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Study on the Effect of Thermal Treatment on the Properties of Kelat (*Syzgium spp*) Wood

Muhammad Afiq Irman Bin ABD Latif
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DECLARATION

I declare that this thesis entitled "Study on The Effects of Thermal Treatment on The Properties of Kelat Wood (*syzgium spp*)" is the results of my own research except as cited in the references

Signature : ______________________________

Student's Name : MUHAMMAD AFIQ IRMAN BIN ABD LATIF

Date : 8/2/2024

Verified by:

Signature : ______________________________

Supervisor's Name : DR. ANDI HERMAWAN

Stamp : ______________________________

Date :

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In the name of Allah, the Most Gracious and the Most Merciful.

All raises to Allah, and with His guidance I was able to finish this thesis within the given timeframe. Praise be to Allah that raise for the chances, difficulties, and resources He provided me with to finish this thesis. Through the process, I got so much experience, both academically and personally

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May God grant them success in this life as well as the afterlife.

Study on The Effects of Thermal Treatment on The Properties of Kelat Wood (*syzgium spp*)

ABSTRACT

Thermal treatment of wood has grown greatly in recent years and is still evolving as an industrial procedure to improve a variety of wood qualities. Wood extracted from forest plantations generally has inferior properties and thus has limitations in its uses. Therefore, an additional process is necessary to improve the properties of the wood. This study is proposed to improve the properties of the wood by using thermal modification technology. As a result, Kelat wood was selected to be examined under the heading of thermal modification. Wood was processed into 300×200×50 mm dimensions and exposed to three distinct temperature of 150, 180, and 210°C for 30, 60, and 120 minutes by using an oven. The properties of the modified wood, including density, weight loss, colour changes, water absorption, thickness swelling, and bending strength were then investigated. The findings of this study are as follows the effect of temperature and duration on density, water absorption, impact bending and thickness swelling were less significant. While the effect of heat treatment is very significant for weight loss, bending properties and colour changes. Thus, Kelat wood could be used for wider end-use product such as pole wood, furniture, parquet flooring, and for construction purposes.

Keywords: Kelat wood, Thermal modification, Physical and Mechanical properties

Kajian Kesan Rawatan Terma Terhadap Sifat Kayu Kelat (***syzgium spp***)

ABSTRAK

Rawatan haba kayu telah berkembang pesat dalam beberapa tahun kebelakangan ini dan masih berkembang sebagai prosedur perindustrian untuk meningkatkan pelbagai kualiti kayu. Kayu yang diekstrak dari ladang hutan umumnya mempunyai sifat yang lebih rendah dan dengan itu mempunyai batasan dalam penggunaannya. Oleh itu, proses tambahan diperlukan untuk memperbaiki sifat kayu. Kajian ini dicadangkan untuk meningkatkan sifat kayu dengan menggunakan teknologi pengubahsuaian terma. Akibatnya, kayu Kelat dipilih untuk diperiksa di bawah tajuk pengubahsuaian terma. Kayu diproses menjadi 300-gram 200-gram 50 mm dimensi dan terdedah kepada tiga suhu yang berbeza 150, 180, dan 210-gram C selama 30, 60, dan 120 minit dengan menggunakan ketuhar. Sifat-sifat kayu yang diubah suai, termasuk kandungan kelembapan, ketumpatan, penurunan berat badan, perubahan warna, penyerapan air, pembengkakan ketebalan, dan kekuatan lenturan kemudiannya disiasat. Penemuan kajian ini adalah seperti berikut kesan suhu dan tempoh pada ketumpatan, penyerapan air, lenturan impak dan pembengkakan ketebalan kurang ketara. Walaupun kesan rawatan haba sangat penting untuk penurunan berat badan, sifat lenturan dan perubahan warna. Oleh itu, kayu Kelat boleh digunakan untuk produk penggunaan akhir yang lebih luas seperti kayu tiang, perabot, lantai parket, dan untuk tujuan pembinaan.

Kata kunci: Kayu Kelat, Pengubahsuaian Terma, Fizikal dan Mekanikal kayu

TABLE OF CONTENT

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Greenhouse gases are known to accumulate up in the atmosphere as a direct result of human activity. These gases are known to have an effect on climate change, which may ultimately lead to global warming. An increase in the concentrations of greenhouse gases is partially attributable to human activities. These activities include the synthesis of materials, which requires the utilisation of fossil fuels. As a result of this, reducing emissions of greenhouse gases such as carbon dioxide into the atmosphere has emerged as one of the most pressing concerns facing society in the present society.

Trees capture carbon dioxide and use sunlight and water to grow wood while also releasing oxygen into our atmosphere, which is why trees are better for the environment. Wood is a renewable resource that may be utilised for a variety of purposes, but cement and metal take a lot more energy to extract. As a result, wood is an environmentally friendly, multipurpose natural substance that can be used structurally as well as non-structural to produce amazing results. Due to its high hygroscopicity, wood can be prone to dimensional instability when used for diverse purposes, making it less durable than other materials.

For years, researchers have been working to find new and better ways to make wood more long-lasting and stable, including wood modification technology, which entails treating the material physically, and mechanically.

According to certain reports, wood's TT has a considerable impact on the structure of the wood. Physical and mechanical features such as strength and durability enhance when wood products are used for indoor or outdoor functions, such as fencing, siding or decks. In addition to protecting the wood against fungal and insect infestations, treating the wood provides a warm brown colour and improves its structural stability by up to 50%. Without the use of hazardous chemicals, the thermal insulation improves by 5% to 15%. TT degrades part of hemicelluloses and other substances by heating it to 120°C, and may occur to 230°C in an open or closed operation with or without the presence of vapour pressure.

Thermal treatment kelat is examined in this study. It is the goal of this research to determine the effects of temperature treatment and treatment time on the wood's physical and mechanical properties. The wood is heated to various temperatures and durations for this purpose. This study will examine how thermal treatment affects the density, dimensional stability, modulus of rupture (MOR), modulus of elasticity (MOE) and colour changes of the wood

1.2 Problem Statement

It is well known that there is a shortage of long -term timber resources in the timber industry, no matter how much total production has grown. When population growth is combined with sluggish growth rates in native species from forests, it is possible to increase the amount of timber available by altering the quality of timber obtained from rarely used species. Although the wood used in this study can be said to be commercial wood because it is often used, it can still be improved with modifications made to it. Accordingly, this study is proposed to improve the properties of kelat wood for a wider end user by using wood treatment technology.

1.3 Objectives

This study is carried out with the following objectives:

1. To investigate the impact of thermal treatment on the physical properties of the modified wood.
2. To evaluate the impact of thermal treatment on the mechanical properties of the modified wood.

1.4 Scope of Study

This study will conduct the thermal modifications of Kelat wood and evaluate the effects of temperature and duration on the physical and mechanical properties of the wood. Kelat wood will be exposed to heat at different temperatures and durations. The density, dimensional stability, color changes, bending properties, and impact strength of the modified wood are evaluated and compared with the untreated ones.

1.5 Significances of Study

It is commonly known that the fast-growing species of Kelat wood was only employed in certain applications because of its subpar qualities. The goal of this study is to determine whether TT can enhance Kelat wood's qualities for a range of uses. The escalating demand for forest lands has led to an annual decline in the availability of logs and premium wood. As is well known, industrialized nations have established boundaries for tree-logging, which has led to the development of new forest resource alternatives to replace the slow-growing wood species that are now in high demand.

In Malaysia, wood was produced using trees that were taken from production forests. The goal was typically to produce high-quality trees, most of which are slow-growing species that put strain on forested regions. In this case, it is important to implement measures that replace and lessen the burden on the forests caused by quickly developing wood species. It is anticipated that TT will enhance the wood's bending characteristics and dimensional stability. Therefore, our study was crucial to addressing the deficiency of high-quality forest timber and enhancing the value of less valuable commercial species for a range of market items.

CHAPTER 2

LITERATURE REVIEW

2.1 Thermal Treatment of Wood

Wood is a natural material widely used in construction, furniture manufacturing, and various other industries. To improve its performance and durability, different treatment methods are employed, with thermal treatment gaining attention for its ability to alter wood properties. This essay aims to investigate the impact of thermal treatment on the physical, mechanical, and chemical characteristics of wood.

Thermal treatment influences several physical properties of wood, including, density, and colour. Additionally, thermal treatment often leads to changes in wood colour, which can be either enhanced or diminished depending on the treatment parameters.

The mechanical properties of wood, such as strength, stiffness, and impact resistance, undergo significant changes during thermal treatment. While some thermal processes may result in a reduction in strength, others can lead to improvements in certain mechanical properties. The alteration of lignin and hemicellulose structures, as well as the crystallinity of cellulose, contributes to these changes. Understanding the relationship between thermal treatment conditions and mechanical properties is crucial for optimizing wood performance in specific applications.

Thermal treatment is a promising method for altering the physical, mechanical, and chemical properties of wood, thereby expanding its range of applications. However, achieving the desired balance between improved characteristics and potential drawbacks requires careful consideration of treatment parameters. Further research is needed to explore the long-term effects of thermal treatment on wood properties and to develop guidelines for optimizing the process based on specific end-use requirements. As we continue to seek sustainable and efficient materials, understanding the intricacies of thermal treatment on wood properties becomes essential for harnessing its full potential.

2.2 Wood Properties

There are many kinds of wood, each of which has its own unique set of physical and mechanical characteristics. Wood is a tremendously versatile material. In addition to that, it is a resource that can be renewed and possesses an outstanding strength ratio. Wood is a required construction material since the energy supplies of creating a usable end-product from wood are significantly lower when compared to the energy requirements of producing an equivalent end-product from competitive materials such as plastic, steel, or concrete. Wood may absorb moisture in a humid environment and expel it in a dry one. The moisture content of wood varies as a function of the surrounding environment due to various environmental variables (temperature and humidity). Under constant temperature and humidity circumstances, wood has an equilibrium moisture content (EMC) at which it is neither acquiring nor losing moisture. The EMC represents a point of equilibrium between the wood and its surroundings.

As the necessity to prevent environmental pollution arises, lumber companies all over the globe have eventually begun to restrict the amount of chemicals used to enhance the attributes of wood. Therefore, thermal modification is an ecologically beneficial option that may be used on wood. It is a resource-efficient method that results in wood products with a minor environmental impact and a longer service life, boosting their durability, stability, and characteristics. The new qualities of thermally modified wood make softwood species more appealing by substantially altering their attributes. Wood is characterised quantitatively by its physical qualities, which include its behaviour in response to external effects other than those exerted directly on it. These characteristics consist of directional qualities, moisture content, dimensional stability, thermal resistance, density, chemical resistance, and resistance to decay. It is crucial to be familiar with the wood's physical properties since these features can have a substantial impact on the performance and strength of the timber when it is utilised in structural applications.

To thrive, wood decay fungi and other timber organisms need adequate oxygen, temperature, moisture, and food. If wood is kept dry, it will not deteriorate (moisture content less than 20%). But if kept underwater for an extended period at an appropriate depth, wood generally does not degrade. Problems with wood degradation can occur when timber is situated between these two extremes. To avoid deterioration, an architect or engineer could select naturally resilient species or treated wood to prevent it from getting wet. The anatomical qualities and species of wood influence the natural durability of wood against deterioration mechanisms and processes. There is low resistance to degradation and rapid failure in harsh settings in the outer zone or sapwood of all species generally. The inherent durability of heartwood varies by species. Cells in the sapwood gradually die, causing the heartwood to form. Toxic extractives that are deposited in the cell wall of some species are made from the sugars that are present in the cells. An EPA-registered, hazardous preservation chemical can be utilized to progress the durability of wood.

2.3 Wood Treatment

Wood is a sustainable and environmentally friendly natural material. Both structural and non-structural uses are made of it. It has great mechanical quality. Wood's hygroscopicity, which results in dimensional instability, is one of its main disadvantages. The significant hygroscopicity and low durability of wood, in particular, severely limit for its outside use. Wood treatment is a broad word that refers to the use of chemical, mechanical, biological, or physical developments to change the qualities of a material. The entire range of changes that occur to wood once it leaves the forest is included in this definition of wood treatment. “Wood treatment involves the activity of chemical, biological, or physical agent onto the material, resulting in a desired property enhancement during the service life of the treatment wood," according to Hill.

The treatment wood should be safe to use under normal conditions, and there should not be any release of toxic chemicals either while being used, during disposal, or following recycling. If the alteration is designed to increase biological resistance, the method of action should be non-biocidal. It should be emphasised that the use of a hazardous chemical in the creation of modified wood is not necessarily prohibited, provided that no hazardous residues remain after the wood modification process is completed. A key component of the definition of wood modification is the intervention at the cell wall level to alter the properties of wood. The three techniques used commercially are thermal, chemical, and impregnation modification. Each of these has advantages and disadvantages in terms of the modified wood's qualities and the modification process's complexity. Even though commercial advancements in wood modification have only occurred within the last decade or two, most of the technologies currently in use have a lengthy history.

The use of chemical, physical, or biological techniques to modify a material's qualities belongs within the broad category of wood modification. The objective is to enhance the functionality of the wood, which leads to enhancements in dimensional stability, resistance to decay, resistance to weathering, and other properties. It is important that the modified wood is non-toxic when used and that its disposal does not produce harmful residues. Significant advancements in wood modification technologies, particularly in the commercial sector, have occurred over the last five years. This technology is not going away. Chemical treatments, thermal modifications, thermo-hydro and thermo-hydromechanical modifications, biological treatments, and physical treatments are four types of procedures that can be used to modify wood. In this study, Kelat was thermally modified at different temperatures and durations to estimate the effectiveness of the thermal modification method on wood for its properties and structural changes.

Thermal treatment is a firm viable technology recently used in improving the durability and dimensional stability of timber. Thermal modification rises with uppermost market value amongst all modification processes in many countries. At temperatures above 180°C, chemical components of wood cell walls varying. Hydrolysis of hemicelluloses and cellulose causing the reduction of sorption in water molecules whereas leads to the changing of wood dimensional stability and durability. In manufacturing scale, thermal modification is conducted at temperatures between 180 and 240°C, varying on the wood species and the proposed use. An extensive range of hardwood and softwood species is used for thermal treatment until recently. Thermally modified timber (TMT) is regularly used for many woods production such as decking, cladding, furniture, and interior joinery. TM also modified in timber cells that efficiently reduce the cell moisture inside of the wood. However, this technology methods do not engage with temperatures above 240 °C, subsequently causing degradation whereas wood becomes too unadorned to make the process commercially valued. Depending on the level of modification desired, the heat-treatment procedure employs temperatures ranging from 180 to 240°C for uttermost from a few minutes to many hours.

Thermally treated wood in its new attributes fast-growing species more appealing by theatrically altering their qualities. Furthermore, thermal modification of fast-growing species reduces the creation of wood dust during remanufacturing procedures treated below 200°C. Among the advantages of thermally altering wood, dimensional stability of the wood rises, displaying low values of shrinkage and swelling, due to modifications in the polymeric elements of the cell wall. This stops water molecules from connecting with the cellulose structure, lowering the treated wood's hygroscopicity. The thermal modification of wood has been the subject of extensive investigation as of late as a result of the rising need to develop non-hazardous methods for enhancing the durability of wood while avoiding the utilisation of potentially hazardous chemicals. Heating wood causes irreversible changes to occur in the chemical, physical, and mechanical properties of the material. The degree to which these changes take place is dependent on the kind of treatment, the amount of time they are exposed to, the temperature at which they are carried out, and the make-up of the wood. It is more vital to pay attention to the temperature than the amount of time it takes to heat anything. The equilibrium moisture content of wood that has been subjected to heat treatment is lower, and the dimensional stability of the wood is improved. Heat treatment increases the resistance of wood against fungal attack.

Wood that has been thermally modified is permanently altered, either by employing chemicals, compressing it, or heating it, such that its attributes are no longer the same as they were before. Wood that has been thermally treated is heated to alter its structure. Besides, to prevent the wood from burning, it is heated to temperatures above 180°C while being deprived of oxygen. The chemical structure of the wood is altered during the process, increasing the material's tensile strength and stability. Wood cells that have had their organic compounds stripped out will not absorb as much water as those that have not. This will result in less warping and twisting of the boards produced from the thermally treated wood. As a result, insects and fungi prevented. Consequently, what is left is a long-lasting wood that is resistant to dampness, rot, and insect infestation. Before kiln drying, water is held in cell walls along with cell itself while after kiln drying, some water is still held in the cell walls. However, after undergone with thermal modification, cell walls disintegrate permanently reducing water storage.

2.4 Effect on Thermal Treatment

The most industrially useful wood modification process is thermal modification, some of which are already on the market. They all operate on the principle that high temperatures (over 150°C) cause chemical changes in the cell wall constituents. At these temperatures, a wide range of reactions occur, including hydrolytic polysaccharide splitting, radical and oxidation reactions as well as the various condensation reactions. During the thermal modification, many different chemical transformations occur as a result of the treatment. Hemicelluloses are the first cell wall components to be affected by the treated temperatures typically used during the processes (Militz and Altgen, 2014). Therefore, the properties such as durability and dimensional stability benefit.

On the other side, heat treatment weakens and discolours materials because of the partial breakdown of cell wall composites. Wood modification is therefore not utilised for load-bearing parts. Claddings, garden timber, decking, and other applications are the most common. Interior design is another area where it is used due to its dark colour by thermally modification procedure. The density of thermally modified wood is lower than that of untreated wood because of the heat degradation in cell wall elements and mass loss during treatment. In general, durability is increased based on the temperature and duration applied. The wood's mechanical qualities are also degraded concurrently. Heat treatment therefore always involves a trade-off between improved fungus resistance and diminished strength qualities (Leithoff and Peek, 1998; Ewert and Scheiding, 2005; Esteves et al., 2009).

Furthermore, thermally modifying softwoods at temperatures below 200℃ reduces the manufacture of wood dust during remanufacturing processes. The thermal modification process uses temperatures ranging from 150 to 260°C for depending on the desired level of modification, in between a few minutes and several hours. It was found that one advantage of thermally modifying wood is that its dimensional stability increases, with low shrinkage and swelling values driven on by modifications to the polymeric elements of the cell wall. Thus, it prevents water molecules from bonding with the cellulose structure, lowering the treated wood's hygroscopicity. Besides, the colour change of wood in determining the value of products based on their presence is an important parameter.

As a result, the darkening of the wood caused by the degradation of hemicellulose and lignin, as well as their conversion into extractive chromophores, improves the aesthetic properties of the treated wood. Furthermore, the mechanical properties can be affected by the intensity of the treatment. In order to prevent a major loss in mechanical qualities, which could restrict the material's range of applications, it is essential to establish the appropriate processing conditions for each species of wood. After heat treatment at temperatures exceeding 200℃, the static bending in both modulus of rupture and the modulus of elasticity are dramatically lowered.

2.5 Characterization Techniques

The study of thermally treatment Kelat wood was characterized its properties by using several testing’s, which is Dimensional Stability and UTM. The characterization was characterizing the effect on Kelat properties after the thermal treatment by following the process.

2.6 Colour Change

When comparing the original samples and the modified terms, it can be seen that the colour of kelat wood changes with different temperatures and durations of thermal treatment. The colour of the thermally treated kelat wood ranged from pale milky white to slightly brown at 160 degrees Celsius for 30, 60 and 90 minutes, to brown at 180 degrees Celsius for 30, 60 and 90 minutes. kelat became darker after 90 min of treatment at 200 C, compared with 30 and 60 min at 200 C. Untreated samples had a hue range from creamy white to brownish brown. Several chemical processes that take place during the heating process are responsible for the colour change in the wood. Since these findings are comparable to those reported by McDonald et al., (2000), aldehydes and phenols may be produced from degraded carbohydrates during thermal modification of kelat, and this may be responsible for the development of colourful chemicals during chemical reactions.

2.7 Universal Testing Machine UTM

A Universal testing machine (UTM) is utilised to evaluate the mechanical properties in bending, tension and compression of a specific test specimen by applying compressive, tensile, and transverse stresses. The machine's moniker reflects the variety of tests it can do on various types of materials. The use of UTM, various tests such as flexural, peel, bend, friction, tension, and spring test. can be conducted. UTM offers the load application value as well as the consistent displacements. The load deflection graph is derived from the observed value. The load value is shown on the Y-axis, while the displacement is shown on the X-axis. The displacement represents the movement of the crossheads during load application. The load deflection graph can be used to calculate the specimen's yield strength, elastic modulus, and stress-strain analysis.

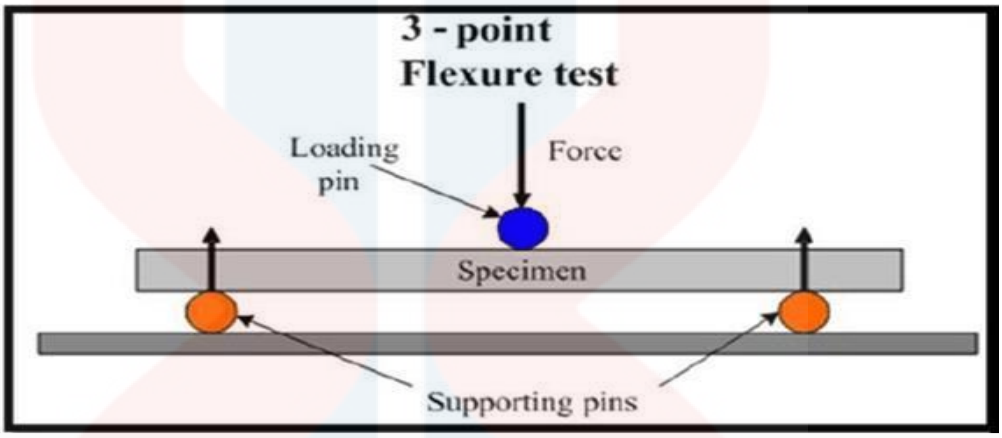
o 

Figure 2.7: Illustration of 3-point bending test

CHAPTER 3

MATERIALS AND METHODS

3.1 Raw Materials

In this study, Kelat (*syzgium spp*) wood was obtained from a local sawmill in Bandar Jeli, Kelantan was used as raw material for thermal treatment. The wood was cut using circular saw into dimensions of 300 mm in length, 200 mm in width, and 50 mm in thickness and air-dried for one month. The wood was then oven-dried at a temperature of 70°C to a moisture content of 12%.

3.2 Methods

3.2.1 Thermal Treatment

A total of three wood samples was exposed to three different temperatures and durations as shown in Table 3.2.1. In this study, thermal treatment was carried out in three-phase. In phase 1, the wood samples were heated to a temperature of 100°C until approximately zero moisture content attained. In phase 2, the temperature was set to three different temperatures and durations. In phase 3, the temperature was gradually decreased to 80-90°C and the treatment finish.

Table 3.1: Thermal modification schedules

<table>
<tr><td colspan="2">HEAT TREATMENT</td></tr>
<tr><td>TEMPERATURE (°C)</td><td>DURATION (MIN)</td></tr>
<tr><td colspan="2">PHASE 1</td></tr>
<tr><td>100</td><td>24(HOURS)</td></tr>
<tr><td colspan="2">PHASE 2</td></tr>
<tr><td>150</td><td rowspan="3">60</td></tr>
<tr><td>180</td></tr>
<tr><td>210</td></tr>
<tr><td rowspan="2">180</td><td>30</td></tr>
<tr><td>120</td></tr>
<tr><td colspan="2">PHASE 3</td></tr>
<tr><td>80-90</td><td>30</td></tr>
</table>

Table 3.2.1: Thermal Modification Schedules

3.2.2 Density Measurement

The wood was processed into the sample with a 300×200×30 mm dimensions. The volume of the sample was determined after measuring its width, length, and thickness using digital calliper. Following that, the mass of the sample was measured, and the density was calculated using the following equation.

$$\rho = \frac{W_o}{V}$$

Where ρ is wood density (g/cm^3) of the sample, W_o is mass of the wood sample

(g), and V is volume of the wood sample (m^3).

3.2.3 Weight Loss Measurement

Oven-dried weight of the samples before and after thermal treatment was measured. The dimensions of the test samples from treated and untreated wood were 300 mm in length, 200 mm in width, and 50 mm in thickness. Then, the weight loss of the samples due to heat treatment was calculated according to the equation below:

$$WL\ (\%) = \frac{W_0 - W_1}{W_0}$$

Where WL is the weight loss due to the heat treatment, W_0 and W_1 are the oven dried weight of the sample before and after thermal treatment.

3.2.4 Colour Changes Measurement

The colour of sample before and after thermal modification was measured by using smartphone. The CIELAB colour index of the sample was then measured using Colour Analyzer application. The colour index was defined by the following Cartesian Chromatic coordinates: Lightness L*[1], which varies from 0 (black) to 100 (white); a* and b* coordinates, which define the chroma (the colours varying from green to red along the a* axis and from blue to yellow along the b* axis). The differences in the lightness (ΔL*), the chroma coordinates (Δa*) and (Δb*), and the colour changes (ΔE*) were calculated using the following equations.

$$\Delta L^* = L_1^* - L_0^*$$

$$\Delta a^* = a_1^* - a_0^*$$

$$\Delta b^* = b_1^* - b_0^*$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Where 0 and 1 indicate the colour after thermal modification and the initial colour index coordinate of the samples respectively.

3.2.5 Water Absorption Measurement

The wood was processed into the sample with 20×30×50 mm dimensions. In water, the thermally modified and controlled wood sample were immersed. After 1,2,3,5 and 24 hours of prolonged immersion, the mass of the sample was measured. Water absorption was calculated by using following equation.

$$WA\ (\%) = (\frac{W_1 - W_0}{W_0}) \times 100$$

Where WA: water absorption (%); W_1: weight of the samples after immersions (g); W_0: the initial weight of the samples (g)

3.2.6 Thickness Swelling Measurement

Using the same sample with water absorption measurement above, the dimension of the sample in the tangential direction was measured using digital micrometre after 24 hours immersion. The thickness swelling was calculated by using following equation.

$$Thickness\ swelling\ (\%) = \left(\frac{L_1 - L_0}{L_0}\right) \times 100$$

Where L_1: dimension after immersion (mm), L_0: dimension before immersion (mm).

3.2.7 Bending Properties Measurement

Bending properties measurement was performed on the thermally modified and control wood sample using a Universal Testing Machine. The dimensions of the wood sample were 20×30×300 mm. Three-point bending test was conducted over an effective span of 260 mm with 5 mm/min loading speed. The modulus of rupture (MOR) and modulus of elasticity (MOE) of the sample were calculated by using following equations.

$$MOR = \frac{3PL}{2bd^2}$$

Where MOR: Modulus of rupture; P: Maximum load weight; L: Distance of buffer; b: Sample width; and d: Sample thickness.

$$MOE = \frac{\Delta PL^3}{4\Delta Ybd^3}$$

Where MOE: Modulus of elasticity; P: Load; L: Distance of buffer; b: Sample width; d: Sample thickness; and ΔY: Flexibility in load.

3.2.8 Impact Strength

The wood sample was processed into the sample with a 20×20×50 mm dimension. The formula for calculating impact strength is:

$$\boldsymbol{Impact\ strenght} = \frac{\boldsymbol{E}}{\boldsymbol{A}}$$

Where, $\boldsymbol{E}$ is the energy absorbed during fracture (joules). $\boldsymbol{A}$ is the cross-sectional area of the specimen (mm^2).**CHAPTER 4**

RESULTS AND DISCUSSION

4.1 Effect of Temperature on The Properties of Modified Kelat Wood

4.1.1 Density

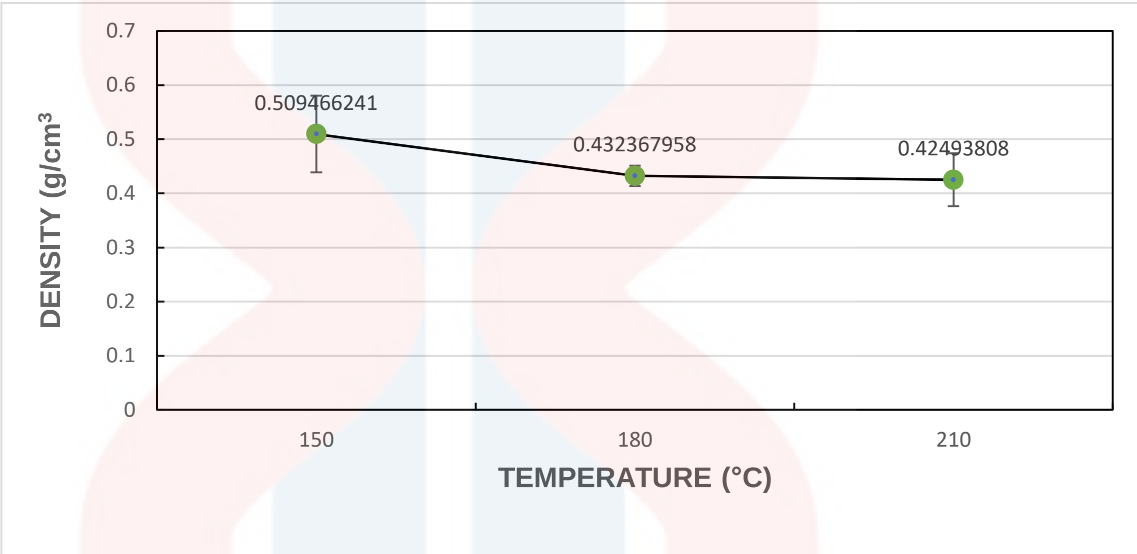


Figure 4.1.1: Effect of various temperature on density

The figure 4.2 shows the effect of different temperatures on density. When compared to the control sample, the sample treated at the density values provided for kelat wood at different temperature levels, namely 150°C, 180°C, and 210°C, offer valuable insights into the material's physical characteristics under varying thermal conditions. Density is a fundamental property that influences the strength, durability, and overall mechanical behaviour of wood. At 150°C, the density of kelat wood is recorded as 0.509 g/cm³. This baseline density is a crucial reference point for understanding how the wood responds to moderate heat. As the temperature increases to 180°C, the density decreases to 0.432 g/cm³, indicating that the wood undergoes a reduction in mass or volume. One reason is that the molecules in a substance move more slowly when the temperature is low. This means that they are packed closer together, which makes the substance denser. When the temperature is high, the molecules move faster and farther apart, which makes the substance less dense.

4.1.2 Weight Loss

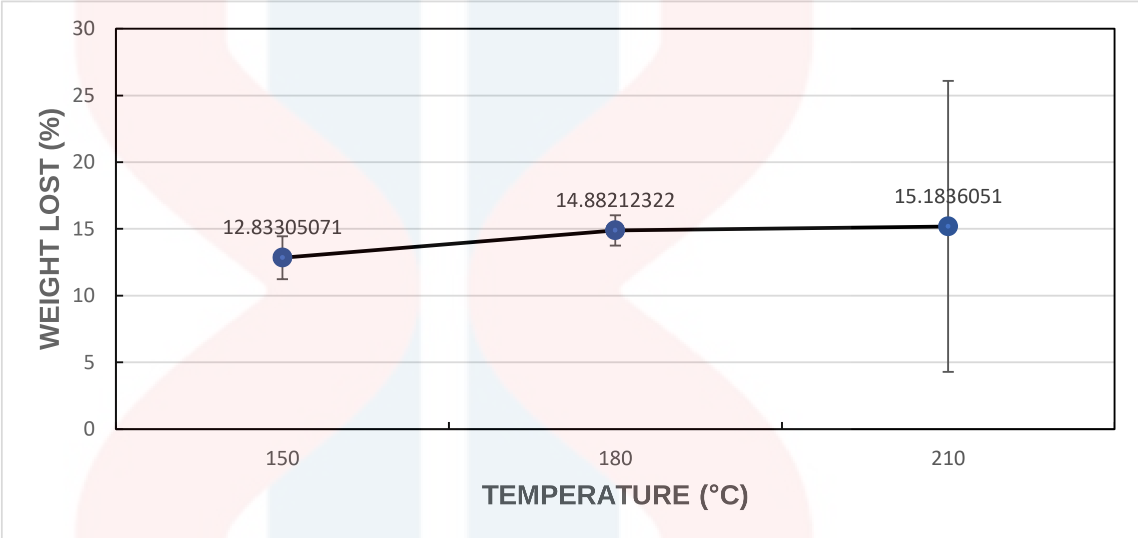


Figure 4.1.2: Effect of various temperature on weight loss

The figure 4.1.3 shows the weight loss data provided for kelat wood at different temperature levels (150°C, 180°C, and 210°C) offers valuable insights into how the wood undergoes changes in mass when exposed to varying thermal conditions. Weight loss is a critical parameter in understanding the thermal stability and degradation characteristics of wood, which is crucial information for industries involved in heat treatment, drying processes, or applications where weight is a significant factor. At 150°C, the weight loss is recorded as 12.83%. This initial weight loss value indicates that kelat wood experiences a reduction in mass when subjected to moderate heat. As the temperature increases to 180°C, the weight loss further intensifies, reaching 14.88%. This suggests that the wood continues to undergo thermal degradation or other processes that result in the release of volatile components. This is because there is more energy available to break the bonds between the water molecules and the other molecules in the sample. As more water evaporates, the sample loses weight.

4.1.3 Colour Change

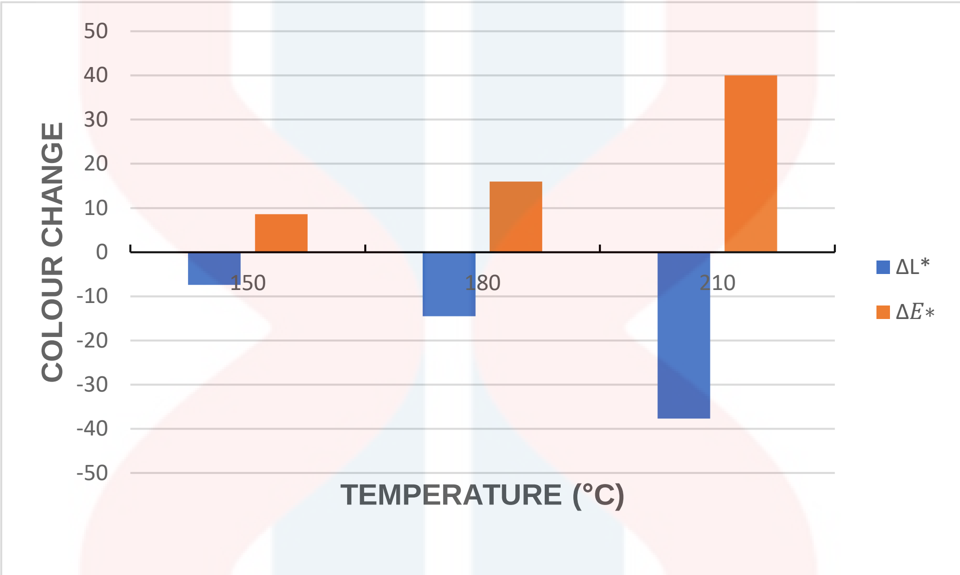


Figure 4.1.3: Effect of various temperature on colour changes

The colour change data for kelat wood at different temperature levels (150°C, 180°C, and 210°C) provides valuable insights into how the wood's visual appearance is affected by varying thermal conditions. Colour change is a significant aspect in applications such as woodworking, furniture manufacturing, and design, as it influences the aesthetic quality and appeal of the final product. At 150°C, the colour change is recorded as -7.4, indicating a decrease in lightness. The negative value suggests a darkening of the wood's colour under moderate heat conditions. The corresponding colour change value of 8.62 indicates a shift in the overall colour, with a magnitude that suggests a discernible but moderate alteration in the wood's appearance. This information is crucial for industries were maintaining or enhancing the natural colour of the wood is essential for product quality. As the temperature increases to 180°C, the colour change becomes more pronounced, with a lightness decrease of -14.5 and a colour change value of 15.94. This indicates a more significant alteration in the wood's colour, likely involving changes in pigments or chemical reactions occurring within the wood structure. Understanding this level of colour change is vital for industries that require precise control over the visual aspects of wood products. The data at 210°C shows a substantial colour change, with a lightness decrease of -37.7 and a colour change value of 39.99. This indicates a significant darkening of the wood, emphasizing the transformative effect of higher temperatures on the wood's appearance. Such drastic colour changes can be important for industries seeking specific aesthetic outcomes or for applications where the visual characteristics of the wood play a critical role. One reason is that the chemical bonds in the substance change as the temperature increases. This can cause the electrons in the atoms to move to different energy levels, which can also change the colour of the substance

4.1.4 Water Absorption

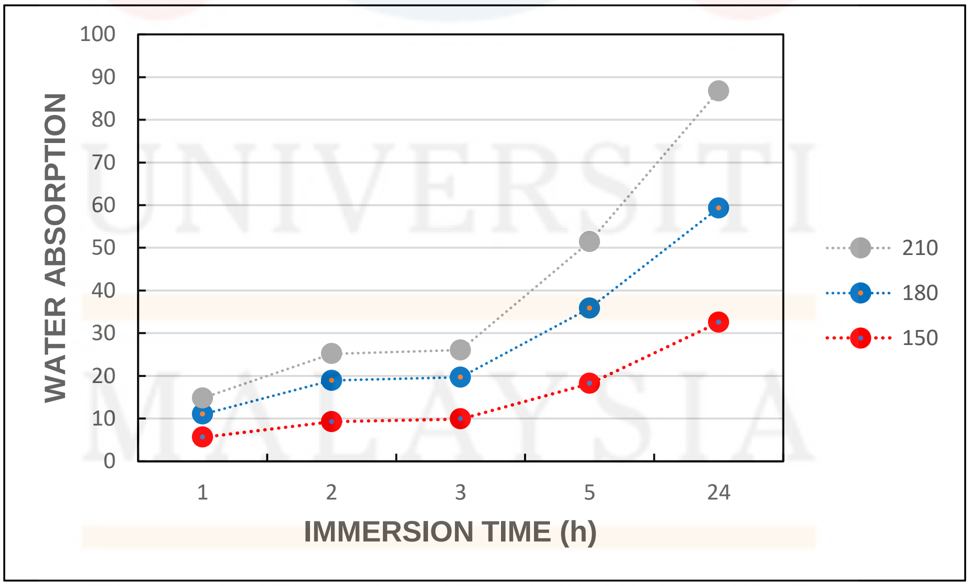


Figure 4.1.4: Effect on various temperature on water absorption

The graph shows that the water absorption increases as the temperature increases. For example, after 5 hours, the water absorption is about 20% at 150 degrees Celsius, but it is about 60% at 210 degrees Celsius. The increase in water absorption with temperature is likely due to a number of factors. One factor is that the water molecules have more kinetic energy at higher temperatures, which means that they are moving faster and can more easily penetrate the sample. Another factor is that the bonds between the atoms in the sample may be weaker at higher temperatures, which would also make it easier for water molecules to penetrate the sample. The results of this experiment could have implications for a number of different fields. For example, they could be used to develop new methods for drying materials, or they could be used to improve the water resistance of materials.

4.1.5 Thickness Swelling

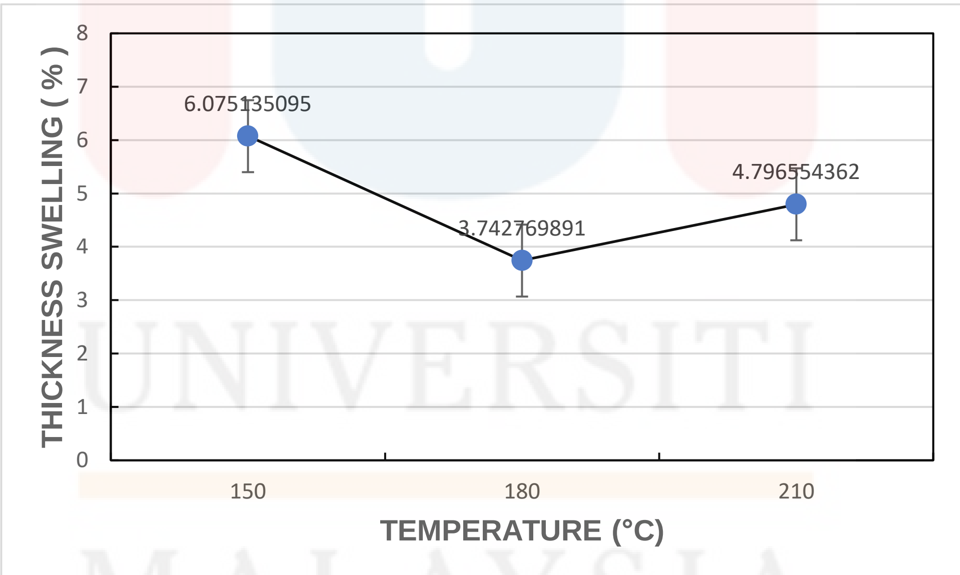


Figure 4.1.5: Effect of various temperature on thickness swelling

The data on thickness swelling for kelat wood at different temperatures (150°C, 180°C, and 210°C) provides insights into how the wood responds to moisture content changes under varying thermal conditions. Thickness swelling is a critical parameter in assessing the dimensional stability of wood, especially in applications where exposure to moisture is a concern, such as in construction or furniture manufacturing. At 150°C, the thickness swelling is recorded as 6.075%. This value represents the percentage increase in thickness compared to the original dimensions when the wood is exposed to moisture at this temperature.

4.1.6 Bending Properties (Mor)

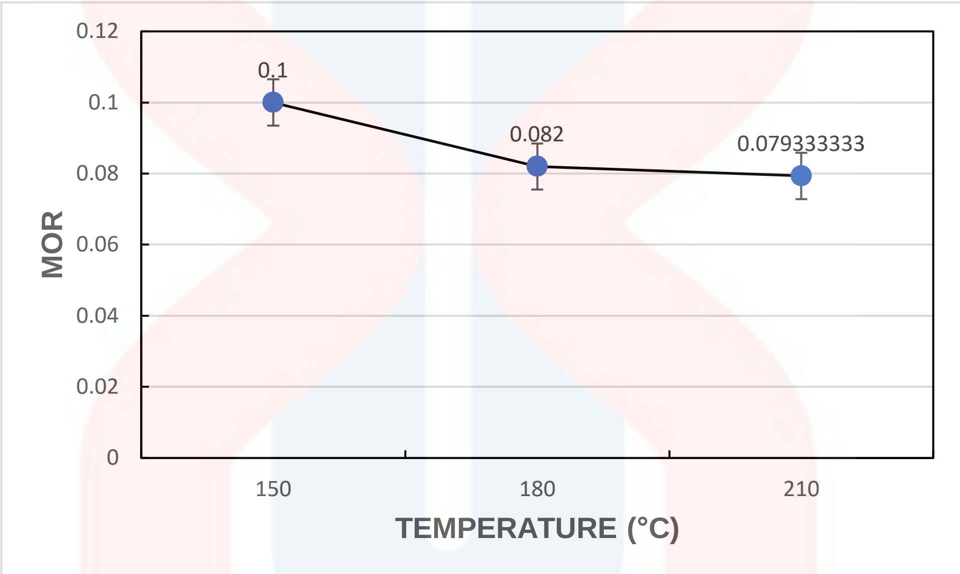


Figure 4.1.6: Effect of treatment temperature on MOR

The data on bending strength for kelat wood at different temperatures (150°C, 180°C, and 210°C) offers insights into how the wood's mechanical properties are influenced by varying thermal conditions. Bending strength is a crucial parameter in assessing a material's ability to withstand applied forces and is essential for applications where structural integrity is a key consideration, such as in construction and woodworking. At 150°C, the bending strength of kelat wood is recorded as 0.1. This value represents the maximum stress the wood can endure during a bending test at this temperature. The standard deviation of 0.0079 indicates a relatively low variability in the bending strength measurements at 150°C, suggesting a consistent response within the sample group under these conditions.

As the temperature increases to 180°C, the bending strength decreases to 0.082. This reduction in bending strength suggests that the wood undergoes changes in its mechanical properties under higher thermal conditions. The lower standard deviation of 0.0061 at 180°C indicates a more consistent measurement of bending strength within the sample group, implying a higher degree of uniformity in the wood's response to bending stress at this temperature. The data at 210°C shows a further decrease in bending strength to 0.0793, with a higher standard deviation of 0.2553. One reason is Changes in the chemical bonds. The high temperatures can cause changes in the chemical bonds between the wood fibres. These changes can make the wood more susceptible to heat conduction.

4.1.7 Bending Properties (MOE)

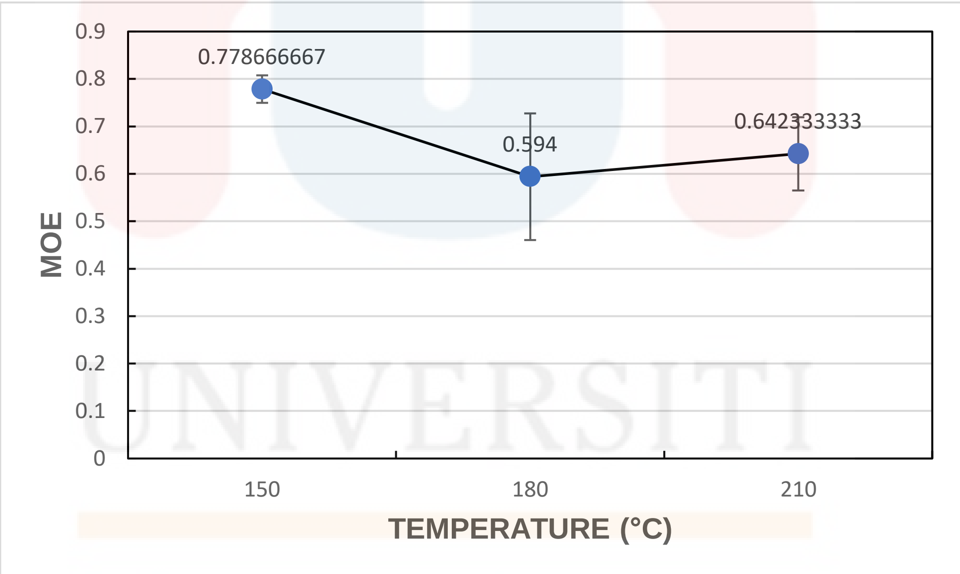


Figure 4.1.7: Effect of treatment temperature on MOE

The data on bending modulus for kelat wood at different temperatures (150°C, 180°C, and 210°C) provides insights into how the wood's flexibility and stiffness change under varying thermal conditions. Bending modulus, also known as flexural modulus or modulus of elasticity, is a critical mechanical property that indicates a material's resistance to bending deformation. Understanding these changes is essential for industries such as construction and engineering, where the material's structural performance is a key consideration. At 150°C, the bending modulus of kelat wood is recorded as 0.7787. This value represents the wood's ability to resist bending deformation at this specific temperature. The relatively low standard deviation of 0.029 indicates a relatively small degree of variability in the bending modulus measurements at 150°C, suggesting a consistent response within the sample group under these conditions. As the temperature increases to 180°C, the bending modulus decreases to 0.594. This reduction in bending modulus indicates that the wood becomes less stiff and more flexible under higher thermal conditions. This is because Initial heating. The sharp increase in temperature at the beginning suggests an initial heating process. The substance could be placed in a hot environment, exposed to a heat source, or undergoing an exothermic reaction that releases heat.

4.1.8 Impact Strength

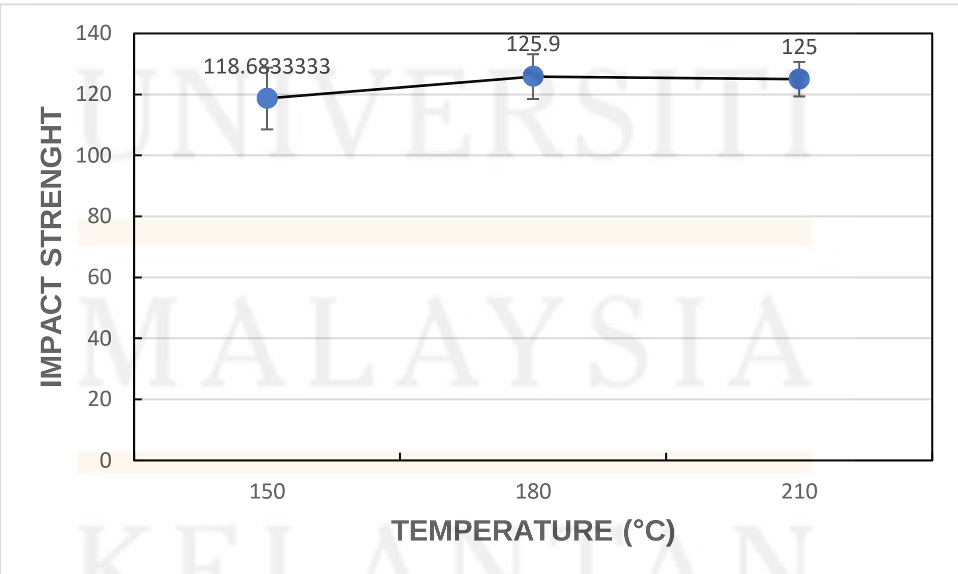


Figure 4.1.8: Effect of treatment temperature on impact strength

The data on impact strength for kelat wood at different temperatures (150°C, 180°C, and 210°C) provides valuable information about how the wood's resistance to sudden forces changes under varying thermal conditions. Impact strength is a critical mechanical property that reflects a material's ability to absorb energy during sudden impact or shock. This information is crucial in applications such as construction, where materials need to withstand potential impact loads. At 150°C, the impact strength of kelat wood is recorded as 118.68, representing the wood's ability to absorb impact energy at this specific temperature. The standard deviation of 10.15 indicates a degree of variability in impact strength measurements within the sample group at 150°C, suggesting that the wood's response to impact forces may vary among different samples. As the temperature increases to 180°C, the impact strength slightly increases to 125.9. Microstructural changes: In some materials, high temperatures can cause changes in their microstructure, such as the formation of new phases or the growth of existing ones. These microstructural changes can also affect the material's mechanical properties, including its impact strength.

4.2 Effect Duration on The Properties of Treatment Kelat Wood

4.2.1 Density

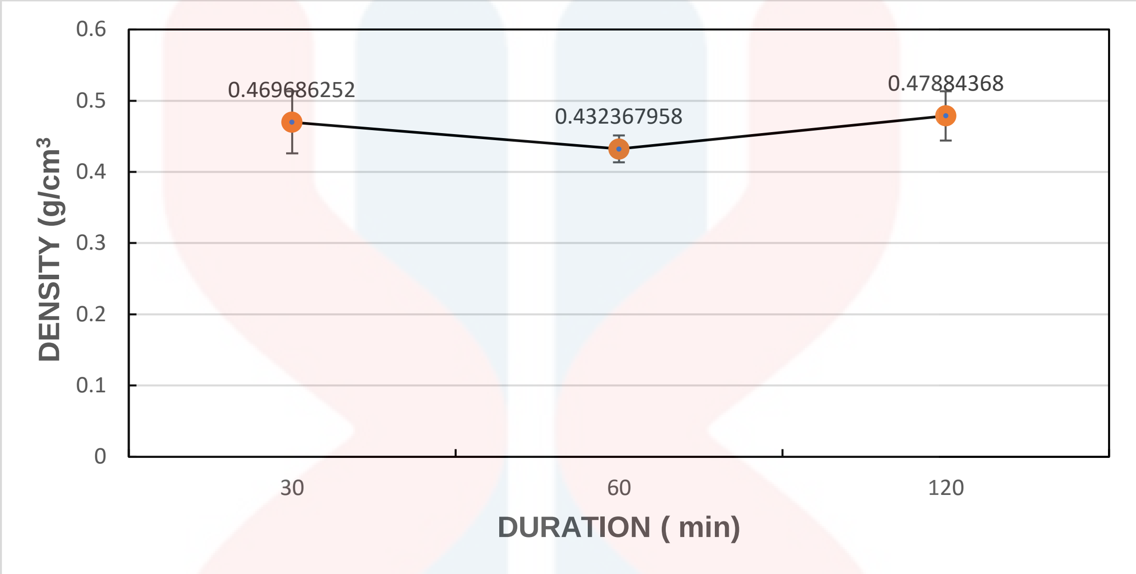


Figure 4.2.1: Effect of various duration on density

The data on density for kelat wood at different durations (30 minutes, 60 minutes, and 120 minutes) provides valuable insights into how the wood's mass per unit volume changes over time. Density is a fundamental property that directly influences various aspects of wood performance, including its strength, durability, and overall mechanical behaviour. At 30 minutes, the density of kelat wood is recorded as 0.4697. This initial density measurement indicates the mass per unit volume after a relatively short duration of exposure. The standard deviation of 0.0437 suggests a moderate degree of variability in density measurements within the sample group, indicating that the wood's response to changes in density may vary among different samples. As the duration increases to 60 minutes, the density decreases to 0.4324. This suggests that the wood undergoes a reduction in mass or volume over time, possibly due to factors like moisture absorption or other structural changes.

4.2.2 Weight Loss

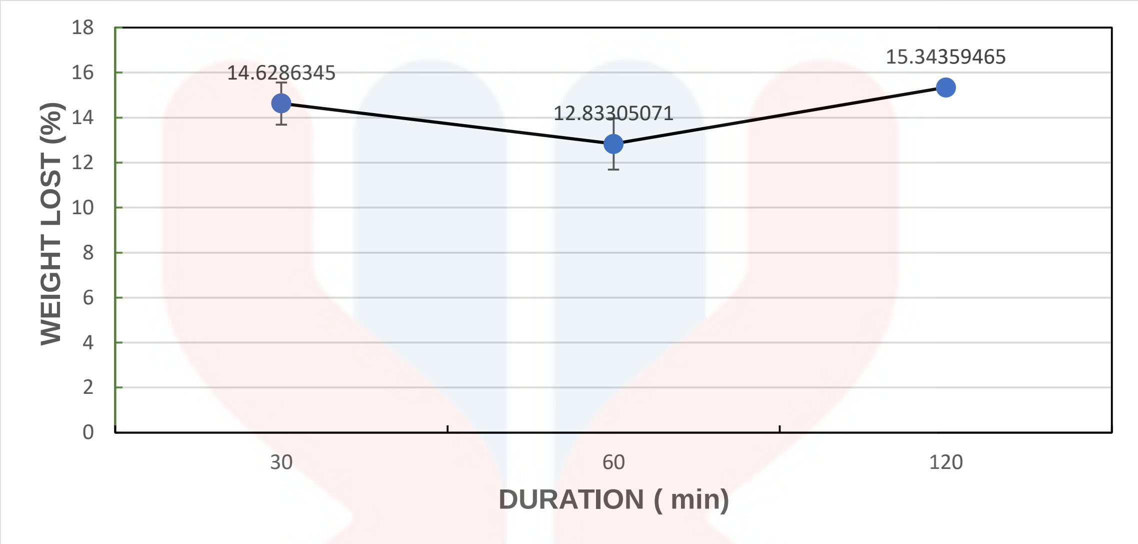


Figure 4.2.2: Effect of various duration on weight loss

The data on weight loss for kelat wood at different durations (30 minutes, 60 minutes, and 120 minutes) provides insights into how the wood undergoes changes in mass over time. Weight loss is a critical parameter in understanding how the wood responds to various environmental conditions, including factors like moisture, heat, or other degradation processes. This information is valuable in industries such as woodworking, construction, and furniture manufacturing where material stability is crucial. At 30 minutes, the weight loss of kelat wood is recorded as 14.63. This initial measurement indicates the reduction in mass after a relatively short duration of exposure. The standard deviation of 0.94 suggests a moderate degree of variability in weight loss measurements within the sample group, indicating that the wood's response to weight loss may vary among different samples. As the duration increases to 60 minutes, the weight loss decreases to 12.83. This suggests that the wood experiences a reduction in mass or volume over time.

4.2.3 Colour Changes

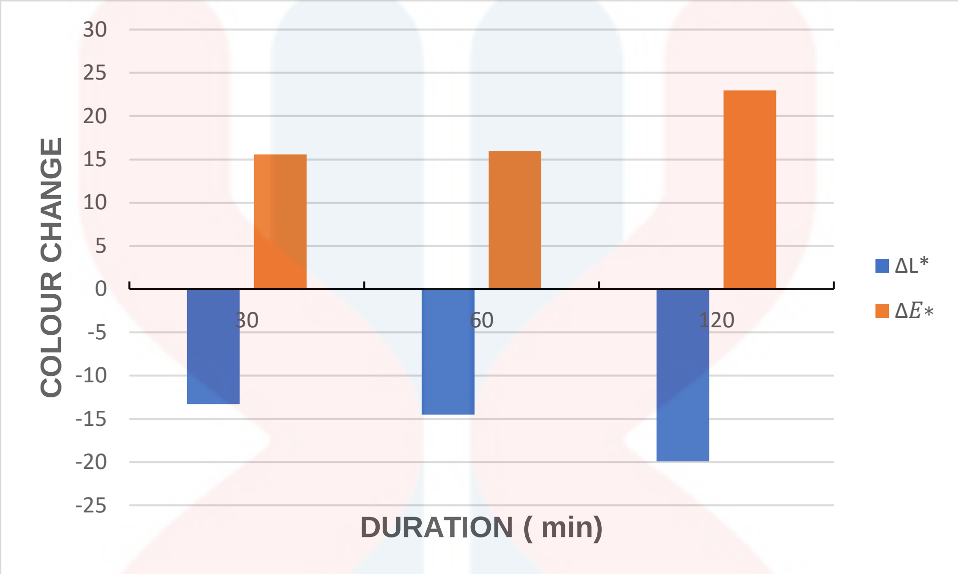


Figure 4.2.3: Effect of various duration on color changes

The data on colour change for kelat wood at different durations (30 minutes, 60 minutes, and 120 minutes) provides valuable insights into how the wood's visual appearance evolves over time. Colour change is a critical parameter in applications such as woodworking, furniture manufacturing, and design, where the aesthetics of the final product are of significant importance. At 30 minutes, the colour change of kelat wood is recorded as -13.3, indicating a decrease in lightness and an associated change in colour. The negative value suggests a darkening of the wood's colour after a relatively short duration of exposure. The corresponding colour change value of 15.59 indicates a significant shift in the overall colour, reflecting alterations in pigments or other factors affecting the wood's appearance. As the duration increases to 60 minutes, the colour change becomes more pronounced, with a decrease in lightness to -14.5 and a colour change value of 15.94. This suggests that the wood continues to undergo changes in colour, with a further darkening effect. The relatively consistent colour change values between 30 and 60 minutes may indicate a steady progression in the alteration of the wood's visual characteristics.

At 120 minutes, the colour change intensifies, with a more substantial decrease in lightness to -19.9 and a higher colour change value of 22.98. This indicates a more significant darkening of the wood's colour over an extended duration. The higher colour change value suggests a more pronounced alteration in the wood's appearance, which can be crucial information for industries were maintaining or achieving specific colours is essential for product quality and customer satisfaction.

4.2.4 Water Absorption

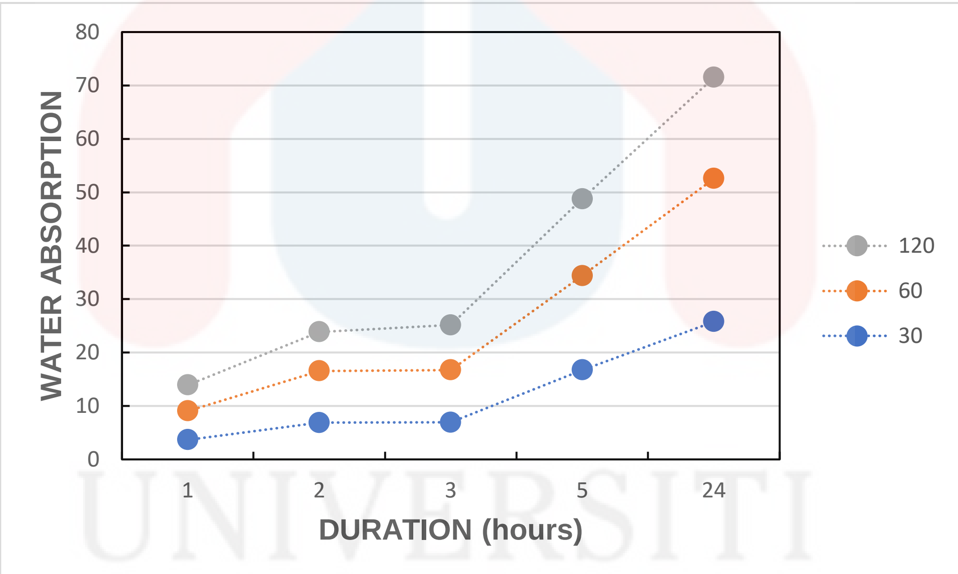


Figure 4.2.4: Effect of various duration on water absorption

The graph shows the percentage of water absorption in a sample over time during four thermal treatments. The x-axis shows the duration of the experiment in hours, and the y-axis shows the water absorption in percent. The four lines represent samples that were treated at 150°C, 180°C, 210°C, and an unspecified reference temperature. The sample treated at 180°C absorbs water slightly faster and reaches a higher equilibrium level than the sample treated at 150°C. This is likely due to the reasons increased mobility and weakened bonds at the higher temperature. The difference in water absorption between these two samples is more pronounced. The sample treated at 210°C absorbs water significantly faster and reaches a much higher equilibrium level. This suggests that the effect of temperature on water absorption becomes more pronounced at higher temperatures. The difference between the sample treated at 210°C and the reference sample is the most significant. This highlights the effect of the thermal treatment on increasing water absorption.

4.2.5 Thickness Swelling

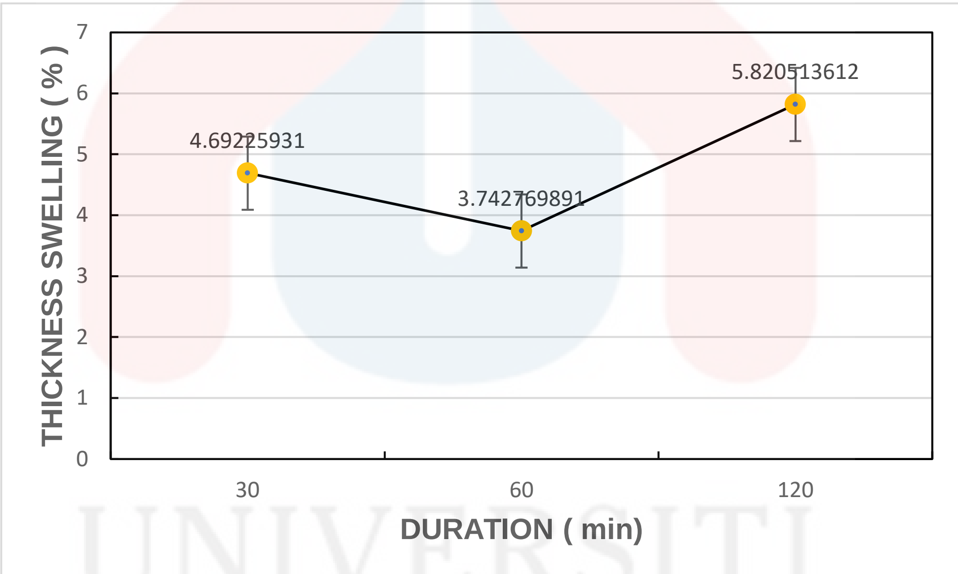


Figure 4.2.5: Effect of various duration on thickness swelling

The data on thickness swelling for Kelat wood at different durations (30 minutes, 60 minutes, and 120 minutes) provides insights into how the wood's dimensional stability changes over time when exposed to certain environmental conditions. Thickness swelling is a crucial parameter in assessing how much a material expands or contracts when it absorbs or loses moisture, and it is particularly important in applications where dimensional stability is critical, such as in construction or furniture manufacturing. At 30 minutes, the thickness swelling for Kelat wood is recorded as 4.69. This measurement indicates the percentage increase in thickness compared to the original dimensions after a relatively short duration of exposure.

4.2.6 Effect of Treatment Duration on MOR

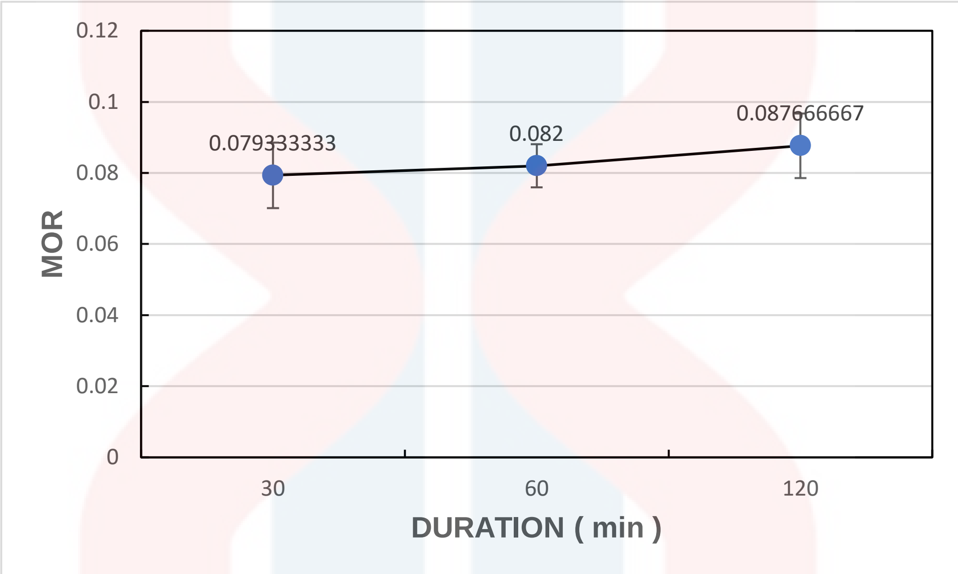


Figure 4.2.6: Effect of treatment duration on MOR

The data on bending strength for kelat wood at different durations (30 minutes, 60 minutes, and 120 minutes) provides valuable insights into how the wood's ability to withstand applied forces changes over time. Bending strength is a crucial mechanical property, reflecting the material's resistance to deformation under stress, and it is particularly important in applications where the wood needs to bear loads or stresses, such as in construction or structural engineering. At 30 minutes, the bending strength of kelat wood is recorded as 0.0793. This initial measurement indicates the maximum stress the wood can endure during a bending test after a relatively short duration of exposure.

4.2.7 Effect of Treatment Duration on MOE

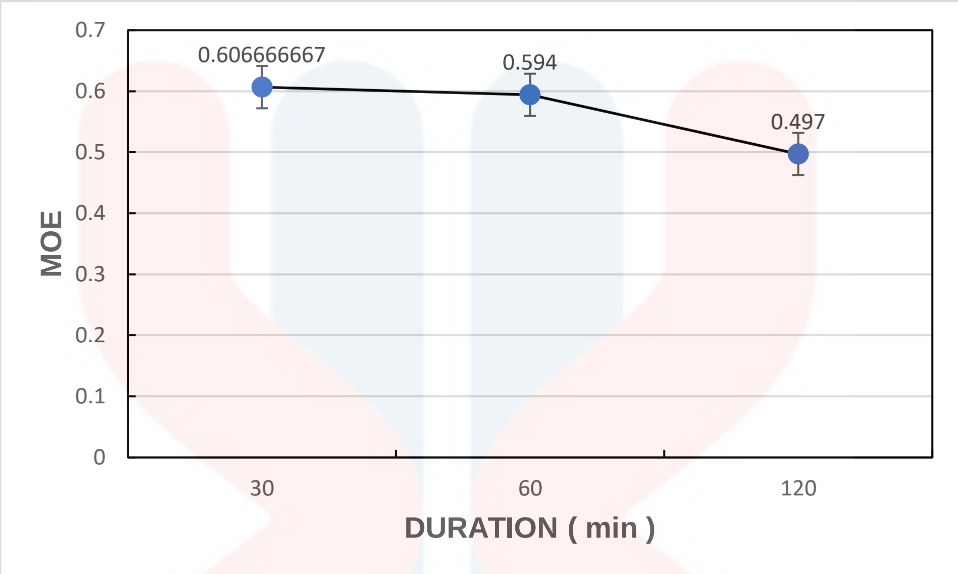


Figure 4.2.7: Effect of treatment duration on MOE

The data on bending modulus for kelat wood at different durations (30 minutes, 60 minutes, and 120 minutes) provides insights into how the wood's flexibility and stiffness change over time. Bending modulus, also known as flexural modulus or modulus of elasticity, is a crucial mechanical property that indicates a material's resistance to bending deformation. This property is essential in applications where the wood needs to maintain its structural integrity and resist deformation under load. At 30 minutes, the bending modulus of kelat wood is recorded as 0.6067. This initial measurement represents the wood's ability to resist bending deformation after a relatively short duration of exposure

4.2.8 Effect of Treatment Duration on Impact Strength

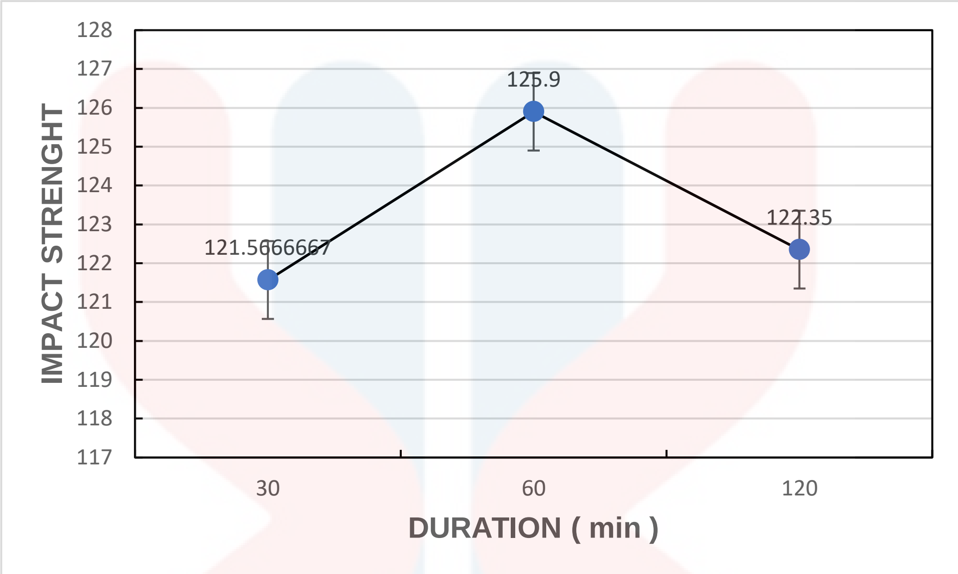


Figure 4.2.8: Effect of treatment duration on Impact Strength

The data on impact strength for kelat wood at different durations (30 minutes, 60 minutes, and 120 minutes) provides insights into how the wood's resistance to sudden forces changes over time. Impact strength is a critical mechanical property that reflects a material's ability to absorb energy during sudden impact or shock. This information is crucial in applications such as construction and woodworking, where materials need to withstand potential impact loads. At 30 minutes, the impact strength of kelat wood is recorded as 121.57, indicating the maximum force the wood can absorb during an impact test after a relatively short duration of exposure. The standard deviation of 5.39 suggests a moderate degree of variability in impact strength measurements within the sample group at 30 minutes, indicating that the wood's response to impact forces may vary among different samples. As the duration increases to 60 minutes, the impact strength slightly increases to 125.9. This suggests that, under higher thermal conditions or prolonged exposure, the wood may exhibit a modest improvement in impact resistance.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The purpose of this study was to investigate thermal treatment field wood. The effect of heat modification treatment on field samples was evaluated based on physical and mechanical properties. To conclude, the results of analysis data for untreated and treated density test, dimensional stability test, flexural property test, color change and impact strength of wood samples are not significant. Wood treated with heat modification changes has more dimensional stability. The bending strength of wood that has undergone heat modification has been improved and increased to higher values. The color characteristics of the treated samples were changed by thermal modification, although enhanced saturation and darkening, redness and yellowing effects were the main changes. This study shows that field wood is thermally modified at 180°C for temperature and 60 minutes to provide better quality wood and meet the requirements of wood quality standards., obtaining higher density and resistance, dark color, and increased dimensional stability. which supports their application for structural reasons. Therefore, heat treatment can be used in field wood to improve the physical and mechanical properties that add value to this wood species for end-use products although no significant differences in all treatments were found.

5.2 Recommendations

It is strongly advised to conduct further study on thermal treatment of quickly growing species, particularly with regard to enhancing the mechanical qualities of wood because these species have irrigation issues) and maximizing the industrial applications of most quickly growing species. Furthermore, research on various temperature and time combinations to enhance the wood's qualities is recommended. The foundation of heat treatment as a wood modification technique is the chemical breakdown of wood polymer by heat transmission. Thus, it is suggested that more research be done on strengthening wood's resistance to decay and providing dimensional stability. These enhancements, which significantly increase mechanical characteristics, call for more research. Finally, it is strongly advised to apply a preservation treatment that involves many chemical tests on wood in order to modify its thermal properties.

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APPENDIX A

Water Absorption Measurement weight (g)

JAM	TEMPERATURE 150	SD	TEMPERATURE 180	SD	TEMPERATURE 210	SD
1	5.624009539	0.876649	5.402400206	0.36441	3.760474142	0.744044
2	9.256588803	0.959831	9.675314069	0.485281	6.252155815	0.973744
3	9.879196837	1.150127	9.796237297	0.48595	6.360322114	0.976683
5	18.21173926	0.448328	17.65304932	0.668884	15.59340907	3.717029
24	32.50411167	1.231157	26.80989723	1.489586	27.43511769	2.54009

JAM	30 MINUTE	SD	60 MINUTE	SD	120 MINUTE	SD
1	3.647864788	0.563638	5.402400206	0.36441	4.864309672	1.198699
2	6.865761246	0.752104	9.675314069	0.485281	7.319179157	1.806794
3	6.931932955	0.808706	9.796237297	0.48595	8.418810228	1.645206
5	16.71889964	1.564946	17.65304932	0.668884	14.39640807	5.220589
24	25.76303527	1.075838	26.80989723	1.489586	18.92736128	6.034058

Color Changes

Sample	Before (L)	Before (a)	Before (b)	After (L)	After (a)	After (b)	ΔL*	Aa	Ab	$\Delta E*$
Control	64.9	6.4	30.4				60.6	3.6	28.1	
Sample A	59.4	9.4	22.9	52	5.2	21.5	-7.4	-4.2	-1.4	8.62
Sample B	57.1	8.2	18.3	42.6	4.5	12.8	-14.5	-3.7	-5.5	15.94
Sample C	71.2	7.3	30.2	33.5	6.2	8.2	-37.7	-1.1	-22	39.99
Sample D	60.7	7.9	24	47.4	2.5	17.9	-13.3	-5.4	-6.1	15.59
Sample E	58.9	9.3	24.4	39	4.1	12.9	-19.9	-5.2	-11.5	22.98

	ΔL*	$\Delta E*$
150	-7.4	8.62
180	-14.5	15.94
210	-37.7	39.99

	ΔL*	$\Delta E*$
30	-13.3	15.59
60	-14.5	15.94
120	-19.9	22.98

Bending MOE (Bending modulus)

Sample	Control	A	B	C	D	E
1	0.504	0.778	0.627	0.725	0.92	0.038
2	0.562	0.808	0.447	0.63	0.425	0.78
3	0.497	0.75	0.708	0.572	0.475	0.673
Average	0.521	0.778667	0.594	0.642333	0.606667	0.497
SD	0.035679	0.029006	0.133593	0.077242	0.272504	0.40109

	MOE	SD
150	0.778667	0.029006
180	0.594	0.133593
210	0.642333	0.077242

	MOE	SD
30	0.606667	0.272504
60	0.594	0.133593
120	0.497	0.40109

Bending MOR (Bending strenght)

Sample	Control	A	B	C	D	E
1	0.067	0.106	0.078	0.057	0.09	0.098
2	0.073	0.103	0.079	0.49	0.074	0.084
3	0.08	0.091	0.089	0.039	0.074	0.081
Average	0.073333	0.1	0.082	0.195333	0.079333	0.087667
SD	0.006506	0.007937	0.006083	0.255347	0.009238	0.009074

	MOR	SD
150	0.1	0.007937
180	0.082	0.006083
210	0.079333	0.255347

	MOR	SD
30	0.079333	0.009238
60	0.082	0.006083
120	0.087667	0.009074

Impact Strength

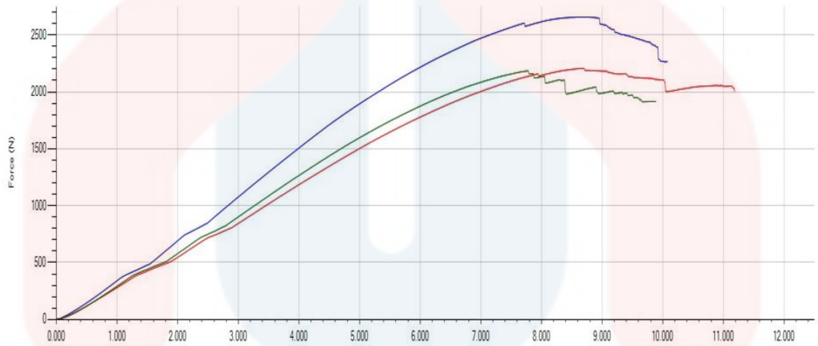
Sample	Control	A	B	C	D	E
1	68.9	125.7	118.05	128.8	115.35	120.65
2	78.9	123.3	127.05	127.7	125	124.4
3	82.55	107.05	132.6	118.5	124.35	122
Average	76.78333	118.6833	125.9	125	121.5667	122.35
SD	7.066883	10.14598	7.342854	5.65597	5.393592	1.899342

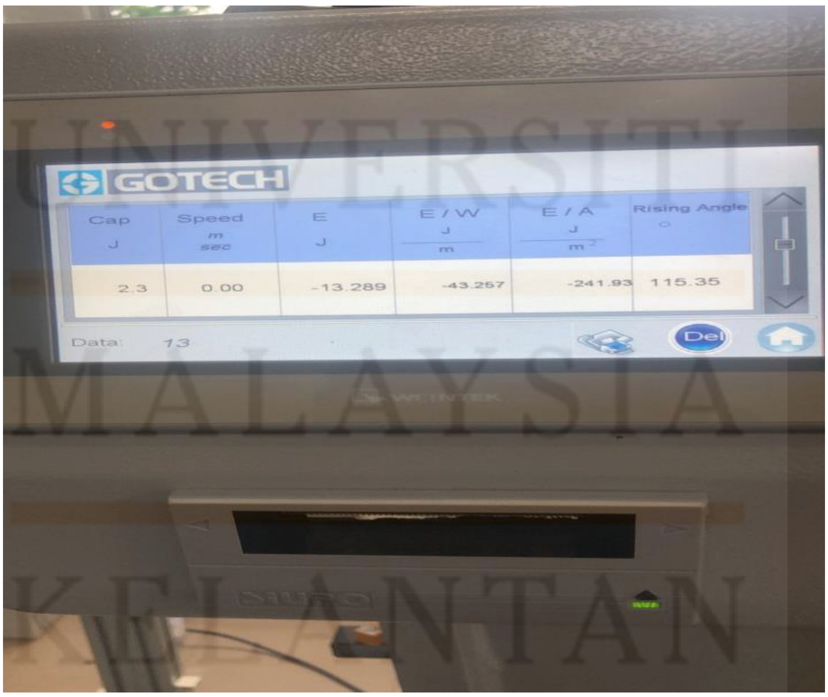
	IS	SD
150	118.6833	10.14598
180	125.9	7.342854
210	125	5.65597

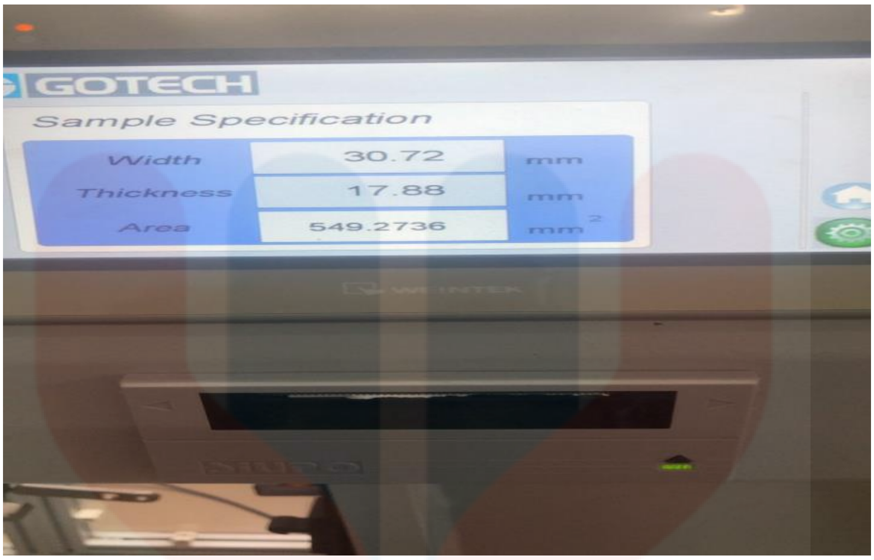
	IS	SD
30	121.5667	5.393592
60	125.9	7.342854
120	122.35	1.899342

APPENDIX B

		Bending Modulus	Bending Strength @ Peak (N/mm²) (N/mm²)
1	2656.700	0.920	0.090
2	2206.200	0.425	0.074
3	2184.500	0.475	0.074
Min	2184.500	0.425	0.074
Mean	2349.133	0.606	0.079
Max	2656.700	0.920	0.090
S.D.	266.581	0.273	0.009
C. of V.	11.348	44.950	11.348
L.C.L.	1686.901	-0.071	0.057
U.C.L.	3011.366	1.284	0.102






GOTECH
Sample Specification
Width
30.72
mm
Thickness
17.88
mm
Area
549.2736
mm2