Comparison of Compression Parallel to Grain of *Acacia* Hybrid for Untreated and Treated at Different Combination of Age Groups

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Sarawak's wood-based industries face challenges due to a shortage of wood-based raw materials. Research on the *Acacia* hybrid species is limited, but it is crucial for the timber engineering field. *Acacia* hybrids have been selected for reforestation projects due to their rapid growth. Since 2001, various license holders have planted *Acacia mangium and* its hybrids on over 245,000 hectares in Sarawak. The species were collected from a plantation area owned by Daiken Sarawak Sdn Bhd. Tests on physical properties, namely moisture content (MC) and basic density, were carried out. Meanwhile, tests on mechanical properties for both untreated and treated samples were also conducted, including static bending tests (modulus of rupture, MOR and modulus of elasticity, MOE) and compression parallel to the grain test. All the tested samples were in air-dry condition, with the MC ranging from 12 % to 19 %. The specimens were prepared according to BS 373:1957 and Method of Testing Small Clear Specimens of Timber. All tested results were analyzed using statistical methods to determine mean results. All the results that had been tested were analyzed using statistical analysis as mean results. Comprehensive testing of *Acacia* hybrid wood treated with copper chrome arsenic (CCA) has significantly improved its physical and mechanical properties. The treatment results in higher density and strength, influenced by growth and structural variations of the wood. It also enhances moisture retention, boosting the wood's hydrophobic properties and durability. Treated wood shows increased Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) in static bending tests, demonstrating enhanced resistance to bending and structural integrity. Compression tests reveal that treated wood is 27% stronger than untreated, confirming its superior ability to withstand compressive forces. From this study, the best age combination product is 10y+10y, and it can be concluded that the comprehensive testing of *Acacia* hybrid wood reveals treatments enhance its physical and mechanical properties.
Keywords: Acacia hybrid, mechanical properties, physical properties, wood, specimens.

1. INTRODUCTION

Malaysia believes that its natural forest resources are valuable and precious, greatly improving the nation's economic and environmental conditions. For usage in load-bearing beams, columns, ties, and other structural applications, Malaysian wood is exported. Due to its versatility and simplicity of use in producing a wide range of shapes and sizes, wood has several advantageous properties. It offers efficient thermal insulation and a great strength-to-weight ratio. *Acacia* species, especially hybrids, play an important part in the wood sector due to their rapid growth and adaptability. *Acacia* is used to make furniture, pulp, and paper, making it lucrative in markets in Europe, North America, and Asia Food and Agriculture [1]. However, species-specific trade data is restricted since Acacia is frequently bundled with other tropical hardwoods in international reports by the Food and Agriculture Organization of the United Nations (FAO) [1]. According to [1], the demand for tropical hardwoods is increasing, with *Acacia* making a substantial contribution. Countries such as Vietnam and Indonesia are major exporters, while specific worldwide trade numbers for *Acacia* hybrid are difficult to estimate [2].

Industry plays a vital role in the economy, driving substantial growth through export revenues and providing numerous job opportunities. The sector specialises in producing high-demand products such as furniture and plywood. Advanced processing technologies increase production efficiency and waste reduction, enhancing sustainability. Growing trees are typically used to create lumber or timber, which is a wood that may generate objects with a minimum size. It is mostly used to construct buildings or for other purposes. According to Mohamed [3], the timber business in Malaysia provides wood products for both domestic and foreign markets. Regardless of being a significant market for timber supplies. Additionally, there are many other applications for wood, including those for fuel and construction, which is its most important

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application in the building sector.

Malaysia's timber industry, significantly bolstered by the cultivation of *Acacia* hybrid, remains a crucial economic pillar. The genetic and ecological differences between *Acacia mangium* and *Acacia* hybrid result in notable differences between the two species. *Acacia mangium,* a perennial tree from the *Fabaceae* (*Mimosoideae*) family, is native to Australia and Asia and is commonly known as Black Wattle, Hickory Wattle, or Mangium. [4]. *Acacia mangium* is commonly planted in tropical areas and is prized for its quick growth and suitability for pulp and lumber. *Acacia mangium* has been a popular choice for reforestation and the rehabilitation of abandoned shifting cultivation areas since the 1970s [5]. The *Acacia* hybrid, on the other hand, is a crossbreed of *Acacia mangium* and *Acacia auriculiformis* that was created specially to improve characteristics like growth rate and wood density [6]. This fast-growing species, ideal for reforestation and short-rotation forestry, supports sustainable timber production. *Acacia* hybrid is extensively used for high-quality wood products like furniture and plywood, and it is prized both locally and internationally. According to Daniel [7], the Forestry Department estimates that 9.2 million hectares, or 75 % of Sarawak's 12.33 million hectares, are covered by forests. Both Permanent Forest Estate (PFE) and Protected Forest are the two typical classifications for the forest area. In Malaysia, one of the most important fast-growing species implemented in plantation forestry is *Acacia mangium.* Sarawak features a wide range of indigenous, fast-growing timber species. In Sarawak, *Acacia mangium* represents the largest portion of forest plantations, cultivated on a 15-year cycle aimed at producing general-purpose timber [8]. Some of these species have been identified as potential alternatives for light wood industry applications and engineering structural design purposes [9]. The second-generation *Acacia mangium* and the *Acacia* hybrid were the two planting materials that were implemented in the state of Sarawak [10]. *Acacia* from plantations is a versatile wood that may be developed to create increased products such as transformed into premium products like furniture, flooring, and interior design elements due to its durability and attractive appearance. Additionally, it can be used to create engineered wood products such as plywood, veneers, and composites, which have widespread applications in construction. Therefore, *Acacia* is perfect for indoor and outdoor furniture and construction materials, which can increase the number of products. Yamamoto et al. [11] highlighted the significance of these species for plantations, attributing their value to fast growth, good wood quality, and their ability to tolerate diverse soil types and pH levels. Similarly, a study by Ismaili [12] found that the organic soils in Kuching, Sarawak, are highly acidic, with pH levels consistently below 4.5. A study found that *Acacia mangium* species had been recommended for structural applications [13, 14].

According to Ashaari [15], wood species with a density below 1000 kg/m³ (the density of water) will float on the surface of the water. The greater the wood's density, the more compact it is, and its mechanical properties are correspondingly stronger [16]. Though timber density often correlates with strength, it should not be regarded as the only indicator of timber's strength [17]. According to Laskowska [18], the criteria encompass various aspects, including the fundamental attributes of the utilized wood (such as appearance, permissible defects, natural durability, density, and strength), dimensional tolerances, wood surface condition, moisture content, the types of adhesives used, and the characteristics of adhesive bonds.

The species of timber used for this study is *Acacia* hybrid. *Acacia* hybrid appears to have a lot of beneficial characteristics, including quick growth, straighter bole, less tapering, and resistance to heart rot. In just two years, the tree may reach a height of 8 to 10 metres and a diameter at breast height (DBH) of 7.5 to 9.0 cm. According to Somyos [19], *Acacia* hybrids grow in areas with annual precipitation between 1200 and 1850 mm, temperatures between 12 and 35 °C, and heights between 50 and 350 m. In some aspects, the *Acacia* hybrid differs from the *Acacia auriculiformis and* the *Acacia mangium*. Young *Acacia* hybrid trees have bark that resembles *Acacia auriculiformis's* but is more greenish white. According to Chaw and Mitlöhner [20], physically and mechanically, the *Acacia* hybrids combine traits from the natural forms of their parents, *Acacia mangium* and *Acacia auriculiformis,* such as moisture absorption, shrinkage, static bending, resistance to slide and split, and rupture strength. The lack of research on *Acacia* hybrids, particularly its compressed and chemically treated forms, creates economic uncertainty. This uncertainty deters investors, limiting comprehensive economic data. Without sufficient studies, it's difficult to compare the product with existing equivalents in the furniture, construction, and timber sectors. As Malaysia's focus on this species is in its early stages, the lack of formal economic analysis delays understanding its market potential, posing challenges in attracting investment and commercialising the product [21]. Therefore, further research is needed to assess its viability.

This research aims to evaluate and compare the physical and mechanical properties of untreated and treated small clear laminated *Acacia* hybrid specimens from Sarawak, categorised by different age group combinations. The study includes both untreated and treated laminated samples at ages 10-10, 12-12, and 14-14 years, as well as mixed-age combinations of 10-12, 10-14, and 12-14 years. At this age, the wood quality, density, and structural features are ideal for different kinds of applications, including furniture, building, and paper manufacture [22]. The study's use of a different age range of 10-14 years is expected to identify differences in wood qualities as trees change from young to mature wood, offering more information on their performance and value. Research by Ismaili et al. [23] indicated that *Acacia* hybrids exhibit early maturity, especially around the ages of 9 to 10. Objectives include determining the properties of these laminates, assessing their behaviour across varied age combinations, and identifying the most effective age group combinations for optimal strength performance under copper chrome arsenic treatment.

2. METHODOLOGY

2.1. Preparation of material

Acacia hybrid was the sample utilised in the trial, and it was collected from the forest at the Daiken Sarawak Sdn. Bhd. planting site in Bintulu. Three trees of the same species, ages ten, twelve, and fourteen, were gathered. The 10-year-old tree is located at N 03°20'42.1" E 113°26'51.7", the 12-year-old tree is located at N 01°05'425" E 110°56'590", and the 14-year-old tree is located at N 03°21'19.5" E 113°27'33.0". 22 centimetres above breast height (DBH) was the measurement point. To help in identification, the logs were then split into logs and marked according to age. After that, all of the logs were moved to the Sarawak Forestry Department Laboratory, so that materials could be prepared.

After completing the air-drying process, the structural timber planks will be cut into 10 mm-sized planks according to the standard testing method Tan et al. [24], which was adopted from BS373:1957 [25]. Various combinations of *Acacia* hybrid for untreated specimens include ages 10-10, 12-12, 14-14, and mixes 10-12, 10-14, and 12-14 years old. The treated laminates also follow these combinations. These laminates will be bonded using Phenol Resorcinol Formaldehyde (PRF), as shown in Fig. 1.

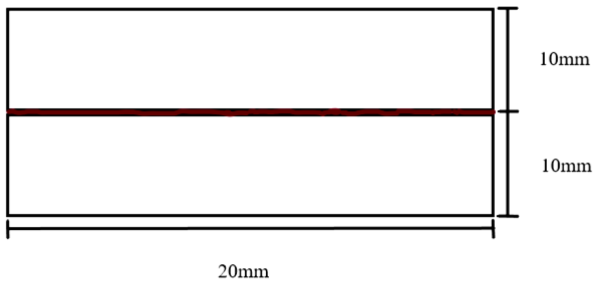

Fig. 1. Laminated products of *Acacia* hybrid after gluing

Subsequently, both untreated and treated laminates will be cut to specifications illustrated in Fig. 2 and Fig. 3, detailing the creation of small clear laminated *Acacia* hybrid samples under different conditions, set for testing. This process is in accordance with Tan et al. [24], which was adopted from BS 373:1957 [25]. This comprehensive testing comprises 4 tests, spanning physical and mechanical evaluations. Each laminate configuration will need 15 samples to ensure reliable data. Consequently, each combination requires 50 samples, culminating in a total of 100 samples each for untreated and treated laminates. The testing will take place at the Sarawak Forestry Department Laboratory in Kuching, Sarawak. Fig. 3 depicts the process of treating these laminates with a 10 % Copper Chrome Arsenic (CCA) solution, aligning with the Testing Methods for Plantation Grown Tropical Timbers. CCA treatment was selected for this study due to its widespread usage in the timber industry in the country [22].

2.2. Process of laminated *Acacia* hybrid

The samples, categorised by their ages of 10, 12, and 14 years, undergo moisture content assessment with the MS6900 moisture meter to ensure they remain below 12 %. These samples are then cut to 15 mm thickness using the Holytek Industrial Corp HR-12TR machine. Following this, the samples are planed to a uniform 10mm dimension using a GT-610A planing machine. These 10mm samples are then further cut to maintain uniform dimensions and subsequently glued using phenol resorcinol formaldehyde with a 15 % hardener to create laminated products. These laminates are sorted into age-based categories (10-10, 12-12, 14-14) and mixed-age combinations (10-12, 10-14, 12-14).

The laminated products are compressed at approximately 9.65 MPa using a Tahei Machinery Work LTD type C79-A machine and kept under pressure for 1-3 days to strengthen the adhesive bond. After the pressing, the laminated products are cut into specimens and further processed into smaller pieces using an Altendorf-C45 machine, ready for mechanical testing. The test samples then undergo a full-cell treatment with a 10 % copper-chrome arsenic (CCA) solution. Initial and final vacuums are applied to maximise preservative absorption and ensure thorough treatment. The process concludes with measurements of sample weights and dimensions before and after treatment to calculate fluid absorption and verify treatability.

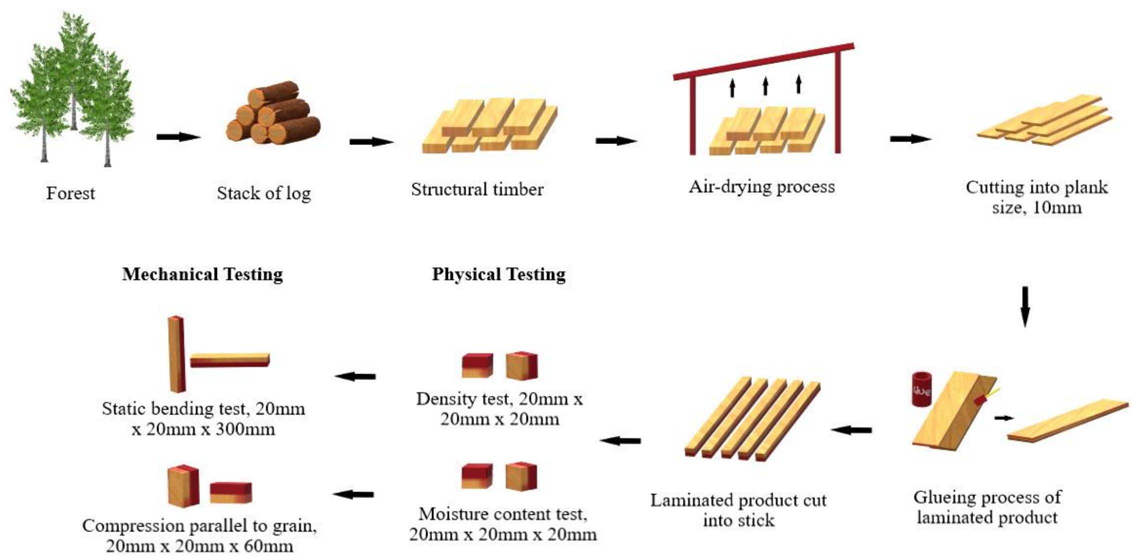

Fig. 2. Process of untreated small clear laminated products of *Acacia* hybrid

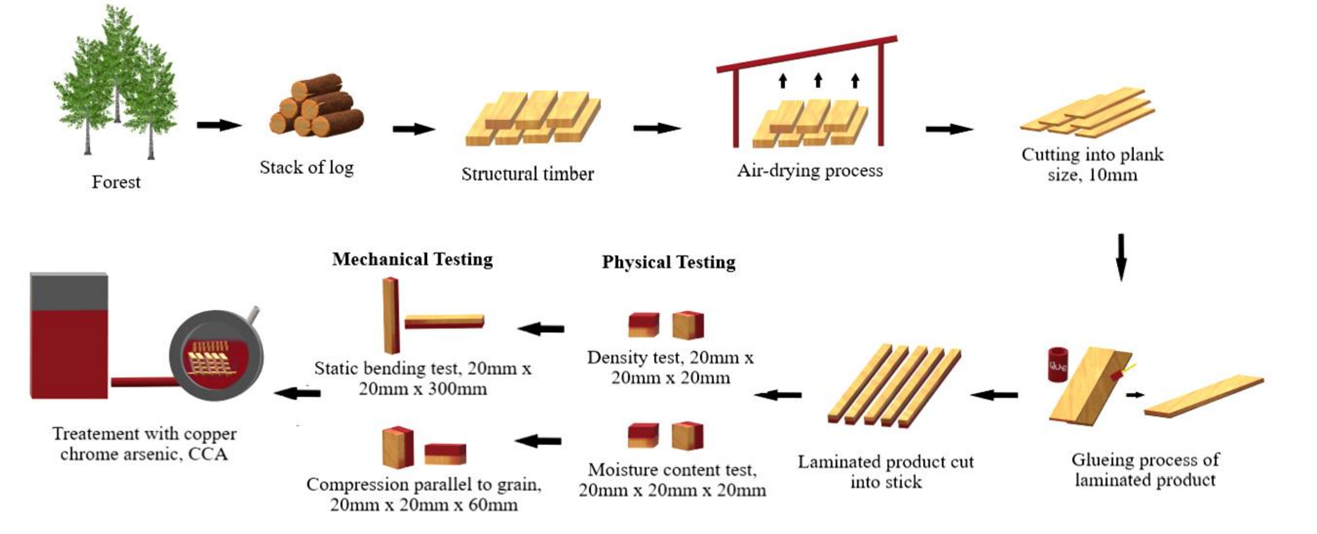

Fig. 3. Process treated of small clear laminated *Acacia* hybrid

2.3. Laboratory work

To conduct additional testing, the prepared sample is brought to the lab. Every sample examined complies with British Standard 373:1957's guidelines for examining small clear wood specimens [25]. The physical characteristics of the samples are examined before any strength tests are carried out to ensure reliable findings. Moisture content and basic density are two important physical characteristics that must be taken into consideration. The quality of moisture significantly influences the stability and strength of the wood. However, maintaining a moisture content between 15 % and 19 % is challenging as some wood is drying rapidly. Achieving air-dry conditions, as prescribed by ITTO's Testing Methods for Plantation Grown Tropical Timbers, the testing method for plantation-grown tropical timbers [24] and BS373:1957 [25], depending on whether the wood is dry or green, give different percentage of moisture contents (MC). The moisture level of wood must be 19 % or less to be classified under dry conditions. However, wood can be considered to be in a green condition when the moisture content rises beyond 19 % [26]. The mass of the test specimen for the sample should be measured and should be put dried in an electric oven at a temperature of 103 ± 2°C for 24 hours to take the constant weight of the sample. The moisture content should be recorded as the following Eq. 1:

$$\text{Moisture content, \%} = \frac{m_1 - m_0}{m_0} \times 100. \quad (1)$$

The unit weight was employed to calculate the base density, representing the ratio between the oven-dry mass of a wood sample and its green volume. The green volume of the samples was determined through the water displacement method, while their dry weight was measured using an electronic balance. Eq. 2, presented below, was utilized for density calculations:

$$\text{Basic density } \left(\frac{\text{g}}{\text{cm}^3}\right) = \frac{\text{Oven dried weight}}{\text{Green volume}}. \quad (2)$$

There have two types of strength tests were conducted in this study: static bending and compression tests. The tests were carried out using the Universal testing machine by Instron 5569 to determine the strength values of the specimens. The static bending test was performed using the three-point bending method, with the testing as shown in Fig. 4.

Fig. 4. Static bending testing

The purpose of this test is to measure the failure of the sample. The specimens for static bending tests have a rectangular cross-section, with dimensions set at 20 mm × 20 mm × 300 mm, aligned along the material's longitudinal axis. Supported at both ends with the load applied centrally, this configuration induces stress and deformation via a bending moment. The three-point bending method is used, spacing the support points 280 mm apart. An Instron 5569 Universal Testing Machine, Norwood, MA, USA, conducts the test, maintaining a constant loading speed of 6.0 mm/min. The loading head's contour has a radius of 30 mm to match the beam, allowing for precise deflection measurements at the beam's mid-length. This data is used to calculate the modulus of rupture (MOR) and modulus of elasticity (MOE) in megapascals.

$$\text{MOR, N/mm}^2 = \frac{3}{2} \times \frac{FL}{WT^2}, \quad (3)$$

where F is the maximum load, N; L is the span, mm; W is the width, mm; T is the depth, mm.

$$\text{MOE, N/mm}^2 = \frac{L^3}{4WT^3} \times \frac{\Delta F}{\Delta l}, \quad (4)$$

where L – span, mm; W – width, mm; T – depth, mm; $\Delta F/\Delta L$ – slope of graph, N/mm.

The compression test is beneficial for testing the strength and serviceability of timber used as a column, post or truss member. This test will give the maximum load and maximum stress exerted by the specimen. The dimensions of the test samples will be 20 mm × 20 mm × 60 mm, which facilitates the application of load in a straight line along the grain using an Instron 5569 Universal Testing Machine, Norwood, MA, USA. The ends of the rectangular test samples must be smooth and parallel to the force axis to ensure data consistency. During the test, the top compression platen will always remain parallel to the bottom compression platen. Testing will be conducted at a constant loading speed of 6.0 mm/min. The compressive stress at maximum load, measured in megapascals, will be calculated using the specified formula. This test follows the testing method for plantation-grown tropical timbers Tan et al. [24], and BS 373:1957 [25].

$$\text{Compressive stress at maximum, N/mm}^2 = \frac{F}{A} \tag{5}$$

where F is the maximum load, N; A is the cross sectional area, mm^2.

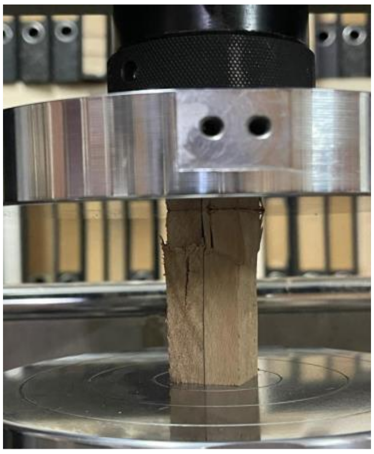

Fig. 5. Compression parallel to grain testing

3. RESULTS AND DISCUSSION

3.1. Testing results

3.1.1. Density

Density is calculated by dividing the mass of the material by its volume. The mass is usually measured using a scale or balance, while the volume can be determined through various methods depending on the nature of the material. Fig. 6 shows the density results of untreated and treated *Acacia* hybrid wood. The highest density recorded for the combination of untreated *Acacia* hybrid wood is 10y+14y, at 0.594 g/cm³. Conversely, the lowest recorded density combination for untreated *Acacia* hybrid wood is 12y+14y, measuring 0.456 g/cm³. Additionally, the highest density recorded for treated *Acacia* hybrid wood is 10y+12y, at 0.815 g/cm³.

Meanwhile, the lowest recorded density combination for treated *Acacia* hybrid wood is 10y+10y, at 0.742 g/cm³. Due to its heterogeneous nature, timber exhibits varying strength properties, even within a single species, and this was supported by the research conducted by Ismaili et al. [27].

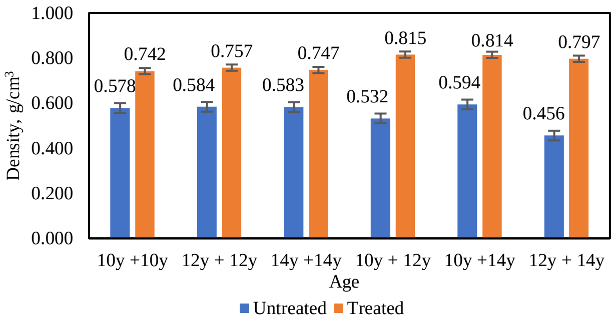

Fig. 6. Comparison density of *Acacia* hybrid for untreated and treated

The presence of defects like knots and sloping grain can accentuate these differences, with some species being more prone to such imperfections [28]. The variation in density across different combinations and ages of *Acacia* hybrid wood may be influenced by factors such as growth rate, wood structure, and moisture content. According to Ismaili et al. [9], while timber density is somewhat indicative of its strength, it should not be considered the definitive measure of its strength. A study conducted by Yahya et al. [29] shows that the density of matured 13-year-old *Acacia mangium* superbulk species was less compared to 10-year-old species, and this was due to a reduction of survival rate, leading to a decrease in both its density and mechanical properties. This observation is further corroborated by the findings of Afifi et al. [30], who examined the growth patterns of *Acacia mangium*, demonstrating that as the stand age increased, both the survival rate and stem density declined.

Fig. 6 compares the density of untreated and treated *Acacia* hybrid wood, revealing that the density of the treated wood is higher. This increase is attributed to the application of copper chrome arsenic (CCA) treatment, which not only enhances the density but also slightly improves the strength properties of the *Acacia* hybrid. The penetration of CCA into the wood fibers is believed to enhance the material's resistance to decay, insects, and weathering, contributing to these changes. According to Lansbury and Beder [31], these improvements in physical properties are significant in industries where strength and durability are crucial, such as in construction, furniture making, and outdoor structures. The results show a percentage increase in strength for treated *Acacia* hybrid samples across various age combinations such as 10y+10y, 12y+12y, and so forth, with specific instances showing up to a 25 % increase in strength compared to untreated samples. This data underlines the effectiveness of CCA treatment in bolstering the density and strength of *Acacia* hybrid wood, making it more suitable for demanding applications. Though there 10% concentration of CCA treatment used in this study, the percentage of CCA used follows the safe limit as stated in the testing method for plantation-grown tropical timbers [24]. The treatment procedure adhered to recognised standards. In accordance with industry best practices, these rules guarantee controlled and limited chemical consumption, preserving sustainability and reducing environmental effects. According to the Australian Pesticides and Veterinary Medicines Authority [32], copper and chromium in treated timber do not pose a significant risk to public health, as exposure levels fall below safety thresholds. Additionally, the assessment concluded that proper use of CCA or arsenic trioxide products is unlikely to result in harm to humans, animals, plants, or the environment [32]. In summary, the findings highlight that treated samples exhibit not only higher density but also improved strength, demonstrating the treatment’s efficacy in enhancing material properties.

3.1.2. Moisture content

The moisture content of wood, defined as the amount of water relative to its dry weight, significantly influences its physical properties, including density, strength, dimensional stability, and durability. In general perspective, material having high moisture content has low density. However, a study conducted by Ismaili [33] shows that timber was not slightly influenced by timber density. Nonetheless, the change in condition from green to dry does not markedly affect the basic density of timber, which remains within the range of 19 to 32 percentage points, however, the presence of water significantly influences wood strength, with lower moisture content generally correlating with higher strength levels compared to wood with higher moisture content [34]. Fig. 7 shows the results of untreated and treated moisture content of the *Acacia* hybrid. Fig. 7 shows the highest result is 15.871 for the age 10y+14y, followed by 15.065 % for 12y+14y, 13.638 % for 10y+12y, 12.663 % for 10y+10y, 12.470 % for 14y+14y, and the lowest result, 10.570 %, is observed at the age of 12y+12y.

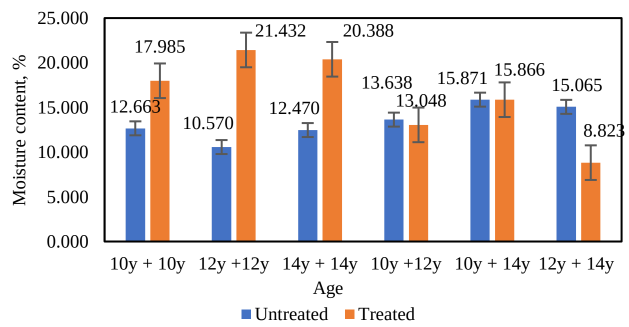

Fig. 7. Comparison of moisture content of *Acacia* hybrid for untreated and treated

Additionally, Fig. 7 shows the highest result for moisture content for treated *Acacia* hybrid, which is 21.432 % for the age 12y+12y. The second-highest result is 20.388 % for 14y+14y, followed by 17.985 % for 10y+10y, 15.866 % for 10y+14y, and 13.048 % for 10y+12y. Results show that there is an increase in moisture content when samples are treated. This result is supported by the study by Ferreira et al. [35], where the sample treated using CCA treatment increased moisture content. The lowest result of moisture content is observed for 12y+14y, measuring 8.823 %. According to Fu et al. [36], having an impact on the mechanical and physical qualities of wood, moisture is a major outside component that contributes to wood splitting and deformation. While high moisture content makes wood softer, weaker, and more prone to deformation and decay. The increase in strength with reduced moisture content is due to the shortening and strengthening of hydrogen bonds linking the microfibrils. However, the influence of moisture is less significant on certain mechanical properties of timber [37], and this is also supported by Yahya and Ismaili [29] in their study.

Fig. 7 shows the comparison of untreated and treated moisture content. It shows the detailed comparison of moisture content between untreated and treated *Acacia* hybrid wood, highlighting variations across different age groups. For untreated wood, moisture content peaks at 15.871 % in the 10y+14y age group, then gradually diminish to the lowest level of 10.570 % seen in the 12y+12y age group. This range suggests that as the *Acacia* hybrid ages, its natural moisture retention capabilities may diminish slightly. The obvious rise in moisture content indicates how well the treatment procedure improved the wood's capacity to hold water. It is significant that even the lowest moisture content in treated wood, 8.823 % in the 12y–14y age group, has a wider variation than in untreated wood, suggesting that treatment might affect moisture retention to differing degrees based on the age and condition of the wood. The physical characteristics and appropriateness of the wood for different uses are affected by treatment techniques, which not only raise the moisture content overall but also influence the uniformity of moisture retention across age groups.

3.1.3. Static bending

Static bending is a critical test in timber engineering used to assess the bending properties of wood. This test involves applying gradual loads to a timber specimen until failure occurs, measuring parameters such as the modulus of elasticity (MOE) and modulus of rupture (MOR). These parameters are vital for structural design, helping ensure that timber elements like beams can withstand loads without failing or bending excessively. According to Sanni and Ekundayo [38], the creation of engineered wood products like glued-laminated timber was caused by advancements in glue technology as well as an increased level of interest in environmentally friendly building practices. The modulus of rupture (MOR) is a measure of a material's ability to withstand bending or flexural stress before breaking. Fig. 8 displays the results of untreated modulus of rupture (MOR), with the highest MOR recorded at age 10y+10y (92.95 N/mm²), followed by 10y+14y (91.130 N/mm²), 10y+12y (85 N/mm²), 12y+14y (71.6 N/mm²), and 12y+12y (53.5 N/mm²).

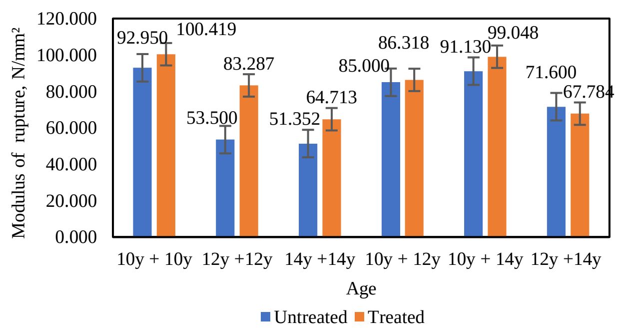

Fig. 8. Comparison modulus of rupture, MOR of *Acacia* hybrid for untreated and treated

The lowest untreated MOR is at age 14y+14y (52.352 N/mm²). Additionally, Fig. 8 shows the highest treated MOR is at age 10y+10y (100.419 N/mm²), followed by 10y+14y (99.048 N/mm²), 10y+12y (86.318 N/mm²), 12y+12y (83.287 N/mm²), and 12y+14y (67.784 N/mm²), with the lowest treated MOR at age 14y+14y (64.713 N/mm²). A higher MOR value suggests greater resistance to bending and better structural integrity, making it a crucial parameter in the design and evaluation of construction materials.

The modulus of elasticity (MOE), also known as Young's modulus, is a measure of a material's stiffness or rigidity when subjected to tensile or compressive stress. According to Lee & Kim [39], in most cases, the previous models have employed the modulus of elasticity (MOE) as a measure of laminar strength to forecast glulam performance. Most of the models in use today only take into consideration the variations between individual timber pieces because their starting point is MOE, which was determined during the long-span test. Fig. 9 displays the results of untreated MOE, with the highest value recorded at age 10y+14y (11866 N/mm²), followed by 10y+10y (11458 N/mm²), 12y+14y (11260 N/mm²), 10y+12y (11100 N/mm²), and 14y+14y (9546 N/mm²). The lowest untreated MOE is observed at age 12y+12y (8651 N/mm²). Additionally, Fig. 9 shows the highest treated MOE recorded at age 10y+10y (15691 N/mm²), followed by 10y+14y (15378 N/mm²), 14y+14y (14357 N/mm²), 12y+14y (13578 N/mm²), and 12y+12y (12875 N/mm²), with the lowest treated MOE observed at age 10y+14y (12698 N/mm²).

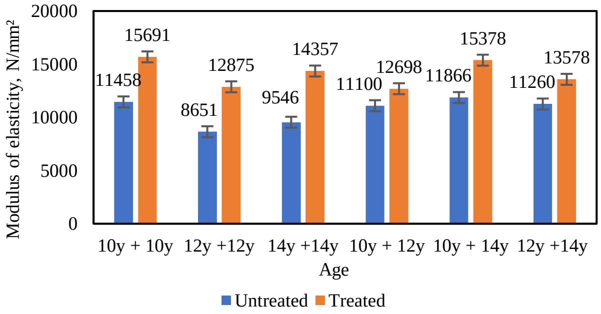

Fig. 9. Comparison modulus of elasticity, MOE of *Acacia* hybrid for untreated and treated

According to Jakob, Mahendran, & Gindl-Altmutter [40], these variances result from the varying characteristics of wood at different ages. Younger wood often has fewer formed fibres and a greater moisture content, which reduces rigidity. On the other hand, older wood is stiffer due to its more developed fibres. Higher MOE values result from combinations such as 10y+14y, which combine the flexibility of younger wood with the mature rigidity of older wood. By strengthening the structural characteristics of the wood, treatment procedures can greatly increase the MOE, particularly in younger wood Guller [41]. This can be most clearly observed by the 10y+10y combination, which yields the greatest treated MOE. On the other hand, combinations like 12y+12y could not provide the best possible balance of attributes, which would lead to lower MOE results.

Fig. 8 and Fig. 9 show the comparison modulus of rupture (MOR) and modulus of elasticity (MOE) for untreated and treated. Fig. 8 shows the comparison of modulus of rupture (MOR) between untreated and treated samples, revealing notable differences. According to Ssemaganda et al. [41], various chemical treatment preservation procedures are used to extend the longevity of wood objects made of eucalyptus. Demand treatment with either Creosote or CCA is the most common technique of wood preservation in Uganda [38]. The CCA treatment has been used to treat *Acacia* hybrid specimens. In untreated specimens, the MOR typically demonstrates a lower value compared to treated counterparts. The percentage increase in the strength of treated *Acacia* hybrid samples relative to the untreated counterparts. These percentage values signify the extent of improvement in strength for different combinations of age groups, such as 10y+10y, 12y+12y, 14y+14y, 10y+12y, 10y+14y, and 12y+14y. Therefore, the difference between untreated and treated wood indicates a 13 % increase in strength, suggesting that the treated samples are 13 % stronger than the untreated *Acacia* hybrid wood. Such findings emphasize the significance of treatment methods in bolstering the mechanical properties of materials, thereby enhancing their suitability for various applications in construction, engineering, and beyond.

Similarly, Fig. 9 showcases discernible differences in MOE between untreated and treated samples. Treated specimens typically display higher MOE values, underscoring the effectiveness of treatment processes in augmenting material stiffness and rigidity under stress. The elevated MOE in treated samples signifies enhanced structural integrity and resilience to deformation. The percentage increase in strength of treated *Acacia* hybrid samples relative to untreated counterparts is substantial, indicating treated samples are 28 % stronger. These findings underscore the importance of treatment methods in enhancing material properties for various applications in construction and engineering. Results also show that the laminated sample combined with 10 years old show greater improvements, and this also supported a study by Yahya et al. [38] where 10 years old *Acacia mangium* superbulk species had better mechanical properties. Their study also reported that treated *Acacia mangium* superbulk samples had increased the strength values of MOR, MOE, and compression parallel to grain by 3.81 %, 4.23 % and 3.66 % after samples treated with 10 % CCA preservative. A previous study by Andy [42] similarly observed an increase in the shear strength of southern pine trees when treated with CCA. Moreover, research by Faria et al. [43] highlighted the effect of CCA preservation on the physical and mechanical properties of Eucalyptus camaldulensis wood, showing an improvement in the analyzed properties.

3.1.4. Compression parallel to grain

Compression parallel to the grain, also known as longitudinal compression, is a mechanical property that describes how a material responds to compressive forces applied parallel to the direction of its grain structure. According to MS 544: Part 3 [44], a glulam structural element's success depends on its compressive strength parallel to the fibres. Due to the element serving as a beam, its upper and lower fibres will be compressed and tensioned, necessitating strong construction to sustain the applied load. Fig. 10 shows the results of compression parallel to grain for untreated *Acacia* hybrid. The highest result is 59.917 N/mm² for the age 10y+10y, followed by

59.714 N/mm² for 12y+14y, 59.447 N/mm² for 10y+14y, 53.173 N/mm² for 14y+14y, 44.511 N/mm² for 12y+12y, and the lowest result, 46.217 N/mm², is observed at the age of 10y+12y. Additionally, Fig. 10 shows the highest result for treated compression parallel to the grain, which is 93.324 N/mm² for the age 10y+10y. The second-highest result is 59.714 N/mm² for 12y+14y, followed by 59.447 N/mm² for 10y+14y, 53.173 N/mm² for 14y+14y, and 46.217 N/mm² for 10y+12y. The lowest result of compression parallel to the grain is observed for 12y+12y, measuring 44.511 N/mm².

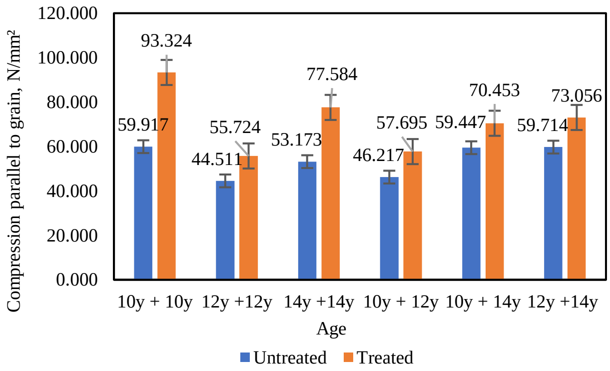

Fig. 10. Comparison of compression parallel to grain for untreated and treated

A comparison of the compression parallel to the grain of *Acacia* hybrids, both treated and untreated, is shown in Fig. 10. According to MS 544: Part 3 [44], the compression parallel requires considerable resistance to applied stresses because, as beams, they undergo tension in their lower fibres and compression in their upper fibres. The findings in Fig. 10 indicate that treated *Acacia* hybrid wood exhibits greater compression parallel to the grain compared to untreated *Acacia* hybrid wood, suggesting that the treatment process enhances the wood's ability to withstand compressive forces along its grain structure. The results in Fig. 10 show the percentage increase in the strength of treated *Acacia* hybrid samples relative to the untreated counterparts. These percentage values signify the extent of improvement in strength for different combinations of age groups, such as 10y+10y, 12y+12y, 14y+14y, 10y+12y, 10y+14y, and 12y+14y. Therefore, the difference between untreated and treated wood indicates a 27 % increase in strength, suggesting that the treated samples are 27 % stronger than the untreated *Acacia* hybrid wood. From this study, it can be concluded that the untreated samples increased in strength when treated, as proved in the study conducted by Ismaili et al. [23]. Soltis and Winandy [45] determined that CCA treatment does not influence knot size and location; however, specimens in the higher strength percentiles are more reliant on clear wood strength, which is impacted by the treatment. Timber strength varies among species but can be enhanced by adding elements that improve strength; a study by Yahya et al. [37] observed that CCA preservative treatment acted as the catalyst to boost the timber's strength performance.

4. CONCLUSIONS

Based on the result obtained in the experimental study regarding the comprehensive testing of *Acacia* hybrid wood reveals how treatments enhance its physical and mechanical properties. Density tests show that treated wood has higher densities across various age groups than untreated wood, due to copper chrome arsenic (CCA) treatment. This treatment penetrates wood fibers, increasing their resistance to decay, insects, and weathering, making the wood better suited for structural and outdoor applications. Moisture content analysis indicates higher retention in treated samples, suggesting that treatment modifies the wood's hydrophobic properties, improving its dimensional stability and durability.

Static bending tests reveal that treated wood possesses a higher modulus of rupture (MOR) and modulus of elasticity (MOE), providing greater resistance to bending and enhanced structural integrity, which is ideal for load-bearing applications. Compression tests parallel to the grain show a significant increase in strength in treated wood, which is essential for structural elements like beams under tension and compression. For structural design purposes, the results from small clear tests should not be used directly; they must first be converted into allowable or permissible stresses [46]. Overall, the results highlight the effectiveness of chemical treatments in improving *Acacia* hybrid wood's durability and mechanical properties, making it highly suitable for demanding construction and engineering applications.

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