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Effects of Moisture Content on Variations in the Strength Properties of *Pachyelasma Tessmannii* and *Chrysophyllum Delevayi* Timbers

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ABSTRACT

Wood moisture content plays a crucial role in determining the strength properties of timber. This study investigates the effects of moisture content on the variations in the strength properties of *Pachyelasma tessmannii* (Ire) and *Chrysophyllum delevayi* (Osan) timbers species from Ilorin, North central Nigeria. The research aims to provide valuable insights into the relationship between moisture content and strength characteristics of these two timber species. A comprehensive literature review was conducted to gather existing knowledge on the topic. The research utilized wood samples from the two timber species, of which were subjected to controlled moisture content levels of 12%, 15% and 18%. The physical and various strength properties, including modulus of rupture (MOR), modulus of elasticity (MOE) and compression strength, were evaluated at different moisture content levels. The results indicated that both timber species exhibited a significant correlation between moisture content and strength properties. Higher moisture content was found to negatively impact the strength characteristics of the timbers. The results of the wood samples densities at 12% MC for each species were 904.20 Kg/m^3 and 525.00 Kg/m^3 respectively for Ire and Osan. At 12%, 15% and 18% MC, Ire has the highest MOE values of 5228.31 MPa, 7626.20 MPa and 8410.02 MPa respectively. At 15% and 18% MC, Ire has the highest MOR values of 126.90 KPa and 137.70 KPa respectively. At 12% MC, Osan has the highest MOR value of 58.28 KPa. At 12% MC, Osan and Ire had the same perpendicular compressive strength value of 15.0 KPa. At 15% and 18% MC, Ire has the highest perpendicular compressive strength values of 25.00 KPa and 27.50 KPa respectively. At 12%, 15% and 18% MC, Ire has the highest parallel compressive strength values of 50.76 KPa, 57.30 KPa and 57.5 KPa respectively.

1. INTRODUCTION

Timber is a widely used natural resource, known for its structural and aesthetic properties. However, the physical and mechanical properties of wood are significantly influenced by moisture content (Barcík, *et.al.*, 2019). Moisture content refers to the amount of water present in the wood, which can vary depending on environmental conditions and processing methods. Moisture content affects the strength, dimensional stability, and durability of timber, making it a crucial parameter to consider in the design and utilization of wood products (Smith & Johnson, 2022).

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DIO

Pachyelasma tessmannii and *Chrysophyllum delevayi* are two structural timber species commonly found in the tropical region. They possess unique characteristics and have been utilized for different purposes, such as furniture, flooring, and construction (Smith & Johnson, 2022)

However, limited research has been conducted on the effects of moisture content on the strength characteristics of both *Pachyelasma tessmannii* and Chrysophyllum *delevayi* timber species. Understanding the variations in strength properties with changing moisture content is essential for optimizing their utilization and ensuring structural integrity (Fernandez & Silva, 2023).

This research aims to bridge this gap by examining the variations in strength properties, including modulus of elasticity (MOE), modulus of rupture (MOR), and compressive strength, under different moisture content conditions. The findings will contribute to enhancing the knowledge of these timber species and inform practical applications in the field of wood engineering and construction.

1.1. Moisture Content and Wood Properties

Moisture content is an essential parameter that influences the physical and mechanical properties of wood (Brown & Lee, 2023). It plays a critical role in determining the strength, dimensional stability, and durability of wood-based products. Moisture affects wood through several mechanisms, including swelling, shrinkage, and chemical reactions (Garcia, *et al.* 2023). As the moisture content of wood changes, its structural properties can vary significantly, impacting its overall strength. Wood undergoes hygroscopic swelling or shrinkage, resulting in variations in its mechanical behaviour. This change in dimensions can affect the strength properties of wood, such as modulus of elasticity, compressive strength, and bending strength. High moisture content leads to decreased strength properties due to the softening and weakening of wood cell walls. Conversely, low moisture content can result in increased brittleness and reduced flexibility (Adhikari, *et al.* 2016).

The strength properties of timber are influenced by the moisture content due to the unique structure and composition of wood. When timber absorbs moisture, the cell walls in the wood fibers swell, causing the timber to expand. This expansion can result in various changes in the mechanical properties of the timber, including strength (Anderson, *et al.*, 2023).

One of the key effects of moisture content on timber is its influence on dimensional stability. As the moisture content of timber increases, the timber expands, and as it decreases, the timber contracts (Adetayo *et al.*, 2019). These dimensional changes can lead to warping, twisting, and splitting of the timber. Such deformations can significantly affect the strength properties of *Pachyelasma tessmannii* and *Chrysophyllum delevayi* timbers (Silva, *et al.*, 2022).

Moisture content also affects the strength of timber by influencing its mechanical properties, such as modulus of rupture (MOR), modulus of elasticity (MOE), and compression strength. Studies have shown that as moisture content increases, the MOR and MOE of timber decrease. This reduction in strength is primarily attributed to the weakening of the hydrogen bonds that hold the wood fibers together. The reduction in MOR and MOE indicates a decrease in the timber's ability to resist bending and deformation under load (Wang & Ross, 2018).

Furthermore, the compression strength of timber is also influenced by moisture content. As the moisture content increases, the compression strength of timber decreases. This reduction can be attributed to the lubricating effect of water molecules between the wood fibers, which reduces the frictional resistance during compression. Consequently, the timber becomes more susceptible to compression failures (Adetayo & Dahunsi, 2019).

In addition to the mechanical properties, moisture content can also affect the biological properties of timber. High moisture content provides favourable conditions for the growth of fungi, bacteria, and insects, leading to decay and degradation of the wood. This decay can significantly compromise the strength properties of *Pachyelasma tessmannii* and *Chrysophyllum delevayi* timbers, reducing their load-bearing capacity and durability (Johnson & Brown, 2023).

Existing literature indicates that moisture content plays a critical role in determining the strength properties of wood. High moisture content can lead to reduced strength, dimensional instability, and increased susceptibility to decay and fungal attack. Studies have shown that moisture content affects various strength properties, including bending strength, compression strength, and impact strength. The relationship between moisture content and strength properties is influenced by factors such as wood species, anatomical characteristics, and environmental conditions (Adetayo & Dahunsi, 2017).

Studies have reported the influence of moisture content on the strength properties of various timber species. For instance, (Salmén & Burgert, 2009) demonstrated that moisture content significantly affects the bending strength of wood. As the moisture content increases, the wood fibers lose their strength and become more susceptible to deformation and failure.

Wang and Ross (2023) investigated the effects of moisture content on the mechanical properties of various timber species and found that as moisture content increased, there was a decrease in strength properties such as modulus of elasticity and modulus of rupture. Similarly, Chen, *et al.* (2020) studied the impact of moisture content on the compressive strength of timber and observed a decrease in strength with increasing moisture content. Zhang, *et al.*, (2018), observed that an increase in moisture content led to a reduction in the compressive and tensile strength of Pinus radiata wood. The weakening of the wood's cellular structure and the reduction of intermolecular bonds were identified as the main reasons for the decrease in strength.

In the investigation conducted by (Zięba & Kozakiewicz, 2021). on effects of temperature and duration of heat treatment on the physical, surface, and mechanical properties of Japanese cedar wood. A 35-year-old Japanese cedar logs was used for the experiment which was divided into three groups and was subjected to three different temperatures. The result drawn from the experiment is that the surface colour of the wood darkened progressively with increasing treatment temperature and duration, and the mechanical properties decrease with an increase in the treatment temperature and duration.

In their work on the effect of temperature on the compressive strength parallel to the grain of bamboo scrimber (Smith & Jones, 2022), a total of 152 specimens was used for the experiment and they are assembled into two groups namely: during-fire and post-fire, tests were carried for during and after exposure to high temperatures. The result of the experiment indicates that there were significant differences in compressive properties between the during-fire and post-fire groups. At one temperature level, the compressive strength and modulus of elasticity of the post-fire group were significantly higher than those properties of the during fire group, but the ductility coefficient was reversed.

2. METHODOLOGY

The wood samples used for this research were two species of timbers namely

Pachyelasma tessmannii (Ire) and *Chrysophyllum delevayi* (Osan)

The wood samples used was collected from the wood mill (sawmill) in Ilorin, Kwara state, North central, Nigeria as shown in figure 1. The two wood species are principally used for structural purpose, and were ordered and gotten for various test.

Figure 1: Sawing through timber into desired shapes

2.1 Sample Preparation

Wood samples of *Pachyelasma tessmannii* and *Chrysophyllum delevayi* timbers obtained were cut to the 20mm x 20mm x 60mm for physical test, both moisture content and density tests as shown in Figure 2. The wood samples were conditioned in a controlled environment to achieve different moisture content levels. The desired moisture content levels will be determined based on the range commonly encountered in practical applications.

Figure 2: Wood samples for physical test

Figure 3: Wood samples for mechanical test

The dimension of wood samples used for mechanical test is 20mm x 20mm x 300mm as displayed in Figure 3. Equipment and Standard were used for the determination of various strength properties were carried out in accordance with BS 373 (Method of Testing Small Clear Specimens of Timber).

The strength tests were carried out with the aid of a Universal Testing Machine as shown in Figure 4, having a maximum load capacity of 50KN at FRIN, Wood Department, Jericho Nigeria, Mechanical Engineering laboratory.

Figure 4: Universal testing machine

2.2 Moisture Content and Density Measurement

Moisture content was determined by weighing the samples before and after drying in an oven at a specific temperature. The moisture content was calculated as a percentage of the weight loss. Multiple measurements were taken for each sample to obtain representative values.

The Moisture Content was calculated as expressed as MC according to equation 1 below.

$$MC(\%) = \frac{\text{original mass} - \text{ovendry mass}}{\text{ovendry mass}} \times 100$$

(1)

Density is a measure of the wood substance contained in a given volume in accordance to the British, Nigerian and European codes. Equation 2 expressed the measure of density of a wood sample test as follow.

$$\rho\ (g/m^3) = \frac{\text{mass}}{\text{volume}}$$

(2)

2.3. Testing of Strength Properties

Mechanical tests were conducted on the samples at different moisture content levels using standard testing procedures. The tests included MOE, MOR, and compressive strength measurements. A universal testing machine was used to apply the appropriate load and record the corresponding data.

Modulus of Rupture (MOR) is expressed in Kilo paschal (KPa). MOR reflects the maximum load-carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. MOR is an accepted criterion of strength, and the formula is as given in equation 3 shown below, by which it is computed is valid only to the elastic limit.

$$\text{MOR (KPa)} = \frac{3P_{max}l}{2bd^2}$$

(3)

where Pmax is maximum applied load (N), L is bending span (mm), b is width of the specimen (mm) and d is depth of the specimen (mm).

Modulus of Elasticity (MOE) is the measure of the stiffness of wood is termed the modulus of elasticity (or coefficient of elasticity). It is the ratio of stress per unit of area to the deformation per unit of length. The MOE can be expressed by equation 4 below.

$$\text{MOE (MPa)} = \frac{\Delta Pl^3}{4\Delta\partial bd^3}$$

(4)

where ΔP is increment of load below the limit of proportionality (N),

L is bending span (mm), Δδ is increment of deflection corresponding the load (mm), b is width of the specimen (mm) and d is depth of the specimen (mm).

Compressive strength: Wood samples were prepared from two directions and positions (parallel and perpendicular) to the grain. The loading plates approach each other at a constant rate of 0.300mm/min as specified in code, as shown in Figure 5.

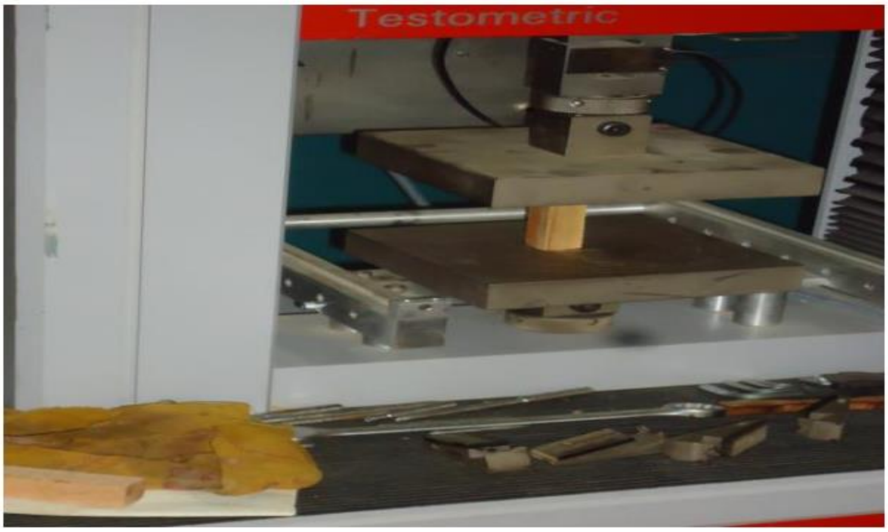

Figure 5: Compression Set-up

After each test, the maximum compressive strength parallel and perpendicular to the grain will be read directly from the recorded printout chat. The testing machine automatically divided the load sustained during the test with the cross-sectional area of the specimen, before recording it as a stress value on the chart.

a. parallel and perpendicular to the grain: Maximum compressive strength parallel-to-grain is expressed in KPa. Maximum compressive strength (CS) parallel and perpendicular to grain was calculated using equation 5 below:

$$\text{CS (KPa)} = \frac{\text{Force at Failedure (N)}}{cross - sectional\ are\ (mm^2)} \quad (5)$$

3. RESULTS AND DISCUSSION

The obtained data on the strength properties of *Pachyelasma tessmannii* and *Chrysophyllum delevayi* timbers at different moisture content levels were statistically analyzed. The analysis revealed significant variations in MOE, MOR, and compressive strength values as moisture content changed. These variations can be attributed to the hygroscopic nature of wood and the resulting structural changes at the cellular level.

3.1 Density and Moisture Content

The minimum, maximum and the mean densities of each species specimen at their corresponding Moisture contents (MC) 12, 15, 18% were shown in Tables 1, 2 and 3.

At 12%, 15% and 18% MC, Osan had the lowest density value of 525± Kg/m^3, 537.5 kg/m^3 and 645.8 kg/m^3respectively. At 12%, 15% and 18% MC, Ire had the highest density value 904.2 kg/m^3 and 1091.7 and 1129.2 kg/m^3 respectively.

Table 1: *Density @12% Moisture Content*

Species	Mean	Standard	Variance	Range	Minimum	Maximum
	Density (Kg/m^3)	Deviation			(Kg/m^3)	(Kg/m^3)
Ire	904.20	98.89	9,778.42	242.22	783.09	1025.31
Osan	525.00	102.06	10,416.67	250.00	400.00	650.00

Table 2: Density @15% Moisture Content

Species	Mean	Standard	Variance	Range	Minimum	Maximum
	Density (Kg/m^3)	Deviation			(Kg/m^3)	(Kg/m^3)
Ire	1091.70	190.49	36,285.93	466.60	858.40	1325.00
Osan	537.50	249.03	62,016.67	610.00	232.50	842.50

Table 3: Density @18% Moisture Content

Species	Mean	Standard	Variance	Range	Minimum	Maximum
	Density (Kg/m^3)	Deviation			(Kg/m^3)	(Kg/m^3)
Ire	1129.20	241.17	58,161.83	193.40	549.10	742.50
Osan	645.80	69.77	4,867.80	170.90	560.35	731.25

The values of density of each species at their corresponding moisture contents are illustrated in the column chart of Figure 6.

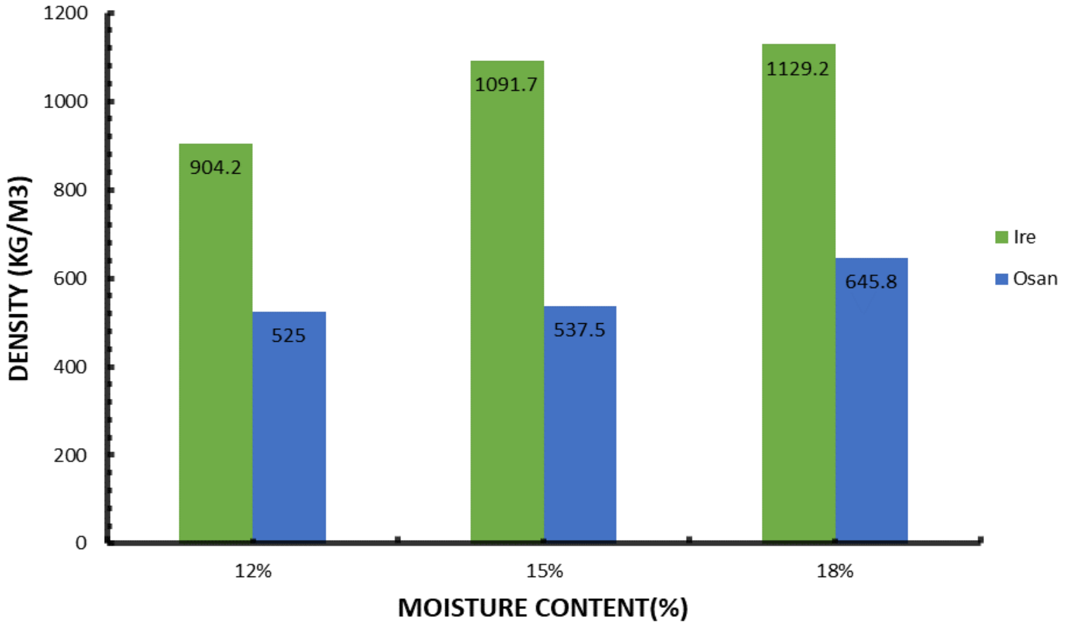

Figure 6: Graph of Density vs Moisture Content

3.2. Modulus of Rupture and Moisture Content

Tables 4, 5 and 6, showed the minimum, maximum and the mean modulus of rupture of each species specimen at their corresponding Moisture contents (MC) 12, 15, 18%. At 15% and 18% MC, Osan had the lowest modulus of rupture value of 67.61 KPa and 78.08 KPa respectively. At 12% MC, Ire has the lowest modulus of rupture value of 43.99 KPa. At 15% and 18% MC, Ire has the highest modulus of rupture value of 126.90 KPa and 197.70 KPa respectively. At 12% MC, Osan has the highest modulus of rupture value of 58.28 KPa respectively.

Table 4: Modulus of Rupture @12% Moisture Content

Species	Mean MOR (Kpa)	Standard Deviation	Variance	Range	Minimum (KPa)	Maximum (KPa)
Ire	43.99	4.91	24.08	12.02	37.98	50.00
Osan	58.28	17.94	321.79	43.94	36.31	80.25

Table 5: Modulus of Rupture @15% Moisture Content

Species	Mean MOR (Kpa)	Standard Deviation	Variance	Range	Minimum (KPa)	Maximum (KPa)
Ire	126.90	19.02	361.93	46.60	103.60	150.20
Osan	67.61	18.74	351.14	45.90	44.66	90.56

Table 6: Modulus of Rupture @18% Moisture Content

Species	Mean MOR (Kpa)	Standard Deviation	Variance	Range	Minimum (KPa)	Maximum (KPa)
Ire	137.70	35.03	1,226.94	85.80	94.80	180.60
Osan	78.08	14.35	205.80	35.14	60.51	95.65

Figure 7 illustrated the column chart of the values of modulus of rupture of each species at their corresponding moisture content.

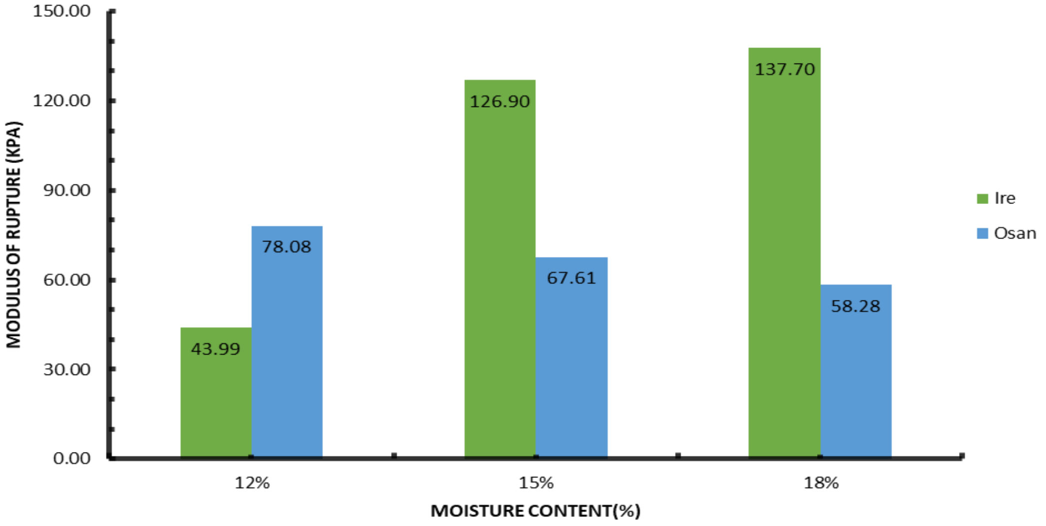

Figure 7: Graph of MOR vs Moisture Content

3.3. Modulus of Elasticity and Moisture Content

Tables 7, 8 and 9 showed the minimum, maximum and the mean modulus of elasticity of each species specimen at their corresponding Moisture contents (MC) 12, 15, 18%. At 12%, 15% and 18% MC, Osan had the lowest modulus of elasticity value of 3909.31 MPa, 4504.33 MPa and 5375.92 MPa respectively. At 12%, 15% and 18% MC, Ire has the highest modulus of elasticity value of 5228.31 MPa, 7626.20 MPa and 8410.02 MPa respectively.

Table 7: Modulus of Elasticity @12% Moisture Content

Species	Mean MOE (MPa)	Standard Deviation	Variance	Range	Minimum (MPa)	Maximum (MPa)
Ire	5228.31	1,105.49	1,222,102.35	2707.88	3874.37	6582.25
Osan	3909.74	967.76	936,560.85	2370.52	2724.48	5095.00

Table 8: Modulus of Elasticity @15% Moisture Content

Species	Mean MOE (MPa)	Standard Deviation	Variance	Range	Minimum (MPa)	Maximum (MPa)
Ire	7626.20	1,529.95	2,340,750.96	3747.60	5752.40	9500.00
Osan	4504.33	425.62	181,148.28	1042.54	3983.06	5025.60

Table 9: Modulus of Elasticity @18% Moisture Content

Species	Mean MOE (MPa)	Standard Deviation	Variance	Range	Minimum (MPa)	Maximum (MPa)
Ire	8410.02	1,755.45	3,081,609.33	4299.96	6260.04	10560.00
Osan	5375.92	1,535.49	2,357,720.76	3761.16	3495.34	7256.50

Figure 8 illustrated the column chart of the values of modulus of elasticity of each species at their corresponding moisture content.

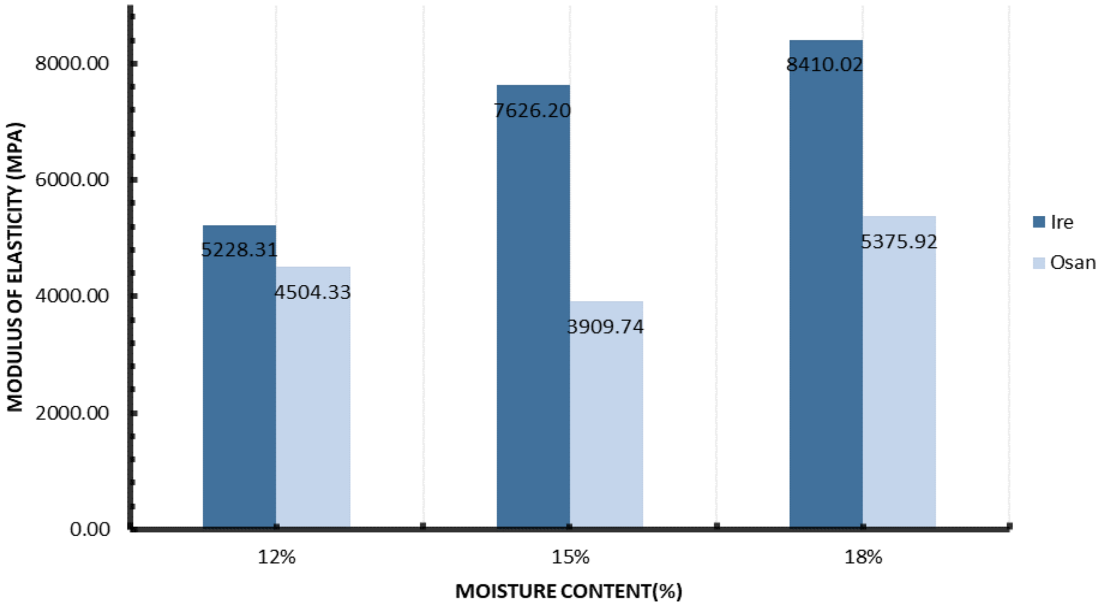

Figure 8: Graph of MOE vs Moisture Content.

3.4. Compressive Strength (Parallel to the grain) and Moisture Content

Tables 10, 11 and 12 showed the minimum, maximum and the mean Compressive strength (parallel to the grain**)** of each species specimen at their corresponding Moisture contents (MC) 12, 15, 18%. At 12%, 15% and 18% MC, Osan had the lowest Compressive strength value of 28.89 KPa, 35.08 KPa and 41.25

KPa respectively. At 12%, 15% and 18% MC, Ire has the highest Compressive strength value of 50.76 KPa, 57.30 KPa and 57.57 KPa respectively.

Table 10: Compressive strength parallel @12% Moisture Content

Species	Mean comp par (Kpa)	Standard Deviation	Variance	Range	Minimum (KPa)	Maximum (KPa)
Ire	50.76	11.86	140.75	29.06	36.23	65.29
Osan	28.89	4.99	24.89	12.22	22.78	35.00

Table 11: Compressive strength parallel @15% Moisture Content

Species	Mean comp par. (Kpa)	Standard Deviation	Variance	Range	Minimum (KPa)	Maximum (KPa)
Ire	57.30	12.76	162.86	31.26	41.67	72.93
Osan	35.08	8.26	68.28	20.24	24.96	45.20

Table 12: Compressive strength parallel @18% Moisture Content

Species	Mean comp par. (Kpa)	Standard Deviation	Variance	Range	Minimum (KPa)	Maximum (KPa)
Ire	57.54	6.09	37.10	14.92	50.08	65.00
Osan	41.25	7.70	59.28	18.86	31.82	50.68

Figure 9 illustrated the column chart of the values of compressive strength (parallel to the grain) of each species at their corresponding moisture content.

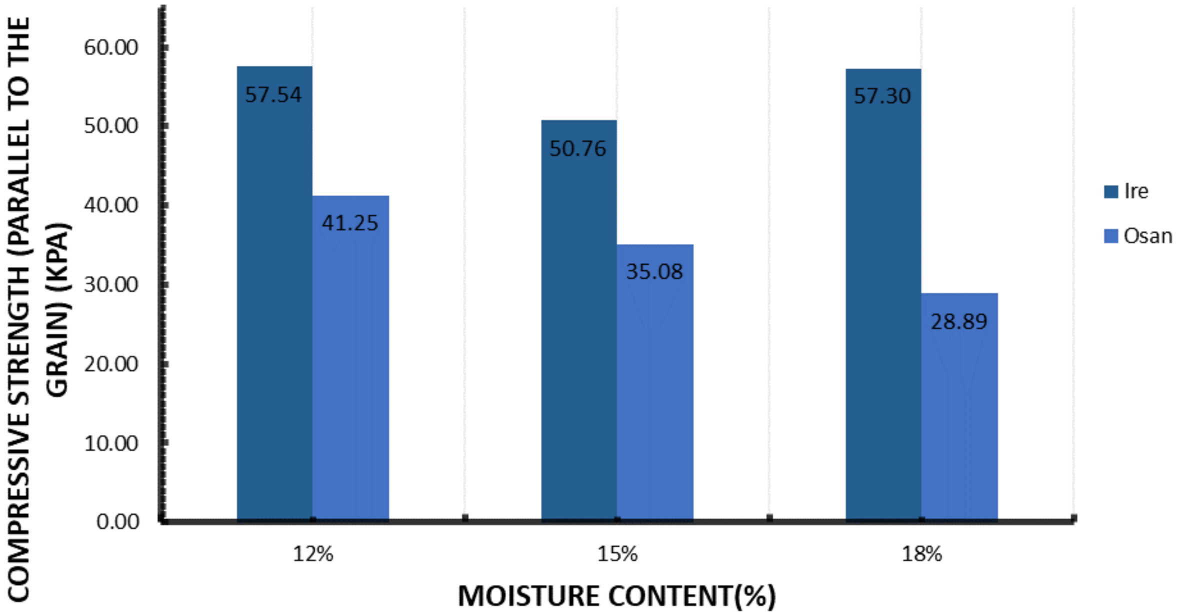

Figure 9: Graph of Compressive Strength (Parallel to the grain) vs Moisture Content.

3.5. Compressive Strength (Perpendicular to the grain) and Moisture Content

Tables 13, 14 and 15 showed the minimum, maximum and the mean compressive strength (perpendicular to the grain**)** of each species specimen at their corresponding Moisture contents (MC) 12, 15, 18%. At 15% and 18% MC, Osan had the lowest compressive strength value of 17.50 KPa, 17.50 KPa respectively. At 15% and 18% MC, Ire has the highest Compressive strength value of 25.00 KPa and 27.50 KPa respectively.

Table 13: Compressive strength perpendicular @12% Moisture Content

Species	Mean	Standard	Variance	Range	Minimum	Maximum
	comp perp (Kpa)	Deviation			(KPa)	(KPa)
Ire	15.00	2.19	4.79	5.36	12.32	17.68
Osan	15.00	1.29	1.66	3.16	13.42	16.58

Table 14: Compressive strength perpendicular @15% Moisture Content

Species	Mean	Standard	Variance	Range	Minimum	Maximum
	comp perp. (Kpa)	Deviation			(KPa)	(KPa)
Ire	25.00	1.63	2.67	4.00	23.00	27.00
Osan	17.50	1.76	3.08	4.30	15.35	19.65

Table 15: Compressive strength perpendicular @18% Moisture Content

Species	Mean	Standard	Variance	Range	Minimum	Maximum
	comp perp (Kpa)	Deviation			(KPa)	(KPa)
Ire	27.50	12.10	146.42	29.64	12.68	42.32
Osan	17.50	7.74	59.91	18.96	8.02	26.98

Figure 10 illustrated the column chart of the values of compressive strength (perpendicular to the grain**)** of each species at their corresponding moisture content.

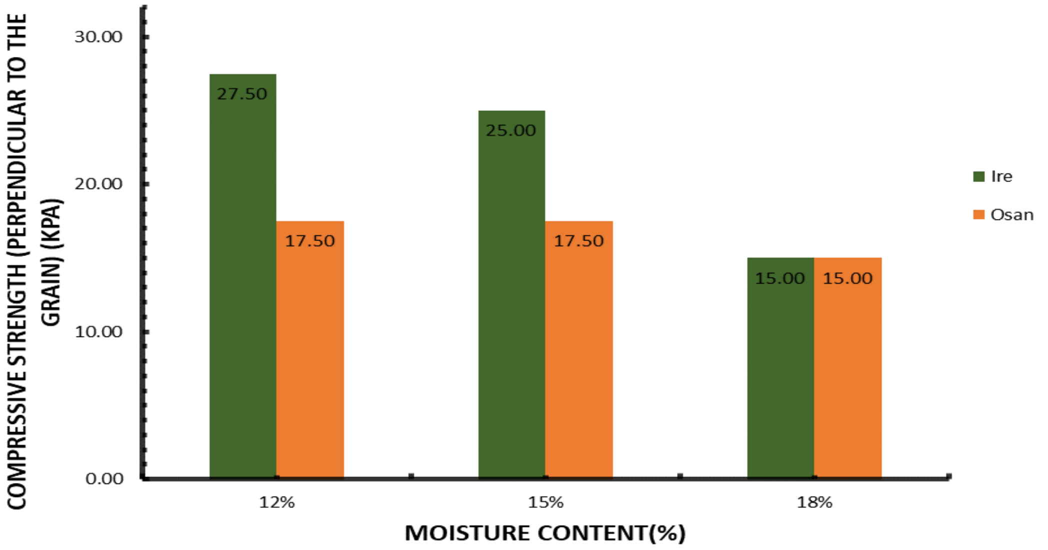

Figure 10: Graph of Compressive Strength (Perpendicular to the grain) vs Moisture Content

3.6. Discussion of Results

From the results of the mechanical tests, it can be deduced that.

1. At 12%, 15% and 18% MC, Ire has the highest modulus of elasticity values of 5228.31 MPa, 7626.20 MPa and 8410.02 MPa respectively.
2. At 15% and 18% MC, Ire has the highest modulus of rupture values of 126.90 KPa and 137.70 KPa respectively. At 12% MC, Osan has the highest modulus of rupture value of 58.28 KPa.
3. At 12% MC, Osan and Ire had the same perpendicular compressive strength value of 15.0 KPa. At 15% and 18% MC, Ire has the highest perpendicular compressive strength values of 25.00 KPa and 27.50 KPa respectively.
4. At 12%, 15% and 18% MC, Ire has the highest parallel compressive strength values of 50.76 KPa, 57.30 KPa and 57.5 KPa respectively.

Further research is warranted to explore additional aspects of the relationship between moisture content and wood strength, such as the long-term effects of moisture cycling and the influence of treatment methods on moisture content-related variations.

4. CONCLUSION

Moisture content plays a critical role in determining the strength properties of *Pachyelasma tessmannii* and *Chrysophyllum delevayi* timbers. This study has provided valuable insights into the effects of moisture content on the modulus of elasticity, modulus of rupture, and compressive strength of these wood species. The findings emphasized the importance of considering moisture content in the design and utilization of timber materials. The moisture content grouped in three categories (12%, 15%, and 18%) for each of the two selected species.

The physical tests results showed that, at 12%, 15% and 18% MC, Ire has the highest density value of 904.2 kg/m^3, 1091.7 kg/m^3 and 1129.2 kg/m^3 respectively.

The species that possess the higher values derived from these conclusions shows that they possess higher strength than the other wood species of lesser values.

Based on the result obtained in this study, the following recommendations are made:

1. Proper Moisture Control: It is crucial to control and maintain the moisture content of *Pachyelasma tessmannii* and *Chrysophyllum delevayi* timbers within an optimal range to ensure their dimensional stability and strength properties. Proper storage conditions and moisture control measures, such as drying and conditioning, should be implemented during processing, transportation, and storage.
2. Pre-Treatment: Pre-treatment methods, such as kiln drying or air drying, can help reduce the moisture content of timbers and enhance their strength properties. Proper pre-treatment processes should be employed to achieve the desired moisture content range suitable for the intended applications.
3. Design Considerations: Engineers and architects should consider the effects of moisture content on the strength properties of *Pachyelasma tessmannii* and *Chrysophyllum delevayi* timbers during the design phase. Adequate safety factors and design adjustments should be incorporated to account for the potential variations in strength due to changes in moisture content.
4. Regular Moisture Monitoring: Regular monitoring of the moisture content in timber structures is crucial to identify potential moisture-related issues and take

appropriate remedial measures promptly. Non-destructive testing techniques, such as moisture meters, can be used for convenient and accurate moisture monitoring

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