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**Study on The Effects of Thermal Treatment on The
Properties of Medang Wood (*Cinnamomum porrectum*)**

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**A reported submitted in fulfilment of the requirements for the
degree of Bachelor of Applied Science (Forest Resource
Technology) with Honours**

**FACULTY OF BIOENGINEERING AND TECHNOLOGY
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2024

DECLARATION

I declare that this thesis entitled “Study On The Effects Of Thermal Treatment On The Properties Of Medang Wood (*Cinnamomum porrectum*)” is the results of my own research except as cited in the references.

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ACKNOWLEDGEMENT

Alhamdulillah, all praises to Allah SWT for the strength and His blessing in my final year project journeys. First and foremost, I would like to express my appreciation and sincere thanks to my supervisor, Dr Andi Hermawan, for providing me with the opportunity to gain experience and for his continuous guidance, support and advice throughout every step to be able to accomplish this project successfully. This is definitely an invaluable experience.

Other than that, I owe a special thanks to my fellow research teammates, Muhammad Syafiq, Muhammad afiq, Muhammad Idham, Muhammad Nasharuddin and Muhammad Jalal for sharing their positive energy, exchanging knowledge and providing valuable memories that making me feel extremely spirited. Their assistance made the whole process possible to me. My fellow undergraduate students should also be recognized for their support.

Besides, I have to thank to the Faculty of Bioengineering and Technology (FBKT) for proving me with all the equipment and facilities that I need during my project journey. Not to forget, thanks to all the laboratory assistants, especially Cik Afifi, Cik Qamal, Kak Nisa and Kak Syida for their assistance in handling scientific equipment and their immense support and dedicated time throughout in finishing my research.

Most importantly, none of this could have happened without my family. I am very grateful for the support and encouragement from my family. My parents, who offered their patience, love, understanding and endless support, are to be thankful. A big thanks to Ma, Abah, and Adik for their unconditional love. I cannot forget their support and I hope I will receive the same love and guidance in my future endeavours as well.

Lastly, I want to thank me for believing in me, for doing all this hard work, for having no days off, for never quitting, for always being a giver and trying to give more than I receive, for trying to do more right than wrong, for always be strong-minded, for being me at all times. I want to make this journey memorable for my whole life. Thankyou!



Study On The Effects Of Thermal Treatment On The Properties Of Medang

Wood (*Cinnamomum porrectum*)

ABSTRACT

The market demand for timber is continuously rising now and future. However, the high-quality standard timber may not be able to encounter the use in current years due to the scarcity of timber from the forests. Therefore, wood modification technology to increase the properties of the timber is beneficial to meet the requirement for various functions and expand its life service. This study is proposed due to the shortage of high-quality timber from forests, and the Malaysians government has promoted fast-growing species to replace the timber. In this regard, thermal treatment has been developed and by exposing timber to the heat that leads to the structural changes of the timber. This research aims to study effects of thermal treatment on the physical and mechanical properties of Medang wood. Medang wood samples was processed into 300×200×30 mm in dimensions and were undergone in the treatment based on duration and temperature with three different temperatures of 150, 180 and 210 °C, and three different duration of 30, 60 and 120 minutes. The evaluation was involving with several testing including density, weight loss, color changes, water absorption, thickness swelling, bending properties, and impact strength. The results show that the thermal modification significantly affect the physical and mechanical properties of the Medang wood.

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

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Kajian Kesan Rawatan Terma Terhadap Sifat Kayu Medang (*Cinnamomum porrectum*)

ABSTRAK

Permintaan pasaran untuk kayu terus meningkat sekarang dan akan datang. Walau bagaimanapun, kayu standard berkualiti tinggi mungkin tidak dapat digunakan pada tahun-tahun semasa kerana kekurangan kayu daripada hutan. Oleh itu, teknologi pengubahsuaian kayu untuk meningkatkan sifat kayu adalah bermanfaat untuk memenuhi keperluan untuk pelbagai fungsi dan memperluaskan perkhidmatan hayatnya. Kajian ini dicadangkan kerana kekurangan kayu berkualiti tinggi daripada hutan, dan kerajaan Malaysia telah mempromosikan spesies yang tumbuh pesat untuk menggantikan kayu itu. Dalam hal ini, rawatan haba telah dibangunkan dan dengan mendedahkan kayu kepada haba yang membawa kepada perubahan struktur kayu. Penyelidikan ini bertujuan untuk mengkaji kesan rawatan haba terhadap sifat fizikal dan mekanikal kayu Medang. Sampel kayu Medang telah diproses kepada dimensi 300×200×30 mm dan telah menjalani rawatan berdasarkan tempoh dan suhu dengan tiga suhu berbeza iaitu 150, 180 dan 210 °C, serta tiga tempoh berbeza iaitu 30, 60 dan 120 minit. Penilaian itu melibatkan beberapa ujian termasuk ketumpatan, penurunan berat badan, perubahan warna, penyerapan air, bengkak ketebalan, sifat lenturan dan kekuatan hentaman. Hasil kajian menunjukkan pengubahsuaian haba secara signifikan mempengaruhi sifat fizikal dan mekanikal kayu Medang.

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

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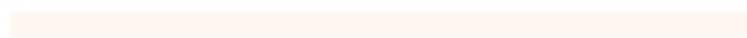


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CHAPTER 1

INTRODUCTION

1.1 Background of Study

It is widely acknowledged that the accumulation of greenhouse gases in the atmosphere due to human activity, sometimes known as the "greenhouse effect," modifies the climate adversely and increases the likelihood of global warming. Because of processes like material synthesis, which requires extensive fossil fuel combustion, human activities increase the concentration of greenhouse gases in the atmosphere. A green approach has been promoted and is now the top priority in order to minimise the quantity of greenhouse gases, such as carbon dioxide, discharged into the atmosphere.

Conversely, trees absorb carbon dioxide and use water, sunshine, and nutrients to grow wood, releasing oxygen into the atmosphere. Removing wood from trees for a variety of purposes uses less energy than removing other materials, including metal and cement, which are used as building materials. Wood is therefore a multipurpose, environmentally beneficial natural substance that has remarkable results in its qualities and is utilised for both structural and non-structural reasons. However, the drawbacks of utilising wood for a variety of purposes include its weak resistance to assaults by biodegrading organisms and dimensional instability brought on by its high hygroscopicity.

Much research has been conducted to improve the durability and dimensional stability properties of the wood, such as wood modification technology that involves the

physical, mechanical, and chemical treatment of the wood. (Kubovský et al) investigated a heat treatment in the wood application and suggested that this thermal treatment is an environmentally friendly and effective low-cost treatment method that improves in microbial resistance of the wood and enhance its dimensional stability without using any toxic chemicals.

According to reports, heat treatment of wood has a major impact on the structure of the wood. The physical and mechanical characteristics of wood are also impacted by thermal treatment, which enhances the use of wood products for both interior and outdoor applications such decks, siding, and fences. According to (Lee et al., 2018), treated wood gives off a warm brown hue and can increase dimensional stability by up to 50% while providing protection against fungus, rot, and most insects. Partially hemicelluloses and other materials are broken down by TM by heating them to 120°C, which can happen in an open or closed process with or without vapour pressure. (Xu et al, 2019).

This study investigates the properties of thermally modified Medang wood (*Cinnamomum porrectum*). The focus of the study was on the effects of temperature treatment and duration on the physical, mechanical and biodegradable properties of the wood. For this purpose, the wood is exposed to heat at different temperature and durations. The effects of thermal treatment of the wood on the density, dimensional stability, modulus of rupture (MOR) and modulus of elasticity (MOE) properties of the wood against subterranean termite are examined.

1.2 Problem Statement

The market demand for timber is continuously rising now and future. However, the high-quality standard timber may not be able to encounter the use in current years due to the scarcity of timber from the forests. Therefore, wood modification technology to increase the properties of the timber is beneficial to meet the requirement for various functions and expand its life service. In this regard, thermal treatment has been industrialized and by exposing timber to the heat that leads to the structural changes of the timber.

This study was proposed due to the shortage of high-quality timber from forests, and the Malaysians government has promoted fast-growing species to replace the timber. However, fast-growing species were found to have inferior properties, thus requiring additional processing to improve their properties for various functions. Therefore, the effects of thermal treatment on Medang wood properties were proposed in this study.

1.3 Objectives

The objectives of this study are as follows:

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 Medang wood and evaluate the effects of temperature and duration on the physical and mechanical properties of the wood. Medang wood will be exposed to heat at different temperatures and durations. The density, dimensional stability, colour 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 Medang wood was only employed in certain applications because of its subpar qualities. The goal of this study is to determine whether heat treatment may enhance Medang 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, industrialised 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, harvested trees from production forest was used for wood production, usually aiming for high-quality trees which most of them are slow-growing species causing pressure in forested areas. In this matter, it is considerable to carried out solutions by using the fast-growing timber species to replace and reduce the forest pressure occurred. Thermal treatment is expected to improve the dimensional stability and bending properties of the wood. Thus, this study was essential to fill the shortage of high-quality timber from the forest and add value to the lesser commercial species for various market products.

CHAPTER 2

LITERATURE REVIEW

2.1 Thermal Modification of Wood

Commercial production of heat modification wood (TMT) typically occurs at temperatures ranging from 160 to 240 degrees Celsius. This results in a material that is darker in colour and more resistant to microbes than unaltered wood. However, it also significantly reduces strength, especially in the area of fracture resistance due to its decreased ductility. As a result, TMT is not appropriate for many load-bearing applications (Callum Hill, Michael Altgen & Lauri Rautkari, 2021). Thermal modification is defined as occurring beyond this temperature, and heating wood below this point can cause irreversible changes. The chemistry of thermal deterioration, especially lignin, varies below about 150 C (Callum Hill, Michael Altgen & Lauri Rautkari, 2021). The thermal modification procedure does not employ temperatures beyond 240 C because the wood degrades too much for the process to be commercially viable (Callum Hill, Michael Altgen & Lauri Rautkari, 2021).

Harry Tiemann, a kiln specialist at the Forest Products Laboratory in Madison, Wisconsin, burned air-dried wood in superheated steam at 150 C and observed a reduction in TMT hygroscopicity in 1915 (Callum Hill, Michael Altgen & Lauri Rautkari, 2021). The Forest Products Laboratory continued similar study in the 1930s and 1940s, resulting in patents (Callum Hill, Michael Altgen & Lauri Rautkari, 2021). Early attempts in the

United States involved heating buried wood beneath molten metal at temperatures ranging from 160 to 260 degrees Celsius. This was not a commercial success, as one might expect. Throughout the 1970s and 1980s, research and development continued, with multiple failed commercialization attempts in Germany. (Callum Hill, Michael Altgen & Lauri Rautkari, 2021). However, there was a resurgence of interest in thermal and commercial landscape modifications that were ideal for this technology in the 1990s. (Callum Hill, Michael Altgen & Lauri Rautkari, 2021). The well-established commercial technology of TMT which was increasingly used in exterior cladding, deck and wood applications in the twenty-first century, with European TMT output currently exceeding 500,000 m³ (Callum Hill, Michael Altgen & Lauri Rautkari, 2021).

2.2 Wood Properties

There are several varieties of wood, and each has a special set of mechanical and physical properties. Wood is an incredibly adaptable material. Furthermore, it is a resource with an exceptional strength-to-weight ratio and the ability to be replenished. Since making a useful end product from wood requires a substantially smaller amount of energy than manufacturing an equal end product from competing materials like plastic, steel, or concrete, wood is a necessary building resource. In a humid environment, wood may absorb moisture; in a dry one, it may release moisture. Wood's moisture content fluctuates depending on the external factors it is exposed to, such as humidity and temperature. 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.

Over time, timber businesses worldwide have limited the quantity of chemicals used to improve the qualities of wood as the need to prevent contamination of the environment has grown. Thus, thermal modification is a wood-related environmentally friendly choice. This resource-efficient process increases the durability, stability, and qualities of wood products while having a minimal negative impact on the environment over a longer service life. Softwood species are rendered more desirable by the new characteristics of thermally treated wood, which significantly modify their characteristics. Wood's physical characteristics, such as how it reacts to other influences other than those applied directly to it, are what quantitatively define 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.

Wood decay fungus and other timber organisms require the right conditions of oxygen, moisture, and food in order to grow and thrive. Wood that is maintained dry (moisture content less than 20%) won't degrade. However, wood usually doesn't deteriorate if left submerged for a long time at the right depth. When wood is located in the middle of these two extremes, deterioration issues may arise. An architect or engineer might use naturally durable species or treat the wood to keep it from becoming wet in order to prevent damage. The species and anatomical characteristics of wood affect how resistant it is to degradation mechanisms and processes. Sapwood of all species typically has little resilience to deterioration and fails quickly in severe environments. Heartwood's natural resilience differs depending on the species. The sapwood's cells progressively die and give way to the heartwood. Certain species' cell walls contain toxic extractives that

are manufactured from the sugars found there. Wood may be made more durable by using a hazardous preservation chemical that is certified with the EPA.

2.3 Wood modification

Wood is a natural material that is both ecologically friendly and sustainable. It is used for both structural and non-structural purposes. Its mechanical quality is excellent. One of wood's biggest drawbacks is its hygroscopicity, which causes dimensional instability. Wood's notable hygroscopicity and poor durability, in particular, significantly restrict its outside use. The term "wood modification" encompasses a wide range of processes, including chemical, mechanical, biological, and physical ones, that are used to alter a material's properties. The entire range of changes that occur to wood once it leaves the forest is included in this definition of wood modification. "Wood modification involves the activity of chemical, biological, or physical agent onto the material, resulting in a desired property enhancement during the service life of the modified wood," according to Hill.

Under normal circumstances, the modified wood should be safe to use, and there shouldn't be any harmful chemical releases during use, disposal, or recycling. The mode of action should not be biocidal if the modification is intended to boost biological resistance. It is important to note that, as long as no harmful residues are left behind once the wood modification process is finished, using a hazardous chemical to create changed wood is not always illegal. The alteration of wood characteristics at the cell wall level is a crucial aspect of the concept of wood modification. Thermal, chemical, and

impregnation modification are the three methods that are employed in the commercial world. 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.

Wood modification is a wide term that includes the use of chemical, physical, and biological approaches to change a material's properties. Improving the wood's functioning is the goal, and doing so improves its dimensional stability, decay resistance, weather resistance, and other qualities. It's critical that the modified wood is non-toxic when in use and that disposing of it doesn't leave behind any hazardous materials. Over the past five years, significant breakthroughs in wood modification technologies have been made, especially in the commercial sector. 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, Medang 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.

Recently, thermal modification has been utilised to improve the dimensional stability and durability of timber, making it a feasible technique. In many nations, thermal modification has the highest market value of all modification procedures. The chemical components of wood cell walls change at temperatures higher than 180°C. The decrease of sorption in water molecules caused by the hydrolysis of cellulose and hemicelluloses alters the dimensional stability and durability of wood. Depending on the kind of wood and intended use, thermal modification is carried out at temperatures ranging from 180 to 240°C at the manufacturing scale. Up until recently, a wide variety of hardwood and

softwood species were employed in thermal modification. Timber that has been thermally treated (TMT) is commonly used to produce various wood products, including furniture, cladding, decking, and interior joinery. Additionally, TM was altered in timber cells to effectively lower the moisture content of the wood's cells. But this technology doesn't work at temperatures higher than 240 °C, which leads to deterioration and makes the wood too plain for the procedure to be worth a profit. The heat-treatment process uses temperatures ranging from 180 to 240°C for a maximum of a few minutes to several hours, depending on the required degree of alteration.

Thermally treated wood dramatically changes the properties of fast-growing species, making them more aesthetically pleasing. Additionally, when fast-growing species are thermally modified, less wood dust is produced during the remanufacturing process when the temperature is lowered below 200°C. One benefit of thermally modifying wood is that it becomes more dimensionally stable, with reduced shrinkage and swelling as a result of changes to the cell wall's polymeric components. This reduces the hygroscopicity of the treated wood by preventing water molecules from attaching themselves to the cellulose structure. Recent years have seen a great deal of research conducted on thermal modification of wood, driven by the growing desire to find non-toxic ways to improve wood's durability without using potentially dangerous chemicals. The chemical, physical, and mechanical qualities of wood undergo permanent changes when heated. The type of treatment, the length of time it is applied, the temperature at which it is applied, and the composition of the wood all affect how much of these changes occur. The temperature is far more important to monitor than how long something takes to heat up. When wood undergoes heat treatment, its equilibrium moisture content decreases and its dimensional stability increases. Wood that has been heat-treated is more resistant to fungus invasion.

Thermally modified wood has undergone irreversible changes due to the application of chemicals, compression, or heating, leaving it with different properties than previously. Thermally treated wood is heated to change its composition. In addition, the wood is heated to temperatures exceeding 180°C while being oxygen-starved in order to stop it from burning. During the process, the wood's chemical structure changes, improving the material's stability and tensile strength. Water absorption is reduced in wood cells that have had their organic components removed compared to those that have not. As a result, the boards made from the heat-treated wood will twist and warp less. Consequently, fungus and insects were avoided. What's left over is a durable wood that is impervious to moisture, decay, and insect infestation. Water is retained in the cell walls together with the cell itself before to kiln drying, and some water is retained in the cell walls following kiln drying. Nevertheless, upon heat modification, cell walls irreversibly dissolve, decreasing the amount of water that may be stored.

Any species of wood can be thermally modified, however thick hardwoods are not needed because they are naturally resistant to rot, fungus, insects, and moisture. The only way to alter the appearance of oak and other hardwoods is by heat treatment. The rich, dark brown colour that thermally treated wood has gives it an easy to identify appearance. It is therefore appropriate for softwoods or light hardwoods that are probably good candidates for heat treatment.

2.4 Effect on Thermal Modification

Emulgel Thermal modification, certain versions of which are now commercially available, is the most industrially useful method of wood modification. All of them work on the premise that components of the cell wall undergo chemical changes at temperatures more than 150°C. Numerous processes take place at these temperatures, such as the different condensation reactions, radical and oxidation reactions, and hydrolytic polysaccharide splitting. As a result of the treatment, several distinct chemical reactions take place during the thermal modification. According to (Militz and Altgen ,2014), hemicelluloses are the first parts of the cell wall to be impacted by the high temperatures that are usually employed throughout the operations. Consequently, qualities like dimensional stability and durability are advantageous.

Conversely, heat treatment causes a partial disintegration of cell wall composites, which weakens and discolours materials. Thus, wood modification is not used on elements that are intended to support weight. The most popular uses are for decking, garden wood, cladding, and other purposes. Because of its dark hue and heat alteration process, interior design is another field in which it finds application. Because of mass loss and heat-induced cell wall element disintegration, thermally modified wood has a lower density than untreated wood. 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, during remanufacturing procedures, the production of wood dust is decreased when softwoods are thermally modified at temperatures lower than 200°C.

Depending on the required amount of alteration, the thermal modification method employs temperatures between 150 and 260°C for a few minutes to many hours. One benefit of thermally altering wood has been discovered: low shrinkage and swelling values are caused by changes to the cell wall's polymeric components, which improves the wood's dimensional stability. Therefore, it reduces the hygroscopicity of the treated wood by preventing water molecules from connecting with the cellulose structure. In addition, a crucial factor in assessing a product's worth based on its existence is the way wood changes colour.

Thus, the darkening of the wood brought about by hemicellulose and lignin breakdown and their transformation into extractive chromophores enhances the treated wood's visual qualities. Moreover, the degree of treatment might have an impact on the mechanical qualities. To ensure that no significant mechanical quality loss occurs, which might limit the material's potential uses, it is crucial to determine the right processing conditions for any type of wood. Following heat treatment at temperatures over 200°C, there is a significant reduction in both the modulus of rupture and the modulus of elasticity for static bending.

2.5 Characterisation Techniques

The study of thermally modified Medang wood was characterized its properties by using several testings, which is Dimensional Stability and UTM. The characterization was characterizing the effect on Medang properties after the thermal modification 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 Medang wood changes with different temperatures and durations of thermal treatment. The colour of the thermally treated Medang 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. Medang 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 Medang, and this may be responsible for the development of colourful chemicals during chemical reactions.

2.7 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.

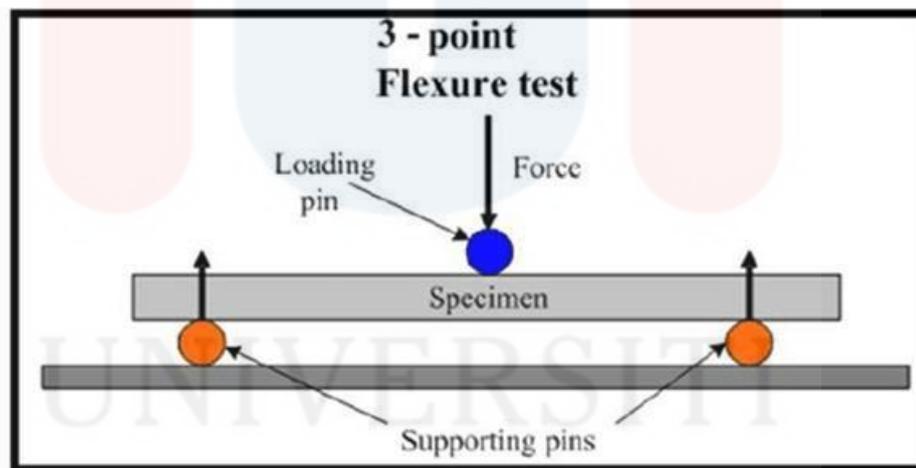


Figure 2. 1: Illustration of 3-point bending test

CHAPTER 3

MATERIALS AND METHODS

3.1 Raw Materials

In this study, Medang wood (*Cinnamomum Porrectum*) was obtained from a local sawmill in Jeli, Kelantan was used as raw material for thermal modification treatment. The wood was further processed using circular saw into dimensions of 300 mm in length \times 200 mm in width \times 20 mm in thickness and air-dried for a month. The wood was then oven dried at temperature of 70°C to a moisture content of 12%.

3.2 Methodology.

3.2.1 Thermal Modification

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

Table 3. 1: Thermal modification schedules

HEAT TREATMENT	
TEMPERATURE (°C)	DURATION (MIN)
PHASE 1	
100	24(HOURS)
PHASE 2	
150	60
180	
210	
180	
	30
	120
PHASE 3	
80-90	30

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3.2.2 Density Measurement

The wood was processed into the sample with a 300×200×30 mm dimension. 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 according to the equation below:

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

Where ρ is wood density (g/cm³) of the sample, m is mass of the sample (g), and V is volume of the wood sample (cm³).

3.2.3 Weight loss Measurement

Weight of the samples before and after thermal modification was measured. The dimensions of the sample were 300×200×30 mm. Then, the weight loss of the samples due to heat treatment was calculated according to the equation below:

$$WL (\%) = \frac{w_0 - w_1}{w_0} \times 100$$

Where WL is the weight loss due to the heat treatment, w_0 and w_1 are the sample weight before and after thermal modification.

3.2.4 Color Change Measurement

The color of sample before and after thermal modification was measured by using a Colour Reader. The color index was defined by the following cartesian chromatic coordinates: lightness L^* , which varies from 0 (black) to 100 (white); and a^* and b^* coordinates, which define the chroma (the colors vary from green to red along 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 color change (ΔE^*) were calculated using the following equation:

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

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

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

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

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

3.2.5 Water Absorption Measurement

The wood was processed into the sample with a 20×20×50 mm in dimension. The thermally modified and control wood sample were immersion in the water. After 1, 2, 3, 5, and 24 hours of prolonged immersion, the mass of the sample were measured. Water absorption was calculated using the following equation.

$$WA (\%) = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100$$

Where WA is water absorption (%), W_{wet} is weight of the samples after immersion (g) and W_{dry} is the initial weight (g).

3.2.6 Thickness Swelling Measurement

Using the same sample with water absorption measurement above, the dimension of the wood samples in tangential direction were measured using the digital micrometer after 24 h of immersion.

$$Thickness Swelling (\%) = \frac{l_{wet} - l_{dry}}{l_{dry}} \times 100$$

where l_{wet} is dimension after immersion (mm) and l_{dry} is dimension before immersion (mm).

3.2.7 Bending Properties Measurement

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

$$Impact\ Strength = \frac{E}{A}$$

Where, *E* is the energy absorbed during fracture (joules). *A* is the cross-sectional area of the specimen (mm²)

RESULTS AND DISCUSSION

4.1 Effect of Temperature on The Properties of Modified Medang Wood

4.1.1 Density

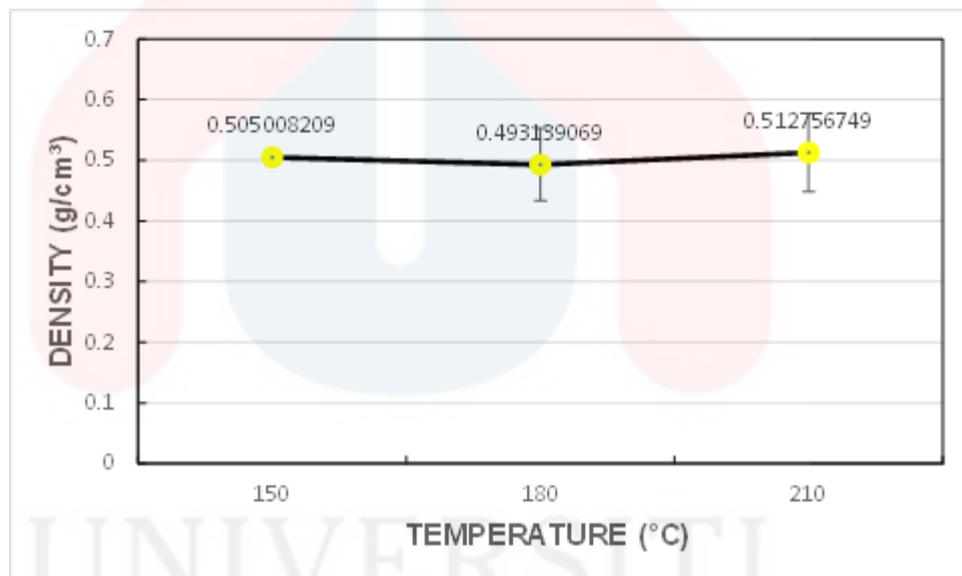


Figure 4. 1: Effect of various temperature on density

Figure 4.1 shows the effect of different temperatures on density. When compared to samples treated at 150°C and 180°C, the density decreased to 0.5 and 0.49 g/cm³. Compared to the Medang wood sample at a temperature of 210°C shows an upward pattern with 0.51 g/cm³. Meanwhile, the sample treated at 180°C has a lower effect on Medang wood among the treated samples. The figure shows that the influence of temperature on density was not substantial. Due to thermal degradation of cell wall

components and mass loss during treatment, the density of wood treated at higher temperature should have lower density. The release of byproducts is the cause of the increased mass loss that occurs throughout the heat treatment process. This is a consequence of the thermal degradation of lignin and as a direct result of the transfer of volatile compounds, the wood density will decrease (Owoyemi JM, 2016). However, as stated above, there was no substantial difference between the samples treated at 150, 180 and 210 °C.

4.1.2 Weight loss

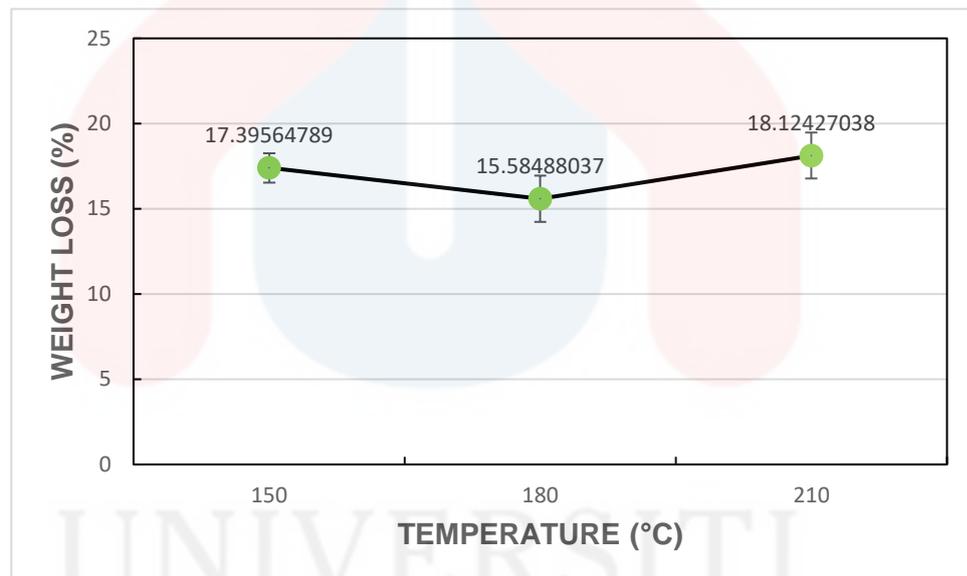


Figure 4. 2: Effect of various weight loss in temperature

Figure 4.2 shows the effect of various treatment temperatures on the weight loss of the sample. Each sample weight was recorded before and after the heat treatment was carried out to obtain the rate of weight loss and evaluate the effect of different temperatures on this rate. It was found that a temperature of 210°C caused the highest weight loss in the sample which was 18.12% followed by a temperature of 150°C with a

weight loss rate of 17.39%. However, the sample treated at 180°C had the lowest weight loss rate which is 15.58%. The reason of this tendency was unclear, and need further investigation is needed. In general, samples heated to 150°C results in the loss of water and extractives as well as changes in chemical bonds, whereas a sample heated to 180°C results in the greatest degradation of the wood's macromolecular constituents, and a sample heated to 210°C results in total degradation of the wood's constituents. As stated above, this is because as the treatment temperature increase the release of by-products increased mass loss that occurs throughout the heat modification process.

4.1.3 Colour Changes

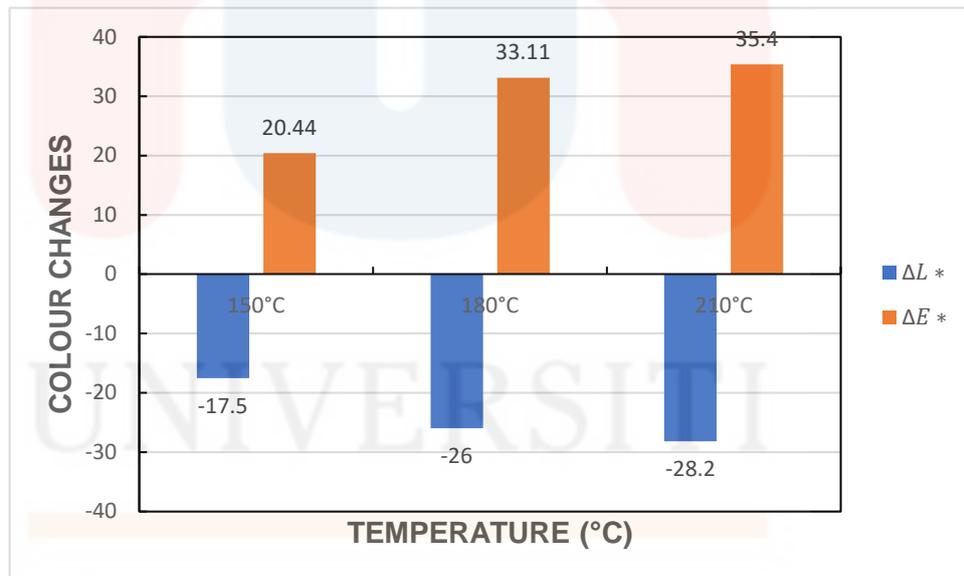


Figure 4. 3: Effect of various temperature on color changes

Figure 4.3 shows the color change in the sample after heating to various temperatures. All treated samples were recorded L^* (Brightness) a^* (red-green) and b^* (yellow-blue) values before and after the treatment to obtain the rate of color change that occurred. The results show that the sample treated at 210°C is seen to have the most

significant reduction in brightness. Therefore, the ΔE^* value of this sample is the highest, followed by samples treated at 180 and 150 °C. This is because the brightness of the wood accentuates the overall color change. The loss of wood brightness during treatment is due to the production of hemicelluloses and extracts, thermal degradation products, or lignin polymerization processes. As shown above, the colour change in the sample increases as the temperature increases.

4.1.4 Water Absorption

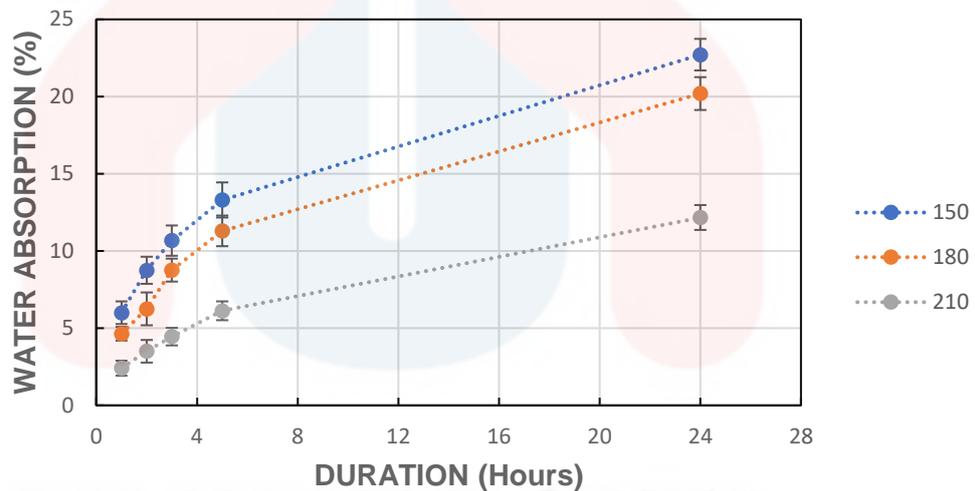


Figure 4. 4: Effect on various temperature on water absorption

Figure 4.4 shows the water absorption rate of the sample after 1, 3, 4, 5 and 24 h of immersion in water. All samples were found to experience a continuous increase in weight while immersed in water. Moreover, the figure shows that the rate of water absorption decreases with increasing treatment temperature. After 24 hours of immersion, the sample at 150°C produced the highest water absorption rate of 22.7%. Meanwhile, the sample treated at 180°C has a water absorption rate of 20.2%. It was found that the

sample treated at 210°C had a water absorption rate of 12.16% which was the lowest among the treated samples. This was expected given the process by which hydrophilic hydroxyl groups attract moisture to their surface by creating hydrogen bonds. Therefore, the heat treatment used in this study has a positive effect on increasing the dimensional stability of Medang samples.

4.1.5 Thickness Swelling

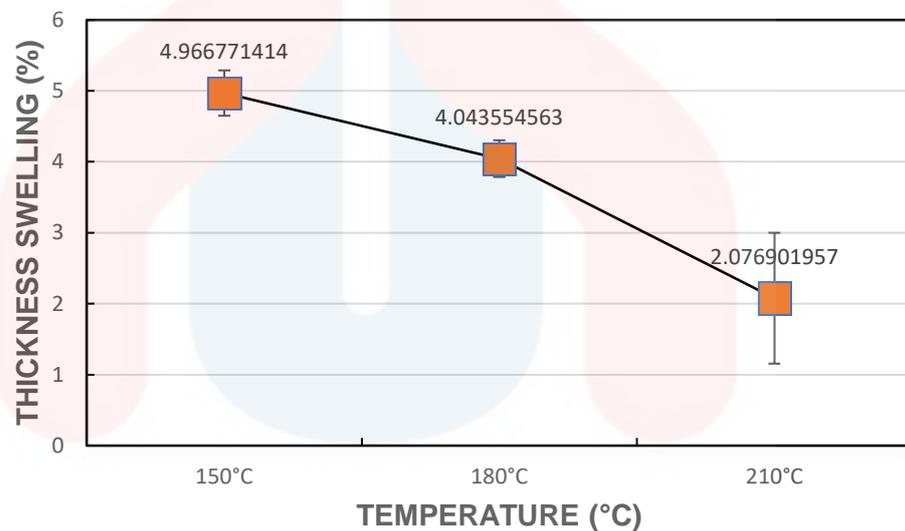


Figure 4. 5: Effect of various temperature on thickness swelling

Figure 4.5 shows the rate of thickness swelling for wood samples treated at different temperatures. As shown above, the graph displays a gradually decreasing pattern as the temperature increases. It was found that the 150°C sample reached the highest value yielding 4.96%, followed by the sample treated at 180°C showing a slight decrease of 4.04%. Meanwhile, the sample treated at a temperature of 210 °C is the lowest thickness swelling resulting in 2.07%, respectively. The 210°C sample had the lowest thickness swelling, a higher temperature tap may facilitate better bonding between fibers or

particles in the material. This enhanced bonding can result in a denser, denser structure that is less prone to swelling when exposed to water. Nevertheless, the thermal modification used in this research is effective to improve the dimensional stability of the sample.

4.1.6 Bending Properties (MOR)

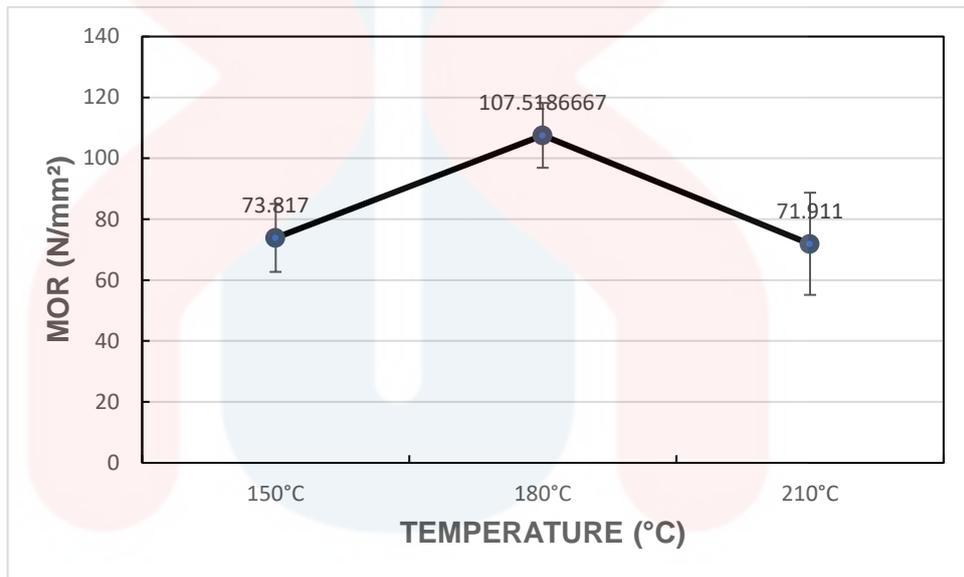


Figure 4. 6: Effect of treatment temperature on MOR

Figure 4.6 shows a comparison in MOR values for samples treated at different temperatures of 150, 180, and 210 °C. Samples treated at 180°C clearly display higher values than samples at 150°C and 210°C. According to the figure, the MOR value of the 150°C sample is 73.82 N/mm² and increases as the temperature increases to 107.52 N/mm² at 180°C. The difference in this increase is 33.7N/mm². A decreasing pattern has occurred to 71.91 N/mm², at 210°C. The difference in this decrease is 35.61 N/mm². This is because, at higher temperatures, the cellulose component of wood begins to degrade. Cellulose is the main structural component of wood fibers, providing strength and

rigidity. As the cellulose degrades, the wood fibers lose their integrity, resulting in reduced strength.

4.1.7 Bending Properties (MOE)

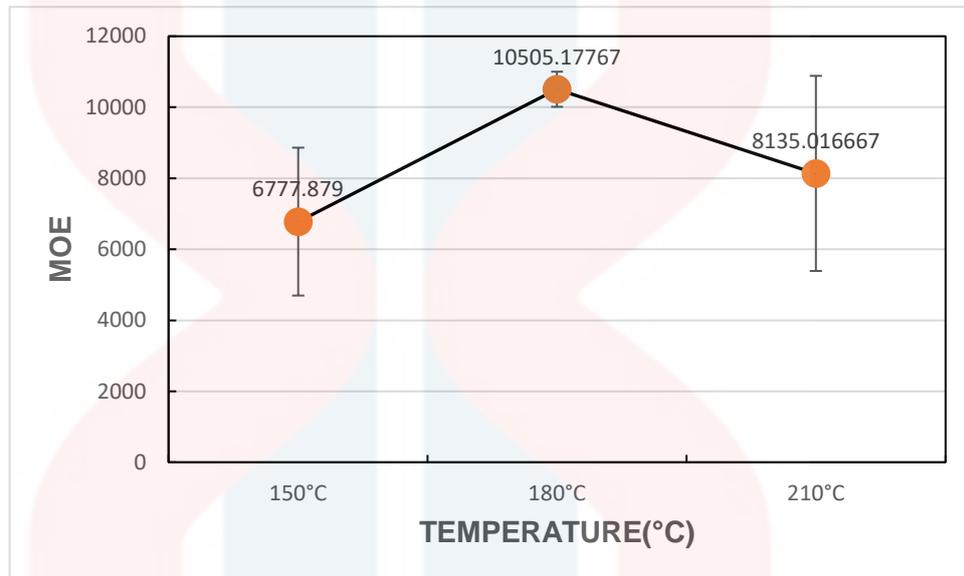


Figure 4. 7: Effect of treatment temperature on MOE

Figure 4.7 shows a comparison of MOE values for samples treated at 150, 180, and 210 °C. As stated in the data above, the MOE value at 150°C is 6777 N/mm² which is the lowest MOE value among the treated samples. However, when at a temperature of 180°C it increased to 10505 N/mm² and at a temperature of 210°C the MOE value decreased to 8135 N/mm². This can be concluded that the Medang wood sample that exceeds the temperature of 180°C will experience a decrease in the MOE value. At higher temperatures during heat treatment, these polysaccharides undergo thermal degradation, leading to a reduction in their mechanical properties. As a result, the overall stiffness of the wood decreases, causing a decrease in MOE.

4.1.8 Impact Strength

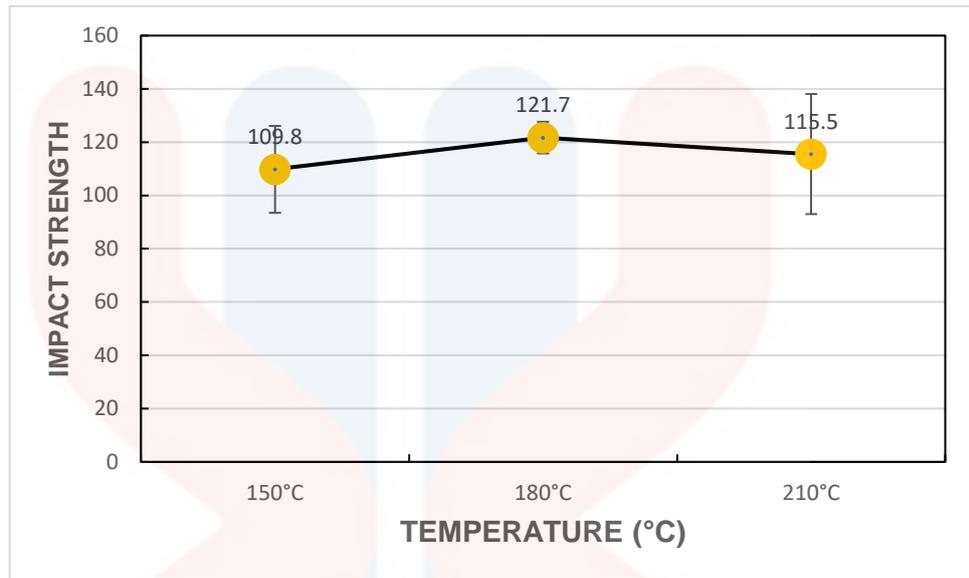


Figure 4. 8: Effect of treatment temperature on impact strength

Figure 4.8 shows the effect of temperature differences on impact strength with the trend of the graph increasing from 150 to 180°C and decreasing again at 210°C. It was found that the lowest impact strength value was found in the sample treated at 150°C which was 109.8 J. while the highest value was obtained in sample 180 which was 121.7 J. In addition, the wood sample subjected to the temperature of 210 °C was decreased to 115.5 J. The decrease in impact bending strength of heat-treated wood at higher temperatures is often associated with an increase in brittleness. This is because higher heat treatment temperatures can induce the formation of defects such as checks, splits, and cracks within the wood. These defects act as stress concentration points, promoting brittle fracture rather than ductile deformation when the wood is subjected to impact loads.

4.2 Effect of Duration on The Properties of Modified Medang Wood

4.2.1 Density

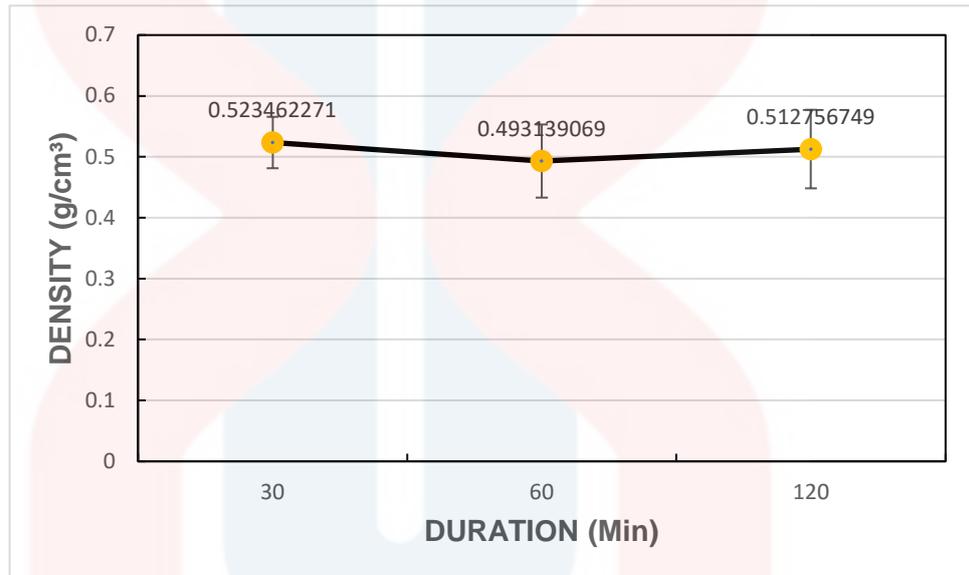


Figure 4. 9: Effect of various duration on density

Figure 4.9 shows the effect of different periods on density. As shown above, when the sample size increases from 30 to 120 minutes, there is little fluctuation in density. The density starts at 0.523 g/cm³ for the 30 minute sample, decreases to 0.493 g/cm³ for the 60 minute sample, and then increases slightly to 0.512 g/cm³ for the 120 minute sample. This variation may be attributed to a number of factors, including the inherent heterogeneity of the wood, the presence of defects, and natural variability in tree growth conditions. The figure shows that the influence of temperature on density was not substantial. Due to thermal degradation of cell wall components and mass loss during treatment, the density of wood treated at higher temperature should have lower density.

The release of byproducts is the cause of the increased mass loss that occurs throughout the heat treatment process. This is a consequence of the thermal degradation of lignin and as a direct result of the transfer of volatile compounds, the wood density will decrease (Owoyemi JM, 2016). However, as stated above, there was no substantial difference between the samples treated at 30, 60 and 120 min.

4.2.2 Weight loss

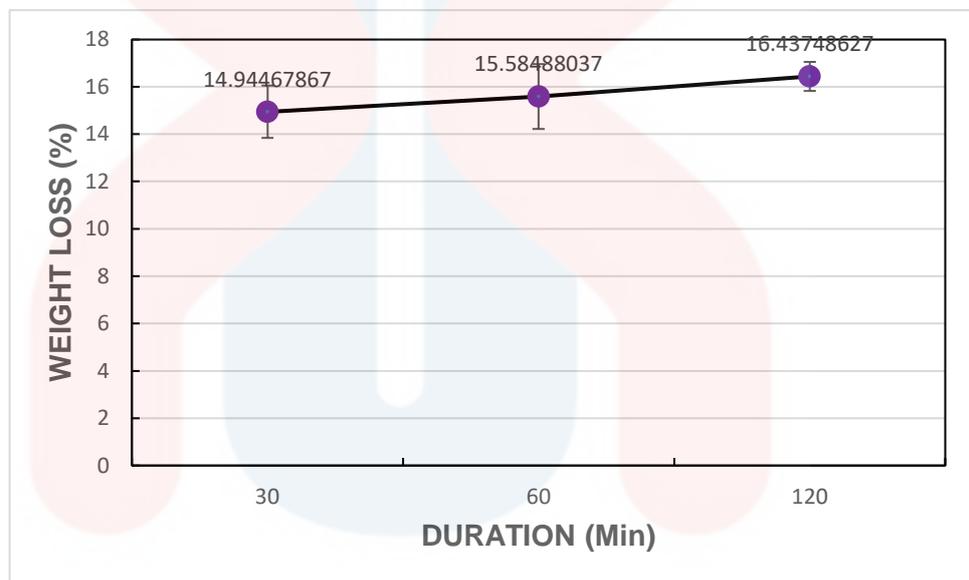


Figure 4. 10: Effect of various duration on weight loss

Figure 4.10 shows the effect of various treatment periods on the rate of weight loss in the sample. The data revealed a gradual increase in weight loss as the duration of exposure increased. At 30 minutes, the wood experienced a weight loss of about 14.94%, which increased slightly to 15.58% at 60 minutes and further to 16.44% at 120 minutes. This trend indicates that when wood is exposed to certain conditions for longer periods, more moisture is lost or chemical changes occur, resulting in increased weight loss. Weight loss of wood is typically due to the loss of moisture. When wood is heated, the water molecules in the wood vibrate more and more, eventually escaping as steam. This

process is called desorption. The longer the wood is heated, the more moisture it will lose, and the greater the weight loss will be.

4.2.3 Colour Changes

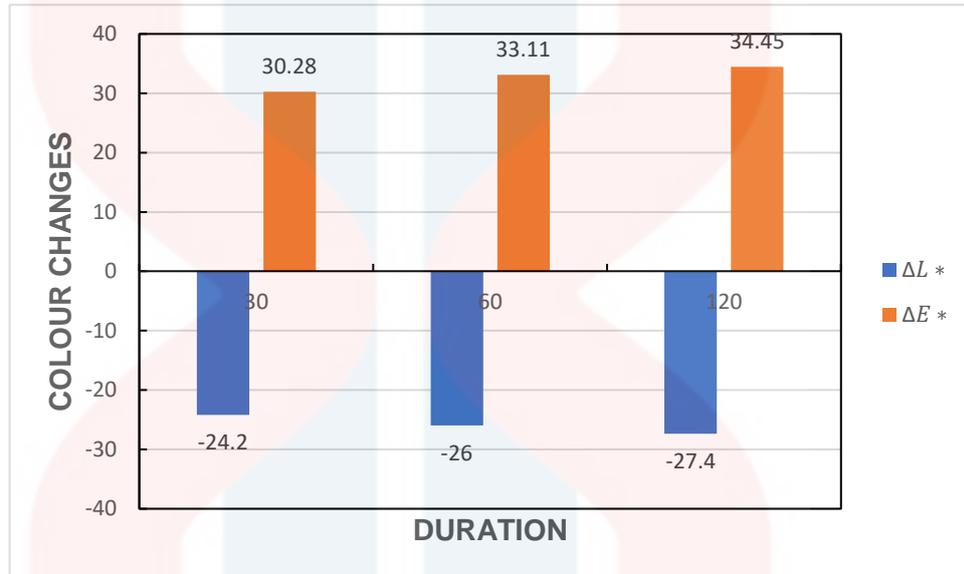


Figure 4. 11: Effect of various duration on color changes

Figure 4.11 illustrates the colour changes in the sample after heating at a temperature of 180°C for 30, 60, and 120 minutes. All treated samples were recorded L* (Brightness) a* (red-green) and b* (yellow-blue) values before and after the treatment were carried out to obtain the rate of colour changes that occurs. The results show that the samples treated for 30 minutes were seen to have the lowest colour reduction in brightness compared to other treated samples. Therefore, the ΔE^* value of this sample was the highest, followed by the sample treated for 60 and 120 minutes. This is because the darkness of the wood surface highlights the overall colour change. The degradation of wood brightness is caused by the emergence of hemicelluloses and extracts, thermal degradation products, or lignin polymerization interactions during treatment.

4.2.4 Water Absorption

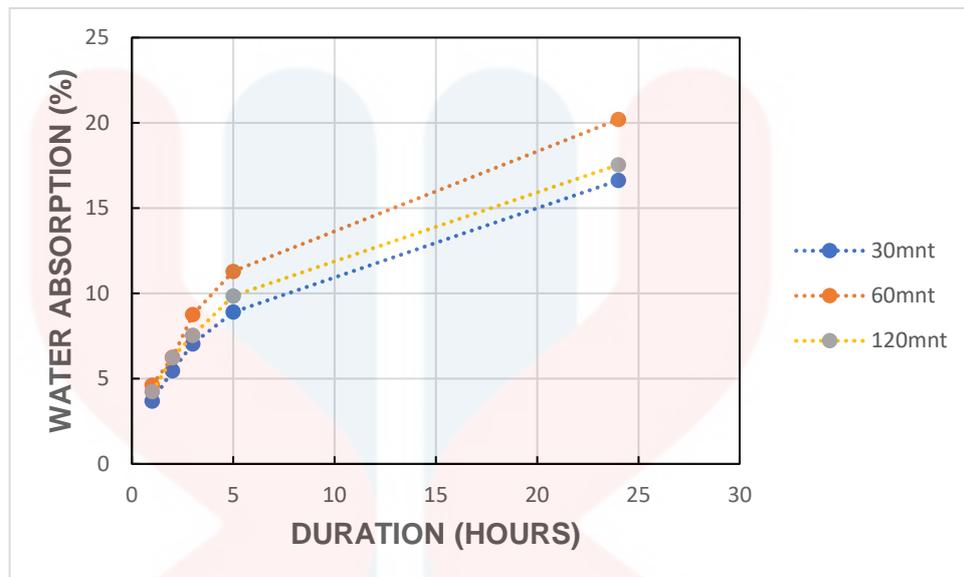


Figure 4. 12: Effect of various duration on water absorption

After soaking in water for 1, 3, 4, 5, and 24 hours, the water absorption rate of the sample is shown in Figure 4.12. As a result of immersion in water, it was found that all sample samples experienced a stable increase in weight. In addition, the figure showed that increased treatment duration resulted in higher water absorption rates. The sample was heated for 60 minutes absorb 20.2% more water after soaking for 24 hours. water absorption rate of 16.62% was observed for samples heated for 30 minutes, while an absorption rate of 17.5% was measured for a sample heated for 120 minutes. When compared to other treated samples, the sample heated for 60 minutes had the highest rate water absorption, but the 30-minute sample had the lowest rate. this ensures that the dimensions of the medang wood will remain unchanged even after being exposed to moisture. Based on the figure, heat treatment does not have any influence on increase the dimensional stability of the sample. More investigation is needed because it is not possible to determine the factors that cause the appearance of this pattern.

4.2.5 Thickness Swelling

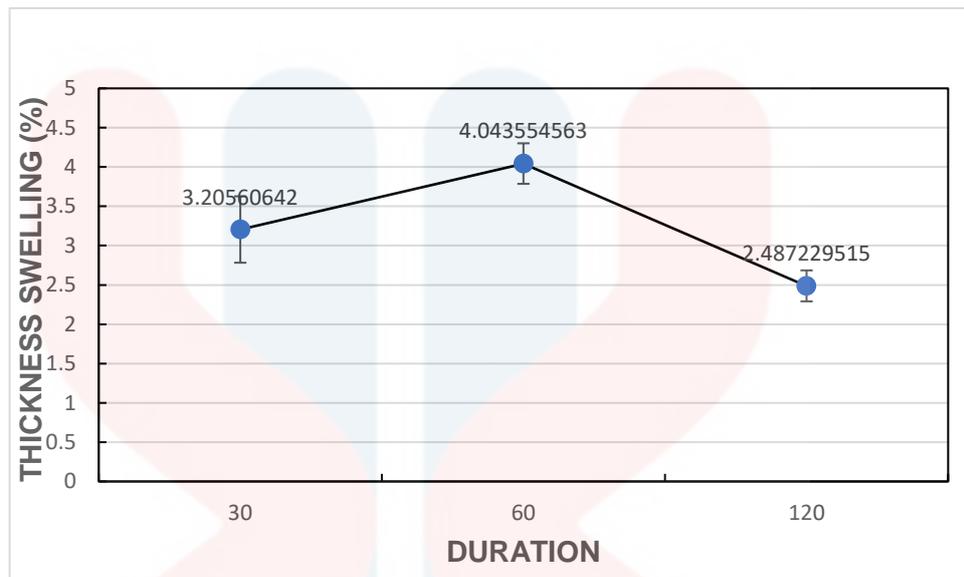


Figure 4. 13: Effect of various duration on thickness swelling

Figure 4.13 shows data showing fluctuations in swelling thickness over exposure period. At 30 minutes, the thickness swelling was about 3.21%, which increased to 4.04% at 60 minutes before decreasing to 2.49% at 120 minutes. This trend suggests a dynamic relationship between exposure time and the wood's ability to absorb and retain moisture. Factors such as wood species, cell structure, and surface treatment can affect the rate and extent of thickness swelling. The 120 minutes sample had the lowest thickness swelling, a higher temperature tap may facilitate better bonding between fibers or particles in the material. This enhanced bonding can result in a denser, denser structure that is less prone to swelling when exposed to water. Nevertheless, the thermal modification used in this research is effective to improve the dimensional stability of the sample.

4.2.6 Bending Properties (MOR)

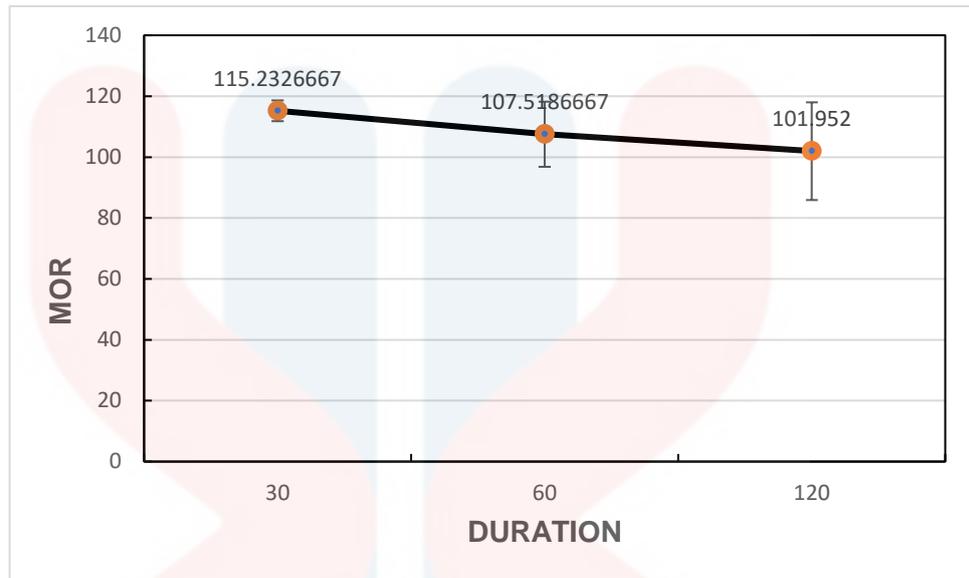


Figure 4. 14: Effect of treatment duration on MOR

Figure 4.14 shows the variation in MOR with respect to exposure duration. At 30 minutes, the MOR was approximately 115.23 N/mm², which decreased slightly to 107.52 N/mm² at 60 minutes and further to 101.95 N/mm² at 120 minutes. This trend indicates a potential decrease in the mechanical strength of wood with prolonged exposure to certain conditions, which may indicate deterioration or structural changes occurring in the material over time. This is because, longer exposure to high temperatures during heat treatment can result in more extensive thermal degradation of wood components such as cellulose, hemicellulose, and lignin. This degradation weakens the overall structure of the wood, reducing its ability to withstand bending stresses and leading to a decrease in MOR.

4.2.7 Bending Properties (MOE)

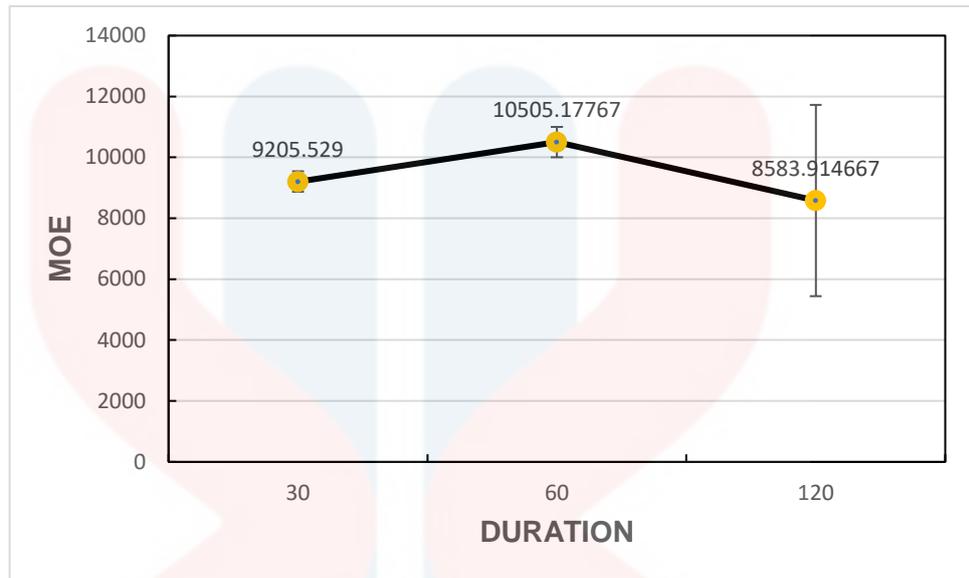


Figure 4. 15: Effect of treatment duration on MOE

Figure 4.15 shows the variation in MOE over exposure duration. At 30 minutes, the MOE was approximately 9205.53 N/mm², which increased slightly to 10505.18 N/mm² at 60 minutes before decreasing to 8583.91 N/mm² at 120 minutes. These trends suggest potential changes in wood stiffness with prolonged exposure to specified conditions, indicating possible changes in the structure or internal properties of the material over time. This is because longer exposure to high temperatures during heat treatment can cause more extensive thermal degradation of wood components such as cellulose, hemicellulose and lignin. This degradation weakens the molecular structure of the wood, resulting in a decrease in stiffness and, consequently, a lower MOE.

4.2.8 Impact Strength

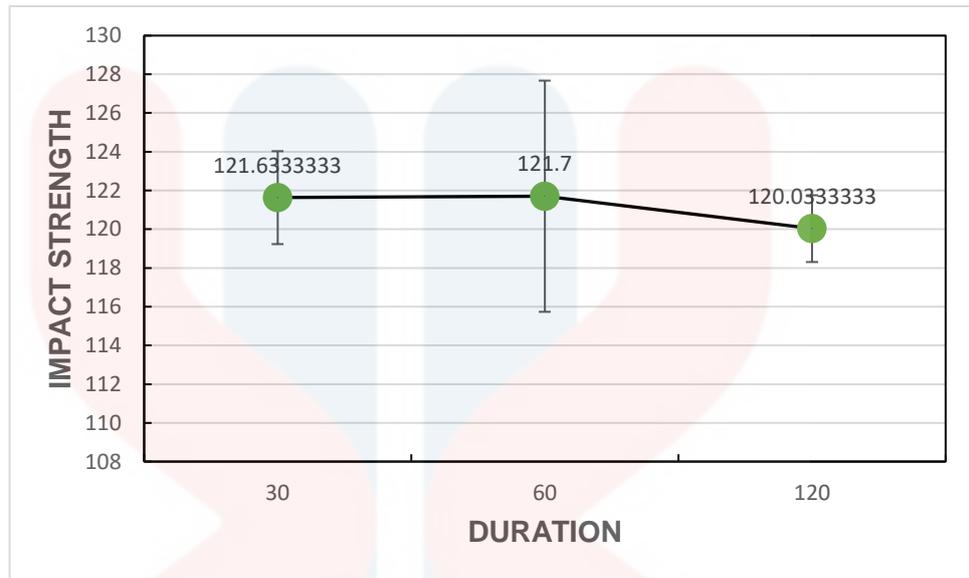


Figure 4. 16: Effect of treatment duration on Impact Strength

Figure 4.16 shows fairly consistent impact strength values across different time intervals. At 30 minutes, the impact strength was approximately 121.63 J, which remained relatively stable at around 121.7 J at 60 minutes before decreasing slightly to 120.03 J at 120 minutes. This trend indicates that exposure time to certain conditions may have minimal influence on the impact resistance of wood within a given range. This is because, extended heat treatment durations result in more significant removal of moisture from the wood. While controlled moisture removal can enhance dimensional stability, excessive loss of moisture can lead to increased brittleness and reduced impact strength, as the wood becomes less able to absorb energy before fracturing

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The purpose of this study was to investigate thermally modified 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

Further research on thermal modification on fast growing species is highly recommended, especially on improving the mechanical properties of wood as this species have irrigation complications and to make use of most fast-growing species to the maximum uses for industrial purposes. In addition, the study on different types of temperature and duration applied, to improve the properties of the wood is also suggested. Heat treatment as a wood modification process is based on chemical degradation of wood polymer by heat transfer. Therefore, further study on improving the resistances of wood to decay and provides dimensional stability is proposed. These improvements, which effectively in mechanical properties extensively for further studied. Lastly, the preservative treatment using several chemical testings on wood for thermal modification is categorically suggested to control wood degradation complications due to fungal rot or decay, sap stain, mold, or wood-destroying termites.

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APPENDIX A

Table 5. 1 : Raw data of (MOR)

Sample	A (150,60mnt)	B (180,60mnt)	C (210,60mnt)	D (180,30mnt)	E (180,120mnt)
1	61.064	118.932	58.448	117.308	107.133
2	81.864	105.827	66.531	111.257	114.804
3	78.523	97.797	90.754	117.133	83.919
Average	73.817	107.5187	71.911	115.2327	101.952
SD	11.17004	10.66857	16.81153	3.44414	16.08113

Table 5. 2: Raw data of (MOE)

Sample	A (150,60mnt)	B (180,60mnt)	C (210,60mnt)	D (180,30mnt)	E (180,120mnt)
1	8140.066	10986.57	8655.759	8858.822	10058.04
2	7813.738	9994.129	5167.622	9221.528	10721.38
3	4379.833	10534.84	10581.67	9536.237	4972.325
Average	6777.879	10505.18	8135.017	9205.529	8583.915
SD	2083.168	496.8833	2744.332	338.9908	3145.264

Table 5. 3: Raw data of impact strength

Sample	A (150,60mnt)	B (180, 60mnt)	C (210, 60mnt)	D (180, 30mnt)	E (180,120mnt)
1	110.9	125.8	131.5	124.4	120.6
2	125.55	114.85	125.3	120.2	121.4
3	92.95	124.45	89.7	120.3	118.1
Average	109.8	121.7	115.5	121.6333	120.0333
SD	16.32781	5.970553	22.55748	2.396525	1.721434