American Journal of Materials Research
2019; 6(2): 11-20
http://www.aascit.org/journal/ajmr
ISSN: 2375-3919

American Association for Science and Technology

Contribution to the Study of Variations of Physical Properties of *Pericopsis elata* with Respect to Different Stages of Growth

Fouotsa Woutsop Christian Martial[1, 3], Foadieng Emmanuel[1, 2, 3, *], Mtopi Fotso Blaise Eugene[3], Azeufack Ulrich Gael[1, 3], Talla Pierre Kisito[1], Fogue Medard[3]

[1]Laboratoire de Mécanique et de Modélisation des Systèmes Physiques (Faculty of Sciences), Department of Physics, University of Dschang, Dschang, Cameroon

[2]Higher Technical Teachers' Training College, Kumba, University of BUEA, Cameroon (HTTTC), Kumba, Department of Civil Engineering and Forestry Techniques, University of Buea, Buea, Cameroon

[3]Laboratoire d'Ingénierie des Systèmes Industriels et de l'Environnement (IUT-FV), Bandjoun, University of Dschang, Dschang, Cameroon

Email address

christianfouotsa@yahoo.fr (F. W. C. Martial), foidienge@yahoo.fr (F. Emmanuel), fmtopig@yahoo.fr (M. F. B. Eugene), ulrichazeufack@gmail.com (A. U. Gael), tpierrekisito@yahoo.com (T. P. Kisito), medard_fog@yahoo.com (F. Médard)

[*]Corresponding author

Citation

Fouotsa Woutsop Christian Martial, Foadieng Emmanuel, Mtopi Fotso Blaise Eugene, Azeufack Ulrich Gael, Talla Pierre Kisito, Fogue Medard. Contribution to the Study of Variations of Physical Properties of *Pericopsis elata* with Respect to Different Stages of Growth. *American Journal of Materials Research.* Vol. 6, No. 2, 2019, pp. 11-20.

Received: March 24, 2019; **Accepted**: May 12, 2019; **Published**: June 15, 2019

Abstract: The assamela (afrormosia) of scientific name "Pericopsis Elata" (Harms), large tree of high commercial value, is an exploited species. It is considered "endangered" by IUCN (International Union for the Conservation of Nature). The operating diameter was set at 100 cm making rare the ready-to-harvest trees. Studies recommended by the Cameroonian government as part of the activities of ITTO/ CITES project, should be made to determine a new minimum operating diameter knowing that the diameter increases with age. No credible solution is provided in the scientific literature to compensate for its scarcity for exploitation. In addition, little or no information is available describing the variation of its physical properties over time in order to find the age for which its wood has good physical properties to be marketable. It is in this context that the present work has been undertaken. In this study, we adopted an experimental approach to evaluate the physical properties of this species exploited in southeastern Cameroon. Then, we studied the variations of these properties according to the age of the tree in order to propose tracks for their exploitation. Thus, tests carried out in the laboratory allowed us to estimate the relationship between the physical properties (Percentage of Heartwood, fiber Saturation Point (FSP), shrinkage, Moisture Content, Anhydrous Density, Basic density) and the Age (or Diameter). For this purpose, after three months of natural drying in the laboratory. We have evaluated the above physical properties with respect to age. This study shows that physical properties change as diameter increases, and change very fast from 65 cm diameter. From the analysis of the experimental data, we deduced that the minimum diameter of the exploitable trees must be equal to 80 cm corresponding to the age of about 200 Years. We can also point out a similarity between these results and some of the literature, according to the complex behaviour of biomaterials.

Keywords: Assamela, Pericopsis Elata, Physical Properties, Hygroscopy, FSP, Shrinkage, Density

1. Introduction

The forests of Central Africa are characterized by an important specific richness. Among the species they host are large sun-loving trees exploited for their wood such as the assamela (afrormosia) of scientific name "Pericopsis Elata" (Harms), large tree of high commercial value. Pericopsis elata is a trees species of the family Fabaceae [1], known commercially as Afrormosia or Assamela. This exploited species currently suffers from major regeneration problems on its natural distribution area of the Congo Basin. As such, it is listed in Appendix II of CITES and is considered "endangered" by IUCN [2]. This has led to its classification in Annex II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

In Cameroon, Afrormosia reserves cover an area of about 4,071,857 ha and are mainly limited in the Eastern Region in the basins of the four rivers Dja, Boumba, Ngoko and Sangha. Forest Units (UFA) covers Forty-two percent of this area.

Since 2005, OIBT and CITES have been working together to develop a comprehensive capacity building project on sustainable trade for three species listed in CITES Appendix II. From logging companies, the minimum exploitable diameter (MED) usually depends on the age of the tree. This diameter has been raised to 100 cm and it is a serious problem for loggers because they cannot find enough good quality resources. Trees of Pericopsis elata with a diameter of about 100 cm are rare, and the few that exist have many heartwood defects. This is an important shortfall for both the forestry companies and the Cameroonian state; the wood of Pericopsis elata being felled almost dead, and not alive. This Minimum Exploitable Diameter must be redefined on a scientific basis.

To this purpose, on 26 August and 13 September 2013, the Government of Cameroon and ITTO signed an agreement relating to the implementation of two ITTO / CITES program activities. Then, studies should be made to determine a new minimum diameter for exploitation knowing that its growth average diametric is 0.42 ± 0.14cm per year in natural mixed moist forest [3- 5]. Botanical, physical and mechanical properties have been determined [5]. No credible solution is provided in the scientific literature to reduce its scarcity for exploitation. In addition, little or no information is available describing the variation of its physical properties over time in order to find the age for which its wood has good physical properties to be marketable.

The objectives of our investigatios is the evaluation of the physical properties of Pericopsis elata wood at different stages of growth and the study of the variations of these properties according to the age of the tree in order to propose tracks for their exploitation. In this study, we adopted an experimental approach to evaluate the physical properties of this species exploited in southeastern Cameroon.

2. Materials and Methods

2.1. Presentation of Specie Under Study Species Descriptions

Afrormosia or kokrodua, a large West African tree, is sometimes used as a substitute for teak (Tectona grandis). The heartwood is fine textured, with straight to interlocked grain. The wood is brownish yellow with darker streaks and moderately hard and heavy, weighing about 740 kg.m^{-3} at 12% moisture content [5]. The wood dries readily with little degrade and has good dimensional stability. The heartwood is highly resistant to decay fungi and termite attack and is extremely durable under adverse conditions. Pericopsis elata is often used for boat construction, joinery, flooring, furniture, interior woodwork, and decorative veneer [6].

2.2. Determination of the Percentage of Heartwood

To measure the percentage of heartwood, a maximum of four 5 cm thick slices were taken from each sample tree. The radiuses of the sections of the slices were measured from the marrow to the inner limit of the bark (R_1, R_2, R_3,...) and from the pith at the limit of the heartwood (r_1, r_2, r_3,...) thanks to the pocket meter. Four radiuses were measured for regular sections, and 6 radiuses for irregular sections, according to the strong and small curvatures of the section as shown in Figure 1.

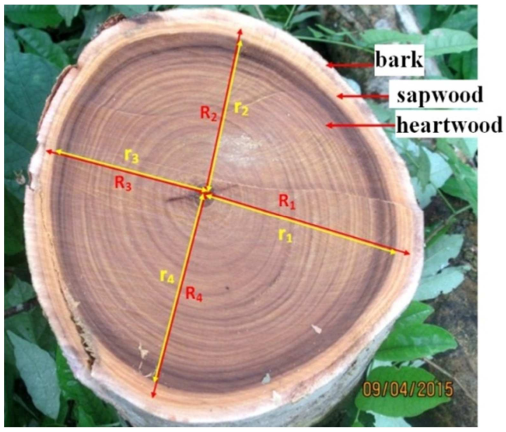

Figure 1. *Measurement of radius on a slice.*

The total areas of the sub-bark section and heartwood were calculated for each wooden slice using the quadratic mean of the radiuses [7-8].

$$S_{TSSE} = \frac{\pi}{4} \cdot \sum_{i=1}^{4} R_i^2 = \pi \sum_{i=1}^{2} D_i^2 \quad (1)$$

$$S_{TSSE} = \frac{\pi}{4} \cdot \sum_{i=1}^{4} r_i^2 = \pi \sum_{i=1}^{2} d_i^2 \quad (2)$$

Where S_{TSSE} is the total area of the section under bark, S_{TD} the total area of the section of the heartwood, R_i the radius of the section under bark in i direction and r_i the radius of the heartwood measured from the bark to the sapwood in i direction, with $D_i^2 = 4R_i^2$ and $d_i^2 = 4r_i^2$.

The percentage of heartwood (% D) was determined for each sample according to equation (3) [9]:

$$\%D = \frac{V_{c_d}}{V_{c_b}} \times 100 = \frac{S_{TD}}{S_{TSSE}} \times 100 \quad (3)$$

where V_{c_d} and V_{c_b} are the volumes of the cylinder generated respectively by the heartwood and the sub-bark wood which was obtained by multiplying respectively the mean total surfaces of the heartwood and the sub-bark section by the height of the trunk taken from each tree.

2.3. Sample Collection

Then the various logs are cut to obtain planks. Half of the planks from a plain-sawn, and the other half of a quarter-sawn. Such approach makes possible to obtain, during the tests, the characteristics in the three directions of orthotropy.

On this basis, 20 planks were selected and sent to the Laboratory for the analysis phase. Figure 2 gives a view of the planks in natural drying in the laboratory.

Figure 2. *Pericopsis elata wood in natural drying in the laboratory.*

Spaces are created between the planks to allow the ventilation which homogenizes and accelerates the drying in natural environment.

2.4. Physical Properties: Experimental Setup

Wood, like many natural materials, is hygroscopic since it gains or losts moisture from the surrounding environment. Many of the challenges of using wood as an engineering material arise from changes in moisture content or an abundance of moisture within the wood. From studies of the effect of moisture on the physical and mechanical properties of wood, several authors have concluded that, below the Fiber Saturation Point (FSP), these properties deteriorates when the humidity increases. [10-22].

2.4.1. Moisture Content

After three months of natural drying, we determined the moisture content of a batch of specimens from each log. For this purpose, according to standard NF B 51-004 [23], cubes of 20×20×20 mm^3 of side are taken from each log and weighed by means of a 0.01g precision electronic balance. The specimens are weighed to obtain the actual mass (m_H), and then, dryed in an oven set at 103 °C until the mass is stabilised. A fast weighing is carried out at the exit from the oven to determine the anhydrous mass (m_a).

The moisture content (*H)* of each specimen expressed as a percentage shall be calculated using the equation 4:

$$H = \frac{m_e}{m_a} \times 100 = \frac{m_H - m_a}{m_a} \times 100 \quad (4)$$

The moisture content is a fundamental characteristic of the state of wood whose affects the others properties [24-31].

2.4.2. Fiber Saturation Point

The fiber saturation point (FSP) corresponds to the limit moisture content for which the cell walls of the wood material no longer absorb water [25-32]. According to the literature, the moisture content of the fiber saturation point varies from 22% to 44% and depends on the species and the temperature. [6, 24-31, 33-34].

To carry out this study, we produced six specimens per diameter. These specimens are free from visible macroscopic defects and are dryed in the oven at 103°C until the mass is stabilized. The test pieces are then weighed and the radial and tangential dimensions measured by the digital caliper. In the following, the specimens are placed in a humid environment where, at regular intervals of time, we measure their current masses on the one hand, and their current dimensions on the other hand. The collected data allow us to calculate the moisture content at the time of the measurement and the relative variations of the dimensions and the volumes. The moisture content corresponding to the fiber saturation point (FSP) is obtained by plotting the shrinkage curve with respect to the moisture content [35].

2.4.3. Shrinkage

Below FSP and during desorption or absorption, a wooden specimen undergoes dimensional variations, which occur only between the saturated state and the anhydrous state [25, 34, 36].

In order to study the shrinkage for each diameter, a set of six specimens is selected for the concerned diameter. According to the recommendations of standard NF B 51-006 [28-35], we have determined for each specimen:
the total shrinkage α_i per log diameter given as:

$$\alpha_i = \frac{K_{i_S} + K_{i_a}}{K_{i_S}} \times 100 \quad (5)$$

The coefficients of shrinkage β_i per log diameter were also determined as:

$$\beta_i = \frac{K_{i_S} - K_{i_a}}{K_{i_S} \times H_S} \times 100 \quad (6)$$

Where: i = R (radial), T (tangential), L (longitudinal), V (volumetric); K_{i_S} is the size of saturated specimen; K_{i_a} the size of anhydrous specimen.

2.4.4. Density

According to Guitard [25], mass density is the ratio between the mass (m_i) and the volume (V_i) of a sample which aims to specify the mass quantity of woody matter contained in a given volume of wood. It is a basic indicator of the mechanical properties of wood [37-40]. The method of sampling, preparation and conditioning of the test specimens is specified in NF B 51-003 [41]. Conventionally, the operational mode for determining the different densities per diameter is governed by standard NF B 51-005 [42] and given in equation 7:

$$\rho_i = \frac{m_i}{V_i} \quad (7)$$

The volume of the sample was measured by a physical process consisting of immersing the specimen kept in water with a thin rod before taking the water level. The difference in volumes gives us the volume of the specimen.

The reference density of wood is that obtained with reference moisture $H = 12\%$, which serves as a reference for comparing wood. Different methods have been used to convert measures of wood density at 12% moisture (ρ_{12}), which are often available in forestry institute databases, into basic wood density (ρ_b). Based on basic wood density data and air-dry wood density data (supposedly close to 12% moisture) for tropical species or genera Chudnoff (1984) and Reyes et al. (1992) have proposed a linear regression between ρ_b and ρ_{12} (Eq. 8) [43-44].

$$\rho_b = 0.0134 + 0.800\rho_{12} \tag{8}$$

Formula (8) can be inverted to compute $\rho 12$ from ρb (Eq. 9).

$$\rho_{12} = \frac{\rho_b - 0.0134}{0.800} \tag{9}$$

2.4.5. Basic Density

The Basic density is obtained by dividing the oven-dry weight by the green (maximum swollen) volume. To determine a single volume of a specimen, it is necessary to measure its volume (V_s) when saturated with water. In the same way, the definition of a single mass for a specimen must exclude any possibility of variation due to the hygrometry, one measures therefore the anhydrous mass (m_a) [45-46]. We define the Basic density (Id) by equation 10:

$$Id = \frac{m_a}{V_s} \tag{10}$$

Since wood is a porous material, it is difficult to measure the volume by immersion. We bypassed this difficulty by using the formula (Eq. 11) [47]:

$$\mathrm{Id} = \frac{1}{\frac{m_S}{m_a} - 0.347} \tag{11}$$

2.4.6. Porosity

Porosity is the ratio of empty volume to total volume. The density of a wood species depends on its porosity and is great when the porosity is small. Knowing the specific density of the wood material itself $\rho_c = 1530\ kg.m^{-3}$ [25, 48], we have also estimated the pores volume rate or porosity (γ), per diameter using equation 12:

$$\gamma = \left(1 - \frac{\rho_a}{\rho_c}\right) \times 100 \tag{12}$$

3. Results

3.1. Percentage of Heartwood

The results show that, this timber is yellow brown. A cross section shows growth rings and contains an average of about 88.7% of heartwood. Table 1 summarizes the percentage of heartwood per diameter.

Table 1. *Percentage of heartwood per diameter.*

Sample	Mean diameter of wood (cm)	Mean diameter of heartwood (cm)	Percentage of heartwood (%D)
1	54	50.5	87.5
2	70	65.8	88.4
3	78	74.1	89.3
4	85	80.4	89.46

3.2. Hygroscopy

The curve of figure 3 gives the variation of the average of the moisture content with respect to the diameter *after more than one month of natural drying of planks previously soaked in water*.

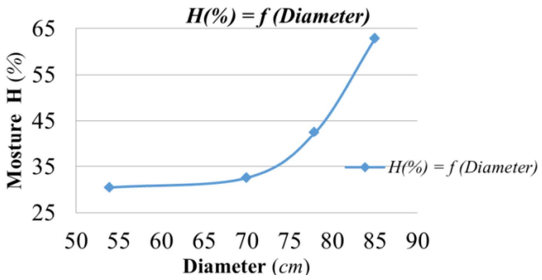

Figure 3. *Moisture content after three months of natural drying with respect to diameter.*

Table 2 Presents the moisture of the specimens of each log after *more than one month* of natural drying of planks *previously soaked in water*.

Table 2. *Moisture content (H) of Pericopsis elata in the laboratory per diameter.*

54 cm				70 cm				78 cm				85 cm			
Specimens	m_H (g)	m_o (g)	H (%)	Specimens	m_H (g)	m_o (g)	H (%)	Specimens	m_H (g)	m_o (g)	H (%)	Specimens	m_H (g)	m_o (g)	H (%)
A1	6.5	4.99	30.26	B1	6.95	5.23	32.88	C1	7.84	5.5	42.54	D1	7.74	4.79	61.58
A2	6.71	5.16	30.03	B2	7	5.28	32.57	C2	7.49	5.3	41.32	D2	7.51	4.62	62.55
A3	6.95	5.42	28.22	B3	7.29	5.5	32.54	C3	7.68	5.4	42.22	D3	8.09	4.99	62.12
A4	7.06	5.25	34.47	B4	7.13	5.45	30.82	C4	7.68	5.33	44.09	D4	8.18	5.03	62.62
A5	7.34	5.54	32.49	B5	7.29	5.48	33.02	C5	7.92	5.53	43.21	D5	7.84	4.81	62.99
A6	6.77	5.19	30.44	B6	7.57	5.72	32.34	C6	7.54	5.3	42.26	D6	7.38	4.55	62.19
A7	7.33	5.49	33.51	B7	7.18	5.39	33.20	C7	7.65	5.36	42.72	D7	7.63	4.66	63.73
A8	6.71	5.27	27.32	B8	7.36	5.61	31.19	C8	7.51	5.35	40.37	D8	7.44	4.54	63.87
A9	6.63	5.06	31.02	B9	7.35	5.51	33.39	C9	7.78	5.45	42.75	D9	7.96	4.85	64.12
A10	7.15	5.49	30.23	B10	7.14	5.39	32.46	C10	7.65	5.35	42.99	D10	7.91	4.87	62.42
A11	6.83	5.35	27.66	B11	6.83	5.14	32.87	C11	7.39	5.21	41.84	D11	8.53	5.22	63.40
A12	7.06	5.44	29.77	B12	7.08	5.32	33.08	C12	7.14	5.01	42.51	D12	8.11	5.02	61.55
Average	30.45			Average	32.53			Average	42.40			Average	62.76		

3.3. Fiber Saturation Point

3.3.1. Determination of FSP

As indicated above, the moisture corresponding to the fiber saturation point (FSP) is obtained by plotting the shrinkage curve with respect to the moisture content. This was done for each diameter. (figure *4. a, b, c, d*) is an illustration of the curve dimension-moisture content per diameter.

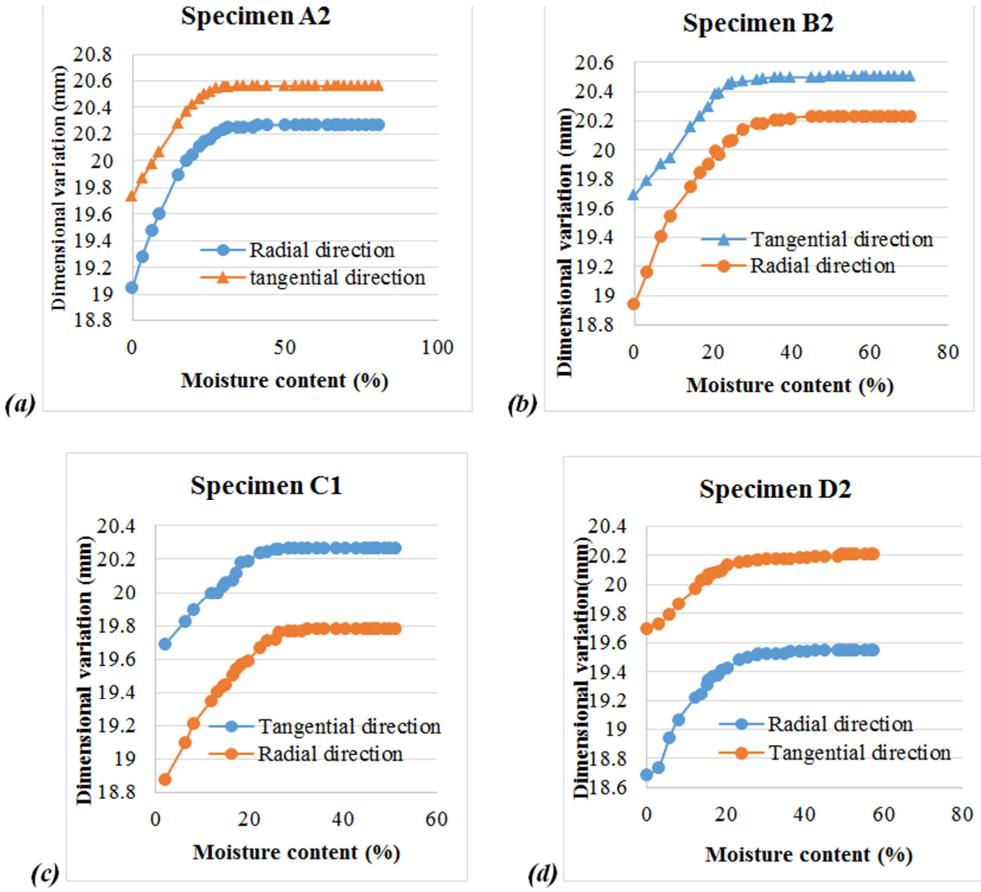

Figure 4. *Shape of hygroscopic curves dimension-moisture content.*

3.3.2. Variation of FSP with Respect to Diameter

The approach here is to study the variation of FSP with respect to diameter. For this purpose, we determined the FSP of twelve specimens per diameter. After verifying that the values are closed to one another, we have averaged for each diameter. Table 3 shows the obtained averages.

Table 3. *FSP by diameter.*

Diameter (*cm*)	54	70	78	85
Mean FSP (%)	30.1	32.0	34.7	34.8

From this table we have plotted the curve of figure *5*, representing the variation of the PSF with respect to the diameter.

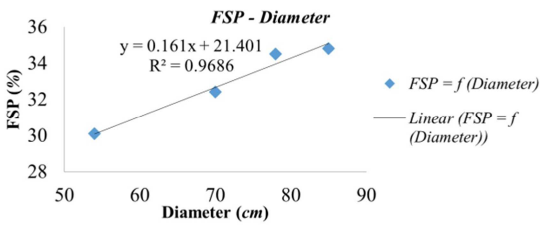

Figure 5. *Variation of FSP with respect to diameter.*

3.4. Shrinkage

In order to study the shrinkage for each diameter, a set of six specimens is selected for the diameter concerned. After having marked the three directions (Longitudinal, Radial and tangential), the three dimensions are measured using the numerical calliper rule. The test pieces are then placed in the oven and when the masses become constant, the dimensions are again measured. According to the expressions (5) and (6), tables 4, 5, 6 and 7 summarise shrinkage for each diameter range.

***Table 4.** Variation of shrinkage for diameter 54 cm.*

Specimens	X_H (mm)	Z_H (mm)	Z_H (mm)	X_O (mm)	Y_O (mm)	Z_O (mm)	α_L	α_R	α_T	α_V	$\alpha_L+\alpha_R+\alpha_T$
1	19.88	19.8	20	19.87	19.53	18.62	0.05	2.35	5.96	8.215	8.36
2	19.8	20.1	19.9	19.79	19.43	19.04	0.051	236	5.27	7.557	7.681
3	20	20.2	19.8	19.99	19.41	19.02	0.05	1.97	5.84	7.742	7.86
4	19.9	19.8	20.5	19.88	20.08	18.75	0.101	2.05	5.3	7.336	7.451
5	20	20.2	19.8	19.98	19.32	19.25	0.1	2.42	4.7	7.106	7.22
6	19.8	20.1	19.9	19.79	19.42	19.11	0.051	2.41	4.93	7.265	7.391
Average							*0.067*	*2.26*	*5.33*	*7.53*	*7.66*
Standard deviation							*0.02*	*0.17*	*0.38*	*0.30*	*0.31*

***Table 5.** Variation of shrinkage for diameter 70 cm.*

Specimens	X_H (mm)	Z_H (mm)	Z_H (mm)	X_O (mm)	Y_O (mm)	Z_O (mm)	α_L	α_R	α_T	α_V	$\alpha_L+\alpha_R+\alpha_T$
1	19.81	20	19.8	19.79	19.84	18.92	0.101	2.06	5.4	5.30	7.301
2	19.89	19.9	20.1	19.88	19.81	18.94	0.05	2.55	4.82	6.24	8.48
3	20	19.8	20.2	19.99	19.41	18.85	0.05	2.23	4.8	8.57	6.46
4	19.99	20.5	19.8	19.98	20.04	19.01	0.05	2.33	7.27	6.19	9.12
5	20	19.9	20.2	19.99	19.45	18.64	0.05	2.64	5.86	9.85	7.06
6	19.8	19.9	19.75	19.77	19.79	18.75	0.152	2.66	5.06	5.73	8.922
Average							0.075	2.41	5.54	6.98	7.891
Standard deviation							0.034	0.21	0.67	0.90	0.72

***Table 6.** Variation of shrinkage for diameter 78 cm.*

Specimens	X_H (mm)	Z_H (mm)	Z_H (mm)	X_O (mm)	Y_O (mm)	Z_O (mm)	α_L	α_R	α_T	α_V	$\alpha_L+\alpha_R+\alpha_T$
1	19.8	20	19.88	19.8	19.53	18.82	0.051	2.35	4.02	6.28	6.42
2	19.82	19.9	20.1	19.8	19.45	19.02	0.151	2.26	4.28	6.54	6.69
3	20	19.82	20.2	19.98	19.21	19.01	0.1	2.98	7.57	10.50	10.65
4	19.9	20.5	20.04	19.8	19.82	18.81	0.101	3.32	6.14	9.71	9.56
5	20	19.8	20.2	19.99	19.28	18.95	0.05	2.63	7.23	9.71	9.91
6	19.8	19.9	20.1	19.77	19.37	19.11	0.101	2.66	4.43	7.11	7.19
Average							0.092	2.7	5.64	8.31	8.40
Standard deviation							0.028	0.3	0.44	0.75	0.70

***Table 7.** Variation of shrinkage for diameter 85 cm.*

Specimens	X_H (mm)	Z_H (mm)	Z_H (mm)	X_O (mm)	Y_O (mm)	Z_O (mm)	α_L	α_R	α_T	α_V	$\alpha_L+\alpha_R+\alpha_T$
1	19.8	20	19.8	19.78	19.49	18.67	0.101	2.6	5.26	8.20	7.96
2	19.8	19.9	20.1	19.78	19.27	18.94	0.101	2.16	6.32	7.90	8.58
3	20	19.8	20.2	19.98	19.3	19.08	0.1	2.53	5.54	8.02	8.17
4	19.9	20.5	19.8	19.88	19.75	18.76	0.101	4.63	5.25	9.73	9.98
5	20	19.8	20.2	19.98	19.27	19.13	0.1	2.68	5.3	7.92	8.08
6	19.8	19.9	20.1	19.78	19.44	18.85	0.101	2.31	6.77	8.48	9.18
Average							0.101	2.82	5.74	8.38	8.66
Standard deviation							0.0004	0.39	0.54	0.33	0.60

The curves of Figure *6* show the variation of the radial and tangential shrinkages with respect to the different diameters.

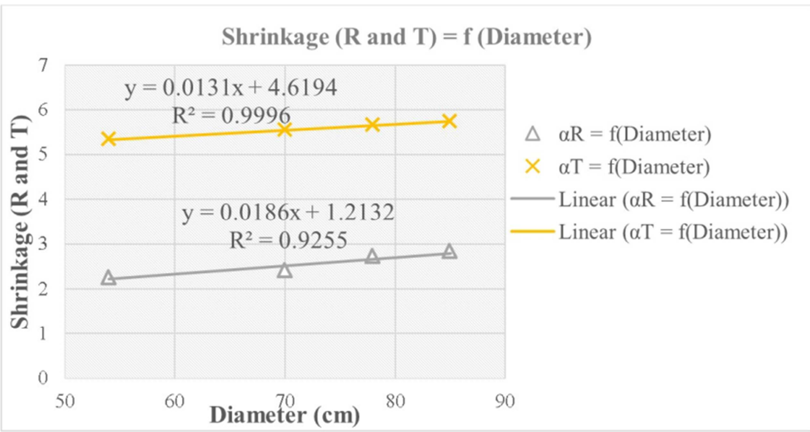

***Figure 6.** Variation curves for Radial and Tangential shrinkage with respect to diameter.*

3.5. Density

3.5.1. Basic Density

Figure 7 gives a shape of the evolution of the Basic density per diameter.

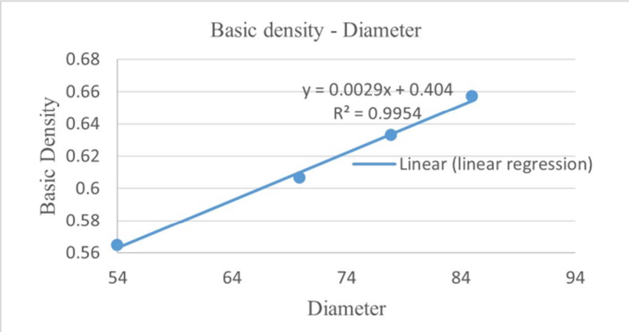

***Figure 7.** Shape of the Curves Basic Density-diameter.*

The Infra-density values of each *Pericopsis elata* sample, by diameter are summarised in Table 8.

***Table 8.** Sample Besic density Values by Diameter.*

Specimen	Diameter (cm)			
	54	70	78	85
1	0.524	0.656	0.674	0.691
2	0.569	0.589	0.679	0.705
3	0.525	0.58	0.658	0.695
4	0.565	0.595	0.595	0.628
5	0.597	0.577	0.597	0.596
6	0.521	0.676	0.631	0.618
7	0.568	0.578	0.618	0.715
8	0.564	0.577	0.597	0.623
9	0.594	0.687	0.594	0.681
10	0.574	0.632	0.605	0.625
11	0.591	0.564	0.629	0.648
12	0.595	0.575	0.725	0.655
Average	0.566	0.607	0.633	0.657
Standard deviation	0.028	0.044	0.042	0.039

3.5.2. Others Densities and Pores Volume Rate

The obtained results, as well as the, anhydrous density, Density at 12% moisture and pores volume rate, are contained in Table 9, for a set of selected specimens with no visible macroscopic defects. For each diameter, the average is determined and figure 8 gives the variation of the average of anhydrous density with respect to the diameter.

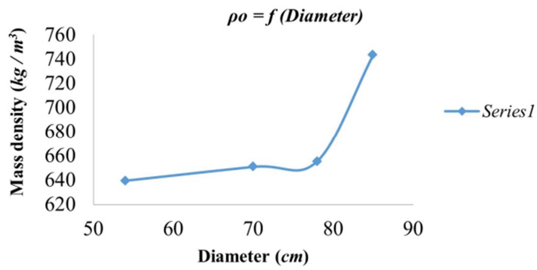

***Figure 8.** Variation of the anhydrous density with respect to the diameter.*

***Table 9.** Anhydrous density, Density at 12% moisture and Pores volume rate per diameter.*

Quantities	Specimens	Diameters (cm)			
		54	70	78	85
anhydrous Mass density ρ_0 (kg.m^{-3})	1	648.26	639.85	629.17	742.12
	2	640.47	646.48	628.34	727.37
	3	625.64	643.90	685.38	720.16
	4	630.69	660.83	673.52	757.95
	5	656.95	661.26	645.83	758.14
	6	634.94	652.95	670.69	754.69
	Average	639.49	650.88	655.49	743.41
	Standard deviation	11.598	8.950	24.38	16.46
Density ρ_{12} at 12% moisture (kg.m^{-3})	Average	0.690	0.742	0.775	0.805
	Standard deviation	12.87	9.93	27.05	18.27
Pores volume rate γ (%)	Average	58.20	57.46	57.16	51.41
	Standard deviation	1.21	1.04	1.12	0.89

4. Discussion

From Table 1, it can be seen that there is no significant difference between the percentage of heartwood of trees of different diameters. This percentage of heartwood is between 87.5% and 89.5% and slightly increases with diameter with an average of 88.67% and a standard deviation of 0.9%.

Experimental values (table 1) of the moisture content show that, under the same drying conditions, the specimens from the smaller diameter logs lose water more rapidly than the specimens from the logs with larger diameter. Figure 4 shows the dimensional changes as a function of the moisture content: it can be seen that the fiber desaturation point increases little with the diameter, from 30.1 to 34.8%, with an average of 32.9%. This increase can be approximated by a linear curve with a correlation coefficient greater than 0.9 (Figure 5), which justifies the accuracy of our results. Thus, under the same conditions, specimens from young trees tend to dry faster than those from old trees. An explanation of this phenomenon may be due to density. Indeed, older trees are denser and therefore have a greater tendency to retain water than young trees.

Tables 3, 4, 5 and 6 of the shrinkage by diameter show that, the average of the shrinkage increases with the diameter, although locally inversions are observed from time to time.

Longitudinal shrinkage is almost negligible as shown in the literature, which proves that the tests were well done [49].

Table 8 shows that the average of Basic density varies sllightly with diameter (Figure 8). The density at 12% moisture is between 0.690 and 0.805, and slightly increase with Diameter, with an average of 0.752 and a standard deviation of 0.049 (Table 9). We can classify this wood among the heavy woods which the density is between 0.70 and 0.85 [50]. The shape of the curve of (figure 8) shows that a linear regression cannot approximate the relationship between the density and the diameter. It is important to note that for the *Pericopsis elata*, no literary reference allows us to corroborate this result, which makes this result a new data for the literature. From the diameter 78 cm, the slope of the density-diameter curve increases strongly. This allows us to conclude that this species can be exploited for diameters close to 80 cm, about 200 years old.

5. Conclusion

This work was devoted to the "The variation of the physical properties of Pericopsis elata with respect to the age (diameter)". The objective was to study the physical properties of this wood species (from the forests of the Eastern Region of Cameroon) and to show how they evolve according to different log ages (diameters). For this purpose, after three months of natural drying in the laboratory, the hygroscopy of the boards from the logs was determined. We noted that the moisture content tended to be constant with low diameters, higher with the larger diameters of the logs. For physical properties, we determined for each diameter: the percentage of wood in the trunk, the saturation point of the fiber, the shrinkage, the anhydrous density and at 12% moisture, and the basic density. In general, we noticed an increasing evolution of these different properties with the diameter of the logs. We can also point out that these results are closed to some of the literature [51-52], proof that the tests have been well done. From the diameter 78 cm, the slope of the mains physical properties-diameter curve increases strongly. This allows us to conclude that this species can be exploited for diameters close to 80 cm, or for trees approximately 200 years old.

Acknowledgements

Our sincere thanks addressed to the NGO ANAFOR for the facilities given during the collection of samples in the forest.

References

[1] F. B. Boyemba (2011), "Écologie de Pericopsis elata (Harms) Van Meeuwen (Fabaceae), arbre de forêt tropicale africaine à répartition agrégée," Thèse présentée pour l'obtention du diplôme de Doctorat/Ph. D, Université Libre de Bruxelles, Bruxelles, 181.

[2] IUCN [International Union for Conservation of Nature] (2012), "IUCN Red List Categories and Criteria", Version 3.1. Second edition. Gland, Switzerland and Cambridge, UK.).

[3] Bourland N., Kouadio Y. L., Colinet G., Doucet J.-L. (2009-2010) "Pericopsis elata (Harms) Meeuwen in the southeastern part of Cameroon: ecological and pedological approaches to improve the management of an endangered commercial timber species". International Forestry Review 12 (5): 111.

[4] Pallisco (200), Fiche essence Assamela. In P-CE-E-04. Version 01 du 20/12/2007.

[5] Tropix7-Cirad (2011), « Fiches techniques essences tropicales (Assamela, teck, etc.) », du 13 septembre 2011.

[6] Forest Products Laboratory (2010), "Wood Handbook-Wood as an engineering material," General Technical Report FPL-GTR-190, Madison, WI: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory. 508 p.

[7] Patrick Purser and Purser Tarleton Russell (1999), "timber measurement manual: Standard Procedures for the Measurement of Round Timber for Sale Purposes in Ireland", Forest Service in the Department of the Marine & Natural Resources, Republic of Ireland.

[8] Francis CAILLIEZ (1980), « Estimation des volumes et accroissement des peuplements forestiers avec référence oartic Hère aux forks tropiceies, Etude FAO- Forêts, centre technique forestier tropical. France, vol. 1 - estirnation des volumes, 107p.

[9] Dilem A. (1995), « Etude de quelques propriétés du bois de Chêne vert (Quercus ilex) dans la région d'El-Hassasna (Saida-Algerie) ». Forêt méditerranéenne t. XVI, N°1, janvier 1995. Institut des sciences agronomiques, Tiaret, Algerie. 74-78p.

[10] W. W. Barkas and R. F. S. Hearmon (1953), "The mechanical properties of wood and their relation to moisture," Part A. In Mechanical properties of wood and paper, Ed. R. Meredith. North. Holl. Publ. Co. Amsterdam.

[11] L. D. Armstrong and R. S. T. Kingston (1962), "The effect of moisture content changes on the deformation of wood under stress", Australian J. Appl. Sci. 13 (4).

[12] F. F. P. Kollmann and W. A. Côte (1968), "Principles of Wood Science and Technology," Springer-Verlag, vol. 1: Solid Wood, New York, EU.

[13] L. C. E. Struik (1978), "Physical Aging in Amorphous Polymers and other Materials", Elsievier, Amsterdam, Netherlands.

[14] J. F. Siau (1995), "Wood: Influence of moisture on physical properties," Virginia Poly Institute and State Univ., Blacksburg, Virginia.

[15] B. Elvy Shane, R. Dennis Gary and Loo-Teck Ng (1995), "Effects of coupling agent on the physical properties of wood-polymer composites", Journal of Materials Processing Technology, Elsevier, Vol. 48, Issue 1-4, P 365-371.

[16] Lianzhen Lin, Mariko Yoshioka, Yaoguang Yao and Nobuo Shiraishi (1995), "Physical properties of moldings from liquefied wood resins", Journal of Applied Polymer Science, Wiley Blackwell (John Wiley & Sons), Vol. 55, Issue 11, P 1563-1571.

[17] Jude O. Iroh and A. Greg (1996), “Physical and chemical properties of polypyrrole–carbon fiber interphases formed by aqueous”, Journal of Applied Polymer Science, Wiley Blackwell (John Wiley & Sons), Vol. 62, Issue 10, P 1761-1769.

[18] W. F. Simpson and A. TenWolde (1999), “Physical properties and moisture relations of wood,” Wood handbook: wood as an engineering material. Madison, WI: USDA Forest.

[19] P. S. Ngohe-Ekam, P. Meukam, G. Menguy and P. Girard (2005), “Thermophysical characterization of tropical wood used as building materials: With respect to the basal density”, J. Construction and Building Materials, Vol. 20.

[20] Suleyman Korkut and Bilgin Guller (2008), “Physical and mechanical properties of European Hophornbeam (Ostrya carpinifolia Scop.) wood”, Bioresource Technology, Elsevier, Vol. 99, Issue 11, P 4780-4785.

[21] V. Glass Samuel (2010), “Moisture Relations and Physical Properties of Wood,” General Technical Report FPL–GTR–19024.

[22] Shabnam Sheshmani, Alireza Ashori and Yahya Hamzeh (2010), “Physical properties of polyethylene–wood fiber–clay nanocomposites”, Journal of Applied Polymer Science, Wiley Blackwell (John Wiley & Sons), Vol. 118, Issue 6, P 3255-3259.

[23] French Standard (1985), “NF B 51-004, Wood – Determination of moisture content,” Paris: AFNOR, 3p.

[24] W. W. Barkas and R. F. S. Hearmon (1953), “The mechanical properties of wood and their relation to moisture”. Part A. In Mechanical properties of wood and paper, Ed. R. Meredith. North. Holl. Publ. Co. Amsterdam.

[25] D. Guitard (1987), “Mécanique du matériau bois et composites,” CEPADUES-EDITIONS, Toulouse, France, I. S. S. N. 0768.2271, I. S. B. N. 2.85428. 152.7, N° Éditeur: 176, 238 p.

[26] J. G. Haygreen and J. L. Bowyer (1996), “Forest Products and wood science,” Third Edition. Iowa State University Press. pp. 243-247.

[27] Wood Handbook (1999), “Wood handbook - Wood as an engineering material,” Gen. Tech. Rep. FPL-GTR-113, Madison, WI: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p.

[28] G. Bortoletto Júnior and J. C Moreschi (2003), “Physical–mechanical properties and chemical composition of Pinus taeda mature wood following a forest fire”, Bioresource Technology, Elsevier, Vol. 87, Issue 3, P 231-238.

[29] T. A. Plekhanova, J. Keriene, A. Gailius et al. (2007), “Structural, physical and mechanical properties of modified wood–magnesia composite”, Construction and Building Materials, Elsevier, Vol. 21, Issue 9, P 1833-1838.

[30] Gökhan Gündüz, Süleyman Korkut and Derya Sevim Korkut (2008), “The effects of heat treatment on physical and technological properties and surface roughness of Camiyanı Black Pine (Pinus nigra Arn. subsp. pallasiana var. pallasiana) wood”, Bioresource Technology, Elsevier, Vol. 99, Issue 7, P 2275-2280.

[31] Irshad-ul-Haq Bhat, H. P. S. Abdul Khalil, Khairul B. Awang et al. (2010), “Effect of weathering on physical, mechanical and morphological properties of chemically modified wood materials”, Materials & Design, Elsevier, Vol. 31, Issue 9, P 4363-4368.

[32] S. Smulski and W. A. Côte (1984), “Penetration of wood by water - borne alkyd resin,” Wood Sci. Technol. 18: 59-75.

[33] A. T. Hansen (1987), “Effets du retrait du bois dans les bâtiments,” Digeste de la construction au Canada, Institut for Research in Construction, National Research Council (NRC), Canada, V. 244F, 4 p.

[34] C. Skaar (1988), “Wood-water relations,” Springer; cop. IX, 283 S.; 25cm: Ill. (Springer series in wood science). P 281.

[35] French Standard (1985), NFB51-006, Wood-Determination of shrinkage, Paris: AFNOR, 6p.

[36] E. McConnell (2011), “Understanding Dimensional Changes in Wood Products,” The Ohio State University Extension, Agriculture and Natural Resources F-72-11.

[37] A. Ylinen (1942), “The influence of latewood ratio and density on strength and elastic properties of softwood,” Acta forestalia fennica. 50: 5-30.

[38] J. Bodig and B. A. Jayne (1982), “Mechanics of Wood and Wood Composites,” Van Nostrand Reinhold Co., N. Y., 712pp.

[39] W. T. Simpson (1993), “Specific gravity, moisture content, and density relationships for wood,” FPL–GTR–76. Madison, WI: U. S.

[40] M. Moutee (2006), “Modélisation du comportement du bois au cours du séchage,” Thèse de doctorat (PhD). Université de Laval, Faculté de Foresterie et Géomatique, Département des Sciences du bois et de la forêt, Québec, Canada, 173p.

[41] French Standard (1985), “NF B 51-003, Wood – General requirements for physical and mechanical test,” Paris: AFNOR, 4p.

[42] French Standard (1985), “NF B 51-005, Wood-Determination of density,” Paris: AFNOR, 5p.

[43] Chudnoff, M. (1984) Tropical Timbers of the World. Agriculture handbook. U. S. Depart- ment of Agriculture, Forest Service.

[44] Reyes, G., Brown, S., Chapman, J. & Lugo, A. E. (1992), “Wood densities of tropical tree species”, General Technical Report-Southern Forest Experiment Station, USDA Forest Service, pp. i + 15 pp.

[45] J. K. Tangka, B. Ndongo and M. Onabid (2001), “Raffia as a structural material in the grassland region of Cameroon”, African Journal of Building Materials, Vol. 05, N°1.

[46] E. Foadieng (2013), “Contribution to the study of the thermomechanical and viscoelastic properties of raffia vinifera bamboo under flexural loads,” Doctoral Thesis (Ph. D), Option: Mechanics-Energetics, University of Dschang, Faculty of Sciences, Cameroon.

[47] Keylwerth R. (1954), “Ein Beitrag zur qualitativen Zuwashsanalyse”, Holz ais Rohund Werktoff. 77-83p., 1954

[48] J. Natterer, J. L. Sandoz, M. Rey et al. (2004), “Construction en bois, matériau, technologie et dimensionnement,” Traité de Génie Civil de l’École Polytechnique fédérale de Lausanne, vol 13, Deuxième édition revue et augmentée, Presses Polytechniques et Universitaires Romandes, CH-1015 Lausannes.

[49] A. J. Panshin and C. De Zeeuw (1980), "Textbook of wood technology," New York, 4ed, 722p

[50] Meriem Fournier, (2015), "Propriétés physiques du bois", LERFOP, GROSPARIS Tech, INRA, M2BFD – UE 938

[51] J. Gérard, A. Edi Kouassi, C. Daigremont et al. (998), "Synthèse sur les caractéristiques technologiques de référence des principaux bois commerciaux africains," CIRAD-Forêt (Campus International de Baillarguet, BP 5035, 34032 Montpellier cedex 01), France, 185 p.

[52] Y. Benoit (2008), "Le guide des essences de bois: 74 essences, les choisir, les reconnaître, les utiliser," Éditions Eyrolles (61, boulevard Saint-Germain, 75240 Paris cedex 05), Deuxième édition, ISBN 978-2-212- 12086-8, 145p. 7.