PRELIMINARY STUDY ON DRYING CHARACTERISTICS OF END-COATED *Brachystegia eurycoma* BOARDS SEASONED UNDER AIR -AND SOLAR KILN DRYING ENVIRONMENT

***[1]Amoo-Onidundu, O. N., [2]Noah, A. S., [1]Olajide, O. B. and [1]Oriire, L. T.**
[1] Department of Forest Products Development and Utilisation, Forestry Research Institute of Nigeria, PMB 5054,
Jericho Hill Estate, Ibadan, Nigeria.
[2]Department of Wood and Paper Technology, Federal College of Forestry, Ibadan.
**aremunath5@gmail.com, 08028227909*

ABSTRACT

Board end-coating is known to control checking which reduce wood drying quality. Information on drying characteristics of end-coated *Brachystegia eurycoma* boards is limited. End-coating of *Brachystegia eurycoma* towards improving its drying quality was investigated. The experiment was conducted at the Forestry Research Institute of Nigeria, Ibadan. Corewood (25mm x 300mm x 2125mm) were sampled from base of a 45year old *Brachystegia eurycoma* log and end-coated with paint to prevent moisture loss prior to air drying (AD) and solar kiln drying (SKD). Twenty-four flatsawn boards (25mm x 300mm x 1800mm) were processed. Boards' initial moisture content was determined. Samples were grouped into three: 8 paint end-coated (PEC), 8 wax end-coated (WEC) and 8 control (CON). Four boards each were seasoned in AD and SKD for 28 days. Final moisture content-FMC (%) and drying rate-DR (%/day) were calculated. Checks were evaluated according to standard procedures. Temperature-T°C and relative humidity-RH% of AD and SKD were measured. The study was a 3x2 factorial experiment in a Randomised Complete Block Design. Data were analysed using descriptive statistics and ANOVA ($p \geq 0.05$). The FMC was least (SKD=9.25 and AD=15.70) in CON and highest (SKD=12.01 and AD=30.49) in WEC. The DR of CON (6.25%/day) and WEC (5.62%/day) were significant different. Percentage of checked boards was highest (100% and 50%) in CON and least (25% and 0%) in PEC for AD and SKD, respectively. Average temperature and relative humidity were 32.75°C and 80.25% in AD and 47.48°C and 57.75% in SKD. End-coating boards with paint produced best drying quality.

Keywords: Boards, temperature, relative humidity, solar kiln and control

INTRODUCTION

Wood is a versatile renewable natural resource. From time immemorial, wood has been used for manufacture of several viable products in domestic and industrial applications (Elder *et al*., 2021). Due to its hygroscopic nature, wood absorbs or desorbs moisture in relation to amount of moisture in its prevailing environment. Upon its exposure to influence of changes in environmental moisture, wood becomes dimensionally unstable in service. Consequently, in order to improve the dimensional stability of wood used in many desired applications, it is imperative to dry or season timber prior to its utilization (Broda *et al*., 2021).Wood drying is one of the major processes involved in wood products manufacture. It is an important aspect of production which affects performance of the resultant wood products. Drying influences wood workability, finishing, treatability and service life. More so, wood becomes less susceptible to the influence of environmental fluctuations which makes it dimensionally unstable in service (Amoo-Onidundu, 2019; Broda *et al*., 2021).

According to Redman *et al*. (2016) the process of wood drying is complex and requires adequate knowledge regarding moisture movement mechanism as it influences the drying outcomes. During drying, the external layers of wood dry more rapidly than the internal ones. The moment moisture in the outer parts dries below the fibre saturation point which is between 25%-30% moisture content, wood starts to shrink. Hence, because the inner layers still remains saturated, shrinkage in external areas becomes uneven. This phenomenon generates stresses in wood. Consequently, the moment stresses in wood exceeds the mechanical strength of the material, it starts to crack and split (Bond and Espinoza, 2016). The type of drying degrade which develops in wood is dependent on wood anisotropic properties and mode of moisture loss at boards surfaces and ends. Defects may result from shrinkage anisotropy, resulting into warping: cupping, bowing, twisting, crooking, spring and diamonding. More so, uneven drying stresses causes rupture of the wood tissue leading to defects such as checks (end, surface or internal), honey combing and case hardening (Hoadley, 2000). Defects caused by wood anisotropic nature are basically connected to wood property such as features such as low density, high knot volume, high spiral grain, large microfibril angle, high longitudinal shrinkage and compression wood. Defects caused by uneven drying stresses may be caused by improper drying techniques, in appropriate drying methods, exposure to unfavorable environmental condition and so on (Bond and Espinoza, 2016).

Researchers are identifying effects of wood properties and drying practices on wood drying quality. Consequently, studies are conducted to develop measures towards reducing incidences of wood drying degrade and improving drying quality (Pinchevska *et al*., 2016). One of such procedures through which defects can be reduced is end-coating treatment on boards. End-coating is the used of pigments, paints, wax, oil, varnish or other substances such as commercial green wood sealers for coating end of boards to control drying processes in order to reduce or prevent defects formation on wood. It has been observed that excessive drying out of water from ends of board can be controlled through end-coating (Armousegar, 2010). Reports revealed that end-coated lumber were less susceptible to end checks and had improved drying quality (Rowell, 2006).

Brachystegia eurycoma is an evergreen tree with a dense, spreading crown; it can grow up to 36 metres tall. The tree is harvested from the wild for its wood, which is used locally and also exported. The texture is medium to coarse; the grain usually deeply interlocked, producing a pronounced roe figure; the wood is also characterized by high lustrous property. Traditionally, the bark has been used to make a coarse cloth used as protection against rain and as a shield against arrows. The heartwood of *Brachystegia eurycoma* is pinkish brown with vague bands and rather distant fine streaks, it is clearly demarcated from the whitish sapwood, wood grain is usually interlocked and the texture is medium. The heartwood is rated as moderately durable. The wood dries rather slowly, with a marked tendency to check and warp. However, upon drying, it becomes fairly stable in service. The wood of *Brachystegia eurycoma* is suitable for flooring, interior trim, interior carpentry, stairs, veneer and plywood (Femi-Ola, 2008).

Materials and Methods

Materials, tools and equipment used for the experiment

Wood samples of *B. eurycoma*, weighing balance, oven, solar kiln, air drying shed, gloss aluminum paint, wax, record book, thermo-hygrometer, marker, biro, stickers, measuring tape, flat table.

Study area

The experiment was carried out at the Forestry Research Institute of Nigeria (FRIN) Ibadan, located on latitude 7°23'15" to 7°24'00" N and longitude 3°51'00" to 3°52'15"E. Annually, the average temperature of FRIN ranges between 18.07˚C and 34.4˚C (for minimum and maximum value respectively). According to Ariwaodo *et al.* (2012) the study area is characterised by two seasons which are distinctly different: The rainy season (which begins in April and end in October) and the dry season (which starts in November and ends in March). A distinct harmattan often characterises the dry season in December.

Timber procurement and preparation of Wood Samples

Timber conversion processes was carried out at the wood workshop, and wood drying experiments (air and solar kiln) were set up at the Department of Forest Products Development and Utilisation, FRIN. Tree of *B. eurycoma* was harvested and corewood was sampled from diameter at breast height of the log. The wood samples (25mm x 300mm x 2125mm) were end-coated with paint to prevent moisture loss prior to drying experiment.

Preparation of oven dry samples for determination of initial moisture content (IMC)

According to FPRL (1999), test samples (25mm x 25mm x 300mm) were obtained at 300 mm away from boards' ends. Initial weight (W1) of samples was measured. Test samples were oven-dried at temperature of 103±2˚C until constant weight (W2) was obtained. The IMC was calculated as shown in Equation 1.

$$IMC = \frac{W1-W2}{W2} X 100 \quad \text{………………………………………………………}1$$

Where:

IMC= Initial moisture Content

$W1$= wet weight of wood

$W2$ =oven dry weight of wood

Dimensioning of sample boards

Twenty-four sample boards were dimensioned into 25mm x 300mm x 1800mm. Equal number of boards (8 samples each) were grouped into three classes: 8 boards were end-coated with paint, 8 boards were end-coated with wax while 8 boards were uncoated (control). Four samples from each group were prepared for air- and solar kiln drying experiments.

Stacking of boards under the air drying shed or in the solar kiln.

Wet weight of boards (WWB) were measured on a sensitive weighing balance. Equal pieces of boards were stacked under the shed (air drying method) and in solar kiln (artificial drying method) with sticker (25mm x 25mm x 300mm) separating alternate boards.

Periodic moisture content

Periodic moisture content is a measure of the amount of water contained in wood and is expressed as a percentage of its oven dry weight. The periodic moisture content of boards was determined using equation 2 according to FPRL (1999) and Timber Queensland (2014).

$$PMC\ (\%) = \frac{CWB-DWB}{DWB}\ X\ 100 \quad \text{…………………………………………………..}2$$

Where:

PMC = Periodic moisture content

CWB = Current weight of board

DWB = Dry weight of board

$$DWB \ = \frac{WWB}{\frac{IMC}{100}+1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

Where:
WWB = Wet weight of board
IMC = Initial Moisture content

Drying rate (DR-%/day)

The drying rates of the wood samples were determined according to FPRL (1999) and calculated using equation 4. The rate of drying was determined on a weekly basis. The drying experiment progressed until wood reaches its equilibrium moisture content (EMC). After 28 days (4 weeks), the average daily DR was calculated.

$$DR=\frac{PMC-CMC}{Time\ (days)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

DR=Drying rate
PMC= Previous moisture content
FMC= Current moisture content

Measurement of environmental conditions (Temperature-T℃ and relative humidity-RH%)

Digital thermo-hygrometers were positioned inside the kiln and under the air drying shed for measurement of environmental condition (T and RH). Readings were taken 10 times daily (between 8:00 am to 5:00 pm) at interval of 1 hour. Measurements of T and RH at the selected period of time is a modification of climatic data capturing system in meteorological information (KNMI, 2000, GLOBE, 2005). Average of daily readings was calculated for weekly evaluation. Overall average of T and RH was calculated after 28 days of drying.

Experimental design

The experimental design adopted was a 3 x 2 factorial experiment in a Randomized Complete block Design (RCBD). Data obtained was subjected to analysis of variance (ANOVA) for significant difference that exist between the drying rate of end-coated boards and control while comparison of means were conducted using Least Significance Difference (LSD) to separate means that are different from one another.

Assessment of Checks

Checks were measured on end-coated and uncoated boards and evaluated according to Rasaily (1993). The planks were placed on flat table and checks were measured using measuring tape.

Results and Discussion

Table 1: The FMC (%) of end-coated and uncoated *Brachystegia eurycoma* wood

End-coat Treatment	FMC of boards Solar	Air
Control	9.25	15.70
Paint	11.49	16.24
Wax	12.01	30.49

FMC represents Final moisture content

Final moisture content (FMC) of end-coated and uncoated *Brachystegia eurycoma* wood was presented in Table 1. Results revealed that FMC of Control, wax-coated and paint-coated boards under solar- and air-drying environments differed considerably. The FMC for solar kiln-dried boards were 9.25%, 11.49% and 12.01% in control, paint-coated and wax-coated boards, respectively. This indicated that moisture migration was highest in Control and least in wax-coated samples. However, due to the fact that FMC of Control (9.25%), paint-coated (11.49) wax-coated (12.01%) boards reached equilibrium moisture content-EMC (12-15%) as stated by TRADA Technology (2011), both end-coated and uncoated solar kiln-dried samples dried to recommended moisture content for applications such as internal joinery in conformity with BS EN 942-2007.

In air-dried samples, the FMC were 15.70%, 16.24% and 30.49% for Control, paint-coated and wax-coated boards, respectively. This implied that moisture loss in wood was highest in Control and lowest in wax-coated. Control (15.70%) attained the range of EMC (12-15%) while paint-coated (16.24%) and wax-coated (30.49%) boards did not. This may mean that the paint and wax pigments used for end coating of boards sealed the fibres pores and reduced the moisture flow to the wood surface. This is in conformity with Haygreen and Bowyer (1989) and Armousegar (2010) that moisture movement from ends of wood is influenced by the type of end coating pigment applied on timber.

With reference to recommended EMC of 12-15%, a comparative study on FMC of control, paint coated-and wax coated boards in SKD and AD environment revealed that solar kiln-dried boards attained lower FMC compared to AD. This indicates better final moisture content compared to AD. The observation is in line with Amoo-Onidundu (2019) and Broda *et al*. (2021) that SKD-dried boards had lower final moisture content.

Table 2: Analysis of variance (ANOVA) for FMC of end-coated and uncoated boards

SV	df	SS	MSS	F	Sig
End coating treatment (ECT)	2	1364.49	6.82.22	1084.50	0.004*
Drying method (DM)	1	1066.13	106.13	99.67	0.003*
ECT*DM	2	367.62	183.81	62.17	0.002*
Error	18	137740.80	7652.27		
Total	23	140539.11			

*value significant at $p \leq 0.05$

ANOVA for FMC of boards was presented in Table 2. Results revealed that effect of end-coating treatment and drying method were statistically significant on FMC of boards at $p \leq 0.05$. More so, effect of interaction between end coating and drying method was significant on FMC. The follow-up test for separating FMC (Table 3) revealed that FMC of Control (24.95) and paint end-coated (27.73) boards were same. However, they were not same with wax end-coated samples (42.56). This implied that end coating of *Brachystegia eurycoma* boards with wax did not have that same influence on moisture flow like paint coating and Control.

Table 3: The follow-up test for separating FMC

End-coating Treatment	FMC (%)
Control	24.95a
Paint	27.73a
Wax	42.56b

Values with same letters are statistically the same

Table 4: Drying rates (%/days) for Control, Paint-coated and wax-coated boards

End-coat Treatment	DR of boards	
	Solar	Air
Control	3.24	3.01
Paint	3.16	2.99
Wax	3.14	2.48

Drying rate for Control, Paint-coated and wax-coated boards is presented in Table 4. Results revealed that drying rate of solar kiln-dried boards were 3.24%, 3.16% and 3.14% for Control, paint-coated and wax-coated, respectively. Highest (3.24%) and least (3.14%) DR values in Control and wax coated samples, respectively, indicates that rate of moisture movement from *Brachystegia eurycoma* boards was highest in uncoated boards and least in wax coated. This may mean that moisture movement was slowed down by coating pigments which blocked fibre pores at boards' ends thereby reducing the rate of moisture flow to the surface. The observation agrees with Armousegar (2010) that end coating reduces moisture loss at boards' end.

The DR of air-dried boards were 3.01%, 2.99% and 2.48 for Control, paint-coated and wax-coated, respectively. Highest (3.01%) and least (2.48%) DR value in control and wax coated samples, respectively indicates that rate of moisture movement from *Brachystegia eurycoma* boards was highest in uncoated boards and least in wax coated. This may mean that wax coating pigments caused highest degree of blockage in fibre pores which are responsible for moisture flow in wood. Hence, drying rate in wax-coated *Brachystegia eurycoma* boards was least.

The DR in solar kiln drying was higher than in air-drying for coated and uncoated boards. This may mean that higher temperature and lower relative humidity in solar kiln chamber- compared to air drying shed (Table 7) favoured the rate of moisture loss in SKD. This is in line with Broda *et al*. (2021) that solar kiln drying environment favours wood drying better than air drying condition.

Table 5: ANOVA for drying rate of of end-coated and uncoated boards

SV	df	SS	MSS	F	Sig
End coating	2	1728.12	864.06	6.88	0.02*
Drying method	1	367.62	367.62	2.93	0.03*
End coat*drying mtd	2	6.13	3.06	0.02	0.04*
Error	18	2260.19	125.57		
Total	23	4362.06			

Ns=not significant

Table 6: The follow-up test for separating drying rate

End-coat Treatment	DR (%/day)
Control	6.25a
Paint	6.15a
Wax	5.62b

Values with same letters are statistically the same

The ANOVA for drying rate of end-coated and uncoated boards was presented in Table 5. Results revealed that effect of treatment (Control, Paint-coated and wax-coated boards) is statistically significant on drying rate of *Brachystegia eurycoma* boards. This implied that Control, paint end-coated and wax end-coated boards dried at significantly different drying rates. The follow-up test (Table 6) revealed that DR of Control (6.25) and paint end-coated samples (6.15) were same, while DR of wax end-coated samples (5.62) was different. This implied that untreated and paint end-coated *B. eurycoma* boards responded to drying (moisture flow) at a similar rate while wax end-coated boards responded to drying at dissimilar rate.

Table 6: Drying defects (checks) on end coated and uncoated *Brachystegia eurycoma* boards

End-coating treatment	Drying method	Total number of boards	Severity of defects			No. of defected boards	% of defected boards
			Mild	Moderate	Severe		
Control	Solar kiln	4	1	1		2	50
	Air drying	4	1	1	2	4	100
Paint end-coated	Solar kiln	4	-	-	-	-	0
	Air drying	4	1			1	25
Wax end-coated	Solar kiln	4	1			1	25
	Air drying	4	1	1	1	3	75

Number of defected boards was evaluated as a percentage of total boards

Drying defects/checks on end-coated and uncoated *Brachystegia eurycoma* boards was presented in Table 6. Results revealed that in Control (samples with uncoated ends), the percentage of boards that developed end checks were 50% and 100% for solar kiln drying and air drying, respectively. On the contrary, 0% and 25% of boards end-coated with paints developed end checks while 25% and 75% of boards end-coated with wax developed end checks in solar kiln-dried and air-dried boards, respectively. It was observed that out of the two categories (end-coated and uncoated boards), end-coated samples performed better in terms of lower percentage of boards with defect formation.

Despite that fact that uncoated *Brachystegia eurycoma* boards attained least FMC (Table 1) with highest DR (Table 4), percentage of boards with check formation was highest. This may mean that the rate of moisture movement from boards with uncoated ends was too high leading to tearing apart of fibres which caused end checks. This is in line with the submission of Filippou *et al*. (2017) that too high rate of moisture loss from boards' ends causes end checks. Considering the results (in relation to defect formation), it could be observed that the drying quality in Control (uncoated boards) is lower compared to end-coated *Brachystegia eurycoma* samples.

A comparative study on response of samples (in terms of defect development) to environmental conditions revealed that solar kiln-dried samples performed better than air dried. This may mean that heat energy distributed within that solar kiln chamber enhanced a more controlled and gradual moisture movement from boards' ends. Hence, drying stresses which causes checks development on wood were regulated. This corroborates Filippou *et al*. (2017) that environmental conditions in solar kiln chambers enhances reduction in timber checks, compared to air drying.

Table 7: Weekly average of daily T and RH

Weeks	Temperature (℃)		Relative Humidity (%)	
	SKD	AD	SKD	AD
Week 1	44.30	30.00	70.90	91.60
Week 2	46.50	32.00	65.10	87.70
Week 3	48.52	33.40	50.90	73.80
Week 4	50.58	35.60	44.10	67.90
Overall average	**47.48**	**32.75**	**57.75**	**80.25**

SKD= Solar kiln; AD= Air drying

Table 7 revealed that average T°C were 47.48 and 32.75 while RH were 57.75 and 80.25 for SKD and AD, respectively. Highest and least T°C in SKD were 50.58 and 44.30 while highest and least RH in AD were 30.00 and 44.10. Least and highest relative humidity (RH%) were 44.10; 70.90 and 67.90; 91.60 for SKD and AD, respectively. The variability in temperature and relative humidity might have been responsible for variations observed in the drying characteristics of end-coated *brachystegia eurycoma* boards seasoned under air -and solar kiln drying environment. Higher temperature and lower relative humidity in SKD could have been responsible for better drying performance which resulted into improved drying characteristics in SKD (Table 1 and Table 4), compared to ADS. This corroborates Filippou *et al*. (2017) that wood drying characteristics is influenced by environmental condition.

CONCLUSION

This study has provided relevant information on effects of end-coating on selected drying characteristics of *Brachystegia eurycoma* such as final moisture content, drying rate and drying defects- which were used as indices for drying quality evaluation. Although, drying rate of Control was higher when compared to treated samples, it was observed that moisture migration from surface of paint- and wax-coated *Brachystegia eurycoma* boards was better controlled. This was evident in terms of lower percentage of defects (end-checked) in end-coated boards and higher percentage of defects in uncoated *Brachystegia eurycoma* wood. It was observed that environmental condition influences final moisture content, drying rate and checking.

Drying of *Brachystegia eurycoma* wood in solar kiln suggested that the drying rate of the species can be increased without causing severe degrade (checks) to boards. Increase in the drying rate of a slow drying species such as *Brachystegia eurycoma*, could be a viable means of improving drying properties and optimizing utilization potentials in the wood industries. More so, drying quality of *Brachystegia eurycoma* could be enhanced under favourable drying condition such as a solar kiln drying environment.

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