-13	5.210E-07	2.714E-13	-1.170
8.964E-06	8.277E-06	-6.868E-07	4.718E-13	5.210E-07	2.714E-13	-1.226
8.982E-06	8.277E-06	-7.048E-07	4.968E-13	5.210E-07	2.714E-13	-1.258
9.004E-06	8.277E-06	-7.275E-07	5.292E-13	5.210E-07	2.714E-13	-1.299

Where,
y_{exp}: creep value obtained experimentally;
Y_{cal}: creep value calculated using the model;
$\bar{y}_{exp}$: means of sample observations
$d_i = \frac{e_i}{\sqrt{\hat{\sigma}^2}}$: standardized residual; $\hat{\sigma}^2$: variance

From these results, the "power" model appears more suitable than the "exponential" model, although thermodynamically inappropriate. This preference is explained by the fact that the power model is more sensitive to uncertainties on points than the exponential law[26]. The power law or the parabolic model should also fit perfectly into the modeling of linear viscoelastic parameters[7].The dynamic elasticity module values can be adjusted according to this model to find the best extrapolated values when predicting deformation of wood structures in the linear viscoelastic area.

Validity of the extension method: extrapolation of creep values

The performance analysis of the extension models studied shows the relevance of using a global model for the evolution of linear viscoelastic parameters as a function of loading duration, rather than constant parameter models adjusted by time slots.
Values can be summarized as follows:
y_{exp}: creep value obtained experimentally;
$Y_{cal,2h}$;: creep value calculated using the 2h model;
$Y_{cal,power}$; $Y_{cal,expo}$: creep value calculated using power or exponential models;
e: relative difference between calculated values and experimental values, and calculated using the following equation:

$$e = \frac{y_{exp} - Y_{cal}}{y_{exp}} \qquad (9)$$

Table 7 below presents the different evaluation indicators during the examination of the models, based on the data collected with a loading time of 2 hours.
Table 7:-Implementationdetailcalculations.

Duration (h)	y_{exp}	$Y_{cal,2h}$	e	$Y_{cal,power}$	e	$Y_{cal,expo}$	e
1	6.219E-06	5.228E-06	16%	5.957E-06	4%	5.942E-06	4%
2	6.946E-06	6.272E-06	10%	7.626E-06	-10%	7.597E-06	-9%
3	7.290E-06	6.480E-06	11%	8.095E-06	-11%	8.058E-06	-11%
4	7.570E-06	6.521E-06	14%	8.226E-06	-9%	8.186E-06	-8%
5	7.819E-06	6.530E-06	17%	8.263E-06	-6%	8.222E-06	-5%
6	8.041E-06	6.531E-06	19%	8.273E-06	-3%	8.232E-06	-2%
7	8.185E-06	6.532E-06	21%	8.276E-06	-1%	8.235E-06	-1%
8	8.308E-06	6.532E-06	22%	8.277E-06	0%	8.236E-06	1%
9	8.530E-06	6.532E-06	24%	8.277E-06	3%	8.236E-06	3%
10	8.652E-06	6.532E-06	25%	8.277E-06	4%	8.236E-06	5%
11	8.693E-06	6.532E-06	25%	8.277E-06	5%	8.236E-06	5%
12	8.842E-06	6.532E-06	27%	8.277E-06	6%	8.236E-06	7%
13	8.932E-06	6.532E-06	27%	8.277E-06	7%	8.236E-06	8%
14	8.982E-06	6.532E-06	28%	8.277E-06	8%	8.236E-06	8%
15	9.004E-06	6.532E-06	28%	8.277E-06	8%	8.236E-06	9%

The performance analysis of the extension models reveals that the extended values are closer to the experimental values than the other values calculated from models established according to the loading duration (for each observation window).

In Table 7, it is noticeable that the extended values calculated using the power model and exponential model are closer to the experimental values than the values directly calculated from the 2-hour model.

Conclusion:-

This study has focused on the influence of loading duration on the linear viscoelastic parameters of wood. Carefully cut samples of Borassus Aethiopum Mart were subjected to a creep test in bending. From these tests, a mathematical model was established to predict the evolution of the dynamic elasticity modulus as a function of loading duration, using the least squares method.

The study's results revealed that the dynamic viscosity modulus remains constant despite increasing loading durations. However, the dynamic elasticity modulus decreases according to the power function $E(t) = at^b$ where $a > 0$; $b < 0$ and $t > 0$ as well as according to the exponential function $E(t) = ae^{bt}$ with $a > 0$; $b < 0$ and $t \geq 0$. Each of these laws creates a bundle that tends to zero when the loading time is relatively long. However, the power function proved to be more suitable for describing this phenomenon.

Furthermore, the study demonstrated that it is possible to characterize the free creep of wood by assessing its linear viscoelastic behavior. The adoption of the Kelvin-Voigt rheological model for creep tests in bending proved to be effective, especially when performed within a maximum loading duration of 15 hours.

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Conflicts of Interest

The authors declare that there are no conflicts of interest that could inappropriately influence, or be perceived to influence, the work reported in this manuscript.

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