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Experimental Characterization of the Influence of Water Content on the Density and Shrinkage of Tropical Woods Coming from Cameroon and Deduction of their Fiber Saturation Points

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Abstract: ***In this study, fiber saturation point (FSP), density and shrinkage of tropical woods come from Cameroon are characterized in function of water content. This study is based on*** **obeche (*triplochiton scleroxylon*), frake (*terminalia superba*), lotofa (*sterculia rhinopetala*) and sapelle (*entandrophragma cylindricum*).** ***It is most important to characterize wood in function of their origins and to integrate a contribution of sapwood and heartwood in the constitution of the plank. Many relationships are obtained with a good intensity regression. We have obtained relationship between shrinkage and basal density of studied wood which can be used to predict shrinkage of many others woods in the same rank of densities. Evolution of volumetric shrinkage with water content permits us to estimate FSP of each wood. Results obtained are a contribution to distinguish some particularity of Cameroonian woods. We observe a small difference between ours results and the results on the same woods present in the literature.***

Keywords: Tropical woods, Characterization, Density, FSP, Shrinkage, Obeche, Sapelle, Frake, Lotofa, Cameroon.

1. Introduction and theoretical relationships

Knowledge of mechanical characteristics is much important to optimize the utilization of wood. During the drying of wood, a drying table is established in function of the future utilization, and also in function of the thermophysical ambient air conditions (temperature and relative humidity). Because wood is hygroscopic material, study relationship between thermophysical characteristics and water content is necessary when we want to estimate the behavior in the equilibrium point or around of this point. If many works are present in the literature on the practical characterization of tropical woods, little of these works indicate history and geographical locally of the samples. In consequently, it is a reason that duration of wood article is reduced and the management of the forest cannot optimized. In this paper, we characterized density, shrinkage and we deduced a fiber saturation point on the variation of shrinkage in function water content. In fact wood is hygroscopic, then each thermophysical parameter varied with humidity which given by a relation:

$$H = \frac{m_h - m_o}{m_o} \cdot 100 \tag{1}$$

Density is a thermophysical parameter who gives much information at each material product. It is a mass of the product per unit volume in the given conditions. In this paper, we used a relation below:

$$\rho = \frac{m_h}{v_h} \tag{2}$$

Where m_h and v_h are respectively mass and volume of the sample.

Density is suitable index for predicting wood quality [1]-[2]. This parameter indicates strength in wood and may predict certain characteristics such as hardness, ease of machining and nailing resistance [3]. Density varies in the same wood species. This variation is function of the type of forest (planted and natural), the age of wood (young or old trees), and the longitudinal and radial directions of the tree. In effect, many researches showed that wood density varied along longitudinal and radial directions from bottom to the up and the pith to the back [1]. Wood density of plantation trees are lower than that of natural forest trees [1] and specific gravity decreases along longitudinal direction from bottom to the up in many studied species [4]. Another research showed that, in the same species, wood density depends on the growth rate.

Shrinkage indicates a relative modification of dimensions of the specie when external conditions change. Because wood is anisotropic, we characterized this parameter according three directions of wood: tangential, radial and longitudinal. We used relation below who define linear shrinkage:

$$R_{ih}(\%) = 100\frac{l_{ih} - l_{io}}{l_{io}} \tag{3}$$

Where i represents' symbol of each direction, o is a symbol in anhydrous condition and h is in the condition at humidity H. l_{ih} is the length of the sample in the direction i at the humidity H. We can define a total shrinkage in the direction i when we change the length in the humidity H by the length of the sample at the saturation l_{is}.

Volumetric shrinkage at the humidity H is given by:

$$R_{vh}(\%) = 100\frac{V_h - V_o}{V_o} \tag{4}$$

Where V_h and V_o represents a volume of the sample respectively at the humidity H and at the anhydrous conditions. We obtained a total volumetric shrinkage when we change volume of the sample at the humidity H by a volume at the saturation. Saturation condition is obtained when water and water vapor occupying all space (pore) of the sample.

We have also determined a fiber saturation point who defines a state of wood when a structure of the sample contains bound water without free water in the pore. When water content is above the humidity at the fiber saturation point, mechanical parameters of the wood are not changes with water content. Below this point, these parameters change with water content. We established also relationship between wood density and water content. Also, relationship between each shrinkage and water content of each studied wood species. Linear regression was used in this study to examine relationship between wood density and total shrinkage (volumetric and each anatomical direction). Regression intensity is used to justify each relationship. Four Cameroonian tropical woods are used: obeche (*triplochiton scleroxylon*), frake (*terminalia superba*), lotofa (*sterculia rhinopetala*) and sapelle (*entandrophragma cylindricum*).

2. Experimental Material and Methods

2.1 Sample preparation

The wood species come from Cameroon in the littoral region forest. We assured that all samples cannot have some default. We used four series of sample. The first is taken after the dryer operation and initial humidity of these samples is estimated at 10% in the ambient relative humidity (65%). The second series is taken in a green Plank in the ambient relative humidity and temperature. The third series is taken directly after to remove the samples in the dessicator when the temperature is 102°C (anhydrous condition) during 24hours. The fourth series is taken after immersion and saturation of sample with demineralization water. This fourth series is also used to determine total shrinkage of each wood species. The wood species were trimmed in the dimension 20mm x 20mm x 19mm (LxTxR) for the first series, 15mm x 24mm x 15mm (LxTxR) for the second series. The samples of the second series are used for to obtain anhydrous samples (third series) and the samples of third series are used to obtain the fourth series. In the previous studies, the authors wait the stabilized condition. In the present study, we used transistorizes conditions because, in his utilization, the wood take all these conditions. For each wood species, we used twenty samples and sample is used to give one experimental point.

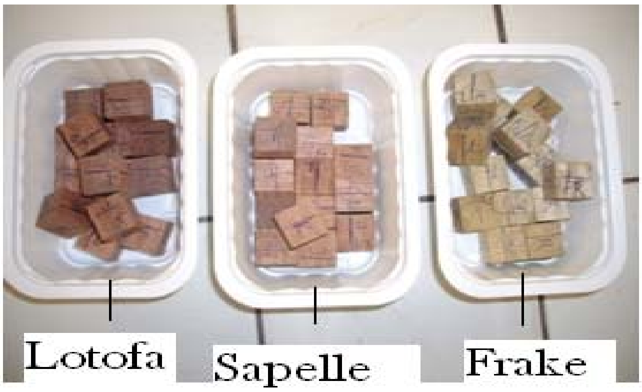

Figure 1: Samples of three of ours four woods

This method permits us to integrate the heterogeneous of the wood in the results. Figure 1 shows the samples of lotofa (heartwood), sapelle and frake. In the case of lotofa wood, we have distinguished heartwood and sapwood as it is presented in figure 2.

Figure 2: Heartwood and sapwood of lotofa wood

2.2 Material Preparation

We have used a digital weighing balance presented in the figure 3 with a precision 0.001g for to weigh a mass of the samples. A dessicator (figure 4) permits us to obtain very quickly the anhydrous mass.

Figure 3 : Digital weighing balance

Figure 4: Electrical Dessicator

Figure 5 presents a vacuum pump used to obtain a volume of ours samples in the saturation condition. Figure 6 presents a digital veneer caliper used to measure the longitudinal, radial and tangential axes.

Figure 5 : vacuum pump

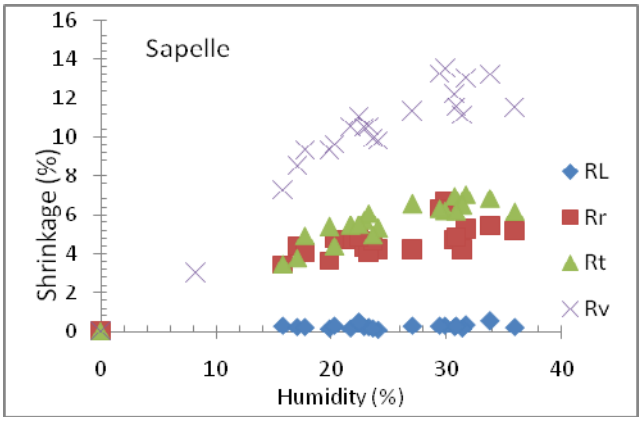

Figure 7 : shrinkage of sapelle wood

Figure 6 : digital veneer caliper

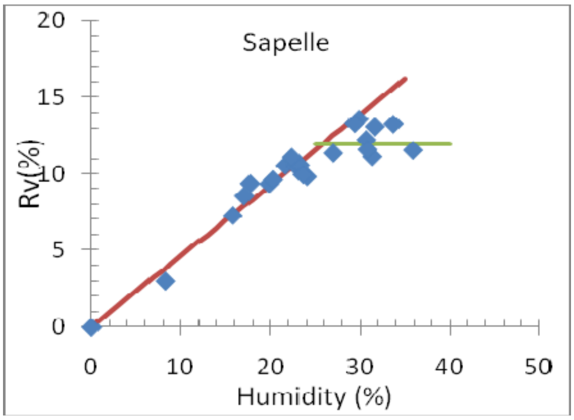

Figure 8 : volumetric shrinkage of sapelle wood and determination of fiber saturation point

2.3 Methods

The twenty samples of ours woods used in each four series describe above are weighing, measured in each anatomical direction for to obtain l_{ih} (and to deduce v_h) and dried until anhydrous state to determine m_o, l_{io} and v_o. then, in each condition, we obtained density, linear shrinkage and volumetric shrinkage in each humidity of each sample by applied respectively relationships (1), (2), (3) and (4). Total volumetric shrinkage and total linear shrinkage in each anatomical direction are obtained between the saturation and anhydrous points as following formulas:

$$R_{vT}(\%) = 100\frac{V_s - V_o}{V_o} \quad (5)$$

$$R_{iT}(\%) = 100\frac{l_{is} - l_{io}}{l_{io}} \quad (6)$$

Where V is the volume, l is the length in an anatomical direction i. indices o, S and T are anhydrous, saturation and Total point. R is the shrinkage in the direction i or volumetric v in %. We obtained the fiber saturation point (fsp) by definition. It is a humidity of the wood such as above this humidity, volumetric and linear shrinkage are constant when humidity of wood changes. Below this point, shrinkage is linear and increases with the humidity [5].

3. Results and Discussion

Figures 7 and 8 shows the evolutions of the shrinkage of sapelle wood with humidity. Is it clear that volumetric shrinkage Rv is great that tangential shrinkage. Longitudinal shrinkage RL is small that the others shrinkages.

Figure 8 shows that before and after ome point (FSP), evolution of shrinkage is in respect of the theoretical explanation given above. We deduce that fiber saturation point of sapelle point is H_{psf} given below:

$$H_{psf} = 25.92\% \quad (7)$$

In a hygroscopic part:

$$R_{vh} = 0.463H(\%) \quad (8)$$

$$R_t(\%) = 0.219H(\%) \quad (9)$$

$$R_r(\%) = 0.179H(\%) \quad (10)$$

$$R_L(\%) = 0.009H(\%) \quad (11)$$

In a non hygroscopic part:

$$R_{vh} = 12\% \quad (12)$$

$$R_{th} = 6.5\% \quad (13)$$

$$R_{rh} = 5.278\% \quad (14)$$

$$R_{Lh} = 0.473\% \quad (15)$$

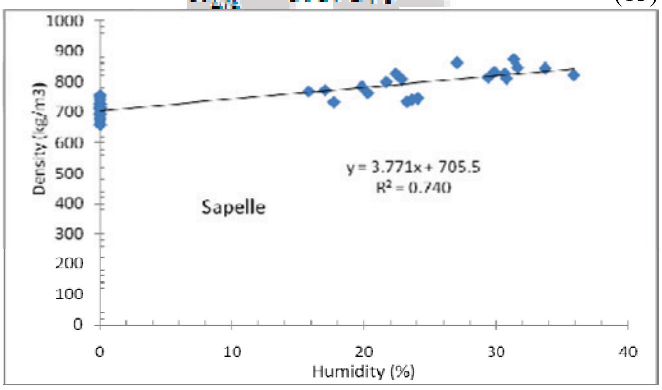

Figure 9 : evolution of density of sapelle with humidity

Figure 9 shows that evolution of density of sapelle wood with humidity is linear and relationship between these physical parameters is:

$$\rho(H) = 3.771H(\%) + 707.5 \text{ (kg/m}^3\text{)} \quad (16)$$

Dispersion of experimental points is influenced by the heterogeneity of the wood. A value of regression intensity is good. Figure 10 gives evolution of shrinkage of frake wood. The number of experimental points cannot permit us to deduce the fiber saturation point. But, evolution of volumetric shrinkage estimates this point near than 25%.

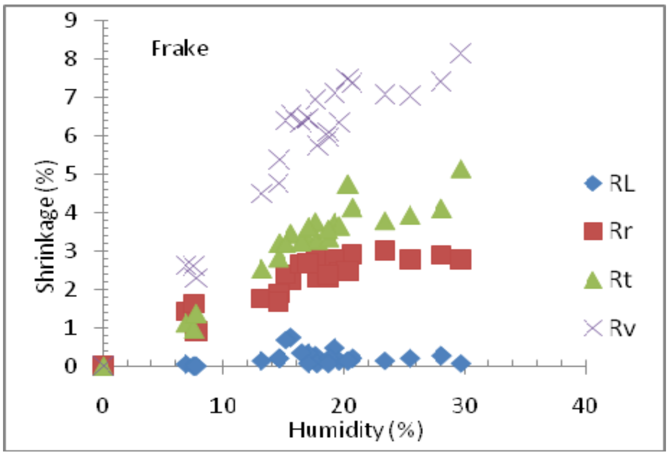

Figure 10 : shrinkages of frake wood

Formulas 17 to 20 estimate different shrinkages of frake wood.

$$R_v(\%) = 0.330H(\%) \quad (17)$$
$$R_t(\%) = 0.185H(\%) \quad (18)$$
$$R_r(\%) = 0.128H(\%) \quad (19)$$
$$R_L(\%) = 0.011H(\%) \quad (20)$$

The same observation with shrinkages of sapelle can to be do. Volumetric skrinkage Rv is great to tangential shrinkage Rt, tangential shrinkage is great than radial shrinkage Rr and these shrinkages are great than longitudinal shrinkage. Also, we observe that sapelle wood is lest stable than frake wood. Figure 11 presents the evolution of density of frake with humidity. We observe that density of frake wood is lest than a density of sapelle wood. Formula between density and humidity of frake is given by (21).

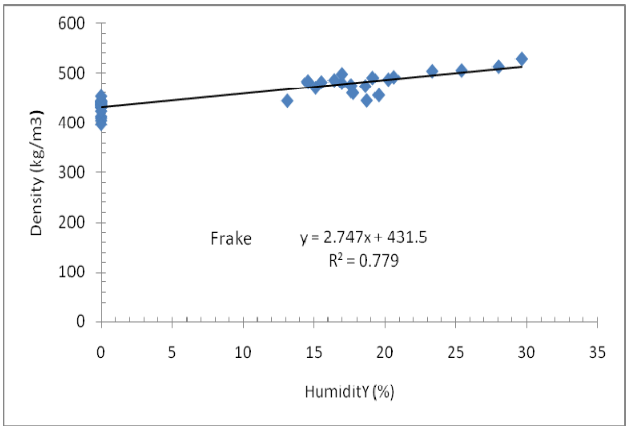

Figure 11 : evolution of density of frake with humidity

$$\rho(H) = 2.747H(\%) + 431.5 \text{ (kg/m}^3\text{)} \quad (21)$$

In the case of lotofa wood, we have distinguished sapwwod of heartwood. But, we have the samples that humidity is not good. In figure 12, we observe evolution of shrinkages of sapwood and figure 14 shows evolution of shrinkages of heartwood of lotofa. Comparisons between values of different types of shrinkages give above in the case of frake and sapelle are observed. Figures 13 and 15 give evolutions of densities of sapwood and heartwood of lotofa respectively. We note that heartwood is most dense that sapwood as literature said [6] and H_{fsp}>20%.

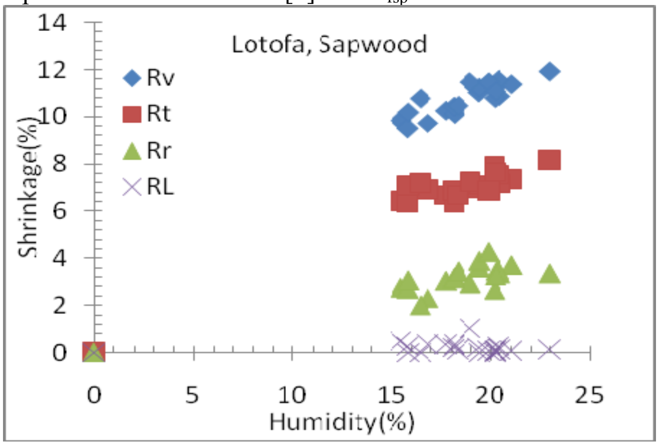

Figure 12 : shrinkages of lotofa wood, sapwood

Formulas 22 to 26 are relative to sapwood of lotofa and formulas 27 to 31 are relative to heartwood of lotofa.

$$R_v(\%) = 0.569H(\%) \quad (22)$$
$$R_t(\%) = 0.375H(\%) \quad (23)$$
$$R_r(\%) = 0.168H(\%) \quad (24)$$
$$R_L(\%) = 0.010H(\%) \quad (25)$$

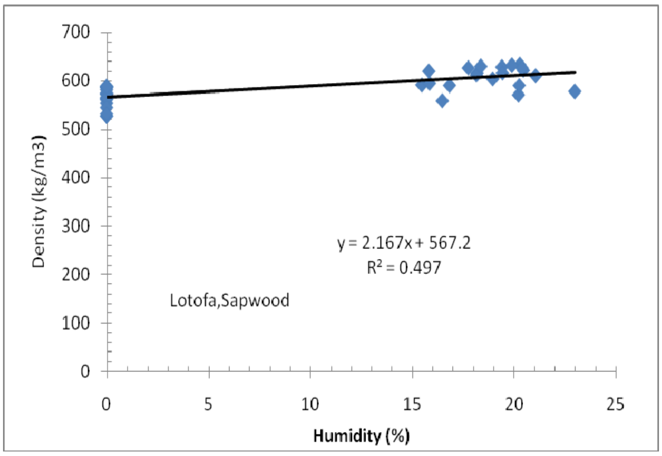

Figure 13 : evolution of density of lotofa with humidity, sapwood

$$\rho(H) = 2.167H(\%) + 567.2 \text{ (kg/m}^3\text{)} \quad (26)$$

Figures 16 and 17 give evolutions with humidity respectively of the shrinkages and density of obeche wood. We note that obeche wood is less dense that the others studied woods. We deduced on the figure 16 the value of the fiber saturation point of this wood is H_{fsp}=30%. It is known that density and shrinkage varied in the same wood.

Literature [1] indicates a variation of density and shrinkage of natural Alder wood respectively between 340 to 470 kg/m³ and 6.63 to 19.25%.

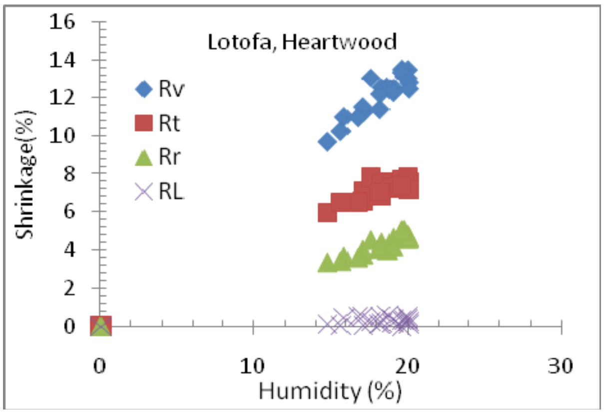

Figure 14 : shrinkages of lotofa wood, heartwood

$$R_v(\%) = 0.656H(\%) \quad (27)$$
$$R_t(\%) = 0.372H(\%) \quad (28)$$
$$R_r(\%) = 0.236H(\%) \quad (29)$$
$$R_L(\%) = 0.016H(\%) \quad (30)$$
$$\rho(H) = 2.230H(\%) + 771.8 \ (\mathrm{kg/m^3}) \quad (31)$$

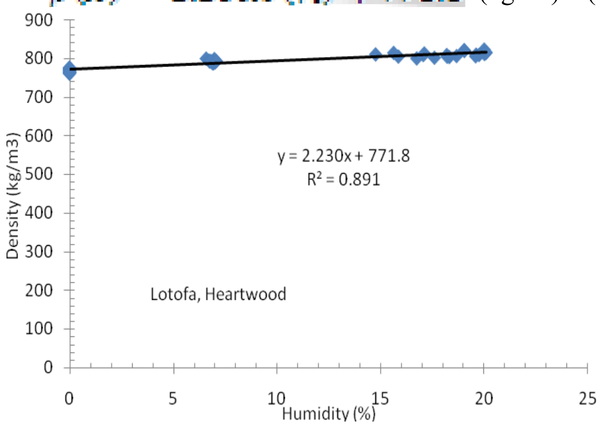

Figure 15 : evolution of density of lotofa with humidity, heartwood

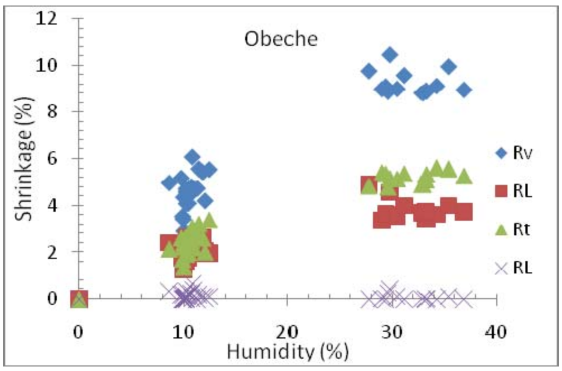

Figure 16 : shrinkages of obeche wood

Formulas 32 to 36 are relative to sapwood of lotofa

$$R_v(\%) = 0.463H(\%) \quad (32)$$
$$R_t(\%) = 0.229H(\%) \quad (33)$$
$$R_r(\%) = 0.129H(\%) \quad (34)$$
$$R_L(\%) = 0.020H(\%) \quad (35)$$
$$\rho(H) = 2.357H(\%) + 450.6 \ (\mathrm{kg/m^3}) \quad (36)$$

We note a great difference between sapwood and heartwood of lotofa wood. Thus, it is important to integrate in the characterization of wood the presence of each part of the trunk in the plank.

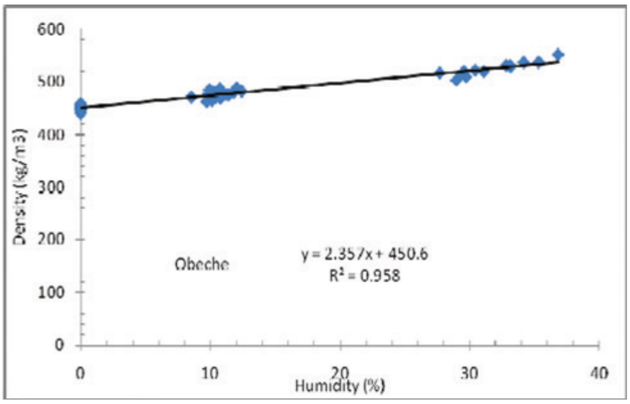

Figure 17 : evolution of density of obeche with humidity

Table 1 shows basal densities and total shrinkages of each wood species. Observations of all shrinkages in a given humidity or the total shrinkages give:

$$R_{VT} \cong R_{TT} + R_{rT} + R_{LT} \quad (37)$$
$$R_V \cong R_T + R_L + R_R \quad (38)$$

Table 1: basal densities and total shrinkages

Table 1a: basal densities and total volumetric shrinkage

Wood species	*ρ_b (kg/m³)*		*R_{VT} (%)*	
	Values	*σ*	*Values*	*σ*
Sapelle	653	15.09	15.43	2.41
Obeche	396.31	3.50	9.65	0.51
Lotofa,sapwood	491.53	15.70	15.36	0.81
Lotofa,heartwood	637.091	3.14	15.89	0.17
Frake	436.69	18.33	10.09	1.19

Table 1b: total tangential and radial shrinkages

Wood species	*R_{TT} (%)*		*R_{rT} (%)*	
	Values	*σ*	*Values*	*σ*
Sapelle	7.85	0.63	6.37	0.79
Obeche	5.38	0.34	4.00	0.56
Lotofa,sapwood	10.11	0.34	4.10	0.51
Lotofa,heartwood	8.05	1.84	7.26	1.79
Frake	4.45	0.62	4.40	0.79

Table 1c: total longitudinal shrinkage and FSP

Wood species	*R_{LT} (%)*		*H_{fsp} (%)*
	Values	*σ*	
Sapelle	0.37	0.18	25.92
Obeche	0.36	0.26	30
Lotofa,sapwood	0.59	0.16	>20
Lotofa,heartwood	0.28	0.10	>20
Frake	0.96	0.39	27

Figure 18 represents the variation of shrinkage with basal density which is anhydrous mass by volume at the saturation point. Formulas 39 to 42 are much important to estimate different shrinkage of tropical Wood. We observe that, except longitudinal direction, shrinkages increase with basal density. In reality, longitudinal shrinkage is neglected in comparison of the others shrinkages.

$$R_{VT}(\%) = 0.022\rho_b(kg/m^3) + 1.298 \quad with\ R^2 = 0.73 \tag{39}$$

$$R_{tT}(\%) = 0.010\rho_b(kg/m^3) + 1.806 \quad with\ R^2 = 0.279 \tag{40}$$

$$R_{rT}(\%) = 0.011\rho_b(kg/m^3) - 0.952 \quad with\ R^2 = 0.853 \tag{41}$$

$$R_{LT}(\%) = -0.001\rho_b(kg/m^3) + 1.154 \quad with\ R^2 = 0.269 \tag{42}$$

Where ρ_b is the basal density of wood in (kg/m^3).

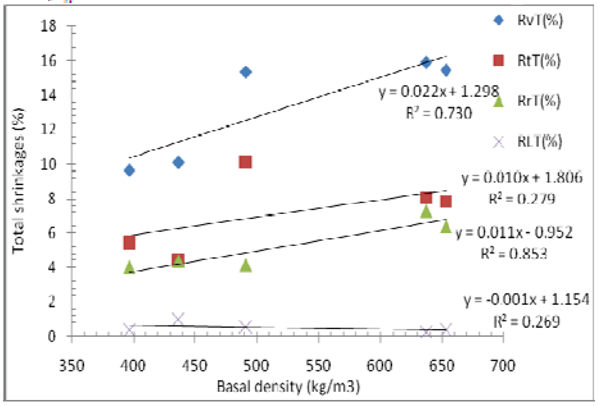

Figure 18: total shrinkages in function of basal density of tropical wood

Table 2 gives a comparison between our study and some previous studies in the literature. We observe some difference between ours results and these present in the literature but, it is possible to class each wood species relative of their shrinkage. Differences can be explained by indications give in introduction.

Table 2: comparison of ours total shrinkages with the literature values

Species	Reference and origin	Total shrinkages in %		
		R_{VT}	R_{rT}	R_{tT}
Obeche	Present study	9.65	4.00	5.38
	[7] Africa	9.20	3.00	5.40
	[3] Nigeria	6.90	-	-
Frake	Present study	10.09	4.40	4.45
	[7] Tropical American	10.80	4.50	6.20
sapelle	Present study	15.43	6.37	7.85
	[7] Africa	14.00	4.60	7.40
	[8] Africa	13.80	5.30	7.70

In the same tree, it is most difficult to obtain one constant value of shrinkage of his wood. In effect, literature shows that for densities near to 500kg/m^3, total tangential shrinkage can to vary between 4 and 13% [9].

4. Conclusion

It is most important to characterize density and shrinkage of the wood of each region because many natural and geographical factors influence these physical parameters. Linear regression can be used to explain influence of water content on density and shrinkage of tropical wood. We obtain good relationship in regard of the intensity of regression. Formulas that we obtained are most important to simulate many process of wood transformation as drying and air transfer between walls of house doing in wood. In the future work, it is important to study the same relationships with integration of many samples come from different trees of the same species.

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