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Physical and Mechanical Properties of White Teak Wood (*Gmelina Arborea*) from Ampana, Poso, Central Sulawesi Based on the Position of the Wood in the Trunk

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Abstract: The basic properties of this wood are also greatly influenced by factors within the wood and external factors such as where the wood grows. This research was conducted from June to September 2024 at the Soil Science Laboratory, Faculty of Agriculture, and the Mechanical Engineering Laboratory, Faculty of Engineering, Tadulako University to determine the physical and mechanical properties of white teak wood from Ampana, Poso, Central Sulawesi. The design method used in this study is RAL Factorial with two factors, namely: Factor A variation of the axial direction (base, middle, tip) and, Factor B variation of the radial direction (near the heart, middle, near the skin), so that there are 9 treatments and each treatment is repeated 5 times. The results of the study showed that both physical and mechanical properties were influenced by the position of the wood in the trunk where the position of the wood in the trunk affects the physical and mechanical properties of the wood studied. Based on the MOE value, the white teak wood studied is included in the strength class V. Based on the MOR value and compressive strength parallel to the grain, the wood studied is included in the strength class III which can be used as raw material for furniture and light construction.

Keywords: Mechanical properties; Physical; White teak

Introduction

The proper use of wood always requires certain requirements, and these requirements, both directly and indirectly, will always be related to its physical and mechanical properties. Among the physical properties that are quite important to know are the specific gravity and shrinkage of wood (Bortoletto, 2003; Apiolaza & Sharma, 2024; Bijak & Lachowicz, 2021). The physical and mechanical properties of wood are one of the indicators that determine the quality of wood, especially carpentry wood (Platonov et al., 2019; Nocetti et al., 2024; Šilinskas et al., 2024). In various uses of wood, the strength of wood is very important to know, especially the types of wood that are traded with their use for construction (Ramage et al., 2017; Arriaga et al., 2023; Kolář et al., 2021).

One type of wood that is traded and widely used in Central Sulawesi is White Teak wood (Rizanti et al., 2018a; Calvano et al., 2023). This is closely related to the increasing cultivation of fast-growing species in community forests along with the decreasing amount of wood from natural forests (Widyati et al., 2022; Rachmat et al., 2021; Liu et al., 2018). For this reason, research on the properties of wood, especially fast-growing wood types, needs to be continuously studied so that its use can be carried out optimally, especially wood from areas where there has not been much wood study and research, such as fast-growing wood from Central

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Sulawesi (Pujirahayu et al., 2021a; Abdulah et al., 2021; Supriatna et al., 2020).

The purpose of this study was to determine the physical and mechanical properties of white teak wood from Ampana District, Posos Regency, Central Sulawesi. The physical and mechanical properties of this wood were measured and observed in different axial and radial directions so that this wood can be used appropriately.

Method

This research was conducted from June to September 2024 at the Soil Science Laboratory, Faculty of Agriculture, and the Mechanical Engineering Laboratory, Faculty of Engineering, Tadulako University. The tools used in this study were a chain saw, meter, band saw, circular saw, caliper, digital moisture meter, camera, calculator, oven, digital scale, desiccator, and UTM. The material used in this study was white teak wood from Ampana District, Posos Regency, Central Sulawesi which was ± 20 years old with a diameter of ± 60.

Research Procedure

Preparation of Test Samples

Sampling was distinguished based on the axial direction (base, middle, and tip) and radial direction (near the skin, middle, and near the heart). For testing physical properties use test samples measuring 2 cm x 2 cm x 2 cm and for testing mechanical properties use test samples measuring 2 cm x 2 cm x 30 cm and 2 cm x 2 cm x 6 cm using the British Standard 373-1957 method.

Testing the Physical Properties of Wood

Water Content

Water content is the amount of water contained in the wood divided by the oven dry weight (OW) and expressed in percent. A test sample measuring 2cm × 2cm × 2cm is first weighed in a fresh state to determine its initial weight; The test sample is then air-dried in a room, then weighed, then the air-dry weight (Bku) is obtained; The test sample is then dried in an oven at a temperature of 103±2°C for ±24 hours; After that the test sample is removed and placed in a desiccator for 10-15 minutes; Then weighed again until the oven dry weight (Bko) is obtained, namely until the weight is constant. Water content can be calculated using the formula:

Description:

KA (ku): Air dry water content

BKT: Furnace dry weight (g)

BKU: Air dry weight (g)

BA: Initial weight (g)

Density

The test sample was weighed for initial weight (BA) and its volume (VA) was measured, then placed in an oven (103±2) °C until constant to obtain its furnace dry weight and volume (BKT and VKT). Wood density was obtained using the following equation:

Shrinkage

The shrinkage tested in this study was the shrinkage from basic conditions to oven-dry conditions. In Hapid (2010), dimension measurement was done using calipers, and the amount of shrinkage for each condition was calculated using the formula:

Description:

D1 = Initial dimension (mm)

D2 = Final dimension (mm)

Testing of Wood Mechanical Properties

Testing of Elastic Modulus (MOE) and Fracture Modulus (MOR)

Static flexural strength was tested using a Universal Testing Machine with a concentrated load. During testing, the test sample was placed horizontally, with a span length of 28 cm. The values of elastic modulus (MOE) and fracture modulus (MOR) were obtained from static flexural testing. A 2cm×2cm×30cm test sample is placed on the UTM with a support distance of 28 cm. The MOE and MOR values are calculated using the equations.

Description:

MOE = Modulus of elasticity (stiffness limit) (N/mm²)

MOR = Modulus of rupture (N/mm²) P = Maximum load (N)

P′ = Load to the proportion limit (N)

y = Deflection/impact that occurs at the proportion limit (mm)

L = Span length/support distance (mm) b = Width of the test sample (mm)

h = Thickness of the test sample (mm)

Parallel Grain Compressive Strength Test

The parallel grain compressive strength is also tested using a Universal Testing Machine. During testing, the sample is placed vertically and immediately loaded until damaged with a loading speed of 0.64 mm/minute. The value of compressive strength parallel to the fiber is calculated:

Description:

P = Maximum load (N) b = Width of test sample (mm)

h = Height of test sample (mm)

Data Processing

The design used in this study is the Factorial RAL with two factors, namely: Factor A variation of the axial direction (base, middle, tip) and, Factor B variation of the radial direction (near the liver, middle, near the skin), so that there are 9 treatments and each treatment is repeated 5 times. According to Mattjik and Sumertajaya (2006) the mathematical model of 2-factor Factorial RAL is as follows:

$$Yijk = \mu + \lambda i + Bj\ (\lambda b)ij + \Sigma ijk \quad (1)$$

Description:
Yijk: Observation value on the i-th axial direction variation factor, the j-th level radial direction variation factor and the k-th replication μ: the actual population mean value λi: the main effect of the i-th axial direction variation
Bj: the main effect of the j-th radial direction variation
(λB)ij : Interaction component of the i-th axial direction variation and the j-th radial direction variation
Σijk : Experimental error
The treatments stated to have an effect on the response in the analysis of variance were then further tested using the Duncan test.

Result and Discussion

The results of the study of the physical and mechanical properties of white teak wood from Ampana, Central Sulawesi can be seen as follows:

Air Dry Water Content

The results of the calculation of water content in this study can be seen in the following Figure:

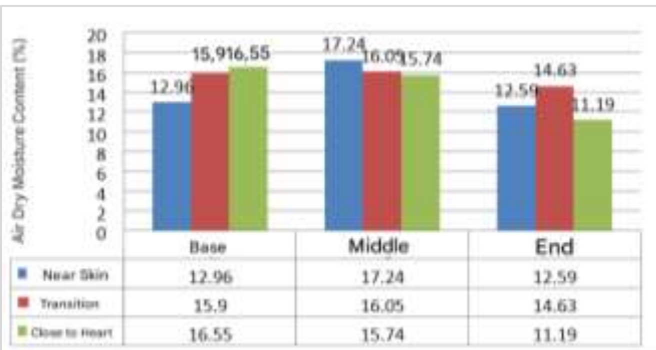

Figure 1. Air-dry water content of white teak wood from Ampana Village, Poso Regency, Central Sulawesi

The results of the study showed that the water content of the wood at the base and middle was higher than at the tip. In the radial direction, the wood near the heart had a higher water content than the wood near the bark and in the transition area at the base of the wood but lower in the middle and tip. The ANOVA results in Appendix 1 show that the axial position of the wood affects the water content, where the position of the wood at the base and middle is not significantly different, while the position of the wood at the tip is different. These results also show that the radial position of the wood does not affect the water content. The average dry air water content ranges from 11% to 17% when compared to a similar study by Q. Zhang et al. (2024), Santos et al. (2020), and Pujirahayu et al. (2021b) who studied white teak wood from Sigi Regency, Central Sulawesi, the dry air water content obtained was 18% to 21% and the highest water content was at the tip, in contrast to the results of this study where the average water content at the tip was the lowest. This can be caused because the wood in the base and middle positions has a higher ratio of heartwood to sapwood, so the water content in that section is also higher. This is related to the age of the wood studied, which is around 20 years compared to the white teak wood studied by Rizanti et al. (2018b), Bahtiar et al. (2023) which is around 10 years old.

Density

The calculation of the density of the wood studied can be seen in the following Figure:

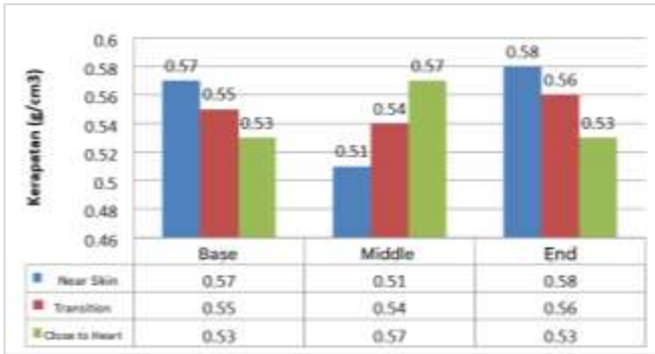

Figure 2. Density of white teak wood from Ampana Village, Poso Regency, Central Sulawesi

The average wood density obtained ranges from 0.51 to 0.58 g/cm^3. The results of Anova wood density data shown in Appendix 2 show that there is no effect of wood position either axially or radially on wood density. However, from the diagram, it can be seen that wood found near the bark and transition areas tends to have a higher density than wood near the heart/pith. This is because the wood near the pith is juvenile wood. When compared to the study of white teak which also came from Central Sulawesi but from Sigi Regency by (Sumarti et al., 2018), with a density of 0.48 to 0.5 g/cm^3, it can be seen that the density of white teak wood from Ampana Village, Poso Regency, Central Sulawesi is slightly higher. This can be influenced by the age of the older tree so the content of heartwood and sapwood is also different and affects the density of the wood.

Tangential Shrinkage

The results of the tangential shrinkage calculation can be seen in Figure 2. It can be seen that the tangential shrinkage of wood ranges from 3 to 6%, lower than the shrinkage of white teak wood from Sigi Regency which ranges from 8%. This is of course greatly influenced by the age and place where the tree grows.

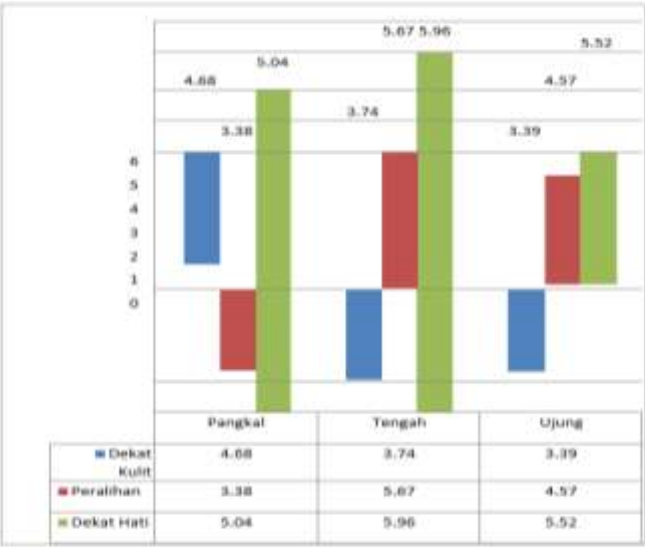

Figure 3. Tangential shrinkage of white teak wood from Ampana Village, Poso Regency, Central Sulawesi

The results of the analysis of variance (Appendix 3) show that tangential shrinkage in the axial direction has no effect, but in the radial direction it has an effect where shrinkage near the skin and transition area is smaller than shrinkage near the heart which is generally juvenile wood

Radial Shrinkage (%)

The results of the calculation of radial shrinkage range from 0.5 to 0.9% as seen in the following figure:

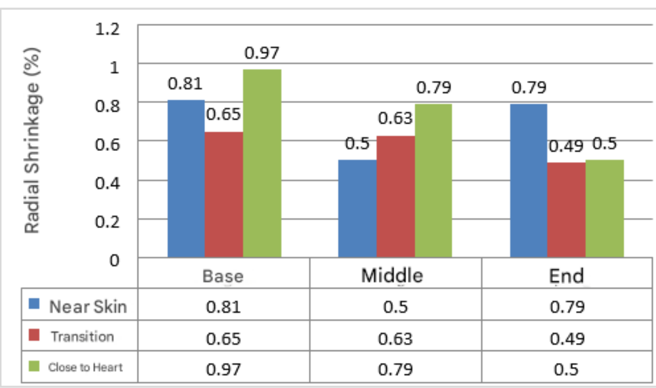

Figure 4. Radial shrinkage of white teak wood from Ampana Village, Poso Regency, Central Sulawesi

The results of the analysis of variance (Appendix 4) show that tangential shrinkage in the axial direction has no effect, although it tends to be higher at the base, but in the radial direction, it has an effect where shrinkage near the bark and transition area is smaller than shrinkage near the heart. According to Santos et al. (2023) and Billard et al. (2020) there is a positive relationship between specific gravity/density and shrinkage. Wood at the base and wood near the bark has a density that tends to be higher because of the greater mass of wood components due to the possibility that heartwood has formed at the base and also in the wood in the transition area and near the bark considering that the age of the wood studied is around 20 years (Wilms et al., 2021; Barbu et al., 2023).

Modulus of Elasticity (MoE)

The results of the study of wood flexural strength (MOE) show a tendency from the base to the tip to be smaller, while in the radial direction, it shows the highest elastic strength of wood in the area near the bark and decreases in the transition area and near the heart. As seen in the following Figure:

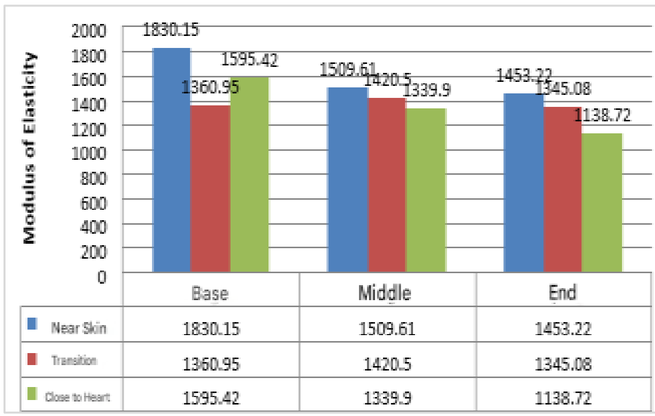

Figure 5. MOE Value of White Teak Wood from Ampana Village, Poso Regency, Central Sulawesi

The results of the analysis of variance (Appendix 5) show that the axial and radial position of the wood has a significant effect on the MOE value/flexural strength of the wood. The position of the wood at the base and middle is not significantly different but is different from the position of the wood at the end. The radial position shows that the MOE of the wood near the bark is higher, and is significantly different from the wood in the transition area and near the heart/pith. When compared to similar research by Damayanti et al. (2019) the MOE value of white teak wood from Sigi Regency is (23,297.49 kg/cm^2) at the base, followed by the middle (18,032.57 kg/cm^2) and the lowest at the end (14.015.68 kg/cm^2), then the MOE of white teak wood from Ampana Village, Poso Regency has a lower MOE. The average value of the Modulus of Elasticity (MOE) of the white teak wood studied was 1443.73 kg /cm^2. Based on the reference SNI

03-3527-1994, this wood is classified as a strength class V (BSN SNI 03-3527-1994).

Fracture Strength / MOR (Kgf)

The results of the MOR/fracture strength calculation show that the fracture strength tends to be lower at the base and higher in the middle to the tip. While the radial direction of the wood near the heart and the transition area are relatively the same, the area near the heart is slightly higher as seen in the following Figure:

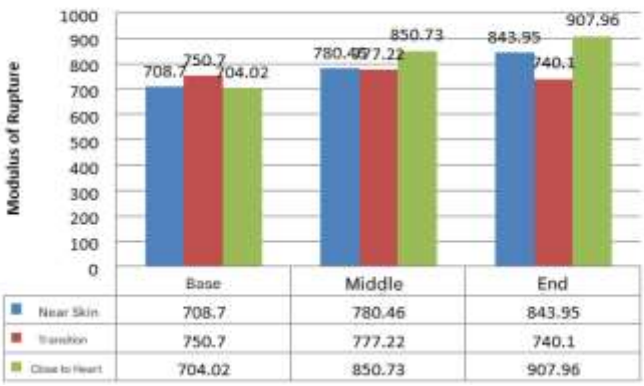

Figure 6. MOR value of white teak wood from Ampana Village, Poso Regency, Central Sulawesi

The results of the analysis of variance (Appendix 6), the radial position of the wood does not significantly affect the MOR but the axial position of the wood has a significant effect, where the MOR at the end is higher than the MOR at the base and middle (F. Zhang et al., 2023; Suranto, 2020; Diao et al., 2022). Further test results show that the wood at the base has a significantly different MOR value compared to the wood at the end but is not significantly different from the middle. This is because the water content of air-dry wood at the end is smaller than the base and middle. The results of the study Knapic et al. (2022), Fridiyanti et al. (2018), and Fruehwald-Koenig et al. (2024), showed that the KA of wood has a very significant effect on MOE, MOR, and compressive strength parallel to the grain.

The mechanical properties of lulu wood studied by Du et al. (2024) and Radojčin et al. (2021), showed that it was higher in air-dry conditions compared to fresh conditions. All mechanical properties of wood tested in air-dry conditions were very significantly different from fresh conditions. The fracture strength of the area near the skin and the transition area tended to be slightly higher than the area near the heart, although statistically with ANOVA it had no effect. The results of the study showed that the MOR value was higher at the tip than at the base and middle, while the MOE value was higher at the base and decreased towards the tip. This is different from the results of the study Iswanto et al. (2023), Ettelaei et al. (2022), and Pipíška et al. (2024) which showed that the MoE value was positively correlated with the MOR value of wood.

The MOR value of wood can determine the strength class of wood, it can be seen in this study that the wood studied can be classified into wood strength class III because the average Modulus of Fracture (MOR) value is 784.87 kg/cm², this is in accordance with the grouping of wood strength classes based on SNI 03-3527-1994 that strength class III has a range of values 437 kg / cm² - 794 kg / cm² (BSN SNI 03-3527-1994).

Parallel Grain Pressure

The parallel grain pressure of the wood studied can be seen in Figure 7. The average value of parallel grain pressure between the base, middle, and tip is relatively not too different, while in the radial direction, the part of the wood near the bark has a higher parallel grain pressure value compared to the wood in the transition area and near the heart/pith.

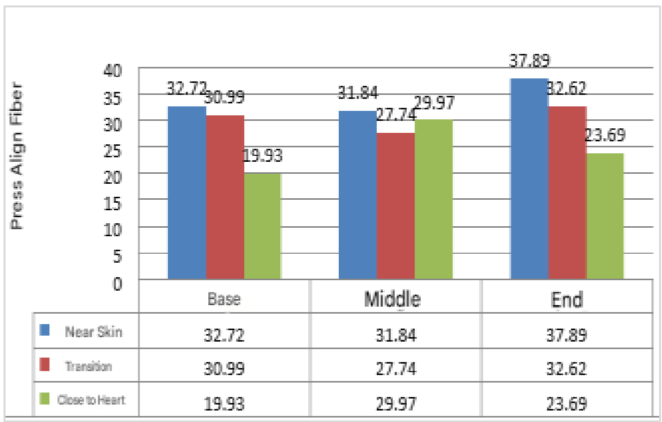

Figure 7. Parallel compression of white teak wood grain from Ampana Village, Poso Regency, Central Sulawesi

The results of the analysis of variance in Appendix 7 show that the parallel compression value of the grain is influenced by the radial position of the wood, but the axial position of the wood has no effect. Further test results show that the position of the wood near the bark has a higher parallel compression value and is significantly different from the position of the wood in the transition section and near the heart/pith. This can be influenced by the water content and also the mass of the wood cells. The water content in wood has a significant effect on the mechanical properties of wood (Mvondo et al., 2017). The average value of the Parallel Compressive Strength (KTSS) of wood is 29.71 N/mm² (3,030 kg/cm²), so the wood studied based on SNI 03-3527-1994 is included in the strength class III ((BSN SNI 03-3527-1994).

Conclusion

Based on the research results, it can be concluded that: The position of the wood in the trunk affects the physical and mechanical properties of the wood studied. Based on the MOE value, the white teak wood studied is included in strength class V. Based on the MOR value and compressive strength parallel to the grain, the wood studied is included in strength class III. Based on the MOE and MOR values and the value of compressive strength parallel to the grain, the white teak wood studied can be used as raw material for furniture and light construction.

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Author Contributions
E. A. M. contributed to research, product development, data analysis, and article writing; I. R. was a supervisor in research activities until article writing.

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Conflicts of Interest
The author declares that he has no conflict of interest.

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