Journal of Agriculture and Social Research (JASR) Vol. 11, No. 2, 2011

SELECTED DRYING CHARACTERISTICS OF PLANTATION GROWN *Gmelina arborea* UNDER AN EXPERIMENTAL SOLAR DRYING KILN

[1*]OGUNSANWO, O.Y. AND [2]AMAO-ONIDUNDU, O.N.
[1]Department of Forest Resources Management, University of Ibadan
[2]Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho Hill, Ibadan, Nigeria.
***Email: ogunsanwokay@yahoo.com Oy.ogunsanwo@mail.ui.edu.ng**

ABSTRACT
High cost of operating the conventional kiln and the inherent limitations of air drying method in wood drying are undesirable to wood industries. Solar wood drying has gained considerable interests because it is efficient and economical. Study on selected drying characteristics (drying rate, moisture gradient and drying defects) of plantation grown Gmelina arborea was carried out. Five Logs of Gmelina arborea were felled and wood samples were prepared from three sampling heights (25%, 50% and 75%). Thereafter, wood samples were selected from three radial positions (inner, middle and outer wood) for each of the sampling heights and labeled for proper identification. Samples were separated into two groups for air and solar kiln drying. Result revealed that for solar kiln dried samples, highest mean values for drying rates (1.1266±0.09, 0.7946±0.07246, 0.4511±0.34269, 0.5327±0.20307 and 0.4253±0.05157) %/day were recorded for 4, 6, 8, 10, and 12 weeks respectively,. Whereas, for air drying, 0.2147 ±0.05788, 0.4007±0.15662, 0.2806±0.04109, 0.5296±0.05322 and 0.3613±0.12435 %/day were recorded for 2, 4, 6, 8, 10 and 12 weeks respectively. The drying factors (temperature and relative humidity) in both solar kiln and air drying shed influenced the drying rate of wood. Results from analysis of variance revealed that solar kiln performs better than air drying in terms of drying rate through out the drying period. Duncan multiple range test (DMRT) was used to separate mean values of drying rate for samples at the selected longitudinal and radial positions. Also, solar kiln dried samples had a better quality in terms of absence of drying defects and desirable moisture gradient between the core and surface of the wood samples.

Keywords: *Gmelina arborea*, solar kiln, air drying and drying characteristics

INTRODUCTION
There are few wood based industries in Nigeria that appreciate the importance of wood seasoning nowadays; hence, large quantities of timber species are used immediately after conversion from logs, leading to insect infestation and attack by fungi, shrinkage and warping in drying out. This practice has perhaps been responsible for the poor reputation of timber as building material in Nigeria (Fajimi, 1983). Reports by Fajimi, (1983) revealed that air drying has been found to be relatively slow and fails in many respects to retard to some reasonable extent infestation by the fungi and insects. Also, the capital expenditure involved in the construction or procurement of the conventional drying kiln is beyond the reach of the local small and medium wood workers. Hence, an essential and profitable step towards increasing the efficiency of the manufacturing process of wood in Nigeria would be to develop an economic system of drying timber in the local areas.

Solar lumber drying offers several advantages in terms of its ability to dry reasonable quantities of lumber. A solar kiln may be easily constructed with readily available building materials. Solar drying of wood has gained considerable interests in the tropics where sunshine is available throughout the year (Gan and Choo, 2001).

Drying characteristics are the indices that show the responses of wood to drying under various dying methods. They include accompanying moisture flow rates (drying rate), moisture gradient and the associated drying characteristics in wood during drying must be known (Lawluvi and Ayensu, 1998). To utilise the full potential of different wood species, the response to wood drying under various dying methods and the accompanying moisture flow rates, moisture gradient and the associated drying characteristics in wood during drying must be known. (Lawluvi and Ayensu, 1998). Reports revealed that that the suitability of any timber for many end uses and secondary manufacturing processes depends on host of factors of which drying rate is one of the prime factors (Uetimane, 2010; Fajimi, 1983).

According to Gan and Choo, (2001) the drying rate can be expressed as percentage moisture content lost or mass of water lost per unit time (day) and can be calculated by either dividing a chosen moisture content or mass of water lost from timber by the time taken to lose this amount, or by selecting a period and dividing the mass loss during that period by the time. It represents the moisture content drop per day. Quality of drying is determined, in large part, by rate of moisture loss. Drying rate is an important parameter because it is closely related to energy consumption and economic feasibility of the process. The final quality to be considered also comprises parameters such as collapse, colour, timber deformation, cracks, case-hardening and the resultant mechanical strength properties, which directly affects marketing. Moisture gradient is expressed as the difference in moisture contents of inner and surface layer of wood (Uetimane, 2010).
As defined by Wengert (2006) and Simpson (1989), a drying defect is any characteristic or blemish in a wood product that occurs during the drying process and reduces the product's intended value. Drying degrade is a more specific term that implies a drying defect that lowers the grade of lumber. Drying characteristics of wood depend on certain factors such as wood species, drying method, drying period or drying schedule, wood properties and so on.

Since solar wood drying has been reported to perform better than air drying, in terms of drying characteristics and resultant wood quality (Jayanetti 1997), it is pertinent to study the functional performance of the constructed experimental kiln and determine its effect on drying characteristics of a selected common hardwood species in Nigerian markets such as *Gmelina arborea*.

MATERIALS AND METHOD

Study area

The experimental solar timber drier was setup at the Forestry Research Institute of Nigeria (FRIN) Ibadan located on longitude 3.51^0 E and 7.23^0 N. There are two distinct seasons: the raining season from April to October and the dry season accompanied by the harmattan (dry weather) in December from November to March. Based on 2010 weather data issued by the Meteorological Information centre of FRIN, the sum of annual rainfall is about 1702.5 mm, mean temperature of 24.8^0C to 32.2^0C, and mean relative density of 76.4%.

Design and construction of the solar kiln

The design was based on external collector type consisting of a solar collector which is connected to an enclosed insulated chamber (Simpson 1989, Chen 1981, Reuss *et al*. 1997b). The solar kiln was made of wooden frame work of desired sizes covered with plywood. The dimension of the box was about 4 x 3 ft. The floor and ceiling were also made of wood which were carefully joined to disallow leakages from joints.

Roofing sheets (aluminum) coated with black paint served as a black body (external collector) on which solar energy was absorbed. A platform of about 1 ft high was constructed as a foundation for the solar kiln. The height and the total length of the kiln were about 4 ft and 7ft respectively. The front part of the kiln consists of a solar collector of dimension 56'' by 36''which was made of aluminum roofing sheets and inclined at an angle of 45^0 to the horizontal making it a box-type collector in accordance to Lumley *et al*. (1981). The walls were double-layered plywood sheets with gap in between them and filled with wood shavings to act as insulator and reduce heat loss within the chamber. Air circulation was provided by two industrial fans of about 50 W powered by electricity or a small generator. The fans were switched on at 10am in the morning and off at 6 pm in the evening. The first fan which was fixed directly under the black body (solar panel) provides air circulation and act as suction which draws the warm air into the timber stacking area of the kiln. While the rear fan at the other end exhumes the air and vapour that passes out of the stacking chamber. The other important components in the dryer were the venting system (8''x 8'') positioned near the solar collector and the rear of the kiln. The vent was adjusted for air regulation. This method permits the hot air which has been moisture laden after passing through the stack to be blown out and also permit in flow of fresh air which after being heated undergoes the same process.

Procurement and preparation of wood samples

Logs of *Gmelina arborea* were sourced from plantation of the Forestry Research Institute of Nigeria, Ibadan. Thereafter, samples were taken from the logs at three different sampling heights: 25%, 50% and 75%. Test samples of dimension 28 x 125 x 1000 mm (in accordance with Uetimane, 2010) were then taken from the outer, middle and inner wood along the radial axis of the bolts. Subsequently, wood samples were separated into two groups (for air and solar kiln drying). Forty five (45) clear test samples were prepared for air and solar drying each. After drying, test samples were evaluated for drying characteristics-drying rate, defects and moisture gradient.

Determination of drying rate

The initial weight (weight before drying) –W_1, of the test samples was taken using a sensitive balance. Wood samples were properly labeled for identification. Thereafter, wood samples were separately dried under the solar kiln and wood stacking shed (for air drying method). At intervals of two weeks, the percentage moisture content (%MC) was calculated based on the dry weight of the test samples. Hence, the drying rate at interval of two weeks (14 days) was calculated as shown in equation 1.

$$Rd = \frac{\Delta \%MC}{14} \qquad \text{.......1}$$

Where:

Rd: is the drying rate

Δ-delta, is the change between two percentage moisture content

$$\%MC = \left(\frac{W1 - W2}{W2} X100\right)$$

W1 is the initial weight

W2 is the final weight

Twice a day (10 am and 4 pm) a thermometer was used to determine the minimum and maximum temperature within the kiln and under the shed. Also, a hydrometer was used to determine the relative humidity based on dry and wet bulb thermometer. To calculate the mean temperature for each day, the minimum and maximum temperature was taken in the morning and in the evening. Thereafter, the values obtained were divided by 2 to determine the mean temperature for the day. Also, to determine the mean relative humidity, the dry bulb and wet bulb temperature was used to calculate the depression. The value from the table gives the relative humidity in percentage. Mean values for each day was determined by finding the average of the value obtained for relative humidity in the morning and evening. Hence, at each interval (14 days) mean temperature and relative humidity were determined. The experiment lasted for 12 weeks after which the final %MC was determined.

Assessment of drying characteristics and seasoning defects

After the drying process, the quality of drying was evaluated by measuring the final MC (based on board weight and sawn samples). Associated drying defects were recorded after drying. According to European standards (EN 13183-1, 2003; ENV 14464, 2003; EN 14298, 2004) moisture gradient was calculated as the difference in MCs of inner and surface layer (5 mm and 10 mm) of the boards. The experimental design for the study was a three factor (2 x 3 x 3) factorial experiment in a completely randomized design (CRD). Test samples were replicated five times.

RESULTS AND DISCUSSION

Table 1 represents summary of the mean value for drying rate (%/day) at weeks 4- 12. It was observed that the mean values vary from week to week with regards to all the factors (drying method, sampling height and radial position) considered. At week 4, the highest mean value for drying rate (1.047±0.065) was recorded for solar drying (50% sampling height). This was followed by 1.039±0.094 and 0.92 ± 0.136 for 70% and 25 % sampling height respectively. Whereas, the lowest mean value (0.15± 0.006) was recorded for air dried samples. In the same manner, at week 12 the highest mean value for drying rate (0.389±0.027) was recorded for solar drying (50% sampling height) while the lowest value (0.233± 0.039) was recorded for air dried samples.

Table 2 revealed that based on drying rate of *Gmelina arborea* wood, there is a significant difference between the drying methods, longitudinal position and interactions (drying method x sampling height, drying method x radial position, and drying method x sampling height x radial position). Follow up test (Table 3) for sampling height based on drying rate of samples was used to separate means. Results revealed that drying rates of

samples selected at 50% and 70% longitudinal positions are the same. While drying rate of samples from 25% longitudinal position is different.
Table 4 reveals the ANOVA for drying rate of *G. arborea* at week 6. It was reveled that only drying method was significant; other factors and interactions were not significant for drying rate of *Gmelina arborea*. This means that there is a significant difference in the drying rate between air drying and the experimental solar kiln. This is in accordance with Jayanetti (1997) and Wengert, (2006).

Table 1: Mean values for drying rate of *Gmelina arborea* at different weeks of drying.

DM	SH	RP	Week 4	Week 6	Week 8	Week 10	Week 12
Air drying	**25 %**	Inner wood	0.215±0.058	0.354±0.208	0.281±0.041	0.364±0.044	0.317±0.062
		Middle wood	0.154±0.015	0.390±0.208	0.196±0.018	0.439±0.063	0.206±0.021
		Outer wood	0.148±0.005	0.386±0.167	0.199±0.021	0.431±0.052	0.214±0.014
		Mean	**0.172±0.029**	**0.377±0.024**	**0.225±0.050**	**0.411±0.072**	**0.246±0.059**
	50 %	Inner wood	0.212±0.002	0.401±0.157	0.297±0.069	0.530±0.053	0.179±0.039
		Middle wood	0.134±0.035	0.354±0.271	0.175±0.078	0.345±0.049	0.281±0.089
		Outer wood	0.159±0.021	0.341±0.275	0.164±0.087	0.396±0.036	0.238±0.114
		Mean	**0.168±0.011**	**0.365± 0.019**	**0.212± 0.016**	**0.424± 0.048**	**0.233± 0.039**
	70 %	Inner wood	0.149±0.002	0.335±0.244	0.245±0.051	0.404±0.096	0.212±0.014
		Middle wood	0.153±0.009	0.383±0.283	0.164±0.087	0.373±0.025	0.227±0.100
		Outer wood	0.148±0.004	0.385±0.292	0.248±0.054	0.266±0.150	0.361±0.124
		Mean	**0.15± 0.006**	**0.368 0.026**	**0.219±0.042**	**0.348±0.087**	**0.267±0.079**
Solar drying	**25 %**	Inner wood	0.780±0.166	0.648±0.236	0.354±0.271	0.533±0.203	0.319±0.096
		Middle wood	0.998±0.060	0.772±0.032	0.341±0.275	0.511±0.041	0.425±0.052
		Outer wood	0.982±0.188	0.713±0.050	0.335±0.244	0.411±0.040	0.378±0.037
		Mean	**0.92 ± 0.136**	**0.711±0.035**	**0.343±0.016**	**0.485±0.052**	**0.374±0.027**
	50 %	Inner wood	1.011±0.124	0.718±0.058	0.383±0.283	0.451±0.055	0.366±0.010

		Middle wood	1.127±0.092	0.795±0.072	0.380±0.283	0.396±0.041	0.411±0.033
		Outer wood	1.002±0.077	0.688±0.074	0.451±0.343	0.459±0.086	0.389±0.057
		Mean	**1.047±0.065**	**0.734±0.037**	**0.405±0.021**	**0.435±0.059**	**0.389±0.027**
	70 %	Inner wood	1.020±0.021	0.676±0.076	0.382±0.239	0.437±0.096	0.364±0.002
		Middle wood	1.067±0.084	0.721±0.064	0.374±0.207	0.430±0.016	0.372±0.018
		Outer wood	1.031±0.023	0.704±0.085	0.361±0.186	0.410±0.093	0.350±0.046
		Mean	**1.039±0.094**	**0.700±0.045**	**0.372±0.060**	**0.426±0.028**	**0.362±0.020**

DR: Drying method
SH: Sampling height
RP: Radial position

Table 2: Analysis of variance (ANOVA) for drying rate of *G. arborea* at week 4

SV	Df	SS	MSS	F	Sig.
Drying method (DM)	1	15.816	15.816	2.597	0.000*
Sampling Height (SH)	2	0.063	0.031	5.135	0.008*
Radial position (RP)	2	0.026	0.013	2.147	0.124ns
DM x SH (Interaction)	2	0.092	0.046	7.594	0.001*
DM x RP (Interaction)	2	0.113	0.057	9.291	0.000*
SH x RP (Interaction)	4	0.027	0.007	1.090	0.368ns
DM* SH* RP	4	0.066	0.016	2.709	0.037*
Error	72	0.438	0.006		
Total	89	47.205			

Mean value with '*' are significant, while values with 'ns' are not significant at $p \leq 0.05$

Table 3: Follow up test (DMRT) for longitudinal position based on drying rate

Longitudinal position	Values
25%	0.5462^{a}
50%	0.5946^{b}
75%	0.6075^{b}

Means with the same alphabets are the same.

Table 4: ANOVA for drying rate of *Gmelina arborea* at week 6

SV	df	SS	MSS	F	Sig.
Drying method (DM)	1	2.679	2.679	79.893	0.000*
Sampling Height (SH)	2	0.004	0.002	0.055	0.947ns
Radial position (RP)	2	0.035	0.017	0.518	0.598ns
DM x SH (Interaction)	2	0.006	0.003	0.092	0.912ns
DM x RP (Interaction)	2	0.020	0.010	0.303	0.740ns

SH x RP (Interaction)	4	0.029	0.007	0.218	0.928ns
DM* SH* RP	4	0.011	0.003	0.081	0.988ns
Error	72	2.415	0.034		
Total	89	31.679			

* Means significant and ns means not significant at p≤0.05

Table 5: ANOVA for drying rate of *G. arborea* at week 8

SV	df	SS	MSS	F	Sig.
Drying method (DM)	1	0.539	0.539	14.835	0.000*
Sampling Height (SH)	2	0.009	0.004	0.120	0.887ns
Radial position (RP)	2	0.041	0.021	0.564	0.571ns
DM x SH (Interaction)	2	0.021	0.010	0.285	0.753ns
DM x RP (Interaction)	2	0.035	0.018	0.487	0.617ns
SH x RP (Interaction)	4	0.006	0.002	0.041	0.997ns
DM* SH* RP	4	0.036	0.009	0.250	0.909ns
Error	72	2.618	0.036		
Total	89	11.197			

* Means significant and ns means not significant at p≤0.05

ANOVA in Table 5 (above) revealed that only drying method is significant. There is no significant difference between other factors and interaction as observed from the result. This means that sample of *G. arborea* selected at any of the sampling height and radial position gave the same result for the drying rate. Hence, at week 8, sampling height and radial position at which the wood samples were selected did not influence drying rate significantly. However, drying method is significant (solar kiln performed better in terms of drying rate for all the weeks).

For week 10 (Table 6) result revealed that there is a significant difference between drying method (Jayanetti, 1997 and Wengert, 2006), sampling height, radial position, interaction between SH x RP and interaction between DM x SH x RP. The follow-up test in Tables 7 and 8 revealed the separation of means that are the same from the ones that are not (for longitudinal position and radial position respectively).

Table 6: ANOVA for drying rate of *G. arborea* at week 10

SV	df	SS	MSS	F	Sig.
Drying method (DM)	1	0.067	0.067	9.808	0.003*
Sampling Height (SH)	2	0.059	0.030	4.372	0.016*
Radial position (RP)	2	0.051	0.026	3.787	0.027*
DM x SH (Interaction)	2	0.021	0.010	1.523	0.225ns
DM x RP (Interaction)	2	0.002	0.001	0.148	0.863ns
SH x RP (Interaction)	4	0.073	0.018	2.674	0.039*
DM* SH* RP	4	0.090	0.023	3.327	0.015*
Error	72	0.488	0.007		
Total	89	16.832			

* Means significant and ns means not significant at p≤0.05

Table 7: Follow up test (DMRT) for longitudinal position based on drying rate

Longitudinal position	Values
25%	0.4481^{b}
50%	0.4293^{b}
70%	0.3867^{a}

Means with the same alphabets are the same.

Table 8: Follow up test (DMRT) for radial position based on drying rate

Radial position	Values
Outer wood	0.3953^{a}
Middle wood	0.4158^{ab}
Inner wood	0.4530^{b}

Means with the same alphabets are the same.

Table 9 revealed that only drying method was significant. There is no significant difference between other factors at their various levels and interaction (except DM x SH x RP Interaction).

Table 9: ANOVA for drying rate of *G. arborea* at week 12

SV	df	SS	MSS	F	Sig.
Drying method (DM)	1	0.360	0.360	90.835	0.000*
Sampling Height (SH)	2	0.000	0.000	0.042	0.959ns
Radial position (RP)	2	0.016	0.008	2.001	0.143ns
DM x SH (Interaction)	2	0.014	0.007	1.750	0.181ns
DM x RP (Interaction)	2	0.017	0.008	2.127	0.127ns
SH x RP (Interaction)	4	0.040	0.010	2.549	0.046*
DM x SH x RP (Interaction)	4	0.093	0.023	5.885	0.000*
Error	72	0.286	0.004		
Total	89	9.574			

* Means significant and ns means not significant at $p \leq 0.05$

Table 10: Correlation matrix between drying rate, relative humidity and temperature for air and solar kiln drying of *G. arborea.*

	RHAD	TEPAD	DRAD	RHSD	TEPSD	DRSD
RHAD	1					
TEPAD	-0.9444*	1				
DRAD	-0.4533	0.7109	1			
RHSD	0.9949**	-0.9453*	-0.4853	1		
TEPSD	-0.9444*	1.0000**	0.7109	-0.9453*	1	
DRSD	-0.8368	0.9526*	0.8093	-0.8299	0.9526*	1

* Significant at 5% level of probability; ** Significant at 1% level of probability
RHAD- Relative density (%) for air drying
TEPAD-Temperature (^{0}C) for air drying
DRAD- Drying rate (%/day) for air drying
RHSD- Relative humidity (%) for solar drying
TEPSD- Temperature (^{0}C) for solar drying
DRSD- Drying rate (%/day) solar drying

Table 10 revealed the relationship between drying rate, relative humidity and temperature for *G. arborea* wood samples dried under air and solar kiln for 12 weeks. Negative sign (-) represents negative correlation; While no sign was used for positive correlation. Each variable down the rows of the first column is correlated with corresponding variable along other columns. For example, relationship between DRSD (Drying rate (%/day) for solar drying) and TEPSD (Temperature (^{0}C) for solar drying) showed a strong, positive correlation at 5% level of significance (0.9526*). This simply indicates that as TEPSD increases, DRSD increases. However, relationship between DRSD (Drying rate (%/day) for solar drying) and RHSD (Relative humidity (%) for solar drying) showed a negative correlation (-0.8299). This means that as RHSD increases, the DRSD decreases. This is in according with the submission of Wengert (2006) and Uetimane (2010).

At the end of the study, only the solar kiln dried wood samples reached moisture content (MC) at which the digital moisture meter could be used to determine the difference in MCs of inner and surface layer of the boards. An indication *HH* on the moisture meter revealed that air dried samples were still wet (above fibre saturated point - FSP of 28% as stated by Wengert, 2006) at the end of the 12th week. Hence, since the digital moisture meter is designed for wood at Moisture Content range of between 0-30 percent, it could not be used for the air dried samples.

Table 11 presents the mean values of moisture gradient (MG) at 12th week of drying. The differences in the MCs between the inner and surface layer of the board is small; this explains why the solar kiln dried samples were not prone to high stresses within the wood fibres which might have caused defects such as splits and checks (Okigbo, 1965). Hence, no drying defect was observed for the kiln dried samples. However, for air dried samples, drying defect observed during the study include warp and stain on the air dried wood. This could be as a result of too high ambient relative humidity experienced under the drying shed during the period of the study. This is in line with Wengert, 2006 who reported that at higher R.H. wood is more prone to warp and stain.

Table 11: Mean values of moisture content (%) and moisture gradient (MG) between the inner and surface portion of *G. arborea* at 12th week of drying.

Drying method	Sampling height	Radial position	Moisture content (%) of wood		
			Outer layer	Inner layer	Mean MG
Air drying	**25%**	Inner wood	18.67	19.67	1.00
		Middle wood	18.66	19.86	1.20
		Outer wood	19.47	20.47	1.00
	50%	Inner wood	19.04	19.84	0.80
		Middle wood	17.99	18.99	1.00
		Outer wood	18.00	18.71	0.71
	75%	Inner wood	18.50	19.22	0.72
		Middle wood	19.99	20.66	0.67
		Outer wood	18.99	19.66	0.67
Solar drying	**25%**	Inner wood	18.80	19.51	0.71
		Middle wood	19.02	19.7	0.68
		Outer wood	19.75	20.43	0.68
	50%	Inner wood	18.52	19.21	0.69
		Middle wood	20.40	21.02	0.62
		Outer wood	20.00	20.55	0.55
	75%	Inner wood	19.02	19.72	0.70
		Middle wood	19.75	20.45	0.70
		Outer wood	18.52	19.22	0.70

CONCLUSION

It is no gain saying that this study has provided relevant information on selected drying characteristics of air and solar kiln dried *G. arborea*. The solar and air drying loads dried at different rates under the changing ambient conditions as the weeks go by. At any particular point in time, changes in the weather conditions of the prevailing environment led to varying drying rate of the stacked wood.

However, based on the results obtained for drying rate, final percentage moisture content and seasoning defects, solar kiln dried *G. arborea* performed better at each week-during the period of study. This is in conformity with the work of many other researchers who carried out similar studies on solar wood drying and reported that solar kiln performs better than air drying of wood. It was observed that the drying conditions (relative humidity and temperature) in the kiln favoured wood drying more than that of air drying; hence, a better result was obtained for kiln dried samples in terms of drying rate, drying defects and moisture gradient.

In conclusion, the experimental solar kiln provided a better result on the selected drying characteristics of *G. arborea* than air drying of wood. Consequently, the setup is an improvement on the air drying method.

REFERENCES

Chen, P.Y.S.; Helton, C.E. (1989): Design and evaluation of a low-cost solar kiln. *Forest Products Journal* 39 (1): 19-22.

European standard (2003): EN 13183-1. Moisture content of a piece of sawn timber- part 1: Determination by oven dry method.

European standard (2003): ENV 14464. Sawn timber- Method for assessment of case hardening.

European standard (2004): EN 14298. Sawn timber – Assessment of drying quality.

Fajimi, A.F (1983): Air and solar kiln drying of *Terminalia superba* and *Tectona grandis*. A Dissertation submitted to the department of Forest Resources Management, University of Ibadan. Pp1-59

Gan, K.S. & Choo, K.T. (2001): Simulation of a Solar Timber Dryer: in Proceedings of the 2nd Asian-Oceania Drying Conference ADC'01, Batu Fernghi, Pulau Pinang, Malaysia 20-23 August 2001. Pp 727-734.

Jayanetti, D.L. (1997): Solar Heated Timber Drying Kilns. Paper presented in "Green Profit for Asian Furniture" seminar held in conjunction with WoodmacAsia97/ FurniTekAsia97. Singapore. 16 Sept., 1997.

Lawluvi and Ayensu, (1998): Thermal Stimulated Moisture Desorption and Drying Characteristics of Tropical Hardwood. *Proceedings* of *IITOIFORIGfTEDB - VAlIPU Conference, City lIotel, Kumasi. Ghana.* 17 - 19 *Feb. 1998.* pp 121-130

Lumley, T.G. and Choong, E.T. (1981): Solar drying of wood in Louisiana. Louisiana Agricultural Experimental Station. Bulletin No:732.

Okigbo, L. (1965): Air drying of Opepe (*Nauclea diderrichii*) poles and its pressure impregnation at high moisture content. *Forest products research reports*. FPRL No. 4. pp 1-8.

Reuss, M., St. Benkert, Aeberhard, A., Martina, P., Raush, G., Rentzel, B.V. and Sogari, N. 1997b. Modelling and experimental investigation of a pilot plant for solar wood drying. Solar Energy Vol.59 Nos.4-6, pp259-270.

Simpson, W.T. and Tschernitz, J.L. (1989): Performance of a solar/wood energy kiln in tropical latitudes. *Forest Product Journal*. Vol. 39, No.1:23-30.

Uetimane Junior Ernesto, Allegretti Ottaviano, Terziev Nasko and Soderstrom Ove (2010): Application of non-symmetrical drying tests for assessment of drying behavior of ntholo (*Pseudolachnostylis maprounaefolia* PAX). Holzforschung, Vol. 64, pp 363-368.

Wengert, Eugene M. (2006): Principles and Practices of Drying Lumber. Lignomat. Pp 1-59.