UNIVERSITI MALAYSIA KELANTAN

Investigation of Radial Variation in Physical and Mechanical Properties of *Hopea Odorata* Wood Planted in Jeli, Kelantan

Haikal Muzaffar Bin Abdul Burhan

A proposal submitted in fulfilment of the requirements for the degree of Bachelor of Applied Science (Forest Resources Technology) with Honours

FACULTY OF BIOENGINEERING AND TECHNOLOGY
UMK

2023

DECLARATION

I declare that this thesis entitled "Investigation of Radial Variation in Physical and Mechanical Properties of Hopea odorata Wood Planted in Jeli, Kelantan" is the results of my own research except as cited in the references.

Signature : _________Ekal________________

Student's Name : HAIKAL MUZAFFAR BIN ABDUL BURHAN

Date : ________08.02.2024___________

Verified by:

Signature : ________________________________

Supervisor's Name : ________________________________

Stamp : ________________________________

Date : ________________________________

ACKNOWLEDGEMENT

First and foremost, Alhamdulillah, thanks to Allah for all His merciful and blessing for giving me strength to complete my Final Year Project Thesis. During the process to finish this project, there are many people on my back to support and help me to encourage this study until accomplishing until finished.

I would like to express my sincere thanks to my supervisor, Dr Andi Hermawan for continued support throughout my final year of research on the project. His professional guidance has always helped me, and her willingness to dedicate his time generously to my research and writing for this thesis has been greatly appreciated.

I am particularly grateful to Muhammad Nur Hakim Bin Muhammad Akhir and Faizatun Nadhirah binti Md Nor Azman for helping and working together until this project succeeds. They really cooperate with me by giving me enough information that I need and full support to finish it together.

Special thanks to my precious family members, particularly parents, Abdul Burhan bin Nawe and Samsiah binti Sundu, who provided me with financial support for completing graduate studies and gave me endless moral support at all times. In addition, thank you to my classmate and friends at UMK for giving me physical and mental encouragement to complete this task for the final year.

I would like to express my gratitude to all laboratory assistance especially Encik Mohd Afifi Bin Shuhaimin and Encik Muhammad Qamal Bin Othman who involved during my laboratory work. Lastly, thank you to all who involved directly or indirectly in helping me to finish my task.

Investigation of Radial Variation in Physical and Mechanical Properties of *Hopea Odorata* Wood Planted in Jeli, Kelantan

ABSTRACT

The title of the study that I conducted was the investigation of radial variation in physical and mechanical properties of *Hopea Odorata* wood planted in Jeli, Kelantan. The objectives of this study is to investigate the variation in density and moisture content of *Hopea odorata* wood from the pith toward bark. Furthermore, this study was also conducted to examine the radial variation in stiffness and strength, and compression strength of *Hopea odorata* wood. This study was conducted in Jeli Area, Kelantan. The method used to conduct research on this tree sample is to test the strength and flexibility of the tree's wood. In addition, this tree sample is also used in testing the density and moisture content of the wood contained in the pith to the wood that near to the bark. Through the research carried out, a comparison between the strength and flexibility of wood from the pith and wood that near to the bark can be detected. In addition, the moisture content and the density of the pith and the wood that near to the bark can also be detected well. In conclusion, through this study, I was able to find out the advantages of the denser, harder, more flexible and lower wood moisture content of the Hopea odorata tree.

Keywords: Hopea odorata, physical properties, mechanical properties, radial variation

Penyiasatan variasi jejari dalam sifat fizikal dan mekanikal kayu *Hopea Odorata* yang ditanam di Jeli, Kelantan

ABSTRAK

Tajuk kajian yang saya lakukan ialah penyiasatan variasi radial dalam sifat fizikal dan mekanikal kayu Hopea Odorata yang di tanam di Jeli, Kelantan. Objektif kajian ini dijalankan adalah untuk mengkaji variasi ketumpatan dan kandungan lembapan kayu Hopea odorata dari empulur hingga ke arah kulit kayu. Selain itu, kajian ini juga dijalankan untuk mengkaji variasi jejari dalam kekakuan dan kekuatan lenturan, dan kekuatan mampatan kayu Hopea odorata. Kajian ini dijalankan di Kawasan Jeli, Kelantan. Kaedah yang digunakan untuk menjalankan kajian ke atas sampel pokok ini ialah dengan menguji kekuatan dan kelenturan kayu pokok tersebut. Selain itu, sampel pokok ini juga digunakan dalam menguji ketumpatan dan kandungan lembapan kayu yang terkandung dalam empulur hingga kayu yang berdekatan dengan kulit kayu. Melalui kajian yang dijalankan, perbandingan antara kekuatan dan kelenturan kayu daripada empulur dan kayu yang berdekatan dengan kulit kayu dapat dikesan. Selain itu, kandungan lembapan kayu dan ketumpatan kayu empulur dan kayu yang berdekatan dengan kulit kayu juga dapat dikesan dengan baik. Secara konklusinya, melalui kajian ini, saya dapat mengetahui kelebihan bahagian-bahagian kayu pokok Hopea odorata yang lebih tumpat, lebih keras, lebih lentur dan lebih rendah kandungan lembapan kayunya.

Kata kunci: Hopea odorata, sifat fizikal, sifat mekanikal, variasi jejari

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MOR	Modulus of Rupture
MOE	Modulus of Elasticity
UTM	Universal Testing Machine
MPa	Megapascals
GPa	Gigapascals

LIST OF SYMBOLS

%	Percentage
kg/m^3	Kilogram per Cubic Meters
kg/cm_3	Kilogram per Cubic Centimeters
σ	Bending Stress
P	Density
E	Bending modulus
σc	Compressive stress

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hopea odorata, or known as Merawan tree, commonly known as "White Thingan" or "Siam Rosewood," is an exquisite and sought-after tropical hardwood revered for its remarkable beauty, durability, and diverse applications. This majestic timber species belongs to the dipterocarpaceae family and thrives in the lush, dense forests of Southeast Asia, particularly in countries like Thailand, Cambodia, Laos, and Vietnam (S. Shishir et al, 2020).

The wood derived from *Hopea odorata* is renowned for its exceptional quality and unique characteristics, making it a prized material in various industries, especially in fine wood working and furniture crafting. Its heartwood, often ranging from pale pinkish-brown to a rich reddish-brown hue, boasts an alluring grain pattern with occasional darker streaks, showcasing a mesmerizing combination of colours that deepen over time. This striking appearance lends an unparalleled elegance to any finished product, from luxurious furniture pieces to ornate musical instruments.

Beyond its aesthetic appeal, Merawan wood possesses exceptional strength, resilience, and natural resistance to decay, making it highly favoured for outdoor applications, including decking, boat building, and exterior construction (J Grogan et al, 2016). Its impressive stability and resistance to warping or twisting, even under changing environmental conditions, further contribute to its desirability among craftsmen and architects seeking longevity and reliability in their creations.

Moreover, this timber species holds cultural significance in several Southeast Asian communities, where it is revered for its symbolic value and traditional uses. In addition to its commercial applications, Merawan wood has historical ties to religious artifacts, ceremonial objects, and architectural elements, adding to its cultural heritage and significance in the region.

Despite its exceptional qualities, the widespread demand for Hopea odorata has led to concerns regarding illegal logging and unsustainable harvesting practices, prompting conservation efforts to protect and sustainably manage this precious hardwood species for future generations to appreciate and benefit from its unparalleled beauty and utility.

The study will involve sampling of *Hopea Odorata* or known as Merawan trees at Jeli, Kelantan and the collection of wood samples with breast heights and radial positions. The physical properties to be measured will include density and moisture content. The mechanical properties to be measured will include modulus of elasticity, modulus of rupture and compression strength. The collected data will be analyzed statistically to determine the significant differences in physical and mechanical properties across the radial profile.

The results of this study can have implications for the forestry and wood processing industry, as it can inform the development of appropriate sawing and processing methods to optimize the use of the wood resource. The study can also provide a better understanding of the variability in wood properties within a tree species, which can help improve the efficiency and sustainability of forest management practices.

1.2 Problem Statement

The problem statement is focused on understanding how the radial variation in physical and mechanical properties of Merawan tree impacts its overall wood quality and suitability for different industrial applications. This problem statement involves analizing the properties of the wood at different radial positions and assessing how these properties affect the wood's strength, durability, and other characteristics. By identifying the best parts of the tree for specific applications based on their physical and mechanical properties, we can ensure that the wood is used efficiently and effectively.

1.3 Objective

The objective of this research are as follows:

1. To examine variation in density and moisture content of *Hopea odorata* wood from pith toward bark.

2. To examine the radial variation in bending stiffness and strength, and compression strength of *Hopea odorata* wood.

1.4 Scope of Study

The radial variation in physical and mechanical properties of Merawan tree is an important area of study that can provide valuable insights into the properties of this species of tree. The physical and mechanical properties of trees vary with their position within the tree, and this variation has implications for the utilization of the tree for various applications. The aim of this study is to investigate the radial variation in physical and mechanical properties of Merawan tree and to determine the factors that contribute to this variation.

The scope of this study includes sampling of trees. The first step in sampling the trees is to sample Merawan trees from Jeli, Kelantan. The trees will be felled using standard procedures, and sections will be taken at different heights and radial positions.

Next, the scope of this study are physical properties. The physical properties of the trees, including density and moisture content, will be determined at different radial positions. The relationship between these properties and the position of the tree within the trunk will be investigated.

Furthermore, the next scope of this study are mechanical properties. The mechanical properties of the trees, including modulus of elasticity, modulus of rupture, and compression strength, will be determined using standard testing procedures. The relationship between these properties and the position of the tree within the trunk will be investigated.

1.5 Significance of Study

The investigation of radial variation in physical and mechanical properties of Merawan tree is significant for several reasons. Firstly, the Merawan tree is an important timber species in many tropical regions. It is known for its high durability, strength, and resistance to decay, making it a valuable resource for the construction industry. Understanding the radial variation in physical and mechanical properties of this tree can help to optimize its utilization and improve the quality of timber products.

Secondly, the radial variation in physical and mechanical properties of Merawan trees is an important factor that influences their performance under different loads and stresses. This variation is caused by differences in the structure and composition of the tree's wood, which can vary from the center to the outer edge of the trunk. Investigating this variation can provide insights into the behavior of the tree under different loads and stresses, which can be used to design better structures and products.

Thirdly, the investigation of radial variation in physical and mechanical properties of Merawan tree can also contribute to our understanding of the underlying physiological and anatomical mechanisms that regulate wood formation and growth. By studying the relationships between physical and mechanical properties and factors such as age, growth rate, and environmental conditions, researchers can gain insights into the complex interactions that determine the properties of wood.

CHAPTER 2

LITERATURE REVIEW

2.1 Hopea Odorata

2.1.1 Taxonomy of Hopea Odorata

Table 2.1: Taxonomy of Merawan tree

Scientific Classification	
Kingdom	Plantae
Order	Malvales
Family	Dipterocarpaceae
Genus	Hopea
Species	Hopea odorata
Phylum	Angiosperms
Class	Eudicots

Hopea odorata, commonly known as Merawan tree, is a exquisite and sought-after tropical hardwood tree belonging to the Dipterocarpaceae family. It is native to Southeast Asia, including countries such as Thailand, Cambodia, Laos, and Vietnam. Merawan tree is known for its remarkable beauty, traditional uses, and medicinal properties. For the taxonomy, the kingdom for this unique tree is plantae and the phylum is angiosperms (S Piazza et al, 2020). Eudicots is the class for this tree and malvales is the order. Last but not least, the genus of the tree is Hopea and the species is Hopea odorata.

Figure 2.1: Pictures of Merawan trees

(Source: James Allsworth, 2021)

2.1.2 Morphology of Hopea Odorata

The Merawan tree, as shown in Figure 2.1, known for its majestic presence in Southeast Asian forests, exhibits distinct morphological features characteristic of the dipterocarpaceae family. These towering evergreen trees can reach impressive heights, often soaring up to 40 meters or more, with a straight, tall trunk that can have a diameter spanning over a meter.

The tree's crown is expansive and domed, adorned with glossy, elliptical leaves that typically measure 5 to 10 centimetres in width and 15 to 25 centimetres in length. The leaves are large, glossy, and leathery in texture. They are arranged alternately along the branches and possess a distinct lanceolate shape, tapering to a point at the apex. The deep green coloration of the leaves contributes to the tree's vibrant presence within the forest canopy. The leaves possess a lustrous, dark green hue on their upper surface, while the underside showcases a lighter shade, often with prominent veins (Lisa Hopfl et al, 2021).

The fruits are characteristic of many species within the dipterocarpaceae family, to which it belongs. They are large, woody capsules known as dipterocarps, containing multiple winged seeds. These seeds are dispersed by wind or animals, contributing to the tree's reproductive success and the dispersal of its genetic material throughout the forest. The fruit of Hopea odorata is a woody capsule, approximately 2 to 3 centimetres in diameter.

Flowering occurs infrequently in these trees, but when in bloom, their small, fragrant flowers cluster together in panicles, emitting a sweet scent that attracts various pollinators. The bark of the tree is smooth and grayish when young, gradually becoming rougher and darker as the tree ages, with distinctive vertical fissures and ridges (J Ghazoul, 2016).

Overall, Merawan tree is a magnificent specimen of the tropical rainforest, characterized by its towering stature, robust trunk, glossy foliage, and vital ecological role. Its morphology is finely tuned to thrive in the dynamic and competitive environment of the forest, making it a symbol of resilience and biodiversity in Southeast Asia's rich natural heritage.

Figure 2.2: Pictures of Merawan flowers and leaves

(Source: Norzielawati Salleh, 2018)

2.1.3 Distribution of Hopea Odorata

In terms of distribution, Merawan can be found at elevations of up to 600 meters on deep, rich soils in lowland tropical forests and evergreen forests (U Shankar et al, 2017). It is usually found close to rivers and streams. This majestic tree species belongs to the dipterocarpaceae family and thrives in the lush, dense forests of Southeast Asia, particularly in countries like Malaysia, Thailand, Cambodia, Laos, Indonesia and Vietnam.

The distribution pattern of Merawan tree is primarily influenced by several ecological factors, including climate, soil conditions, elevation, and precipitation levels. These trees thrive in lowland rainforests, often found in regions with consistent high humidity and rainfall throughout the year. They prefer well-drained, nutrient-rich soils, although they can tolerate a range of soil types, including sandy and clayey soils.

In Malaysia, Merawan tree is commonly found in states like Sarawak and Sabah on the island of Borneo, as well as in peninsular Malaysia, particularly in areas with dense tropical forests. In Indonesia, it occurs in regions such as Sumatra and Kalimantan, where extensive rainforest habitats provide suitable growing conditions. In Thailand, Merawan tree is prevalent in various regions, particularly in the southern parts of the country. It thrives in the diverse habitats of Thailand's tropical forests, contributing to the rich biodiversity of these areas.

Within its distribution range, Merawan tree exhibits a patchy distribution pattern, often forming small populations or clusters within the larger forest ecosystem. This distribution pattern can be attributed to various factors such as seed dispersal mechanisms, competition with other plant species, and historical land use patterns.

Seed dispersal plays a crucial role in the spread and establishment of Merawan tree populations. The species relies on various dispersal agents, including wind, water, and animals, particularly birds and mammals. Seeds are encapsulated within woody fruits, which can be dispersed over long distances by wind or water. Additionally, animals feeding on the fruits may aid in seed dispersal through their droppings, facilitating the germination and establishment of new individuals.

Overall, the Merawan trees distribution across Southeast Asia highlights its adaptability to various tropical environments, contributing to the ecological diversity and richness of the region forests.

2.1.4 Usage of Hopea Odorata

Merawan wood holds significant cultural and commercial importance in Southeast Asia. Renowned for its durability, strength, and resistance to decay, Merawan wood is highly valued in the timber industry.

In construction, Hopea odorata wood is favoured for its sturdiness, making it ideal for crafting sturdy furniture, heavy-duty beams, and durable outdoor structures like bridges and boats. Its resistance to pests and decay makes it a preferred choice for outdoor applications where exposure to the elements is a concern (MV Rao et al, 2022). Beyond its utilitarian purposes, the wood carries cultural significance. In Thailand, it is traditionally used in the construction of temples and sacred buildings due to its perceived spiritual qualities and enduring nature. It is also crafted into intricate carvings and decorative items, showcasing the craftsmanship and beauty of this wood.

Merawan has a long history of medicinal use in traditional systems of medicine. Various parts of the tree, including the bark, leaves, and roots, are used for their medicinal properties. The wood is believed to contain compounds that exhibit anti-inflammatory effects (SC Fang et al, 2008).

Past uses include the treatment of inflammations and related conditions. It is also emit a pleasant fragrance, and its aroma is thought to have soothing effects. It has been used in aromatherapy and as an incense for relaxation purposes. In some traditional practices, the smoke or vapours produced by burning Merawan wood have been used to alleviate respiratory issues, such as coughs and congestion (CPF Pirard et al, 2023).

In recent years, growing concerns over deforestation and habitat loss have prompted efforts to sustainably manage and conserve Merawan tree populations. Forest management practices, such as selective logging and reforestation initiatives, aim to balance the economic benefits of timber extraction with the need to protect biodiversity and ecosystem integrity. Furthermore, initiatives promoting the cultivation of Merawan tree in agroforestry systems offer alternative livelihood opportunities for rural communities while reducing pressure on natural forests.

Beyond its commercial value, the Merawan tree tree plays a crucial role in the preservation of biodiversity and ecosystem stability. As a dominant species in tropical rainforests, it provides habitat and sustenance for a diverse array of flora and fauna, including various species of birds, mammals, insects, and plants (MS Yahya et al, 2023). Its large canopy offers shade and shelter to understory vegetation, helping to maintain soil moisture and prevent erosion. Additionally, the tree's deep roots aid in nutrient cycling and soil aeration, contributing to the overall health of forest ecosystems.

2.2 Variation in Radial Direction

2.2.1 Reason It Happen

The variation in radial direction in the physical and mechanical properties of the Merawan tree can be attributed to several factors. First, growth rings. Merawan tree, like many other tree species, forms annual growth rings as it grows. These growth rings consist of layers of wood formed during different seasons. The properties of wood can vary significantly between growth rings due to variations in factors such as moisture availability, temperature, and nutrient availability during different growing seasons (RJW Brienen et al, 2016). This leads to radial variation in physical and mechanical properties. Second, vessel anatomy. The vascular system of a tree, including the arrangement and size of vessels, can vary radially within the trunk. Merawan tree has a diffuse-porous wood structure, meaning that vessels are relatively evenly distributed throughout the growth rings. However, the size and density of vessels can vary within different growth rings, resulting in radial differences in physical properties such as water transport capacity and permeability.

2.2.2 How to Control

Controlling the radial variation in physical and mechanical properties of Merawan trees can be challenging since some factors are inherent to the tree's growth and development. However, certain management practices can be implemented to minimize the extent of radial variation. First, it can be controlled with doing a silvicultural practices. Proper silvicultural practices can influence the growth and development of trees, including Merawan (N Kamarudin et al, 2011). By implementing techniques such as selective thinning, pruning, and spacing, you can promote more uniform growth and reduce the variation in physical and mechanical properties. These practices help ensure that the trees receive adequate light, nutrients, and space for optimal development.

The next way to control it with growth control system. Controlling the growth rate of trees can help manage radial variation. Slower growth rates can potentially result in more uniform growth rings and wood properties (DM Drew et al, 2008). This can be achieved through techniques like controlling nutrient availability, irrigation, and managing competition from other vegetation.

Environmental control also the relevant way to control the radial variation. Environmental factors can influence radial variation. While it may not be possible to control all environmental factors, you can implement measures to minimize their impact. For example, providing adequate irrigation during periods of drought stress and protecting the trees from extreme weather conditions can help reduce variations in physical and mechanical properties.

2.3 Radial Variation in Physical Properties

2.3.1 Density

Wood density is a crucial parameter that characterizes the mass of wood per unit volume and plays a significant role in determining its mechanical and physical properties. Typically measured in kilograms per cubic meter (kg/m^3) or pounds per cubic foot, wood density varies among different species, affecting their strength, hardness, and durability (DKA Khirey, 2019).

For softwoods, it derived from coniferous trees such as pine and spruce, generally exhibit lower densities ranging from 300 to 600 kg/m³ (R Kask, 2015). These woods are often favoured for construction and carpentry due to their lighter weight and ease of workability. One of the primary characteristics of softwood is its relatively lower density, which contributes to its lighter weight compared to hardwood. This property makes softwood an excellent choice for construction projects where weight is a concern, such as in framing houses or building furniture that needs to be easily transportable.

Additionally, the lower density of softwood often translates to lower cost, making it a more economical option for many applications. Softwood's lower density also affects its mechanical properties. While softwood may not be as strong or durable as hardwood, its lighter weight can still provide sufficient strength for many applications. However, in situations where greater strength and durability are required, hardwood may be the preferred choice.

For hardwoods, it sourced from deciduous trees like oak and mahogany, tend to have higher densities, typically falling between 600 and 1000 kg/m³ (K Haneka, 2005). This increased density contributes to their enhanced strength, making hardwoods preferred for furniture, flooring, and other applications where durability is crucial. The higher density of hardwood gives it several distinct advantages over softwood. Firstly, hardwood tends to be stronger and more durable, making it suitable for a wide range of applications where resilience and longevity are essential. From flooring and cabinetry to high-quality furniture and musical instruments, hardwood's density contributes to its ability to withstand wear and tear over time.

Additionally, the higher density of hardwood often results in enhanced aesthetic qualities. Hardwood typically has a smoother texture and a more intricate grain pattern, which can add beauty and character to finished products. This aesthetic appeal makes hardwood a popular choice for decorative items and architectural features where appearance matters.

Wood density is influenced by various factors, including growth conditions, age, and the specific part of the tree from which the wood is obtained. Typically, older trees and wood from the inner core exhibit higher densities than younger or outer wood. Understanding the density of wood is essential for selecting the right material for specific applications, ensuring optimal performance and longevity.

.

2.3.2 Moisture Content

The moisture content of wood is a crucial factor that significantly influences its physical properties and performance in various applications. Moisture content refers to the amount of water present in wood, expressed as a percentage of the wood's oven-dry weight (BG Tucho, 2019). It is a critical parameter because water has a significant impact on the wood's mechanical strength, dimensional stability, and susceptibility to decay.

Freshly harvested wood contains a substantial amount of water, commonly referred to as green moisture. As wood dries, either naturally through air drying or artificially through kiln drying, the moisture content decreases, leading to changes in the wood's structure and characteristics. Drying wood is essential for enhancing its strength, hardness, and resistance to decay, making it suitable for construction, furniture, and various other applications.

The optimal moisture content for wood depends on its intended use and the environmental conditions it will face. Wood with high moisture content may be prone to warping, shrinking, and insect infestation, while excessively dry wood can become brittle and prone to cracking (A. Moncmanova, 2007). Properly managing and measuring the moisture content of wood is critical for ensuring the quality and longevity of products made from this versatile natural material. Whether in construction, woodworking, or manufacturing, understanding and controlling moisture content is vital for producing durable and reliable wood products.

If making a comparison of moisture content between softwood and hardwood, softwood derived from coniferous trees like pine, spruce, and cedar, typically exhibits a lower moisture content compared to hardwood. This lower moisture content can be attributed to the porous nature of softwood, which allows for quicker drying and moisture release (S Rahimi et al, 2022). Softwood's cellular structure contains larger open spaces, facilitating moisture evaporation and making it more prone to rapid changes in humidity levels. However, this characteristic also makes softwood more susceptible to warping, shrinking, and swelling when exposed to fluctuating environmental conditions.

In contrast, hardwood, sourced from deciduous trees like oak, maple, and cherry, tends to have a higher moisture content than softwood. Hardwood's denser cellular structure and tighter grain pattern contribute to its ability to retain moisture for longer periods (AO Olorunnisola, 2018). This higher moisture content provides hardwood with greater stability and resistance to warping or distortion, particularly in environments with varying humidity levels. However, it also means that hardwood typically requires longer drying times and more meticulous moisture management during processing to prevent issues like cracking or checking.

2.4 Radial Variation in Mechanical Properties

2.4.1 Modulus of Rupture (MOR)

The modulus of rupture (MOR) is a critical mechanical property used to assess the strength and resilience of materials, including wood (B. Niez et al, 2020). Specifically, it measures a material's ability to withstand bending or flexural stress without breaking. In the context of wood, MOR is crucial for evaluating its performance in applications where bending or structural integrity is a key consideration, such as in construction and furniture manufacturing.

Wood's modulus of rupture is determined through a standardized bending test, typically involving a sample supported at its ends and subjected to an increasing load until failure occurs. The MOR is calculated by dividing the maximum applied load by the sample's cross-sectional area. This property is indicative of the wood's ability to endure external forces and stresses, providing valuable information for engineers, architects, and woodworkers in selecting appropriate wood species for specific applications.

Various factors influence the modulus of rupture of wood, including its species, moisture content, grain orientation, and density. Hardwoods generally exhibit higher MOR values than softwoods due to their denser and more complex cellular structure (OM Gonzalez et al, 2020). Additionally, well-seasoned wood tends to have improved MOR as it is less prone to deformation and failure under stress.

Understanding the modulus of rupture is essential for designing structures and products that rely on wood as a primary material. By considering this mechanical property, professionals can make informed decisions to ensure the longevity and safety of wood-based applications in diverse industries.

The strong and durable nature of *Hopea odorata* wood, or known as Merawan, as reflected in its modulus of rupture, makes it suitable for various applications that require structural integrity. It is often utilized in construction projects for beams, trusses, and other load-bearing components. Additionally, the wood's high modulus of rupture makes it desirable for crafting furniture, flooring, and other items where strength and resilience are important factors.

The impressive modulus of rupture of Merawan wood underscores its capacity to withstand bending stresses and resist breakage. This property contributes to its reputation as a valuable timber species in the industry, offering reliable and sturdy wood for a range of structural and decorative purposes.

2.4.2 Modulus of Elasticity (MOE)

The modulus of elasticity (MOE), also known as Young's modulus, is a fundamental mechanical property that characterizes the stiffness of a material. In the context of wood, MOE refers to the material's ability to deform elastically under an applied load and return to its original shape when the load is removed (Z Qin et al, 2018). It is a crucial parameter in understanding the structural behaviour of wood in various applications, such as construction and furniture.

Wood is an anisotropic material, meaning its properties vary with direction. The MOE of wood is influenced by factors such as species, moisture content, and grain orientation. Typically, softwoods like pine and hardwoods like oak exhibit different MOE values due to their distinct cellular structures.

The MOE of wood is expressed in units of force per unit area, commonly megapascals (MPa) or gigapascals (GPa). Values can range from a few thousand MPa for softer woods to over 20,000 MPa for denser hardwoods. Engineers and designers use MOE to predict how much a wooden structure will deform under load, aiding in the determination of suitable materials for specific applications.

Understanding the MOE of wood is crucial in designing structures that require a balance of strength and flexibility. It enables architects and engineers to optimize material usage, ensuring the efficient and safe utilization of wood in a wide range of construction and woodworking projects.

Due to its favourable modulus of elasticity, Merawan wood is often utilized in construction projects, including the production of beams, columns, and flooring materials. It is also sought after in the manufacturing of furniture and other wooden products that require stability and strength.

Overall, the modulus of elasticity, or Young's modulus, is a fundamental mechanical property that quantifies the stiffness and deformation behavior of materials under stress. Its importance in engineering design, analysis, and material selection cannot be overstated, as it enables the optimization of structures and components for performance, reliability, and safety. Understanding Young's modulus allows engineers to predict and control the mechanical behavior of materials in diverse applications, from aerospace to biomedical engineering.

2.4.3 Compression Strength

Compression strength refers to the ability of a material to withstand axial loads pushing towards its center without collapsing or undergoing significant deformation (MC Griffith et al, 2007). In the case of wood, compression strength is a crucial mechanical property that influences its utility in various applications, including construction and furniture.

Wood exhibits anisotropic behaviour, meaning its mechanical properties vary with the direction of the load. The compression strength of wood is generally higher parallel to the grain than perpendicular to it (PB Lourenco et al, 2007). This is because wood fibers, aligned along the grain, offer greater resistance to compression forces.

The compression strength of wood is affected by several factors, including species, moisture content, and density. Different wood species have varying cellular structures and fiber arrangements, leading to differences in their compression strength (LJ Gibson, 2012). Additionally, the moisture content of wood significantly influences its mechanical properties. Wet or green wood tends to have lower compression strength than dry wood due to the presence of water affecting the fiber ability to resist compression (P Navi et al, 2013).

If making a comparison of compression strength between softwood and hardwood, a significant different will be seen. For softwood, it derived from gymnosperm trees such as pine, spruce, and cedar. Softwood generally less dense and has a simpler cellular structure compared to hardwood. This cellular structure consists of elongated cells called tracheid, which provide support and transportation of water and nutrients within the tree. Due to its lower density and simpler structure, softwood tends to have lower compression strength compared to hardwood.

Hardwood, on the other hand, comes from angiosperm trees like oak, maple, and cherry. Hardwood trees typically have a more complex cellular structure with various types of cells including vessels and fibers (JCF Walker et al, 2006). This complex structure contributes to hardwood's higher density and greater compression strength compared to softwood.

One of the primary reasons for the difference in compression strength between softwood and hardwood lies in their cell structure. Hardwood generally has more fibers and vessels, which are responsible for providing mechanical support and strength (RM Rowell, 2005). These fibers are arranged in a more intricate manner compared to the tracheids found in softwood, resulting in greater resistance to compression forces.

Additionally, the growth rings present in both softwood and hardwood play a significant role in determining their compression strength. In softwood, the growth rings are usually less distinct and often consist of uniform layers of cells, whereas in hardwood, the growth rings are more pronounced and can vary in density and composition. The arrangement of these growth rings can affect how the wood responds to compression forces, with hardwood often exhibiting greater resistance due to its denser and more structured growth rings.

Moreover, the type of wood and its specific characteristics can also influence its compression strength. For example, some hardwood species like oak and hickory are renowned for their exceptional strength and are commonly used in applications where high compression strength is required, such as in the construction of load-bearing structures and furniture.

Workers consider the compression strength of wood when designing structures to ensure the material can support the expected loads without failing. Testing methods, such as axial compression tests, or using Universal Testing Machine (UTM) help determine the specific compression strength values for different wood species, enabling informed decision-making in construction and woodworking projects.

In addition, while both softwood and hardwood have their respective strengths and weaknesses, hardwood generally exhibits higher compression strength due to its denser and more complex cellular structure, as well as the presence of distinct growth rings. However, the specific compression strength of a particular type of wood can vary depending on factors such as species, moisture content, and grain orientation. Understanding these differences is crucial for selecting the appropriate type of wood for various applications to ensure optimal performance and durability.

CHAPTER 3

METHODOLOGY

3.1 Material

3.1.1 Wood Disk Preparation

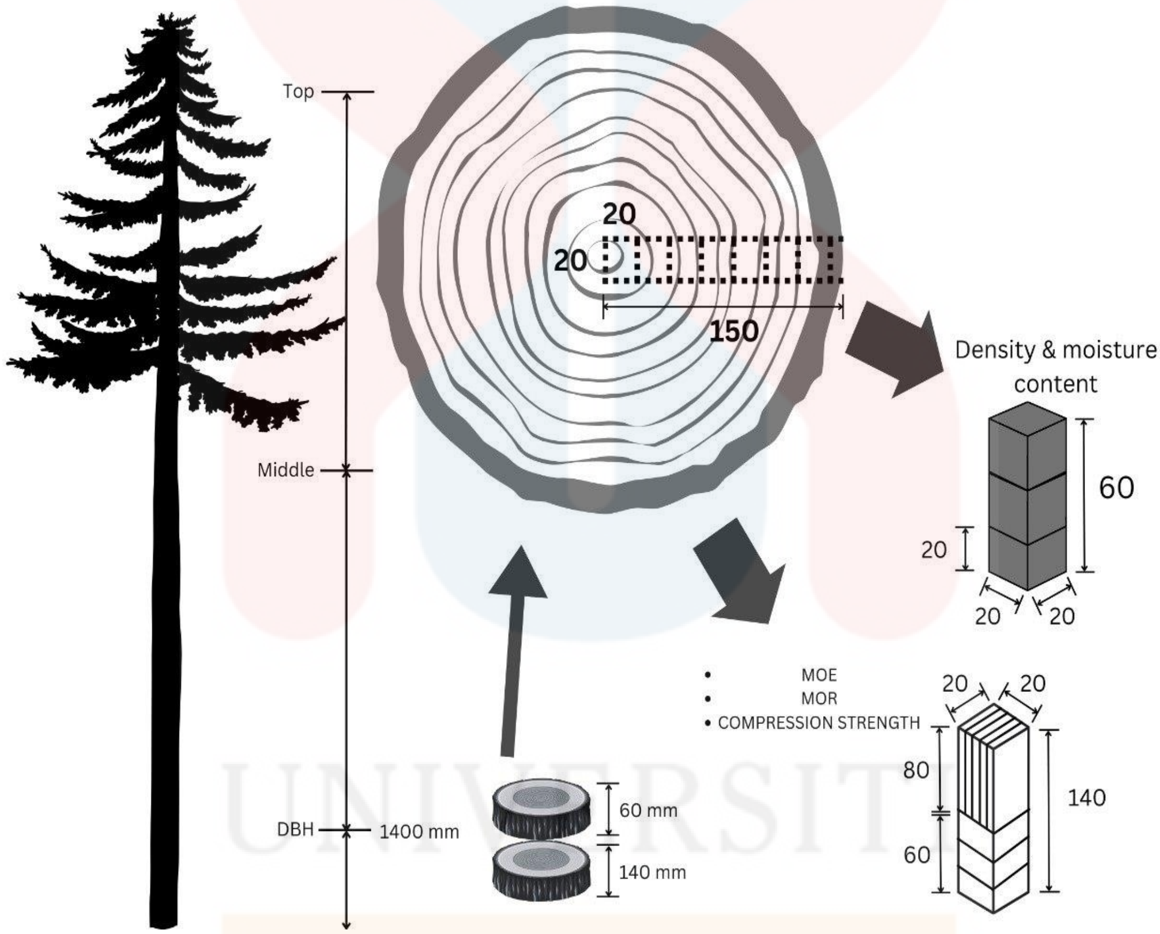


Figure 3.1: Overall specimen preparation process

Hopea odorata wood was taken in Jeli, Kelantan. The age of the tree is 8 to 9 years with a diameter of 30 cm.

3.2 Method

3.2.1 Sample Preparation

Two disks must be taken at breast level which is 1400 mm from the root. The stem will be taken 200 mm long and then cut into 2 disks. The first disk is 60 mm long and the second disk is 140 mm long.

Then, both disks will be cut from pith to bark which is 150 mm width and 20 mm height. From figure 3, for the first disk, the wood will be cut into 7 samples which are 20 mm x 20 mm x 60 mm. After that, each sample will be cut into 3 parts into cubic 20 mm x 20 mm x 20 mm. Next, the wood will be taken to count the density and moisture content.

For the second disk, the wood will be cut into 2 parts which are 60 mm and 80 mm. For 60 mm wood, the wood will be cut radially and become 20 mm x 20 mm x 20 mm while the 80 mm wood will be cut tangentially and will be 80 mm x 20 mm x 5 mm. Next, wood will be taken to determine the MOR, MOE and compression strength.

3.2.2 Density Measurement

Density is a fundamental physical property measuring the mass of a substance contained within a unit volume. The formula to calculate the density of Hopea odorata wood as follow : $P = \frac{m}{v}$

P represent for density, m represent for mass and v represent for volume. It's calculated by dividing an object's mass by its volume. Represented by various units like kg/m^3 or g/cm^3, density quantifies how tightly packed matter is within a given space. Understanding density aids in identifying materials, predicting buoyancy, and determining composition. For instance, less dense substances float on denser ones. Crucial in physics, chemistry, and engineering, density's significance extends to diverse fields, from designing materials to exploring celestial bodies. Its measurement provides valuable insights into the characteristics and behavior of materials, essential for various scientific and industrial applications.

3.2.3 Moisture Content Measurement

Moisture content measurement refers to the quantification of water present in a Hopea odorata wood. The formula to calculate the moisture content of Hopea odorata wood as follow : MC = $\frac{w0-w1}{w1} x\ 100$

W0 represent for weight of samples before drying and w1 represent for weight after drying. The amount of water that contain in the wood is determined by subtracting the weight before drying and after drying, and the moisture content is then calculated as the amount of water divided by the dry weight or total weight.

3.2.4 Bending Properties Measurement

The formula to calculate bending properties measurements for Hopea odorata trees is commonly derived from the principles of beam theory. Two important parameters in this context are bending stress and bending modulus of elasticity.

Bending Stress (σ) = $\frac{Mc}{I}$

Bending Modulus (E) = $\frac{M * c\text{^}2}{3 * \delta}$

σ represents the bending stress in the tree. M is the applied bending moment. c refers to the distance from the neutral axis (center) to the outermost fiber in the tree. I represents the moment of inertia of the tree's cross-sectional shape. E represents the bending modulus, also known as the flexural modulus or modulus of elasticity in bending. δ is the vertical deflection of the tree under the applied load.

These formulas allow for the calculation of bending stress and bending modulus of elasticity for the trees, providing insights into their ability to resist bending forces and their stiffness in bending applications. It is worth noting that tree-specific parameters such as wood density, cross-sectional shape, and moisture content can influence the accuracy of these calculations.

3.2.5 Compression Strength Measurement

The formula to calculate compression strength, specifically compressive stress (σc), is as follows:

Compressive Stress (σc) = $\frac{F}{A}$

σc represents the compressive stress in the material. F is the applied compressive force or load. A is the cross-sectional area of the material perpendicular to the applied force.

This formula is used to determine the compressive strength of the tree, which measures its ability to withstand compression or squeezing forces without deformation or failure. It is commonly employed in engineering and materials testing to assess the load-bearing capacity of various materials, including wood.

When applying this formula to measure the compression strength of a tree, the compressive force (F) would be the maximum force applied to the tree, and the cross-sectional area (A) would be the area perpendicular to the direction of the force. The resulting compressive stress value provides insight into the tree's ability to resist compressive forces and maintain its structural integrity.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Mechanical Test

4.1.1 Density

Table 4.1: Average of density from pith toward bark samples

Samples (MM)	Density	Standard Deviation
10	0.755109	0.041489
30	0.750894	0.102419
50	0.845195	0.027797
70	0.773692	0.019132
90	0.737426	0.029824
110	0.688169	0.016883

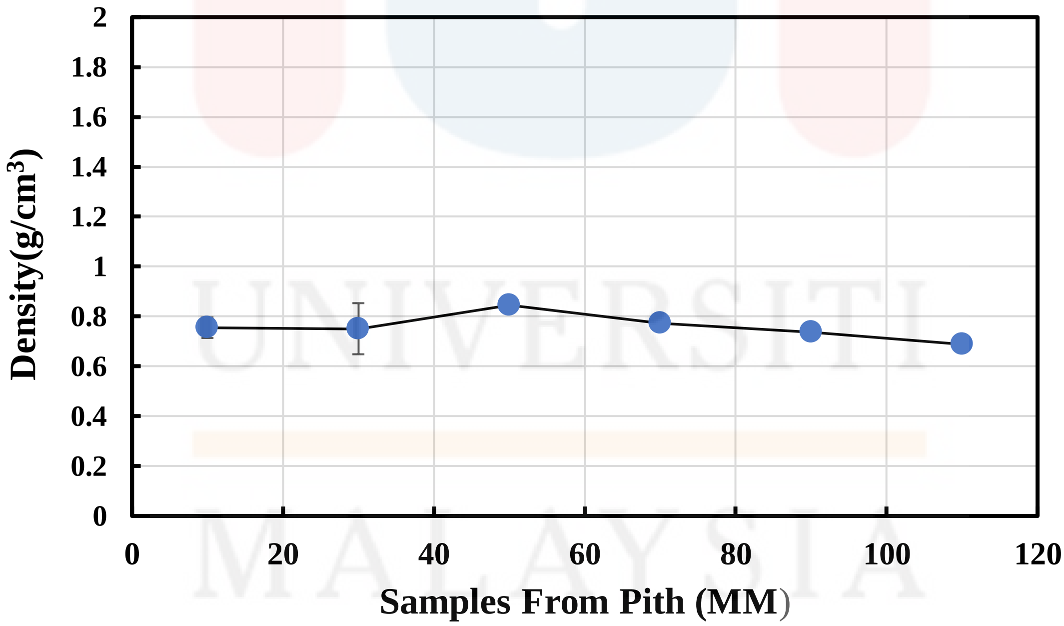


Figure 4.1: Graph of density for pith toward bark samples

The density of Merawan wood from pith toward bark is displayed in Figure 4.1. The graph indicates that samples of pith have an average density that is higher than samples toward bark. Near bark samples have an average density of 0.688169 g/cm3, whereas pith samples have an average density of 0.755109 g/cm3. This particular circumstance arises due to the influence of certain distinct factors.

Merawan wood has a pattern of relatively uniform low specific density on pith, specific density which increases rapidly through the juvenile period followed by a series of annual rings that have a constant specific gravity, though fluctuate from year to year. Hardwood trees such as Merawan often show a reduction in depth specific gravity near bark which causes the pith density to be slightly higher than the near bark density.

Most reports on specific density changes from pith toward bark other than radial changes in wood related to tracheid length. A common pattern for all species of wood include Merawan is to have short tracheids near the center of the tree followed by a rapid increase through the juvenile zone then flattening. However, some species show only slight flattening, and tracheid length can be as much as four to five times greater near the bark from near the pith.

As a tree matures, the inner layers, including the pith wood, undergo a transformation. Cells in the heartwood deposit various substances like resins, gums, and tannins, which contribute to its increased density. These deposits also make pith wood less prone to decay, providing structural support and protection to the core of the tree.

In contrast, wood that near to bark actively participates in the tree's physiological processes, acting as a conduit for water, nutrients, and sugars. Its primary function is to transport sap from the roots to the leaves. To accommodate these functions, wood near to bark has a lower density, allowing for more efficient nutrient and water transport.

4.1.2 Moisture Content

Table 4.2: Average of moisture content from pith toward bark samples

Samples (MM)	Moisture Content	Standard Deviation
10	20.02591	0.438139
30	19.18001	1.217512
50	18.4856	0.374921
70	17.51262	0.388485
90	17.91926	1.134758
110	17.69288	0.394899

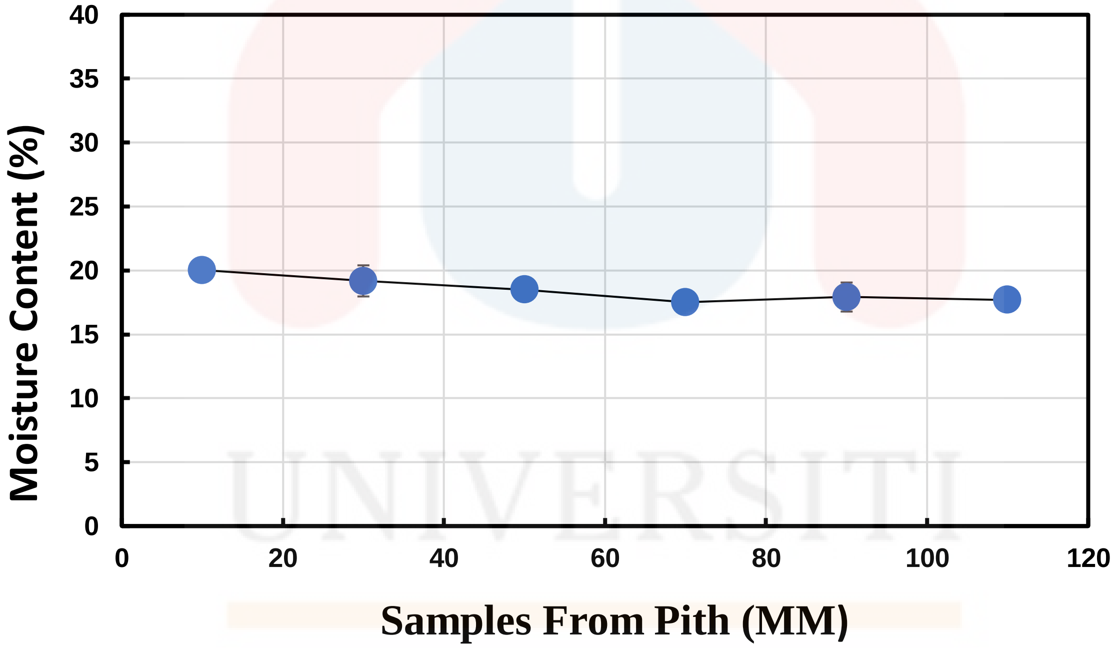


Figure 4.2: Graph of moisture content from pith toward bark

The moisture content of Hopea odorata wood is displayed in Figure 4.2 from pith toward bark. The graph indicates that the pith samples had an average moisture content that was higher than the near bark samples. Samples of pith have an average moisture content of 20.02591 %, whereas samples of near bark have an average moisture content of 17.69288 %. This particular circumstance arises due to the influence of certain distinct factors.

Pith wood typically has a higher moisture content than wood that near o bark due to its location within the tree and its physiological functions. The pith is the central, innermost part of a tree trunk, consisting of soft, spongy tissue. Its primary role is to provide structural support during the tree's early growth stages. As a tree matures, the pith becomes less active in terms of water transport and storage.

Near bark wood is the outer layer of wood, just beneath the bark, and it is responsible for conducting water and nutrients from the roots to the leaves. Near bark wood is actively involved in the tree's water transport system, facilitating the upward movement of water absorbed by the roots through a process called transpiration.

The higher moisture content in pith wood can be attributed to its reduced metabolic activity and decreased involvement in water transport compared to the near bark wood. As a result, the pith retains more moisture because it is not as actively participating in the tree's water management processes. Additionally, near bark wood tends to dry out faster than pith wood, making it a less humid environment.

In summary, the location and physiological functions of pith wood contribute to its higher moisture content compared to sapwood, which is actively involved in water transport and is more prone to drying out.

4.2 Mechanical Test

4.2.1 Modulus of Rupture (MOR)

Table 4.3: Average of Modulus of Rupture (MOR) from pith toward bark samples

Samples (MM)	Modulus of Rupture	Standard Deviation
10	61.59325	16.18939
30	75.21975	10.99231
50	94.5435	9.850083
70	81.885	17.36422
90	84.45525	6.11115
110	91.5835	5.054212

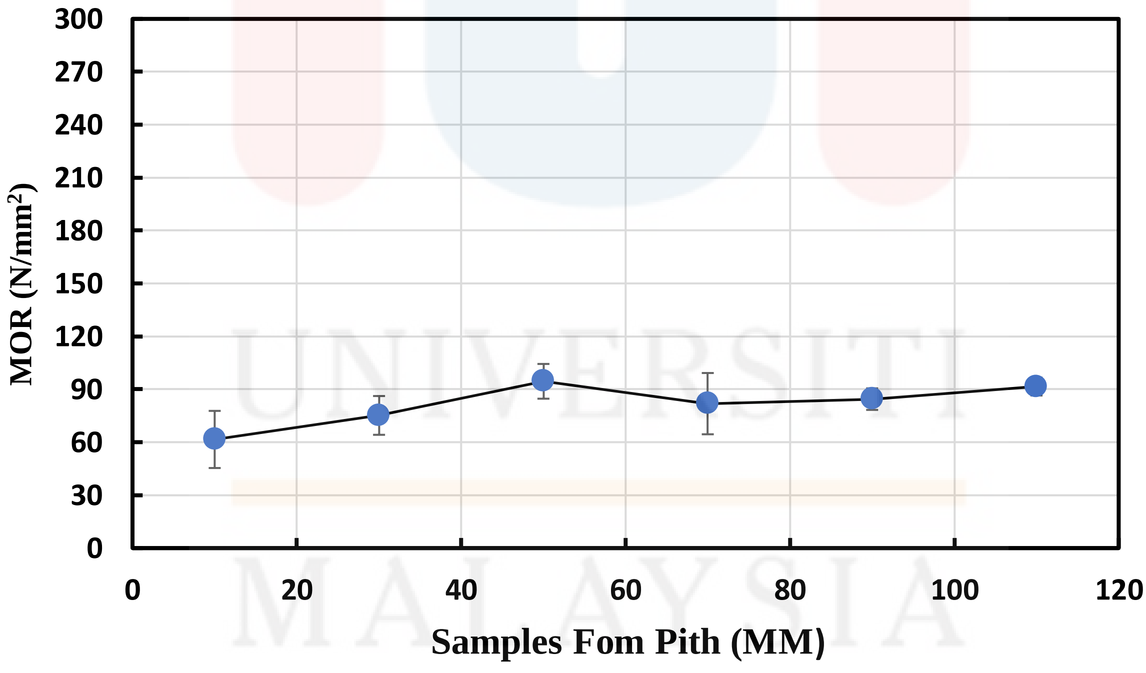


Figure 4.3: Graph of Modulus of Rupture (MOR) from pith toward bark

Figure 4.3 shows the result of Modulus of Rupture (MOR) for Hopea odorata wood from pith to bark. From the graph, it shows that the average modulus of rupture from pith samples is lower than the near bark samples. The average modulus of rupture for pith samples are 61.59325 N/mm^2 while the average modulus of rupture for near bark samples are 91.5835 N/mm^2. This situation occurs because it is influenced by some specific reasons.

Pith wood and near bark wood are two distinct regions within a tree trunk, each with unique mechanical properties. The modulus of rupture (MOR), a measure of a material's ability to withstand bending or breaking under stress, is generally lower in pith wood compared to wood that near to bark due to their inherent structural differences.

The pith is the central, softer portion of the tree trunk, consisting of undifferentiated cells and being less dense than the surrounding wood. Its primary function is to transport water and nutrients during the early stages of growth. Pith cells lack the well-defined structure and mechanical strength found in mature wood, contributing to the lower MOR. The pith's lower density and less organized composition make it more susceptible to deformation and failure when subjected to bending forces.

On the other sides, wood that near to bark, located just beneath the bark, serves as the tree's active transport system, conducting water and nutrients between the roots and leaves. Wood that near to bark is comprised of more developed and organized xylem cells, which provide greater structural support and contribute to a higher MOR. The increased density and fiber alignment in near bark wood enhance its ability to resist bending stresses, making it mechanically stronger than the pith.

Overall, the lower modulus of rupture in pith wood compared to wood that near to bark can be attributed to the pith's less organized structure, lower density, and reduced mechanical strength due to its primary function in the early growth stages of the tree.

4.2.2 Modulus of Elasticity (MOE)

Table 4.4: Average of Modulus of Elasticity (MOE) from pith toward bark samples

Samples (MM)	Modulus of Elasticity	Standard Deviation
10	5465.842	1615.465
30	7278.78	1752.185
50	9454.483	1335.249
70	7498.428	1164.832
90	7929.392	1665.225
110	9180.665	1158.598

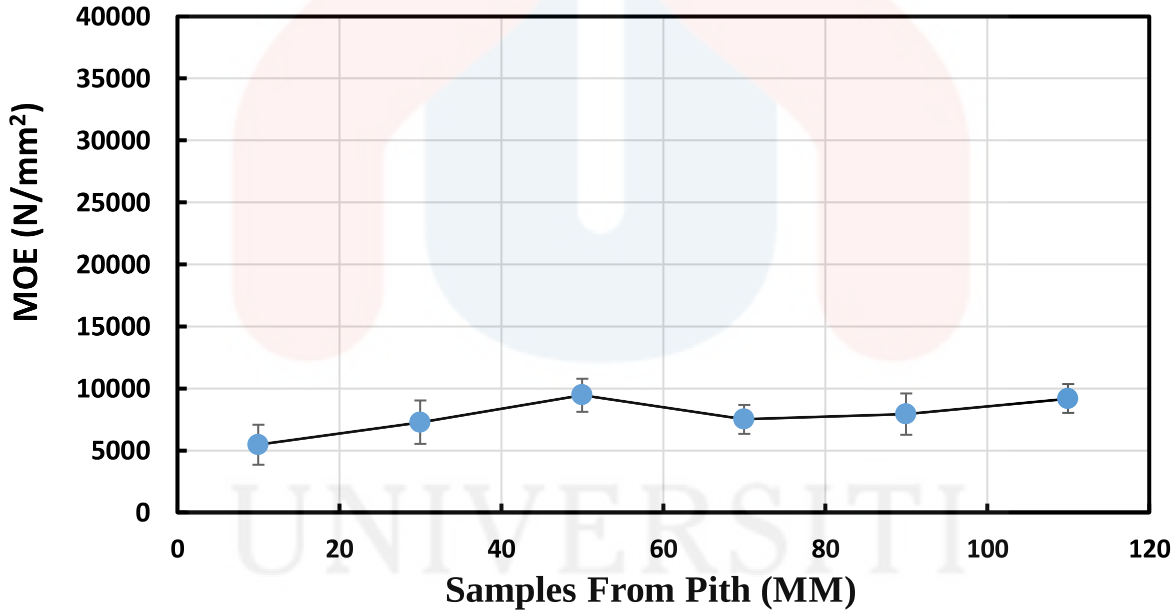


Figure 4.4: Graph of Modulus of Elasticity (MOE) from pith toward bark

Figure 4.4 shows the result of Modulus of Elasticity (MOE) for Hopea odorata wood from pith to bark. From the graph, it shows that the average modulus of elasticity from pith samples is lower than the near bark samples. The average modulus of elasticity for pith samples are

5465.842 N/mm^2 while the average modulus of elasticity for near bark samples are 9180.665 N/mm^2. This situation occurs because it is influenced by some specific reasons.

The difference in modulus of elasticity (MOE) between pith wood and near bark wood can be attributed to the structural and compositional variances within a tree's trunk. Pith that located at the core of the tree, serves as the central axis during growth and contains cells that undergo various stages of maturation. On the other hand, wood that near to bark, the outermost layer, actively transports water and nutrients, contributing to the tree's growth.

The primary reason for the lower MOE in pith wood lies in its composition. Pith cells are less densely packed and undergo less lignification compared to the cells in wood that near to bark. Lignin is a complex polymer that provides rigidity to the cell walls, and its deposition increases as the tree matures. Since pith cells are relatively immature and have a lower lignin content, they are more flexible and less stiff compared to the mature and densely lignified cells in near bark wood.

Additionally, pith wood contains higher moisture content than the near bark wood. The increased water content contributes to the flexibility of pith cells, making them more susceptible to deformation under stress. In contrast, the drier composition of wood that near to bark enhances its stiffness and resistance to deformation, leading to a higher MOE.

In summary, the lower MOE in pith wood compared to wood that near to bark can be attributed to the less mature and less lignified cell structure, as well as the higher moisture content in pith cells, making them inherently less stiff and more flexible.

4.2.3 Compression Strength

Table 4.5: Average of compression strength from pith toward bark samples

Samples (MM)	Compression Strength	Standard Deviation
10	45.12714	2.166492
30	40.00032	2.200625
50	40.76621	10.63867
70	40.83408	4.258055
90	48.82669	1.255187
110	42.87263	0.883909

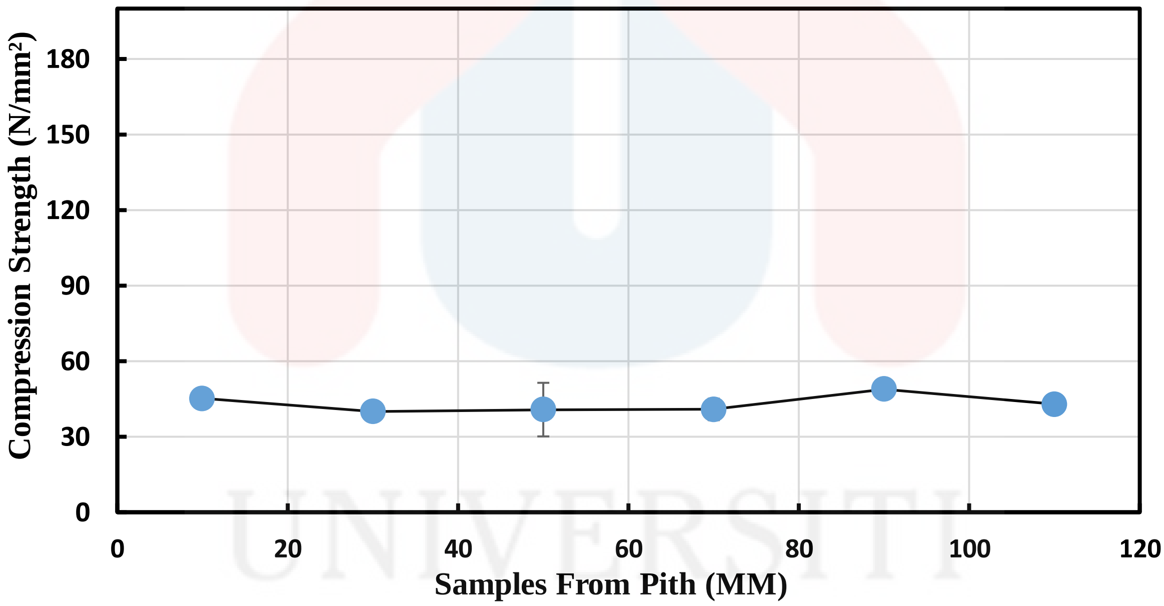


Figure 4.5: Graph of compression strength from pith toward bark

Figure 4.5 shows the result of compression strength for Hopea odorata wood from pith toward bark. From the graph, it shows that the average compression strength from pith samples is higher than the near bark samples. The average compression strength for pith samples are 45.12714 N/mm^2 while the average compression strength for near bark samples are 42.87263 N/mm^2. This situation occurs because it is influenced by some specific reasons.

Pith that located at the center of the tree trunk, serves primarily as a support structure during the early stages of growth. It is composed of parenchyma cells, which are relatively uniform and lack the specialized fibers found in other wood tissues. Despite its central location, pith does not bear significant loads, leading to a lower demand for compression strength.

On the other hand, near bark samples, which surrounds the pith, functions as the tree's water-conducting tissue. It contains living cells responsible for transporting water and nutrients. Near bark wood is characterized by elongated fibers that provide mechanical support to the tree. These fibers are rich in cellulose, a strong and rigid compound that contributes to the compression strength of the wood.

The higher compression strength of pith wood compared to near bark wood can be explained by the absence of specialized fibers in pith, leading to lower mechanical strength. Additionally, the role of pith in supporting the tree during its early growth stages may not require the same level of compression resistance as the structural demands placed on the wood that near to bark.

In addition, the distinct functions and compositions of pith and near bark wood contribute to the observed difference in compression strength, with wood near to bark exhibiting a higher level of resistance to compression forces due to its specialized fiber structure and mechanical demands.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the investigation of radial variations in the physical and mechanical properties of *Hopea Odorata* (Merawan) wood has provided valuable insight into the complex nature of this versatile material. The study revealed a pattern of nuanced variation across radial sections, shedding light on the intricacies of wood structure. Physically, examination of density and moisture content of Merawan wood reveals distinct variations that can be attributed to tree growth patterns and environmental factors. Understanding these variations is important to optimize the use of Merawan wood in different applications, from construction to furniture making. Mechanically, the study investigated modulus of elasticity (MOE), modulus of rupture (MOR) and compression strength across radial sections. These findings illustrate how the mechanical properties of wood exhibit radial dependence, demonstrating the importance of considering this variability in engineering and design processes. This knowledge is essential to ensure optimal wood performance and durability in practical applications. In essence, the comprehensive exploration of radial variation in physical and mechanical properties has not only expanded our understanding of Merawan wood but has also provided a basis for informed decision-making in an industry dependent on this resource. As we move towards sustainable and efficient use of natural materials, this study contributes significantly to the ongoing discourse on optimizing the use of wood resources in an environmentally friendly and economically viable manner.

5.2 Recommendation

In order to further the field's knowledge of radial variation, it would be good if the study was supplemented by studying the chemical properties of Merawan wood. In carrying out a study on chemical properties, the test that needs to be done is extraction on wood samples. Studying the radial variation of wood in chemical properties offers some of advantages, shedding light on the intricate dynamics within tree rings and providing valuable insights into both ecological and industrial realms. With investigating the radial variation in chemical properties, it can prove crucial for optimizing wood utilization in various industries. Wood quality, strength, and durability are directly influenced by chemical properties. A thorough understanding of radial variations allows for targeted wood processing, ensuring that specific sections with favourable chemical attributes are utilized for particular applications. This optimization not only enhances the efficiency of wood-based industries but also minimizes waste, aligning with principles of sustainable resource management. Moreover, such research contributes to the development of advanced wood products and materials. Tailoring wood properties through genetic modification or targeted cultivation becomes feasible with a comprehensive understanding of radial chemical variations. This avenue of research holds promise for creating innovative materials with enhanced durability, resistance to decay, and other desirable characteristics. In essence, investigating the radial variation of wood in chemical properties opens up a wealth of knowledge, bridging the past with the present and paving the way for a more sustainable and technologically advanced future in forestry and materials science.

REFERENCES

Shishir, S., Mollah, T. H., Tsuyuzaki, S., & Wada, N. (2020). Predicting the probable impact of climate change on the distribution of threatened Shorea robusta forest in Purbachal, Bangladesh. *Global Ecology and Conservation*, *24*, e01250. Retrieved from https://doi.org/10.1016/j.gecco.2020.e01250

Piazza, S., Fumagalli, M., Khalilpour, S., Martinelli, G., Magnavacca, A., Dell'Agli, M., & Sangiovanni, E. (2020). A Review of the Potential Benefits of Plants Producing Berries in Skin Disorders. *Antioxidants*, *9*(6), 542. Retrieved from https://doi.org/10.3390/antiox9060542

Macrophylla, S., Grogan, J., Free, C., Morales, G., Johnson, A., & Alegría, R. (2016). *Conservation status of five timber species populations in the forestry concessions of the Maya Biosphere Reserve, Guatemala Estado de conservación de las poblaciones de cinco especies maderables en concesiones forestales de la Reserva de la Biosfera Maya, Guatemala.* Retrieved from https://repositorio.catie.ac.cr/bitstream/handle/11554/8286/Estado_de_la_conservacion_de_las_poblaciones.pdf?sequence=1

Höpfl, L., Sunguroğlu Hensel, D., Hensel, M., & Ludwig, F. (2021). Initiating Research into Adapting Rural Hedging Techniques, Hedge Types, and Hedgerow Networks as Novel

Urban Green Systems. *Land*, *10*(5), 529. Retrieved from https://doi.org/10.3390/land10050529

Ghazoul, J. (2016). Dipterocarp Biology, Ecology, and Conservation. In *Google Books*. Oxford University Press. Retrieved from https://books.google.com.my/books?hl=en&lr=&id=NX4eDQAAQBAJ&oi=fnd&pg=PP1&dq=The+bark+of+the+Hopea+odorata+tree+is+smooth+and+grayish+when+young

Shankar, U., & Tripathi, A. K. (2017). Rainforests north of the Tropic of Cancer: Physiognomy, floristics and diversity in "lowland rainforests" of Meghalaya, India. *Plant Diversity*, *39*(1), 20–36.2016.10.003. Retrieved from https://doi.org/10.1016/j.pld.

Fang, S.-C., Hsu, C.-L., & Yen, G.-C. (2008). Anti-inflammatory Effects of Phenolic Compounds Isolated from the Fruits of Artocarpus heterophyllus. *Journal of Agricultural and Food Chemistry*, *56*(12), 4463–4468. Retrieved from https://doi.org/10.1021/jf800444g

Pirard, C. P. F., & Charoenpanwutikul, A. (2023). Comprehensive review of the annual haze episode in Northern Thailand. *Eartharxiv.org*. Retrieved from https://eartharxiv.org/repository/view/6393/

Ellis, R. H., Mai-Hong, T., Hong, T. D., Tan, T. T., Xuan-Chuong, N. D., Hung, L. Q., Ngoc-Tam, B., & Le-Tam, V. T. (2007). Comparative analysis by protocol and key of seed storage behaviour of sixty Vietnamese tree species. *Seed Science and Technology*, *35*(2), 460–476. Retrieved from https://doi.org/10.15258/sst.2007.35.2.20

Soerianegara. (1993). *Plant Resources of South-East Asia No 5(1)*. Pudoc Scientific Publishers. Retrieved from https://edepot.wur.nl/411143

Gibson, L. J. (2012). The hierarchical structure and mechanics of plant materials. *Journal of the Royal Society Interface*, *9*(76), 2749–2766. Retrieved from https://doi.org/10.1098/rsif.2012.0341

González, O. M., Velín, A., García, A., Arroyo, C. R., Barrigas, H. L., Vizuete, K., & Debut, A. (2020). Representative Hardwood and Softwood Green Tissue-Microstructure Transitions per Age Group and Their Inherent Relationships with Physical–Mechanical Properties and Potential Applications. *Forests*, *11*(5), 569. Retrieved from https://doi.org/10.3390/f11050569

Griffith, M. C., Vaculik, J., Lam, N. T. K., Wilson, J., & Lumantarna, E. (2007). Cyclic testing of unreinforced masonry walls in two-way bending. *Earthquake Engineering & Structural Dynamics*, *36*(6), 801–821. Retrieved from https://doi.org/10.1002/eqe.654

Gute Tucho, B., & Amente, G. M. A. (PhD). (2019, March 1). *COMPARATIVE STUDY OF BURNING EFFICIENCIES OF WOOD OF DIFFERENT MOISTURE CONTENTS*. Ir.haramaya.edu.et. Retrieved from http://ir.haramaya.edu.et/hru/handle/123456789/479

Haneca, K. (2005). *Tree-ring analyses of European oak: implementation and relevance in (pre-)historical research in Flanders*. Biblio.ugent.be. Retrieved from https://biblio.ugent.be/publication/470536

Kask, R. (2015). *The influence of growth conditions on physico-mechanical properties of Scots pine (Pinus sylvestris L.) wood in Estonia*. Dspace.emu.ee. Retrieved from https://dspace.emu.ee/handle/10492/1916

Khirey, D. K. A., & Supervisor, T. H. N. (2019, September 16). *Investigation of the Properties and Suitable Uses for Four Secondary, Lesser-used Wood Species Growing in The Blue Nile State, Sudan*. Repository.sustech.edu. Retrieved from https://repository.sustech.edu/handle/123456789/23848

Moncmanová, A. (2007). Environmental Deterioration of Materials. In *Google Books*. WIT Press. Retrieved from https://books.google.com.my/books?hl=en&lr=&id=9TCiyUfolawC&oi=fnd&pg=PA287&dq=Wood+with+high+moisture+content+may+be+prone+to+warping

Niez, B., Dlouha, J., Gril, J., Ruelle, J., Toussaint, E., Moulia, B., & Badel, E. (2020). Mechanical properties of "flexure wood": compressive stresses in living trees improve the mechanical resilience of wood and its resistance to damage. *Annals of Forest Science*, *77*(1). Retrieved from https://doi.org/10.1007/s13595-020-0926-8

Qin, Z., Niu, R., Tang, C., Xia, J., Feng, J., Dong, D., Zhang, H., Zhang, S., Li, J., & Yao, F. (2017). A Dual-Crosslinked Strategy to Construct Physical Hydrogels with High Strength, Toughness, Good Mechanical Recoverability, and Shape-Memory Ability. *Macromolecular Materials and Engineering*, *303*(2), 1700396–1700396. Retrieved from https://doi.org/10.1002/mame.201700396

Brienen, R. J. W., Schöngart, J., & Zuidema, P. A. (2016). Tree Rings in the Tropics: Insights into the Ecology and Climate Sensitivity of Tropical Trees. *Tree Physiology*, 439–461. Retrieved from https://doi.org/10.1007/978-3-319-27422-5_20

Butterfield, B. (2006). The structure of wood: form and function. *Springer EBooks*, 1–22. Retrieved from https://doi.org/10.1007/1-4020-4393-7_1

Downes, G., & Drew, D. (2008). Climate and growth influences on wood formation and utilisation. *Southern Forests: A Journal of Forest Science*, *70*(2), 155–167. Retrieved from https://doi.org/10.2989/south.for.2008.70.2.11.539

Kamarudin, N., Ismail, M. H., & Zaki, P. H. (2011). Forest Land Use Development and its Benefits toIndigenous Peoples. *Perspektif Jurnal Sains Sosial Dan Kemanusiaan*, *3*(1), 24–38. Retrieved from https://ojs.upsi.edu.my/index.php/PERS/article/view/1589

Lourenço, P. B., Feio, A. O., & Machado, J. S. (2007). Chestnut wood in compression perpendicular to the grain: Non-destructive correlations for test results in new and old wood. *Construction and Building Materials*, *21*(8), 1617–1627. Retrieved from https://doi.org/10.1016/j.conbuildmat.2006.07.011

Muhammad Syafiq Yahya, Sharifah Nur Atikah, Izereen Mukri, Aslinda Oon, Hawa, A., Sanusi, R., Norhisham, A. R., Lechner, A. M., & Azhar, B. (2023). Potential of agroforestry orchards as a conservation set-aside initiative in industrial rubber tree and oil palm plantations for avian biodiversity. *Biodiversity and Conservation*, *32*(6), 2101–2125. Retrieved from https://doi.org/10.1007/s10531-023-02594-y

Olorunnisola, A. O. (2017). Anatomy and Physical Properties of Tropical Woods. *Springer EBooks*, 7–29. Retrieved from https://doi.org/10.1007/978-3-319-65343-3_2

Rahimi, S., Singh, K., DeVallance, D., Chu, D., & Bahmani, M. (2022). Drying Behavior of Hardwood Components (Sapwood, Heartwood, and Bark) of Red Oak and Yellow-Poplar. *Forests*, *13*(5), 722. Retrieved from https://doi.org/10.3390/f13050722

Rao, M. V., & V. Kuppusamy. (2022). Wood Biodeterioration in Marine Environment. *Springer EBooks*, 359–437. Retrieved from https://doi.org/10.1007/978-981-16-8797-6_12

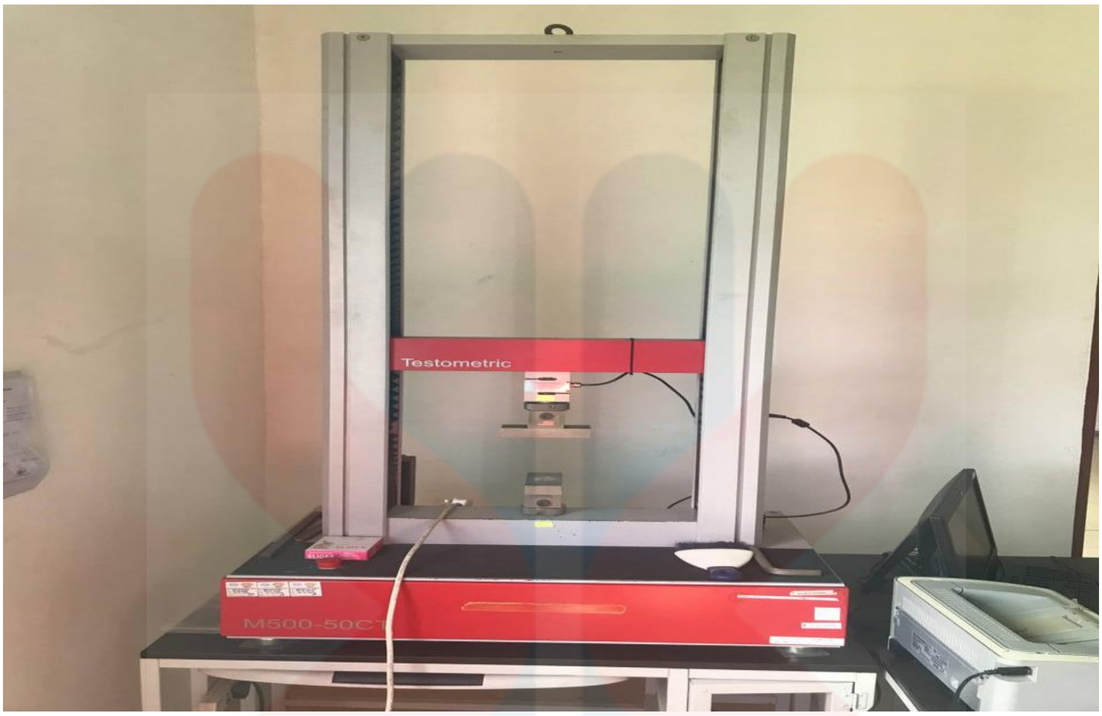
Rowell, R. M. (2005). Handbook of Wood Chemistry and Wood Composites. In *Google Books*. CRC Press. Retrieved from https://books.google.com.my/books?hl=en&lr=&id=ekrLBQAAQBAJ&oi=fnd&pg=PA303&dq=Hardwood+generally+has+more+fibers+and+vessels

Sandberg, D., Haller, P., & Navi, P. (2013). Thermo-hydro and thermo-hydro-mechanical wood processing: An opportunity for future environmentally friendly wood products. *Wood Material Science and Engineering*, *8*(1), 64–88. Retrieved from https://doi.org/10.1080/17480272.2012.751935

APPENDIX

Wood log cutting process

Wood disk cutting process



Universal Testing Machine (UTM)

Running sample process