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Effect of Air-Drying of Brachystegia Laurentii Wood on Some of its Mechanical Properties

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Abstract

The traditional and most cost-effective method of seasoning timber is to stalk it in air and let atmospheric heat and natural air movement remove moisture from it. This paper investigates the effect of air-drying on the mechanical properties of Brachystegia Laurentii (popularly referred to as Eku wood). Over 300 samples of Brachystegia Laurentii were air-dried between one to six months and the mechanical properties of the air-dried samples were compared with their moisture contents. Physical properties i.e., density as well as mechanical properties i.e., modulus of elasticity (MOE), modulus of rupture (MOR), compressive strength and tensile strength were studied. It was observed that mechanical properties were a function of the moisture content of these woods. A polynomial function using least square approach was developed to predict strength from moisture content. This function is expected to serve as a tool for predicting the obtained strength of Brachystegia Laurentii wood during various stages of seasoning. The relationship established can also be used for preliminary strength predictions of Brachystegia Laurentii wood using portable digital moisture meters.

1. Introduction

Generally, in green trees, depending on the type of wood and position of wood fibre in the log, the moisture content (MC) of wood could between 50% to 200% [1]. This high value of MC needs reduced to values less than 15% before it is used in industrial application.

The properties of wood are affected significantly by its moisture content [2]. Proper gluing, machining and finishing are only possible after moisture content of wood is reduced to an appropriate value. This implies that proper drying of wood is necessary for industrial utilization of wood because it reduces effects such as warping, shrinkage and other forms natural degradation. Adequate moisture content of wood improves dimensional stability and mechanical properties [3]. The orthotropic nature of timber is also affected by its moisture content. Timber is orthotropic material and this means that it behaves differently under load, depending on the axes it is loaded on. The analysis of an orthotropic material is more rigorous than that of an isotropic material. This is because of the different properties exhibited by an orthotropic material with respect to its axes (i.e. its three main orthogonal axes). On the order hand, isotropic materials have uniform properties in all its major axes [2].

There are different methods of drying wood air drying, kiln drying, chemical drying, boiling in oil, vapor drying, solvent seasoning, vacuum drying, infrared radiation, high frequency dielectric heating and the superheated steam method [4]. The most common type of drying methods includes the air drying and kiln drying. The thermodynamic and mass transfer within [5]. The air-drying method is limited by atmospheric conditions but can be accelerated by employing methods that permit taking full advantage of the atmospheric conditions. Using fans and heaters can be employed in air drying processes. The kiln drying process, on the other hand, is faster than the air-drying process because of the introduction of higher temperate and better air circulation. Current research in wood drying are mainly directed to improving the kiln drying method [6].

There are couple of tests conducted to ascertain the effect of moisture content on common woods, including the mechanics of water flow in wood [7]. For Japanese cedar (Cryptomeria japonica), for example, the strength of its green round timber and air-dried round timber were compared for bending and compression parallel to the grain and percentages in strength in relation to moisture content obtained [8]. For oakwood, results published works show that moisture content have statistically significant effects on all the measured mechanical properties in oak wood samples [9]. Changes in wood moisture content lead to changes of virtually all physical and mechanical properties (e.g. strength and stiffness properties) of wood [10]. Another effect of changes of the wood moisture content is the associated shrinkage or swelling of the material. The existence of high moisture content can initiate decay or growth of fungi [10]. Though there have been works to simulate heat and mass transfer and mechanical behavior of a wooden board during processing, this paper proposes a simple tool for obtaining fundamental strengths [11]. The correct estimation of timber moisture content and the subsequent initiation of potentially necessary measures are therefore essential tasks during the planning, execution and maintenance of buildings built with wood or wood-based products [12]. As noted, many mechanical properties of wood are affected by moisture content. Traditionally, the strength, P, at moisture content m, in the range from 8 to 25% can be estimated by Equation (1) [13]:

$$P = P_{12}\left(\frac{P_{12}}{P_g}\right)^{(12-m)(m_p-12)} \quad (1)$$

For the purposes of the formula, moisture content of green wood (m_p) is often assumed to be 25% for most species. ASTM D2555 gives ‘‘dry/green’’ ratios of mechanical properties at 12% moisture content compared with green wood. Care must be taken if this formula is used at moisture contents very far below 12%.

Eku wood (i.e. Brachystegia laurentii) is popular in Nigeria and available in commercial quantities in Sapele, in Delta State in the delta region of Nigeria. This work investigates the relations between the seasoning conditions of air-dried Brachystegia laurentii wood and its strength. A quick estimation tool for the mechanical properties of Brachystegia laurentii wood with respect to moisture content is proposed.

2. Methodology

Freshly cut logs were collected from Brachystegia laurentii species available in Sapele, Delta State. The samples were cut into sizes using circular sawing machine. Samples used for obtaining moisture contents and density were cut into five pieces of 25 mm × 75 mm × 450 mm. The moisture content of wood samples was obtained using Equation (2). Corresponding densities of timber were obtained using Equation (3).

$$A = \frac{w_i - w_o}{w_o} \times 100\% \quad (2)$$

$$\rho = \frac{m}{v} \quad (3)$$

Where w_0 is dry weight of timber after allowing to dry in an oven for 24 hours at a temperature of 103 ± 2°C, w_i is the specific weight of timber being tested, m is the mass of the wood and v is the volume of the wood.

Due to the nature of the timber being investigated, air-drying was adopted. The timber specimen was dried between 0 to 6 months (i.e. during the dry season between the months of November to March) and properly sacked in the drying chamber in Sapele, Delta State in order to prevent defects during drying. Over the course of the drying process in Sapele, the average temperature ranged between 68°F to 88°F, wind speed ranged between 4 to 9km/h and the average air pressure was at 1011 millibar. Weight loss due to drying was taken after every drying process using weighing balance for each of the test specimen used. The procedures stated in ASTM's Standard Test Methods for Mechanical Properties of Lumber and Wood-Based Structural Materials were used as a guide in this work[14]. The three-point bending test samples according to ASTM were prepared to dimensions of approximately 70mm × 10mm × 10 mm, while samples for compressive tests were approximately 50mm × 15mm × 15mm. The governing equations from the three-point test, the bending strength and the modulus of elasticity are shown in Equations (4) and (5), while the modulus of rupture (MOR) is related to maximum strength that can be resisted by a member is presented in Equation (6).

$$\rho = \frac{3PL}{2bd} \qquad (4)$$

$$E = \frac{L^3}{4bd^3} \times \frac{P}{x} \qquad (5)$$

$$MOR = \frac{PL}{bd^2} \qquad (6)$$

Where L = span, P = load at failure, b = breadth, and d = depth of specimen, where E = modulus of elasticity and x = deflection.

Five specimen samples were used to determine each value/data point presented in this work. Thus, in order to measure the dispersion or variability points around the mean values, the coefficient variations are presented for each data presented as shown in Equation (7).

$$CV = \frac{\sigma}{\mu} \qquad (7)$$

Where σ is standard deviation and μ is the mean.

3. Results and Discussion

3.1 Moisture content

Table 1 shows the moisture content variation with seasoning of timber within the six months of air drying. The moisture of Eku ranged between 12% and 48%, from green to seasoned wood. It is observed that no defects were noticed in timber due to seasoning and the moisture content and density varied with the duration o seasoning. Also, the high degree of accuracy is obtained in the results as shown by the degree of variability of moisture content as shown in the coefficient of variability presented in Table 1. The results obtained show that equilibrium moisture contents can be achieved by air drying process (the procedure adopted in this study) as shown in [15]. Air drying was stopped at 12% moisture content – this value represents standard moisture content for describing mechanical properties of most woods [16]. Though the densities were observed to reduce with increasing drying duration, it has been shown that density could be a poor predictor of strength in wood [16].

Table 1: Moisture content variation with seasoning.

Months	Density (kg/m^3)	Mean Moisture content	Coefficient of variation (CV)
1	690	48	0.04
2	600	35	0.08
3	556	25	0.06
4	500	20	0.05
5	450	18	0.04
6	416	12	0.1

3.2.Compressive Strength Perpendicular to Grain

Table 2 presents the variation of compressive strength perpendicular to grain with moisture content for the samples tested. Five samples were used to obtain values of strength after each month of seasoning. A trend is observed in the gradual increase in strength with respects to the duration of seasoning. Table 2 shows that moisture content reduced gradually as the duration of seasoning is increased. The compressive strength after seasoning for six months was found to be significantly higher than the green values and no significant distortions were observed in the test specimen. The relationship observed in Table 2 corresponds to published works which show that mechanical properties of wood vary inversely with the moisture content below fiber saturation point. Above fiber saturation point most mechanical properties are constant with changes in moisture content [17].

Table 2: Moisture content variation with compressive strength perpendicular to grain.

Months	Moisture Content	Mean value of Compressive Strength (⊥) (N/mm^2)	Coefficient of variation (CV)
1	48	15	0.1
2	35	25	0.05
3	25	28	0.07
4	20	30	0.05
5	18	35	0.07
6	12	38	0.05

Using least square approximation, the compressive strength perpendicular to grain can be obtained as:

$$P_L = -0.0008(MC)^3 + 0.0719(MC)^2 - 2.5627(MC) + 60.232 \qquad 48 \leq MC \leq 12 \quad (8)$$

Where P_L is compressive perpendicular to grain and MC is the moisture content.

3.3.Compressive Strength Parallel to Grain

Table 3 presents the variation of compressive strength parallel to grain with moisture content for the samples tested. A different set of five samples were used to obtain values of compressive strength after each month of seasoning. A trend is observed in the gradual increase in strength with respects to the duration of seasoning as in the case of compressive strength perpendicular to grain. Table 3 shows that moisture content reduced gradually as the duration of seasoning is increased. The compressive strength parallel to grain was found to significantly increase after 6 months as shown in Table 3. The decreasing moisture content and corresponding increasing compressive strength properties establishes the hygroscopic nature of wood and the moisture content dependent nature of the wood studied. This inverse relationship corresponds to studies on the moisture content and strength relationship of other timbers [18].

Table 3: Moisture content variation with compressive strength parallel to grain

Months	Moisture Content	Mean value of Compressive Strength (‖) (N/mm^2)	Coefficient of variation (CV)
1	48	24	0.06
2	35	25	0.06
3	25	28	0.1
4	20	32	0.05
5	18	36	0.06
6	12	40	0.09

Using least square approximation, the compressive strength perpendicular to grain can be obtained as:

$$P_p = 0.0184(MC)^2 - 1.5557(MC) + 56.415 \qquad 48 \leq MC \leq 12 \qquad (9)$$

Where P_p is compressive strength parallel to grain and MC is the moisture content.

3.4 Modulus of Rupture (MOR) in Bending

Table 4 presents the variation of MOR from conducting 3 -point bending tests. Five samples were used to obtain values of tensile strength after each month of seasoning. A trend is observed in the gradual increase in MOR with respects to the duration of seasoning.

Table 4: Moisture content variation with MOR

Months	Moisture Content	Mean value of MOR (N/mm^2)	Coefficient of variation (CV)
1	48	104	0.08
2	35	222	0.07
3	25	280	0.07
4	20	312	0.09
5	18	380	0.07
6	12	400	0.09

Using least square approximation, the MOR as a function of moisture content (MC) can be obtained as:

$$MOR = -0.003(MC)^3 + 0.2763(MC)^2 - 15.962(MC) + 563.62 \qquad 48 \leq MC \leq 12 \qquad (10)$$

Where MOR is modulus of rupture and MC is the moisture content.

3.5 Tensile Strength

Table 5 shows that while moisture content reduced gradually as the duration of seasoning is increased, the tensile strength of timber tested increase. The values for tensile strength after seasoning for six months was found to be significantly higher than the green values. Also, no significant distortions were observed in the test specimen.

Table 5: Moisture content variation with tensile strength

Months	Moisture Content	(N/mm^2)
1	48	18
2	35	22
3	25	25
4	20	30
5	18	35
6	12	38

Using least square approximation, the tensile strength can be obtained as function of moisture content (MC) as:

$$P_t = 0.0148(MC)^2 - 1.4592(MC) + 54.002 \qquad 48 \leq MC \leq 12 \qquad (11)$$

Where P_t is tensile strength parallel to grain and MC is the moisture content

This is important to note that the regression equations in Equations 9 to 11 serves as a tool for establishing strength properties for design basis, especially when design equations are based on 12% moisture content and experimentally obtain properties were not obtained at desired moisture content. This is similar to the correction equations discussed in [19].

4. Conclusion

This work establishes that moisture content has significant impact on the mechanical properties of Brachystegia Laurentii wood. The relationship between moisture content and strength parameters studied is found to be inversely correlated as observed in other woods studied in relevant literature. It is observed that mechanical properties such as compressive strength and tensile strength increase with decrease in moisture content of Brachystegia Laurentii as a result of increased seasoning duration, while density decreases with increased seasoning duration. It took 6 months for green timbers of Brachystegia Laurentii to be air-dried to a moisture content of 12%. This suggests that water content in green timbers of Brachystegia Laurentii was significant. The observed mechanical properties of Brachystegia Laurentii wood at 12% moisture content meet standard requirements for structural timbers.

The mechanical relationship between strength parameters of Brachystegia Laurentii wood such compressive strength, tensile strength and modulus of rupture are related to moisture content by polynomial functions. These mathematical functions present an effective and approximate estimation of mechanical properties of Brachystegia Laurentii wood for design and investigative purposes for moisture contents between 12% and 48%.

Air drying of Brachystegia Laurentii wood between six months in the dry season of Nigeria reduces the moisture content significantly without introducing defects in wood. Thus, this method of seasoning is recommended for the drying of Brachystegia Laurentii wood. However, it is important to note that Brachystegia Laurentii wood exhibits significant shrinkage and change in density between its green state and seasoned state.

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