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Radial Variation in Physical and Mechanical Properties of Rubberwood Planted in Jeli, Kelantan

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DECLARATION

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

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Radial Variation in Physical and Mechanical Properties of Rubberwood Planted in Jeli, Kelantan

ABSTRACT

The study aims to determine the radial variation of the physical and mechanical properties of rubber trees grown in Jeli, Kelantan. This research aims to understand the radial variability in the physical and mechanical properties of rubber wood, which affects its use, effectiveness, and quality, in order to optimize the use of rubber wood in Malaysia. Apart from that, it promotes environmentally friendly forestry practices as well as renewable and biodegradable resources to reduce pressure on natural forests. It is emphasized to focus on the density, moisture content, bending, and compressive strength from the pith towards the bark to achieve the objective of this study, which is to investigate the radial variation in the physical and mechanical properties of rubber wood. This method is done with two discs taken 1400mm from the root and cut into two discs, one 60mm long and the other 140mm long. The first disk is cut into six samples, each measuring 20mm x 20mm x 60mm. Density and moisture content are calculated. The second disc is cut into 60mm and 80mm sections, with the 60mm wood cut radially to 20mm x 20mm x 20mm, while the 80mm wood is cut tangentially to 80mm x 20mm x 5mm. In order for MOR, MOE, and compressive strength to be determined, Findings show a significant variation in the density of the sample near the pith, which is lower (0.54 g/cm3), while the density of the wood near the bark is higher, which is 0.69 g/cm3, while the MC sample has an average moisture content of 10.40% near the wood. near the pith, and the wood near the bark sample is 10.06%. The compressive strength of the sample has an average value of 102.40 (N/mm^2) for the wood sample near the bark, while the wood near the pith sample is 103.16 (N/mm^2). The wood near the pith sample had a lower MOE of 2188.80 (N/mm^2), while the wood near the bark sample had an average MOE of 6767.61 (N/mm^2). Finally, the wood near the pith sample has a lower MOR of 59.18 (N/mm^2), while the wood near the bark sample has a higher MOR, as shown by 75.33 (N/mm^2). In conclusion through this study, rubber wood had better or comparable qualities compared to other wood species, making it suitable for various wood products and applications.

Keywords:Rubberwood, Radial variation, Physical and mechanical properties, Environmental forestry practices, Rubber wood utilization

Variasi Jejari Sifat Fizikal Dan Mekanikal Kayu Getah Yang Ditanam Di Jeli, Kelantan

ABSTRAK

Kajian ini bertujuan untuk menentukan variasi jejari sifat fizikal dan mekanikal pokok getah yang ditanam di Jeli, Kelantan. Penyelidikan ini bertujuan untuk memahami kebolehubahan jejari dalam sifat fizikal dan mekanikal kayu getah, yang mempengaruhi penggunaan, keberkesanan, dan kualitinya, bagi mengoptimumkan penggunaan kayu getah di Malaysia. Selain itu, ia menggalakkan amalan perhutanan mesra alam serta sumber yang boleh diperbaharui dan terbiodegradasi untuk mengurangkan tekanan ke atas hutan semula jadi. Ia ditekankan untuk memberi tumpuan kepada ketumpatan, kandungan lembapan, lenturan, dan kekuatan mampatan dari empulur ke arah kulit kayu untuk mencapai objektif kajian ini, dilakukan penyiasatan variasi jejari dalam sifat fizikal dan mekanikal kayu getah. Kaedah ini dilakukan dengan dua cakera yang diambil 1400mm dari akar dan dipotong kepada dua cakera, cakera pertama 60mm panjang dan cakera kedua 140mm panjang. Cakera pertama dipotong kepada enam sampel, setiap satu berukuran 20mm x 20mm x 60mm. Ketumpatan dan kandungan lembapan dikira. Cakera kedua dipotong kepada bahagian 60mm dan 80mm, kayu 60mm dipotong secara jejari kepada 20mm x 20mm x 20mm, manakala kayu 80mm dipotong secara tangen kepada 80mm x 20mm x 5mm. Bagi menentukan MOR, MOE, dan kekuatan mampatan, penemuan menunjukkan variasi ketara dalam ketumpatan sampel berhampiran empulur, iaitu lebih rendah (0.54 g/cm3), manakala ketumpatan kayu berhampiran kulit kayu lebih tinggi. , iaitu 0.69 g/cm3, manakala sampel MC mempunyai purata kandungan lembapan 10.40% berhampiran kayu. berhampiran empulur, dan kayu berhampiran sampel kulit kayu ialah 10.06%. Kekuatan mampatan sampel mempunyai nilai purata 102.40 (N/mm2) bagi sampel kayu berhampiran kulit kayu, manakala kayu berhampiran sampel empulur ialah 103.16 (N/mm^2). Kayu berhampiran sampel empulur mempunyai MOE yang lebih rendah iaitu 2188.80 (N/mm^2), manakala kayu berhampiran sampel kulit kayu mempunyai purata MOE sebanyak 6767.61 (N/mm^2). Akhir sekali, kayu berhampiran sampel empulur mempunyai MOR yang lebih rendah iaitu 59.18 (N/mm^2), manakala kayu berhampiran sampel kulit kayu mempunyai MOR yang lebih tinggi, seperti yang ditunjukkan oleh 75.33 (N/mm^2). Kesimpulannya melalui kajian ini, kayu getah mempunyai kualiti yang lebih baik atau setanding berbanding dengan spesies kayu lain, menjadikan ia sesuai untuk pelbagai produk dan aplikasi kayu.

Kata Kunci: Kayu Getah, Variasi Jejari,Sifat fizikal dan mekanikal, Amalan hutan mesra alam,Penggunaan kayu getah

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MOR	Modulus of Rupture
MOE	Modulus of Elasticity
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
N/mm^2	Newtons per mililitre squared

CHAPTER 1

INTRODUCTION

1.1 Background of study

Hevea brasiliensis, known as Rubberwood, is a medium-density tropical hardwood with a light hue, and derived from the Pará rubber tree, typically from trees that are produced on rubber plantations. Generally wood exhibit variation in their properties along the radial and longitudinal directions. Thus, knowing importance of radial variation in rubberwood characteristics is crucial because it has a direct impact on how well the wood fit to a certain use.

Mostly the density of Rubberwood is lowest near the pith and gradually increases towards the bark (Onakpoma, 2019). This radial density variation is primarily influenced by the growth rings present in the wood. Each growth ring represents a year's growth of the tree and consists of two distinct regions which are earlywood and latewood. The earlywood, also known as springwood, forms during the early part of the growing season and is characterized by wider and less dense cells. As a result, the density of the earlywood is generally lower compared to the latewood. The latewood, also known as summerwood, develops later in the growing season and has narrower and denser cells. The latewood is responsible for the darker and harder portions of the growth rings. It contributes to the higher density observed in the wood (Ashaari, 2017).

A key component in dimensional stability for expansion and contraction of wood influenced by moisture content, which affects overall dimensions and especially important in sectors such as furniture manufacture. The rubberwood mechanical qualities, including hardness and strength, and emphasizes how moisture content influences these attributes. In situations involving loads, this knowledge informs the use of rubberwood. Basically, utilizing rubberwood's physical properties attributes responsibly and successfully for a variety of purposes requires a thorough investigation of the wood's moisture content. (Matan & Kyokong, 2003)

The ability of wood to withstand crushing or buckling under tension applied parallel to its grain is known as compression strength. Rubberwood's compression strength is crucial since it establishes whether or not the material is suitable for use in structural elements. The anatomical structure, moisture content, and density of the wood all affect compression strength. The rubberwood moisture content 12% has a modest compression strength of around 32(N/mm^2). However, rubberwood be less compressive strong than other common timbers as teak, and oak. In order to increase rubberwood's compression strength for a given usage, it could thus need to be treated or strengthened. (Zhao et al., 2019)

The highest bending stress that wood can bear before breaking is known as its MOR(modulus of rupture). The measurement of the wood's stiffness under bending is called the MOE (modulus of elasticity). The density and moisture content of the wood will affect the characteristics. In comparison to other hardwoods, rubberwood has a significant MOR and MOE, although it is lower than other standard timbers. Rubberwood may require treatment or reinforcing in order to increase its MOR and MOE for certain applications. Researchers can optimize rubberwood drying and treatment techniques to minimize flaws and improve its properties by examining the MOR and MOE of rubberwood. (Abdul Halip, 2013)

This study was conducted to investigate the radial variation in physical and mechanical properties of Rubberwood planted at Jeli, Kelantan, Malaysia. The physical and mechanical properties including moisture content, density, MOR, MOE and compression strength was evaluated from the pith to the bark.

1.2 Problem Statement

Despite the widespread use of Rubberwood, particularly in construction and furniture production, there is limited understanding regarding its radial variability in physical and mechanical properties. This is because it has an impact on the use, effectiveness, and quality of rubberwood products. Tropical regions, including Malaysia, Thailand, and Indonesia, depend on rubberwood extensively as a plantation crop. Rubberwood is susceptible to imperfections during manufacturing industries and use, including distortion, discolouration, and decay. Optimizing rubberwood product engineering, treatment, and drying can therefore be aided by knowledge of the radial variation in rubberwood's physical and mechanical characteristics.

This research intends to fill this gap by examining the radial variation in terms of density, moisture content, bending, and compression strength from the pith to the bark. However, there is a dearth of thorough and organized data. By evaluating these variations comprehensively, the study seeks to identify significant insights that could inform strategies for optimizing the utilization of Rubberwood across various applications. Additionally, the findings may contribute to the promotion of environmentally friendly forestry practices in Malaysia. By applying various methodologies and strategies to investigate the radial variation in these attributes, this research aims to close this gap. Through a thorough evaluation of these variances, the study aims to uncover important insights that may guide strategies for maximizing rubberwood's use in a variety of applications. Finally, as rubberwood is a renewable and biodegradable resource that can ease the strain on natural forests, the findings might help promote environmentally responsible forestry methods in Malaysia.

1.3 Objective of Study

- To investigate the radial variation in physical properties of Rubberwood planted in Jeli, Kelantan.
- To investigate the radial variation in mechanical properties of Rubberwood planted in Jeli, Kelantan.

1.4 Scope of Study

The physical and mechanical characteristics will be examined in the radial direction of the tree. Moisture content, density, bending, and compression strength of the wood were evaluated from the pith to the bark, with a particular emphasis on the tree's radial orientation. The key factors affecting the qualities of wood examine moisture content closely in order to evaluate its radial distribution. Additionally, it will examine density fluctuations, which will provide insight into the structural makeup of the wood.

Key mechanical characteristics that are essential for evaluating the performance of wood under various loads are bending and compression strength. Radial variations' effects on rubberwood's overall mechanical integrity may be understood by analyzing these strengths from the pith to the bark. Businesses that depend on rubberwood, such building and furniture production, can benefit greatly from this comprehensive approach, which enables a thorough investigation of the material's behavior. The research results will aid in the best use of rubberwood resources and direct future advancements in processing methods for certain radial portions, improving the wood's appropriateness for a range of uses.

1.5 Significance of study

It is important to comprehend the properties variation of Rubberwood. Analyzing the moisture content sheds light on the stability and longevity of the wood from that area. Density analysis is crucial since it directly affects the dimensional stability and strength of the wood. Bending and compression strength tests provide mechanical performance information for buildings, furniture, and other uses. Additionally, as inner wood near the pith typically has more varied juvenile qualities than exterior mature wood, understanding radial variations enables better usage of the wood supply.

CHAPTER 2

LITERATURE REVIEW

2.1 Taxonomy of Rubberwood

According, rubberwood taxonomy is organized into numerous ranks, including kingdom, phylum, class, order, family, genus, and species based on hierarchical system. A group of species with similar traits and evolutionary connections is represented by a rank. The taxonomy is significant because it aids in the identification, categorization, and naming of the Pará rubber tree as well as the comprehension of its biological diversity, evolutionary history, and ecological importance. Additionally, rubberwood's taxonomy serves as a foundation for future studies of its morphology, anatomy, physiology, genetics, and biotechnology. (Priyadarshan, 2017)

Table 1: The Taxonomy of Rubberwood

Kingdom	Plantae
Subkingdom	Viridaeplantae
Imfrakingdom	Streptophyta
Superdivision	Embrophya
Division	Magnoliaphyta
Subdivison	Spermatophyta
Class	Magnoliopsida
Superorder	Rosane
Order	Malpighiales
Family	Euphorbiaceae

Genus	Hevea
Species	*Hevea brasilliensis*

2.2 Morphology of Rubberwood

Figure 2.2:The Morphology of Rubberwood

(Source: Lau et al., 2016).

Rubberwood is the term for wood that comes from the broadleaf tree species, which is indigenous to the Amazon region. With a straight, cylindrical bole that can remain branch-free for up to 27 m, the rubber wood tree can reach a height of 40 m. The tree has simple, trifoliate leaves that are placed oblong and alternately. The leaves consist of three elliptical leaflets with pointy points, measuring around 15 cm in length. The undersides of the leaves seem drab, while the upper surfaces are shiny and smooth. (Hevea Brasiliensis, 2020).

In younger rubberwood trees, the bark is smooth and gray. As the trees get older, their bark turns reddish and gets rough, with many tiny cracks and grooves. When sliced, the inner bark releases a white latex. The tiny rubber wood tree blooms are creamy white or have a hint of yellow in them. They have a faint, disagreeable smell and are grouped in panicles. When fully ripe, the fruit resembles a three-valved capsule that breaks open to reveal three compartments filled with many seeds. (Rubberwood, 2024)

Hence, it has a straight grain and a creamy white to light brown color, which are characteristics of rubberwood tree wood. Approximately 0.56 g/cm3 is its fundamental density, and usually up to 5 cm thick, the sapwood is thinner. It's rather even and delicate in texture, while the flavor and smell of the wood are unremarkable. (Ali et al., 2023)

For a tropical broadleaf plant that produces latex, the rubberwood tree's overall shape is normal, with tall and straight boles; it can reach significant heights. Features adapted to its native habitat in the Amazon rainforests can be seen in the wood, bark, leaves, flowers, and fruits.

2.3 Distribution Area of Rubberwood

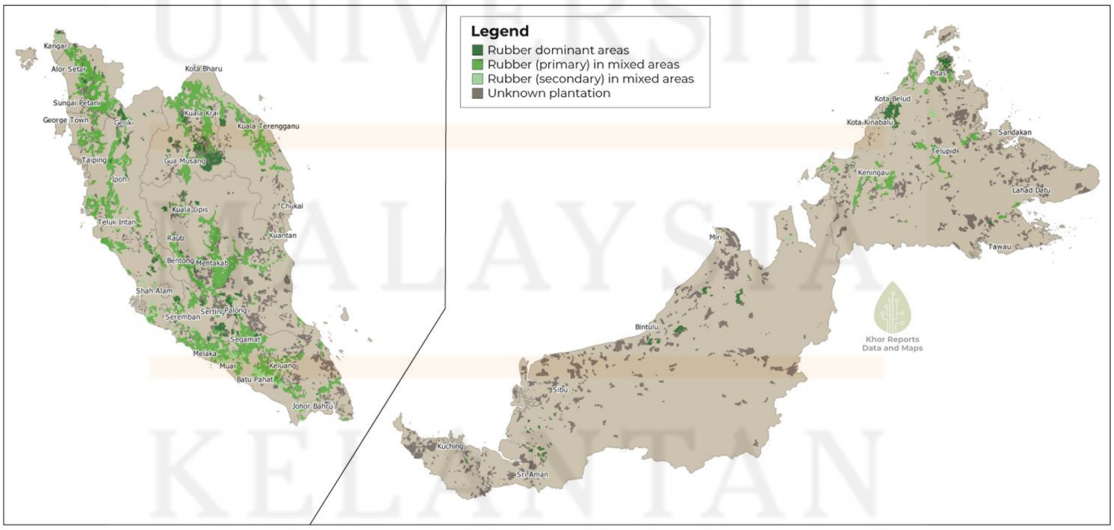

Figure 1: The geographical distribution of Rubberwood in Malaysia

Rubberwood is extensively cultivated throughout Peninsular Malaysia, particularly in the states of Negeri Sembilan, Johor, Pahang, Kelantan, and Terengganu. These states have an abundance of rainfall and the right kind of soil for growing rubber. Jeli and Lipis in Kelantan, Dungun and Marang in Terengganu, Jerantut, Temerloh, and Bentong in Pahang, and Segamat and Kluang in Johor are a few of the important locations. Peninsular Malaysia is home to more than a million hectares of rubber plantations.

The primary rubber-growing regions on the island of Borneo are Sabah and Sarawak, which have excellent soil and climate conditions. The districts of Beaufort, Keningau, Kudat, and Sandakan in Sabah are home to the majority of the state's rubberwood plantations. The divisions of Sri Aman, Sibu, and Miri include the majority of Sarawak's rubberwood regions. About 500,000 hectares of rubber have been planted in Sabah and 350,000 hectares in Sarawak. Overall, the equatorial environment of Borneo and Peninsular Malaysia, with its consistent high temperatures, high humidity, and copious amounts of rainfall between 2000 and 4000 mm per year, offers the best conditions for rubberwood development. Deep, well-drained alluvial soils along river banks, which are common in these areas, are ideal for the species' growth. (Hazir et al., 2020)

2.4 Usage of Rubberwood

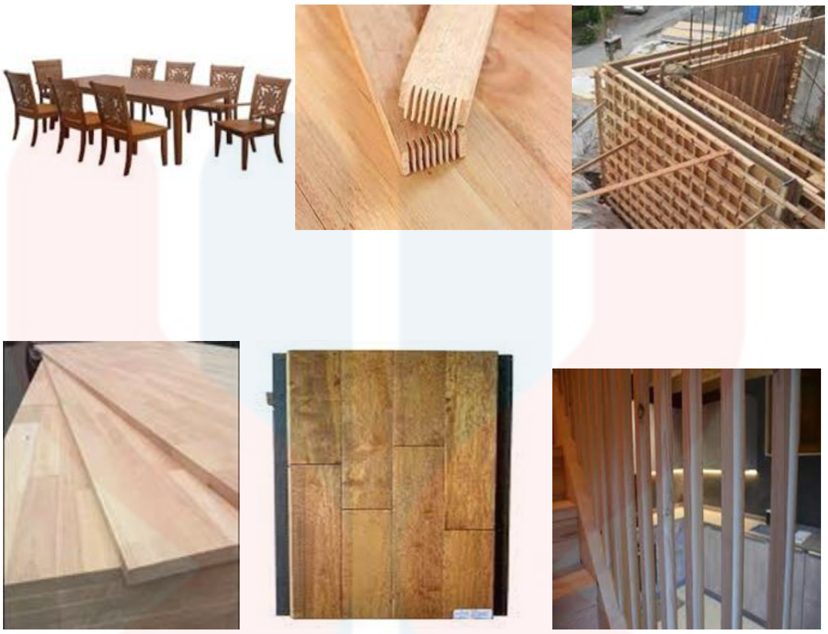

Figure 2.4: The Usage of Rubberwood

(Sources from Faessler, 2021)

The usage of Rubberwood, which is used for flooring, paneling, furniture, buildings, and many other home products. Its light hue, odorlessness, strength, dimensional stability, and affordability make it a very adaptable wood material. Rubberwood is perfect for flooring, staircases, concrete molds, and structural joinery such as windows and door frames in construction. It is used to create aesthetically pleasing wall paneling, handrails, cabinetry, balusters, and parquetry patterns. Rubberwood is becoming a popular material for indoor furniture, such as rocking chairs, dining sets, chairs, and stools. Rubberwood has several uses, which emphasizes its value as a plentiful and renewable hardwood. Rubberwood meets a wide range of performance requirements in a variety of applications, including delicate woodcraft and structural applications.

2.5 Radial Variation

2.5.1 Variation in Radial Direction

2.5.1.1 Reason it happen

The variation in the properties of Rubberwood across its growth rings is influenced by factors such as the structure of the growth rings of the material. The earlywood in growth rings is weaker and less dense, having been generated early in the growing season, while the latewood, formed later in the season, is stronger and more dense. Properties are impacted by changes in the ratio of earlywood to latewood that occur from the pith outward across growth rings.

When heartwood forms, the radial amount of moisture content decreases from the pith outward. Bending and compression strength are reduced with increased moisture content because heartwood is formed, and density also rises radially. Greater hardness and strength are correlated with density.

The microfibril angle at which cellulose is oriented within the cell wall influences characteristics like rigidity. Stiffness increases with distance from the pith because the microfibril angle tends to decrease radially from the pith outward. Juvenile wood, found close to the pith, is weaker and less dense than mature exterior wood. The characteristics of wood change radially as it ages from juvenile to mature. Lower density and strength are usually the outcomes of faster radial expansion. Maturation causes the growth rate to decrease radially from the cambium inward. (J. Paul McLean et al., 2011)

In conclusion, the radial variations in rubberwood's density, compression strength, bending, and stiffness can be attributed to a variety of factors, including shifting the ratios of earlywood to latewood, lowering moisture content, increasing density, decreasing microfibril angle, and shifting from faster to slower growth. As one gets farther away from the pith, the characteristics usually get better.

2.5.1.2 How to Control

The radial variation in Rubberwood's mechanical and physical qualities that happens naturally can be managed in a number of efficient ways. Using techniques like thinning cuts and appropriate planting spacing to generate slower growth and narrower rings is one way to control the growth rate and ring width when growing the trees. As a result, the wood structure becomes more consistent throughout the radius, forming weaker juvenile wood close to the pith and less low-density earlywood. Another crucial method is to reduce the amount of less attractive juvenile wood by milling lumber from the mature outer wood farther away from the pith, but at the expense of yield.

Kiln drying the wood and keeping it at a consistent moisture content prior to testing or usage can also help control radial variances resulting from moisture content discrepancies between heartwood and sapwood. Other useful techniques include chemically treating the wood with treatments like acetylation to lessen swelling and moisture impacts, thermally treating the wood with controlled heating to degrade lignins and hemicelluloses, and pretreating the wood with steaming or chemical baths to partially hydrolyze components like hemicelluloses so mature and juvenile wood are more similar before drying. Rubberwood naturally exhibits radial variability, which can be minimized and controlled by combining boards from different radial positions, using trees chosen for desired homogeneous wood properties, and using standardized testing processes. (Moya et al., 2011)

2.5.2 Radial Variation in Physical Properties

2.5.2.1 Density of hardwood in ring porous

Rubberwood varies in radius from the pith outward because of variations in the structure and characteristics of the wood. In Rubberwood, density rises radially from the pith to the bark. Juvenile wood, which originates during the first five to ten years of growth, is located close to the pith. This is because, because of its broader lumens, thinner cell walls, and lower cellulose content, juvenile wood has a lower density. The juvenile wood of the tree changes into the denser mature wood as it ages. Mature wood is denser due to its larger cellulose content, narrower lumens, and thicker cell walls. The radial density gradient is influenced by the proportion of dense, mature wood that grows radially outward from the pith. Furthermore, radially the growth rate decreases from the cambium inward.

The density of Rubberwood fluctuates from the pith outward due to changes in the wood's composition and properties. Density increases radially in Rubberwood, from the pith to the bark. Juvenile wood, which originates during the first five to ten years of growth, is located near the pith. Juvenile wood has a lower density due to its wider lumens, thinner cell walls, and lower cellulose content. As the tree ages, its juvenile wood transforms into its denser, mature wood. This is because mature wood has thicker cell walls, narrower lumens, and a higher cellulose content; it is denser. The percentage of dense mature wood that radiates outward from the pith affects the radial density gradient. (Gonçalves et al., 2008)

2.5.2.2 Moisture content

Rubberwood's moisture content ranges radially from the pith to the bark. The outer sapwood zone's moisture content is highest close to the bark and steadily drops inside the heartwood. This moisture gradient arises from the fact that heartwood is made up of dormant cells that cannot carry water, whereas sapwood has more live cells and is still involved in radial water and nutrient transport.

In recently cut green Rubberwood, the moisture level can exceed 100% in the vicinity of the bark. The moisture level of sapwood gradually drops to between 30 and 60 percent in the inner mature heartwood as it moves more inward from the cambium into the heartwood. Wet, active sapwood and dry heartwood have varying moisture contents, which causes radial differences in characteristics like shrinkage and density. (AW et al., 2021)

Moisture content is also influenced by age and growth rate. Heartwood makes up a greater proportion of the overall radial thickness of older trees. A more progressive moisture gradient is produced by wider, slower-growing rings than by rapid growth. Radial moisture fluctuation can also be influenced by extractive content, tylose development, and heartwood formation rate. (Sulistyo et al., 2020)

2.5.3 Radial Variation in Mechanical Properties

2.5.3.1 Compression strength

The compression strength shows a radial increasing pattern from the pith to the bark. The main cause of this variations in wood density. The shift from lower-density juvenile wood close to the pith with greater-density adult wood distant from the pith causes density to increase radially. A better compression strength is produced by the denser mature wood's narrower cell lumens and thicker cell walls. The faster juvenile wood growth near pith in weaker wood with broader lumens and thinner cell walls. Cell wall thickness rises with radial slowing of the development rate, enhancing strength. (Nasir et al., 2018).

Compression strength is also affected by moisture content. The exterior sapwood has a larger moisture content than the heartwood, which has a lower moisture content inside. Greater compression strength is correlated with lower moisture content. The variation in moisture content across the various wood portions is a significant factor in determining rubberwood compression strength.

Research consistently show that reduced moisture content in wood is correlated with higher compression strength. This is because the lower moisture content drier heartwood often stronger compression. Understanding this relationship is essential to comprehending rubberwood mechanical characteristics, particularly in situations where compression strength is crucial, like in the construction of load-bearing structures or furniture. (Bao et al., 2001)

2.5.3.2 Modulus of Rupture (MOR)

Modulus of rupture in rubberwood quantifies the highest bending stress that material can bear before rupturing in mechanical characteristic. The wood MOR values can range from 60 to 90 Mpa as the wood ages from juvenile to mature. Rubberwood had anisotropic character that examining the radial variation of MOR, which yields more complex of the material's strength distribution work systematically from the deepest pith to the outside bark.

For optimize the selection and use of certain sections in engineering and construction applications, it is crucial to comprehend radial variations in MOR. By identifying tree segments with increased resistance to bending pressures, practitioners may use this information to guide strategic decisions related to the procurement and processing of materials. The creation of focused treatments or reinforcements to address possible weaknesses in certain radial portions is made possible by insights into radial MOR variations, which also improves rubberwood's overall mechanical dependability.

Furthermore, slower growth yields denser wood with a higher MOR, whereas faster growth generates plantation rubberwood with broader, lower-density growth rings and a lower MOR. As mature, denser wood makes up a larger portion of the radius in older trees, MOR is also impacted by age, typically peaking between 15 and 30 years of age. Standard protocols that take into account specimen size, orientation, and moisture content should be followed, as test methods can also affect MOR variables. Its help maximizes the usage in structural designs by influencing the choice of suitable tree parts for certain uses.

Usually, as the knowledge of rubberwood Modulus of Rupture aids in the creation of efficient needs processing and treatment methods. By ensuring that the wood satisfies the necessary strength criteria for various uses, this improves the wood's overall mechanical performance. In conclusion, rubberwood's Modulus of Rupture is an important factor that affects how well-suited it is for a variety of engineering and manufacturing applications. (Lamaming et al., 2020)

2.5.3.3 Modulus of Elasticity (MOE)

Rubberwood's adaptability goes beyond its modulus of elasticity (MOE) in mechanical property. That bend and how easily it returns require a certain amount of force. Rubberwood MOE is dependent on its radial travel, just like its other characteristics. The MOE rises from the pith to the bark, peaking in the middle and outer layers as we proceed in that direction. The latewood, which consists of densely packed cells that function as tiny springs within the wood, is the reason for this increase in density and presence. Rubberwood's denser outer layers take more force to distort, which makes them more elastic, much like a tightly coiled spring does.

For a variety of applications, it is essential to comprehend the MOE variations. A higher MOE for furniture indicates tables and chairs that won't drop underweight and will keep their shape for many years. A high MOE in flooring guarantees planks that recover from footfalls, averting dents and fractures. On the other hand, a slightly lower MOE gives tool handles some flex, which makes them more comfortable to hold and less likely to cause vibrations to reach your hands. Rubberwood's MOE is beautiful because of its adaptability as well as its variances. Woodworkers and engineers can customize the elasticity to meet their unique requirements by carefully choosing wood from various radial zones. (Riyaphan et al., 2015)

CHAPTER 3

MATERIAL AND METHODS

3.1. Material

Rubber wood had been taken from the sawmill located at Jeli, Kelantan. The age was 25 years with 25 cm diameter. (What Is Rubberwood – the Pros and Cons, 2021)

3.2. Method

3.2.1 Sample Preparation

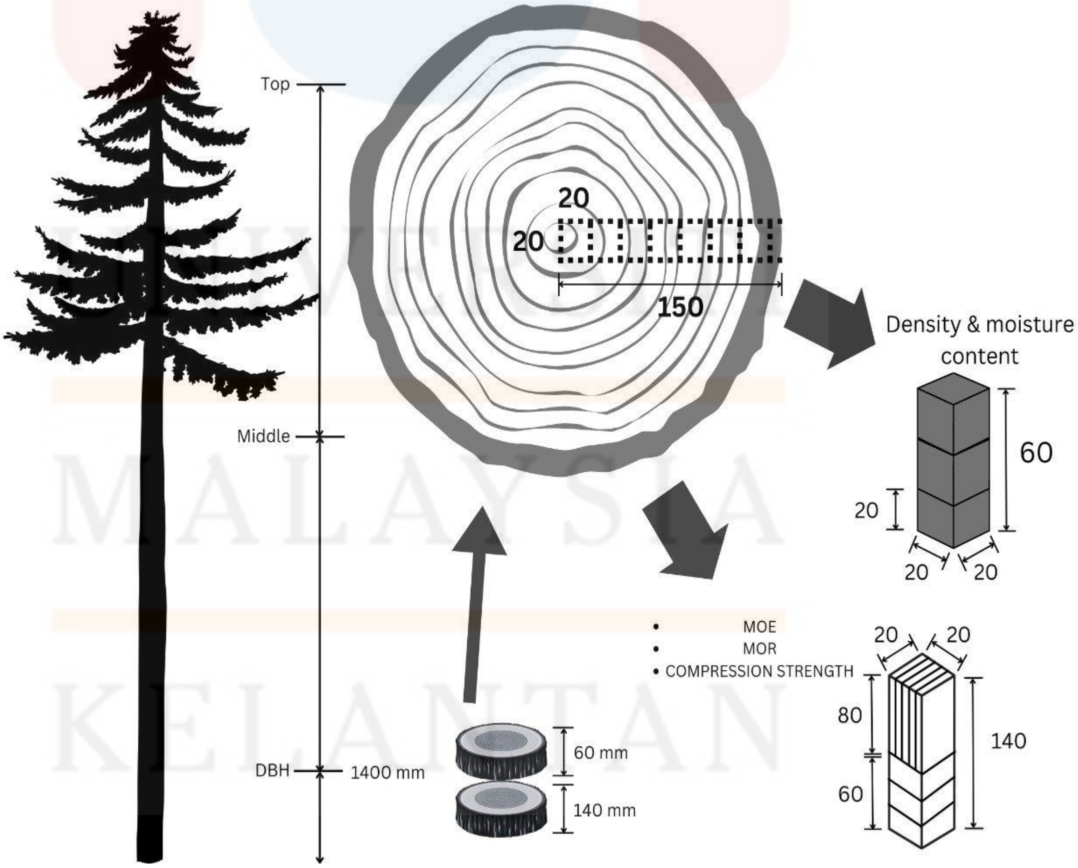

Figure 3.2.1 Illustration of experimental procedure

Two disks were taken at breast level which is 1400 mm from the root. The stem was 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 were cut from pith to bark which is 150 mm width and 20 mm height. As seen in figure 3.2.1, for the first disk, the wood will be cut into 6 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 was taken to count the density and moisture content.

For the second disk, the wood was cut into 2 parts which are 60 mm and 80 mm. For 60 mm wood, the wood was 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. In order to determine MOR, MOE, and compression strength, wood was taken.

3.2.2 Density Measurement

Density is defined as the amount of mass that is concentrated in a specific volume. This idea forms the basis of the density formula. It characterizes a substance's compactness or "heaviness". For understanding principle of density as high density occurs when a specific mass is concentrated in a limited volume while low Density are occurring if the same mass is dispersed over a bigger volume.

The formula for calculate density is shown below in equation 3.2.2:

$$p = \frac{m}{v} \qquad \text{Equation 3.2.2}$$

The ratio of a substance's mass to volume is known as its density. Like any other substance that absorbs water, the density of wood fluctuates as the moisture content changes. This is due to the fact that absorbing moisture makes wood more massive overall and may also alter its volume. The unit of mass density is defined as (m=mass) divided by (v=volume) according to the density equation (m/V). There are various units for mass density in use since there are numerous units for mass and volume that cover a wide range of magnitudes.

The most widely used units for density are probably the SI unit of kilogramme per cubic metre (kg/m3) and the cgs unit of grams per cubic centimeter (g/cm3). 1000 kg/m3 is equal to one g/cm3. The unit of measurement for milliliter is one cubic centimeter, abbreviated as cc. Other, larger or smaller mass and/or volume units, as well as US customary units, may be employed in the industrial setting.

3.2.3 Moisture Content Measurement

The moisture content sample were oven-dry at the temperature of 103 °C for 24 hours, then calculated by taking its dry weight and expressing it as a percentage of the water content of the material. To commence, the first sample (W_1) is usually weighed and then dried until all moisture has been removed. For determine the sample's dry weight (W_2), the weight is then reweighed. After deducting the dry weight from the starting weight ($\frac{W1-W2}{W2}$)x100%, the weight of water in the sample is determined. At last, the moisture content can be computed by applying the following formula: Moisture Content (%) = [(W_1 - W_2) / W_2] * 100%. Several industries, including construction, food processing, and agriculture, employ this computation technique extensively to evaluate the performance and quality of their products.

$$\boldsymbol{MC\% = (\frac{M_{dry}-M_{wet}}{M_{dry}})x100\%}$$

This formula above in equation 3.2.3 is applied when have the sample's original (wet) weight and its sample's weight following a complete drying process. The moisture content is expressed as a percentage by dividing the difference between the wet and dry weights by the dry weight, then multiplying the resulting number by 100.

3.2.4 Bending Properties Measurement

The equation used to determine the bending characteristics of Rubberwood trees is frequently derived from the concepts of beam theory. In this context, the bending stress and the bending modulus of elasticity are two crucial variables.

$$Bending\ stress\ (\sigma) = \frac{Mc}{I}$$

Equation 3.2.4

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

The formula for bending properties as showed in equation 3.2.5 was relates to the bending moment The distance from the neutral axis to the outermost fiber, and the moment of inertia was the cross-section of the beam. “σ” is the bending stress, which is a measure of the internal forces that are generated within the beam due to the bending moment. M is the bending moment, which is the twisting force that causes the beam to bend. “c “is the distance from the neutral axis to the outermost fiber, which is a measure of how far the fiber is from the axis that experiences no deformation during bending. This distance is also known as the "radius of curvature". “I” is the moment of inertia of the cross-sectional area of the beam. This value is a measure of the beam's resistance to bending and is dependent on the shape of the cross-section.

This formula shows that the bending modulus is directly proportional to the bending moment and the distance from the neutral axis, and inversely proportional to the moment of inertia and the angle of rotation where E is the modulus of elasticity, M and δ is the vertical deflection of the tree under the applied load.

3.2.5 Compression Strength Measurement

The formula for calculate compression strength measurement as been shown in equation 3.2.5:

$$Compressive\ stress\ (\sigma c) = FA \qquad \text{Equation 3.2.5}$$

This formula shows where (σc) refers to the compressive stress, F is the applied compressive force or load and A is the cross-sectional area of the material perpendicular to the applied force. Basically, compressive strength is directly proportional to the compressive load and inversely proportional to the cross-sectional area. In other words, a higher compressive load or a smaller cross-sectional area will result in a higher compressive stress and a higher compressive strength.

The compressive strength of the wood is then calculated by dividing the maximum load by the cross-sectional area of the test specimen. The test is usually done on a small, clear, straight-grained section of wood that is free from knots and defects. The test is usually done on small specimens of wood, because the compressive strength of wood can vary greatly depending on the species and location of the tree.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Density

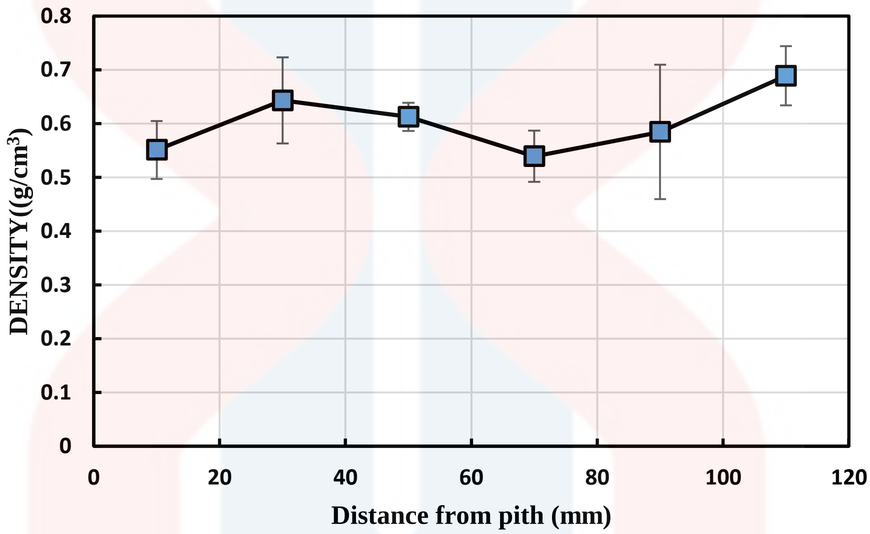

Figure 4.1 Result of density from pith toward bark

Figure 4.1 present the density of *rubber*wood from pith to the bark The graph indicates that samples of wood near the pith have a density that is lower than samples toward bark. As can be seen from the figure, the density of samples near the pith was 0.54 g/cm^3, while the wood density near the bark was 0.69 (g/cm^3). The particular circumstances arise due to the influence of certain distinct factors.

Rubberwood has a pattern which is up and down from pith to bark. (Saffian et al., 2014). An increasing tendency in rubberwood wood density was seen from pith to bark irrespective of planting density that use because there is less competition for light and nutrients at the lower planting density. The radial variation of various stocking densities effects on wood cell characteristics, including vessel frequency, ray area, fiber diameter, lumen diameter, and cell wall thickness. It discovered that the majority of these characteristics had an increasing tendency from bark to pith, which would account for the rise in wood density. In addition, it saw that from pith to bark, the vessel frequency and ray density dropped, which may have the effect of lessening the porosity and strengthening the wood. At cambial age, not stocking density, was the primary factor influencing the radial variation in wood cell properties. (Jarusombuti et al., 2012)

Rubberwood's density exhibits a pattern of considerable up and down from pith to bark due to changes in wood cell characteristics that take place as the tree grows radially. These modifications are associated with the physiological and environmental elements that influence the development of wood and cambial activity.

4.2 Moisture content

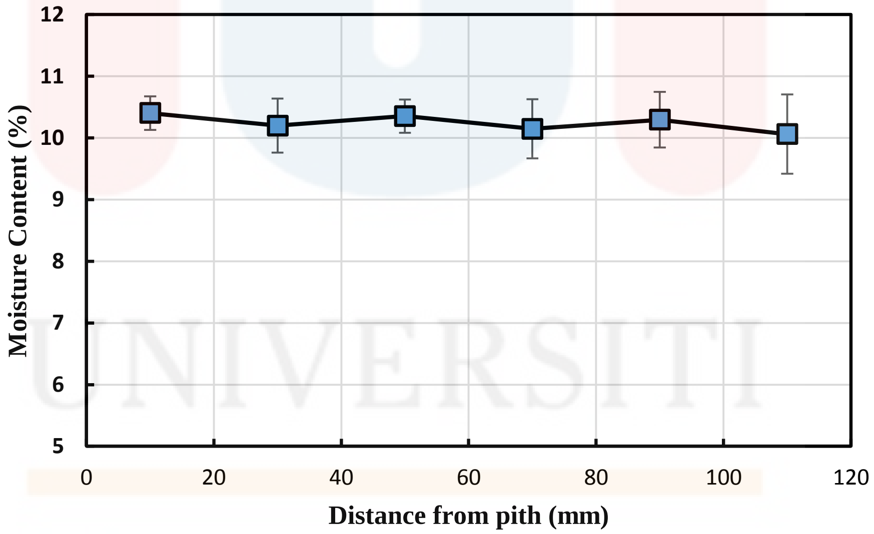

Figure 4.2 Result of moisture content from pith toward bark

Figure 4.2 illustrates the result air-dry moisture content of rubberwood from pith to bark. The graph indicates that samples of wood near the pith have an average moisture content that is higher than samples of wood near the bark. The wood near to pith samples have an average moisture content was 10.40%, whereas the wood near to bark samples have an average moisture content which is 10.06%. Meanwhile, rubberwood has a pattern which is consistently from pith to bark This particular circumstances arise due to the influence of certain distinct factors.

As a result of the wood's had uniform structure and composition, rubberwood's moisture content follows a regular pattern from pith to bark. In contrast to certain other hardwood species, rubberwood wood cells exhibit little variation in size, shape, or density along the radial direction. Neither the moisture content nor the drying behavior of rubberwood are impacted by wood extractives or the amorphous components of the cell wall. The growth rate and stem diameter of rubberwood are not affected by planting density or clonal variety, but they are by the moisture content of the wood.

The rubber wood's moisture content close to the pith, and to use the proper drying techniques and treatments to get the MC down to the required level. Some research indicates that 8% to 10% is the ideal moisture content (MC) for rubber wood used in plywood and furniture manufacturing. Rubber wood needs to be dried, either by kiln drying or another technique, from green or right away following chemical treatment in order to reach this MC. For prevent over- or under-drying the wood, the drying time and temperature must be carefully regulated based on the thickness and starting moisture content of the wood. (Moisture Properties of Wood, n.d.)

Another study proved that the presence of sapwood and heartwood is typically correlated with changes in wood moisture content along the radial direction. Heartwood is generally recognized to have a lower moisture content than sapwood. As a result, the green wood moisture content normally prefers to grow closer to the bark. This is because sapwood is more exposed to the elements as rain, humidity, and evaporation that more vulnerable to these factors. Moreover, the density of live cells and water-transporting and -storing vessels is higher in sapwood. However, because the heartwood is more shielded from the sapwood and bark, it has a lower density of cells and vessels which are frequently packed with resins, oils, and other materials to reduce water absorption and a lower MC. (Ugulino et al., 2020)

4.3 Compression Strength

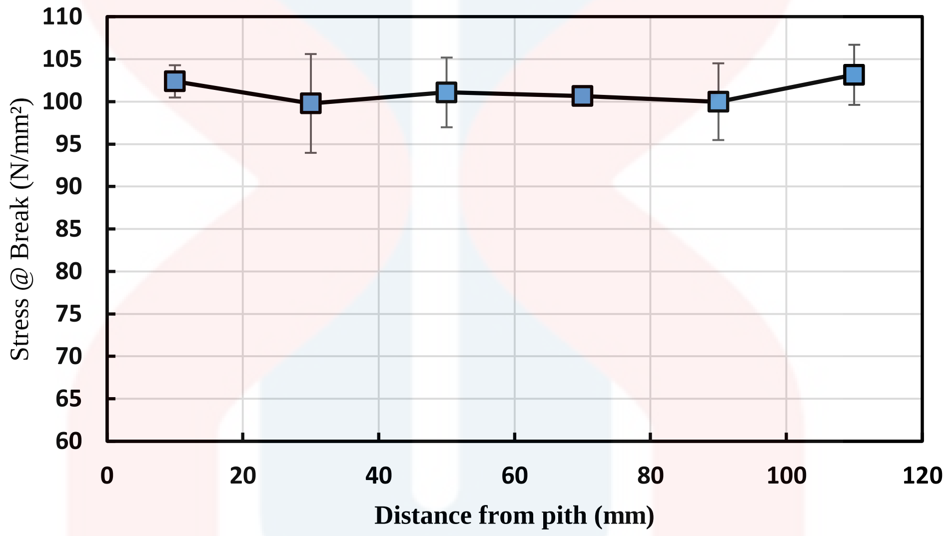

Figure 4.3 Result of Compression Strength from pith towards bark

The Compression Strength of rubberwood from pith to bark is displayed in Figure 4.3. The graph indicates that samples of wood near the pith have a similar average compression strength to samples near the bark. The average compression strength of wood near the bark was 102.40 (N/mm^2), whereas the wood near the pith samples have an average compression strength of 103.16(N/mm^2). This particular circumstances arise due to the influence of certain distinct factors

The pith region is weaker under compression because it has thinner walls and fibers with smaller diameters. Improved compression resistance results from increased wall thickness and fiber diameter as one approaches the bark. The first upward trend can be explained by this. The pith region is weaker under compression because it has thinner walls and fibers with smaller diameters. Improved compression resistance results from increased wall thickness and fiber diameter as one approaches the bark. The first upward trend can be explained by this. Stance arises due to the influence of certain distinct factor.

. Rubberwood shrinks more tangentially, or perpendicular to the grain, than radially, or parallel to the grain, due to anisotropic shrinkage. Further affecting the wood's compression strength is the possibility of internal tensions and microcracks caused by this uneven shrinking, especially in the vicinity of the pith. From pith to earlywood, there is an increase in both fiber diameter and wall thickness, as seen by the first rising trend. But earlywood steeper fiber angle negates this and lowers the strength. The steeper fiber angle and increased cellulose content become more prominent as we approach.

The age of the tree influences the matters, older trees may be stronger overall because of their thicker cell walls and higher latewood content. Growth circumstances, like as soil composition and climate, can also affect the properties of fibers and, in turn, their compression strength. Furthermore, internal stresses and micro cracks can be introduced by processing procedures like drying methods and final product dimensions, which can affect the strength seen in different wood regions latewood, resulting in a last increase in compressive strength near the bark.

4.4 Modulus of Elasticity(MOE)

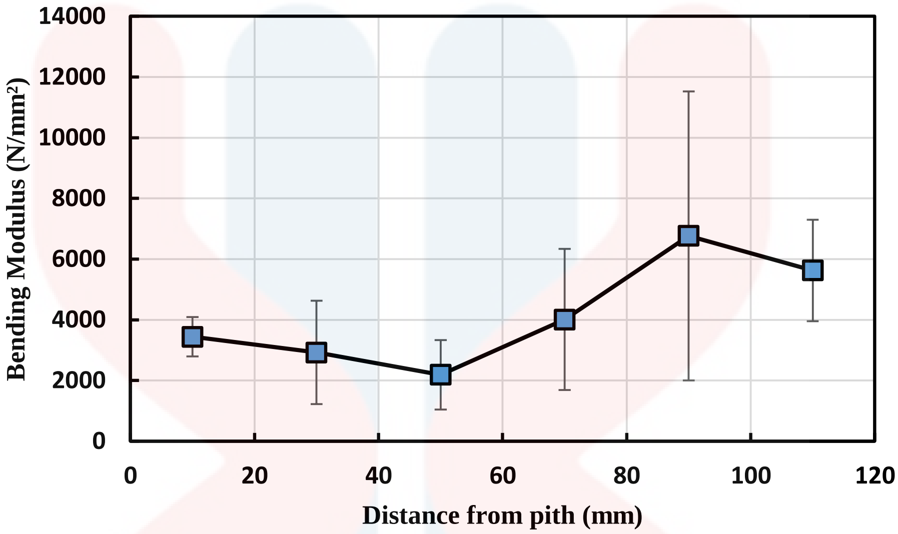

Figure 4.4 Result of Modulus of elasticity(MOE) from pith toward bark

The MOE of *Hevea brasiliensis* wood from pith to bark is displayed in Figure 4.4. The graph indicates that samples of wood near the pith have an MOE that is lower than samples near the bark. The wood near the pith samples have an MOE which is 2188.80 (N/ mm^2), whereas the wood near the bark samples had an MOE which is 6767.61(N/mm^2). This particular circumstance arises due to the influence of certain distinct factors.

Due to the differences in wood cell characteristics between juvenile and mature wood. Compared to mature wood, juvenile wood is characterized by a higher proportion of early wood, smaller and thinner cells, larger microfibril angles, and decreasing density. Due to these traits and lower MOE values, juvenile wood is more prone to warping and shrinking than adult wood and is hence less rigid. In comparison to juvenile wood, mature wood contains smaller microfibril angles, higher densities, longer and thicker cells, and a decreased percentage of early material. Mature wood is stiffer and more stable than juvenile wood because of these properties, which are linked to higher MOE values.

Juvenile and mature wood differ in their mechanical qualities, which have an impact on the wood's stiffness, there is a difference in the MOE of the wood cells between them. By taking MOE measurements along the tree's radial direction, it is possible to identify when juvenile to mature wood transitions. Indicating the transition from juvenile to mature wood, the MOE values rise from pith to bark. Species, location, and growth circumstances all affect the transition point of a tree.

The wood close to the pith is juvenile, whereas the wood close to the bark is adult, which explains why the wood near the pith has a lower modulus of elasticity (MOE) than the mature wood. Compared to mature wood, juvenile wood contains more early wood, smaller, thinner cells, a bigger microfibril angle, less density, and a higher percentage of these characteristics. Due to these traits and lower MOE values, juvenile wood is more prone to warping and shrinking than adult wood and is hence less rigid. Comparing mature and juvenile wood, the former has a higher density, a smaller microfibril angle, longer and thicker cells, and a lower percentage of early wood. Mature wood has a higher MOE value when it possesses these qualities, indicating that it is more stable and stiff than before. (Darmawan et al., 2015)

4.5 Modulus of Rupture(MOR)

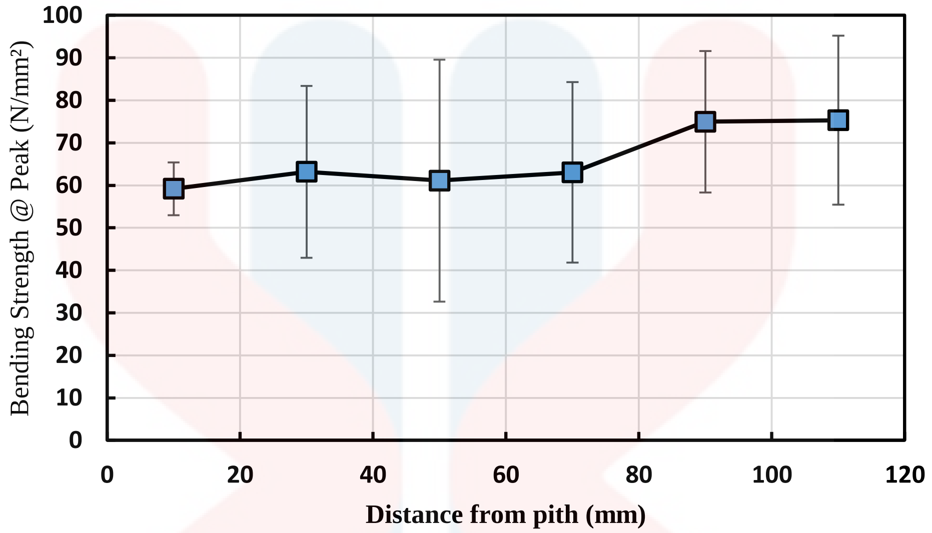

Figure 4.5 Result of Modulus of Rupture (MOR) from pith toward bark

The MOR of rubberwood from pith to bark is displayed in Figure 4.5. The graph indicates that samples of wood near pith which have MOR that lower than samples of wood near bark. The wood near to pith samples have an MOR of 59.18 (N/mm^2), whereas the wood near to bark samples have an MOR of 75.33 (N/mm^2). This particular circumstance arises due to the influence of certain distinct factor.

The wood is intrinsically weaker at the pith because it has smaller diameter fibers with thinner walls. Fibers progressively thicken their walls and grow in diameter as they approach the bark, which adds to their increased bending strength. This explains why MOR first increased.

But fiber properties are not limited to size. Compared to latewood, which is located closer to the bark, earlywood, which is closer to the pith, has a steeper fiber angle. Despite the greater fiber diameter, the steeper angle results in a lesser response to bending forces, which lowers MOR. On the other hand, the latewood fibers' shallower angle provides superior bending resistance, which results in the last rising trend in MOR close to the bark.

MOR is influenced by growth rings and chemical makeup in addition to individual fibers. Rubberwood shrinks more tangentially than radially when it experiences anisotropic shrinkage. Its bending strength may be reduced by internal strains and microcracks caused by this uneven shrinking close to the pith. Further contributing to a lower MOR is the pith region's frequent higher concentration of non-cellulosic components, which soften the wood.

It's important to keep in mind that this description of "pith-to-bark" is just the beginning. A number of variables, such as tree age, growth circumstances, and processing techniques, can affect the precise pattern and degree of MOR variation. For example, because of their higher latewood content, older trees may have higher overall MOR. (Mascia et al., 2022)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In summary, of this study was to look at how rubber wood' physical and mechanical characteristics varied radially. The data demonstrated about density, moisture content, compression strength, modulus of elasticity, and modulus of rupture varied dramatically. Rubber wood's anatomical structure, chemical makeup, and rate of growth all have a major impact on the diversity in wood qualities. In comparison to other wood species or materials, rubber wood was also found to have physical and mechanical qualities that were either better or comparable. Consequently, rubber wood was found to be a desirable and appropriate material for a range of wood products and applications. In addition to investigating rubber wood's possible use in various industries, the study suggested that more research be done to improve the drying and processing techniques for the material. The narrative continues after the radial analysis establishes the framework. An additional layer of intricacy is added by the tangential differences within growth rings that are determined by the interaction of earlywood and latewood proportions. Greater strength in wider latewood bands can result in isolated zones with unique characteristics; this emphasizes the significance of evaluating the full wood cross-section for an accurate assessment.

5.2 Recommendations

In recommendation based on following topic radial variation in physical and mechanical properties enhance the development of latewood in forestry and agriculture. The usage of silvicultural techniques that promote broader latewood bands, which are recognized for to enhance the development of latewood in forestry and agriculture, and their greater strength. This could entail modifying thinning schedules, fertilization timetables, or crown density. Investigate breeding initiatives to choose for faster-growing cultivars with higher amounts of latewood inherently, so increasing total strength and value. Higher latewood content trees may be the ones chosen for applications that demand more strength. Use drying strategies that reduce internal stresses and micro cracks to maintain the wood's natural strength. It is imperative to do research on cutting-edge drying techniques designed especially for rubberwood. Employ cutting-edge cutting and processing methods to minimize waste and optimize the use of priceless latewood-rich greater strength. This could entail modifying thinning schedules, fertilization timetables, or crown density. Investigate breeding initiatives to choose for faster-growing cultivars with higher amounts of latewood inherently, so increasing total strength and value.

When scheduling when to harvest, take into account the final goods that you want. Higher latewood content trees may be the ones chosen for applications that demand more strength. Furthermore, this kind of research helps to create cutting-edge wood goods and materials. A thorough understanding of radial chemical differences makes it possible to tailor the qualities of wood through genetic alteration or targeted cultivation. This line of inquiry has the potential to produce novel materials with improved resilience to deterioration and other desired properties. In summary, examining the chemical property variation of wood along its radial length provides a wealth of information that connects the past to the present and paves the way for a more technologically sophisticated and sustainable future in materials science and forestry.

REFERENCE

Abdul halip, j. (2013). Universiti Putra Malaysia Juliana Binti Abdul Halip Iptph 2013 1 Physical and Mechanical Properties of Particleboard Manufactured from Kenaf (Hibiscus Cannabinus L.) And Rubberwood (Hevea brasiliensis Mull). http://psasir.upm.edu.my/id/eprint/41287/1/IPTPH%202013%201R.pdf

Ali, M. R., Abdullah, U. H., Gerardin, P., Ashaari, Z., Hamid, N. H., & Kamarudin, S. H. (2023). Chemical, Crystallinity and Morphological Changes of Rubberwood (Hevea brasiliensis (Willd. ex A. Juss.) Müll. Arg.) Hydrothermally Treated in Different Buffered Media. *Forests*, *14*(2), 203. https://doi.org/10.3390/f14020203

Ashaari, Z. (2017). *LOW DENSITY WOOD from poor to excellent*. https://pnc.upm.edu.my/upload/dokumen/20170725181150212_Prof_Zaidon_Low_Density_Wood_from_poor_to_excellent.pdf

Aw, M. J., Ar, Z., Fkn, N. M., & Fsm, N. (2021). Sapwood/Heartwood Proportion Of Plantation Logs (Pp. 1–12). Forest Research Institute Malaysia. Https://Info.Frim.Gov.My/Infocenter/Booksonline/Ttb/Ttb111.Pdf

Ayrilmis, N., Jarusombuti, S., Fueangvivat, V., Bauchongkol, P., & White, R. H. (2011). Coir fiber reinforced polypropylene composite panel for automotive interior applications. Fibers and Polymers, 12(7), 919–926. https://doi.org/10.1007/s12221-011-0919-1

Bao, F. C., Jiang, Z., Jiang, X. S., Lu, X. F., Luo, X. L., & Zhang, S.-N. (2001). Differences in wood properties between juvenile wood and mature wood in 10 species grown in China. Wood Science and Technology , 35(4), 363–375. https://doi.org/10.1007/s002260100099

Bustos, c. (2012). Radial variation of mechanical and physical properties of black spruce cell wall determined by nanoindentation and silviscan. Www.academia.edu. Https://www.academia.edu/4844835/radial_variation_of_mechanical_and_physical_properties_of_black_spruce_cell_wall_determined_by_nanoindentation_and_silviscan

Darmawan, W., Nandika, D., Sari, R. K., Sitompul, A., Rahayu, I., & Gardner, D. (2015). Juvenile and mature wood characteristics of short and long rotation teak in Java. *IAWA Journal*, *36*(4), 428–442. https://doi.org/10.1163/22941932-20150112

Effects Of Tree Portion And Radial Position On Physical And Chemical Properties Of Kelampayan (Neolamarckia Cadamba) Wood: Bioresources. (N.D.). Bioresources.Cnr. Ncsu.Edu. Retrieved December 30, 2022, From Https://Bioresources.Cnr.Ncsu.Edu/Resources/Effects-Of-Tree-Portion-And-Radial-Position-On-Physical-And-Chemical-Properties-Of-Kelampayan-Neolamarckia-Cadamba-Wood/

Faessler, T. (2021, July 19). What is rubberwood? - exploring the properties of rubberwood. Woodworking and Wood Treatening Guide. https://woodhappen.com/what-is-rubberwood/

Gonçalves, J., Stape, J., Laclau, J-P., Bouillet, J-P., & Ranger, J. (2008). Assessing the effects of early silvicultural management on long-term site productivity of fast-growing eucalypt plantations: the Brazilian experience. Southern Forests: A Journal of Forest Science, 70(2), 105–118. https://doi.org/10.2989/south.for.2008.70.2.6.534

Hazir, M. H. M., Kadir, R. A., Gloor, E., & Galbraith, D. (2020). Effect of agroclimatic variability on land suitability for cultivating rubber (Hevea brasiliensis) and growth performance assessment in the tropical rainforest climate of Peninsular

Malaysia. Climate Risk Management, 27, 100203. https://doi.org/10.1016/j.crm.2019.100203

Hevea brasiliensis. (2020, November 30). Wikipedia. https://en.wikipedia.org/wiki/Hevea_brasiliensis

J. Paul McLean, Zhang, T., Sandrine Bardet, Beauchêne, J., Thibaut, A., Clair, B., & Thibaut, B. (2011). The decreasing radial wood stiffness pattern of some tropical trees growing in the primary forest is reversed and increases when they are grown in a plantation. Annals of Forest Science, 68(4), 681–688. https://doi.org/10.1007/s13595-011-0085-z

Jarusombuti, S., Bauchongkol, P., Hiziroglu, S., & Fueangvivat, V. (2012). Properties of Rubberwood Medium-Density Fiberboard Bonded with Starch and Urea-Formaldehyde. Forest Products Journal, 62(1), 58–62. https://doi.org/10.13073/fpj-d-11-00114.1

Kijidani, Y., Morita, H., Aratake, S., Tsuyama, T., & Arima, T. (2019). Partial compression strength of sugi (Japanese cedar, Cryptomeria japonica) wood near the pith perpendicular to the grain. Journal of Wood Science, 65(1). https://doi.org/10.1186/s10086-019-1796-2

Lamaming, J., Heng, N. B., Owodunni, A. A., Lamaming, S. Z., Khadir, N. K. A., Hashim, R., Sulaiman, O., Mohamad Kassim, M. H., Hussin, M. H., Bustami, Y., Amini, M. H. M., & Hiziroglu, S. (2020). Characterization of rubberwood particleboard made using carboxymethyl starch mixed with polyvinyl alcohol as adhesive. Composites Part B: Engineering, 183, 107731. https://doi.org/10.1016/j.compositesb.2019.107731

Lau, N.-S., Makita, Y., Kawashima, M., Taylor, T. D., Kondo, S., Othman, A. S., Shu-Chien, A. C., & Matsui, M. (2016). The rubber tree genome shows expansion of gene family associated with rubber biosynthesis. Scientific Reports, 6, 28594. https://doi.org/10.1038/srep28594

Matan, N., & Kyokong, B. (2003, May 23). Effect of moisture content on some physical and mechanical properties of juvenile rubberwood (Hevea brasiliensis Muell. Arg.). 327–340.

Mechanical Properties of Rubberwood from A 35-Year-Old Plantation in Central Kerala, India* - R. Gnanaharan & Tk Dhamodaran. (N.D.). Forest Research Institute Malaysia (Frim). Retrieved February 8, 2024, From Https://Www.Frim.Gov.My/V1/Jtfsonline/Jtfs/V6n2/136-140.Pdf

Moya, R., Diana Aguilar Tovar, Tenorio, C., & Bond, B. (2011). Moisture Content Variation in Kiln-Dried Lumber from Plantations of Vochysia Guatemalensis. Wood and Fiber Science, 43(2), 121–129.

Naji, H. R., Sahri, Mohd. H., Nobuchi, T., & Bakar, E. S. (2013). Radial variation of wood cell features under different stocking densities management of two new clones of Rubberwood (Hevea brasiliensis). *Journal of Wood Science*, *59*(6), 460–468. https://doi.org/10.1007/s10086-013-1357-z

Nasir, V., Nourian, S., Avramidis, S., & Cool, J. (2018). Prediction of physical and mechanical properties of thermally modified wood based on color change evaluated by means of "group method of data handling" (GMDH) neural network. *Holzforschung*, *73*(4), 381–392. https://doi.org/10.1515/hf-2018-0146

Riyaphan, J., Phumichai, T., Neimsuwan, T., Witayakran, S., Sungsing, K., Kaveeta, R., & Phumichai, C. (2015). Variability in chemical and mechanical properties of Pará rubber (Hevea brasiliensis) trees. *ScienceAsia*, *41*(4), 251. https://doi.org/10.2306/scienceasia1513-1874.2015.41.251

Rubberwood | the wood database - lumber identification (hardwood). (n.d.). https://www.wood-database.com/rubberwood/

Rubberwood. (2024, February 5). Wikipedia. https://en.m.wikipedia.org/wiki/Rubberwood

Saffian, H. A., Tahir, P. M., Harun, J., Jawaid, M., & Hakeem, K. R. (2014). Influence of Planting Density on the Fiber Morphology and Chemical Composition of a New Latex-timber Clone Tree of Rubberwood (Hevea brasiliensis Muell. Arg.). Bio Resources, 9(2). https://doi.org/10.15376/biores.9.2.2593-2608

Teoh, Y. P., Don, M. M., & Ujang, S. (2011). Assessment of the properties, utilization, and preservation of Rubberwood (Hevea brasiliensis): a case study in Malaysia. Journal of Wood Science, 57(4), 255–266. https://doi.org/10.1007/s10086-011-1173-2

Ugulino, B., Cáceres, C. B., Hernández, R. E., & Blais, C. (2020). Influence of temperature and moisture content on bark/wood shear strength of black spruce and balsam fir logs. Wood Science and Technology, 54(4), 963–979. https://doi.org/10.1007/s00226-020-01198-x

What is Rubberwood – The Pros and Cons. (2021, December 6). Woodthrive.com. https://woodthrive.com/what-is-rubberwood/#google_vignette

Zhao, B., Yu, Z., Zhang, Y., & Qi, C. (2019). Physical and mechanical properties of rubberwood (Hevea brasiliensis) dyed with Lasiodiplodia theobromae. Journal of Wood Science, 65(1). https://doi.org/10.1186/s10086-019-1843-z

APPENDIX A

Appendix1a: Data result of Moisture Content from pith toward bark

Sample(mm)	Average (N/mm^2)	SD
10	0.551067	0.05404825
30	0.643225	0.080179065
50	0.6127	0.026085117
70	0.53924	0.047597896
90	0.584625	0.124995823
110	0.6889	0.055045254

Appendix 2a: Data result of Density from pith toward bark

Sample(mm)	Average(%)	SD
10	10.40275763	0.272167404
30	10.19985261	0.438499969
50	10.35434374	0.268241947
70	10.1479194	0.479047842
90	10.29527763	0.45251539
110	10.06187441	0.642313186

Appendix 3a: Data result of Compression Strength from pith toward bark

Sample(mm)	Stress @ Break (N/mm²)	SD
10	102.3965149	1.909605394
30	99.79201824	5.807662678
50	101.0968797	4.113646906
70	100.6569426	0.799760747
90	99.99586639	4.519377286

110	103.1611694	3.523856232

APPENDIX B

Appendix 4b: Data result of Modulus of Elasticity from pith toward bark

	AVERAGE	SD
SAMPLE	Bending Modulus (N/mm²)	Bending Strength@ (N/mm²)
10	3441.717667	59.18266667
30	2922.7985	63.19975
50	2188.79925	61.10525
70	4011.32275	63.057
90	6767.60925	74.965
110	5627.907	75.3265

Appendix 5b: Data result of Modulus of Rupture from pith toward bark

	AVERAGE	SD
SAMPLE	Bending Modulus (N/mm²)	Bending Strength @ Peak (N/mm²)
10	652.078517	6.226469331
30	1704.30213	20.222
50	1146.728	28.476
70	2323.504	21.253
90	4759.347	16.664
110	1670.916	19.856

APPENDIX C

Appendix 1c: Modulus of rupture test

Appendix 2c: Air dry sample

Appendix 3c: Moisture Content test

Appendix 4c: Compression Strength test