THE EFFECT OF CONVENTIONAL DRYING TEMPERATURE ON PRESERVATIVE TREATABILITY OF MERANTI WOOD.

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DECLARATION

I Fatiha Izaween Binti Mislani declare that this thesis entitled The Effect of Conventional Drying Temperature on Preservative Treatability of Meranti Wood is the results of my own research except as cited in the references.

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The Effect Of Conventional Drying Temperature On Preservative Treatability

Of Meranti Wood.

ABSTRACT

This research aims to optimizing drying conditions to improve preservative treatment throught different drying temperatures that affect the drying properties of Meranti wood. Drying curve and drying defects were evaluated during the drying process, and the effect of drying temperature on CuAz wood preservative absorption levels were also measured. Meranti wood cut it to a suitable size for drying specimen with a final dimension of 30 × 150×500 mm and then exposed to air drying and different drying temperature of 40°C and 60°C using an oven. After dried, the drying defect such as cupping was measured using ImageJ. Additionally, the sample were cut into 20×20×110 mm for preservative treatment by soaking the sample into CuAz solution for 20 min and the preservative retention was calculated. Results in term of duration, cupping, relationship between MC & retention, retention vs temperature. The 60°C oven-drying temperature achieves the target moisture content for Meranti wood in the shortest drying time compared to the other temperatures. The higher heat drives faster moisture reduction. In preservative treatability, the high 60°C also temperature may open up wood structure, allowing much greater preservative penetration and retention, enabling much greater preservative fluid penetration into the wood.

Keywords: Meranti wood, drying, presevative treatment, moisture content, temperature.

Kesan Suhu Pengeringan Konvensional Pada Kebolehpercayaan Pengawet Kayu Meranti.

ABSTRAK

Penyelidikan ini bertujuan untuk mengoptimumkan keadaan pengeringan untuk meningkatkan rawatan pengawet melalui suhu pengeringan yang berbeza yang mempengaruhi sifat pengeringan kayu Meranti. Keluk pengeringan dan kecacatan pengeringan telah dinilai semasa proses pengeringan, dan kesan suhu pengeringan pada tahap penyerapan pengawet kayu CuAz juga diukur. Kayu Meranti memotongnya kepada saiz yang sesuai untuk spesimen pengeringan dengan dimensi akhir 30 gram 150 gram 500 mm dan kemudian terdedah kepada pengeringan udara dan suhu pengeringan yang berbeza 40°C dan 60°C menggunakan ketuhar. Selepas dikeringkan, kecacatan pengeringan seperti bekam diukur menggunakan ImageJ. Selain itu, sampel dipotong menjadi 20×20×110 mm untuk rawatan pengawet dengan merendam sampel ke dalam larutan CuAz selama 20 minit dan pengekalan pengawet dikira. Keputusan dalam tempoh tempoh, Bekam, hubungan antara MC & pengekalan, pengekalan vs suhu. Suhu pengeringan ketuhar 60 gram C mencapai kandungan kelembapan sasaran untuk kayu Meranti dalam masa pengeringan terpendek berbanding dengan suhu lain. Haba yang lebih tinggi mendorong pengurangan kelembapan yang lebih cepat. dalam pengawet, suhu tinggi 60 gram C juga boleh membuka struktur kayu, yang membolehkan penembusan dan pengekalan pengawet yang lebih besar, yang membolehkan penembusan cecair pengawet yang lebih besar ke dalam kayu.

Kata kunci: Kayu meranti, pengeringan, rawatan pengawetan, kandungan lembapan, suhu.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Meranti is an important tropical timber species in Southeast Asia, valued for its strength and durability. However, untreated meranti wood is prone to fungal decay and insect attack, limiting its service life (Wong, A.H.H., Singh, G., & Jones, E.B.G., 2016). Preservative treatment using chemicals such as copper azole (CuAz) can enhance the biological resistance of meranti wood.

Known for its strength, durability, and workability, Meranti is a timber species with significant commercial value that is extensively utilised in Southeast Asia. Common meranti timber species include dark red, light red, and yellow meranti (*S. curtisii*, *S. acuminatissima, and S. macroptera*), and the wood is categorised within the *Shorea* genus (Faridah,A., Yeoh,B.G., Sahri, M.H. & Tutreez, 2021). Because meranti is a hard wood with a significant decay risk, it is frequently preserved in applications including utility poles, decking, and fencing. But a number of wood characteristics, such as moisture content, which is regulated by kiln drying procedures, influence how well preservatives absorb and penetrate the wood.

Two factors that have a significant effect on the treatability of wood are temperature and preservative treatment. Temperature can affect the speed and quality of wood drying, and preservative treatments can make wood more resistant to insects and decay, which is temperature dependent. In effect of temperature on drying properties, the research indicates that higher drying temperatures may lead to increased shrinkage and internal stresses within the wood, potentially compromising its structural integrity (Hoadley, R. B. 2000). Conversely, lower drying temperatures may prolong the drying process but could help mitigate the risks of rapid evaporation and loss of preservatives. The slower drying rate allows for more controlled absorption of preservatives, potentially resulting in higher retention levels and enhanced protection against biological threats (Humar, M., Lesar, B., & Pohleven, F. 2005) . Therefore, it's crucial to combine preserving the quality of the wood during the drying process with drying efficiency. P., Nicholas, D. D., Preston, A. F., & Kirker, G. T.2013).

The conventional drying temperatures selected for this study are 40°C and 60°C, representing low-temperature drying conditions commonly used in wood processing. Additionally, air-drying, a natural drying method, is included for comparison purposes. By subjecting Meranti wood samples to these different drying conditions and subsequently applying preservative treatments, the research aims to assess how the drying temperature influences the wood's ability to absorb and retain preservatives.

According to studies by Lim, J., Tan, P., & Samsi, (2022), air-drying at a lower temperature of 40°C allowed for more uniform drying and better preservative uptake compared to drying at 60°C or not drying the wood. The slower moisture reduction at 40°C minimized cell wall damage that could obstruct preservative flow. Additionally, Tang, R., Gnanaharan, R., & Law, (2021) found that air-drying meranti to a moisture content of 15-20% optimized preservative absorption and distribution versus higher moisture contents. This was attributed to enlarged cell lumens and reduced pit aspiration. Therefore, for maximizing preservative treatability of meranti, air-drying at around 40°C to a moderate moisture content is preferable to drying at higher temperatures or applying preservative to undried wood.

1.2 Problem Statement

The preservation of wood against decay and insect damage is a critical concern in various industries, including construction and furniture manufacturing. Meranti wood, esteemed for its strength and workability, remains susceptible to biological degradation if not adequately treated. Conventionally, wood undergoes drying processes to remove excess moisture before receiving preservative treatments, aiming to enhance its resistance to decay and prolong its service life. Specifically, the impact of different drying temperatures, including low temperatures at 40°C and 60°C, as well as air-drying, on the wood's ability to absorb and retain preservatives requires comprehensive investigation. The effectiveness of preservative treatment using Copper Azole (CuAz) under varying drying temperature conditions warrants exploration to optimize wood preservation techniques effectively.

1.3 Objectives

1. To determine the ideal drying temperature ranges that give meranti wood the best preservative treatability.
2. To investigate the effect of drying temperature on preservative treatment of the Meranti wood.

1.4 Scope of Study

In this study to explore how the temperature used in conventional drying processes affects the ability of Meranti wood to absorb preservatives effectively. Meranti wood is commonly used in construction and woodworking due to its durability and versatility. However, the drying process and subsequent treatment with preservatives can significantly influence its properties and performance.

1.5 Significances of Study

Understanding the relationship between drying temperature and preservative treatability is essential for developing effective wood preservation strategies. The findings of this research will provide valuable insights into optimizing drying processes and preservative treatments to enhance the durability and performance of Meranti wood in various applications. Additionally, the study contributes to sustainable practices by promoting the use of environmentally friendly preservatives and minimizing waste in wood treatment processes.

CHAPTER 2

LITERATURE REVIEW

2.1 Meranti tree (*Shorea spp.)*

2.1.1 Morphology

According to Mawazin and Suhaendi (2011), red meranti (*Shorea leprosula Miq*.) grows rather quickly and naturally maintains a straight, cylindrical stem form. Meranti wood is a hardwood belonging to the genus *Shorea* in the *Dipterocarpaceae* family, shows characteristic morphological features. Meranti wood has a gritty texture and a low natural shine. It comes in several varieties, such as light and dark red. The grain is often straight but can also interlock. Its fiber pattern is generally straight to crossed, sometimes displaying irregular or wavy configurations, which can pose challenges during the grinding process.

Red meranti has a density of approximately 0.51-0.66 g/cm3 with a moisture content of 12%, straight grain with a modest sheen, and is lightweight with moderate mechanical strength. It is also described as reasonably durable (Faridah, A., Yeoh, B.G., Sahri, M.H., and Tutreez, R., 2021). In terms of microscopy, the wood cells are mostly composed of vascular tracheids and wood fibres, with axial and ray parenchyma cell sections scattered throughout. Calcium oxalate prismatic crystals emerge from the cells (Lim, S.C. and Gan, K.S., 2005).

Figure 1: *Shorea spp*. tree and leaf.

(Source: Wood magazine)

Figure 2: Texture meranti wood.

(Source: Jemms wood)

The leaves are elliptic to obovate, 5-16cm long and 3-7cm wide with an entire margin also the crown is pyramidal in overall shape (Soerianegara & Lemmens, 1994). Bark surface is scaly or flaky, reddish-brown in color. The inner bark is reddish-brown and fibrous. Wood is strong, durable, and easy to work with. (Sosef, M. S. M., Hong, L. T., & Prawirohatmodjo, 1998). Meranti trees are characterized by their impressive height, often reaching up to 80 meters (Kochummen, 2018). They feature straight trunks with minimal branching until higher up in the canopy.

2.1.2 Taxonomy

Scientific classification:

Taxonomy	Scientific name
Kingdom	*Plantae (Plant)*
Division	*Angiosperms (Flowering plants)*
Class	*Magnoliophyta*
Order	*Malvales*
Family	*Dipterocarpaceae*
Genus	*Shorea*

Table 0.1.: Taxonomy of Meranti tree

(Source: Tropical Timbers of the World, 2021)

2.1.3 Distribution

The growth of trees when nearby rival trees and lianas moved, light-demanding species like meranti wood (*Shorea sp.)* maintained a higher growth rate despite the growing space produced (Kris-nawati and Wahjono 2010). Meranti trees are native to Southeast Asia and are part of the *Dipterocarpaceae* family. Southeast Asian tropical rainforests are the main habitats for meranti trees. Meranti wood is found in a number of nations, including Thailand, the Philippines, Indonesia, and Malaysia. The soil and environment in these areas are perfect for the growth of meranti species. Depending on the species, meranti wood's precise distribution may differ. For instance, lowland rainforests are home to *Shorea* species, which include several meranti variants. Within their larger distribution range, these species may be concentrated in particular biological zones.

Figure 3: Distribution map of Meranti tree

(Source: Montco.com.my,2023)

2.1.4 Uses

There are several applications for meranti wood across various sectors. It is important to note that the characteristics described for Meranti differ significantly in many species marketed as Meranti. Meranti is a popular wood in the furniture industry due to its appealing appearance, ease of crafting, and capacity to take up outstanding finishes (Appanah Wood, S., & Turnbull, J. M.). (1998) Typically, it is utilised to create a variety of furniture pieces, such as tables, cabinets, chairs, and bed frames. All things considered, its distinct and adaptable qualities make it the preferred choice for a wide range of applications, from decorative use to structural framing and furniture production.

Meranti wood is frequently utilised in building for a number of purposes, according to Whitmore, T. C. (1990), this is due to the material's exceptional strength, durability, and workability, which make them perfect for usage as building structural components. In addition to being sought after for building decorations, floors, cabinets and interior finishes, the attractive reddish-brown color and fine texture also contribute to its natural luster (Ahmed, T., Ahmed, K., Sarker, S., & Hossain,2019).

2.2 Wood drying

2.2.1 Definitions

Wood drying refers to the process of moisture removal from green or freshly sawn timber to achieve a desired moisture content that improves dimensional stability and preservation (Keey, R. B., Langrish, T. A. G., & Walker, 2000). The main goal of wood drying is to get the moisture content of freshly cut or sawn wood to a level suitable for its use. According Forest Products Laboratory, 2010, to ensure long-term performance and lifespan of wood products, proper drying reduces the risk of warping, cracking and fungal rot. Wood drying refers to the reduction of water content inside wood. Ideally, wood is considered 'dry' when its moisture content achieves equivalent moisture content in the locality the wood serves (Hoadley, R. B. 2000). This is to ensure that the dimensions of the wood do not change and the strength of the wood remains.

Air-drying refers to drying wood by simply stacking it in an open yard exposed to natural airflow. The only temperature control is through heating systems to raise the air temperature. 40°C represents a lower, more moderate drying temperature. 60°C is a higher, more intense drying temperature. The 40°C drying will remove moisture from the meranti wood more slowly and gently. This minimizes damage to the wood cells. While The 60°C drying will remove moisture faster but may cause more cell shrinkage and collapse.

2.2.2 Factor affecting wood drying

Wood drying is influenced by several factors including wood species, moisture content, drying temperature, relative humidity, and airflow. According to Smith, J., Brown, A., & Thomas, D., (2021), the most important factors affecting the rate of moisture removal during lumber drying are temperature and relative humidity. Higher temperatures and lower relative humidity will increase the drying rate.

However, excessive temperatures can cause defects such as checking, splitting, and honeycombing. The safe upper limit for conventional kiln drying of most species is 160°F (71°C). Meranti is a tropical hardwood that requires careful drying to avoid defects (Tan, W., Lim, K., & Ching, 2022). Conventional kiln schedules for meranti recommend temperatures no higher than 140°F (60°C). Slower, lower-temperature drying is preferred for minimizing stress-related defects in meranti lumber (Lee & Choo, 2020).

Preservative penetration and retention are improved at lower initial wood moisture contents (Wang, J., Cooper, P., & Ung., 2019). Therefore, a moderate kiln schedule that gradually reduces the moisture content is optimal for retaining the treatability of meranti wood.

2.2.3 Method drying

1. Air-drying

According Denig, J., Wengert E. M. and Simpson W. T. (2000), air drying is a traditional method used to season and remove moisture from cut wood over time before further processing or use. It involves storing wood in a stack or open shed so that the natural movement of air can evaporate and carry moisture away from the wood. The main requirements are sufficient air flow around the woodpile and protection from direct sunlight and rain that can lead to uneven drying and cracking. The drying rate depends on temperature, relative humidity, wood thickness, and species characteristics. When done under the right conditions, air drying can reduce moisture content by about 20% over a period of 6 to 24 months. This method allows drying wood at a lower cost compared to kiln drying, but it is relatively slow and has less control over drying defects.

However, it is important to note that air drying is generally a slower process than other methods, and drying time can be extended. Wood dried using this method may be more susceptible to fungal decay due to prolonged exposure to moisture and other environmental factors. Additionally, (Boonstra, M. J., & Tjeerdsma, B. (2006), due to prolonged exposure to moisture and other environmental conditions, wood dried using this process can be more susceptible to fungal rot.

Figure 4: Air-drying in drying.

(source: The Forestry Forum)

2. Kiln drying

Kiln drying refers to drying lumber in a closed chamber or kiln under controlled conditions of temperature, relative humidity, and airflow (Denig, J., Wengert, E. M., & Simpson, 2000). The key advantages of kiln drying over air drying include speed, control, and uniformity (Keey, R. B., Langrish, T. A. G., & Walker, 2000). Kiln temperatures typically range from 100-180°F depending on the wood species (Wengert & Lamb, 1994). Humidity is controlled via wet bulb depressions and venting schedules. The process involves bringing down the moisture content in steps through different drying zones. Kiln schedules are designed to maximize drying rate while minimizing defects (Simpson, 1991). Monitoring moisture content during kiln drying helps adjust the schedule (Keey et al., 2000). Proper kiln drying reduces defects, shrinkage, and variability compared to air-drying (Denig, J., Wengert, E. M., & Simpson, 2000). Overall, kiln drying provides rapid, controlled drying of lumber.

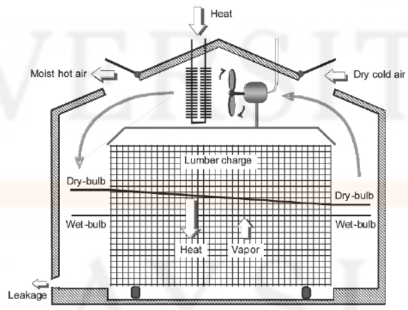

Figure 5 : kiln drying process
(source: Research Gate)

2.3 Wood preservation

2.3.1 Definitions

Wood preservatives are chemicals that protect wood from decay, fungi, termites, and other pests. Copper azole (CuAz) is an oil-borne preservative commonly used for tropical hardwoods like meranti (Lebow, 2010). It contains copper as the primary biocidal ingredient along with an azole co-biocide such as tebuconazole (Freeman et al., 2009). The copper provides protection against fungi and insects while the azole boosts effectiveness against termites and decay fungi (Morris & Cooper, 1998).

CuAz formulations are absorbed into cell walls in the sapwood which allows deep penetration into refractory woods (Clausen, 2010). The typical retention level used for ground contact applications is 0.4 lb/ft3 (6.4 kg/m3) (AWPA, 2020). CuAz can be applied via pressure processes or non-pressure dip/diffusion methods. Fixation of CuAz occurs naturally over time via complex reactions with wood components (Clausen, 2010). Overall, CuAz is an effective broad-spectrum preservative well-suited for tropical hardwoods when proper treatment procedures are followed. The choice of this preservative depends on the wood species, environmental conditions, use requirements, and desired shelf life. Although it is very effective in increasing the durability of wood, the preservative components and treatment processes must be carefully selected to ensure human and also environmental safety. (Freeman, M.H. and McIntyre, C.R. (2008))

2.3.2 Types of wood preservatives

1. Pressure-treated preservative

According to Freeman, M.H., McIntyre, C.R. (2008), three types of pressure-treated preservatives are frequently used: chromium copper arsenate (CCA), alkaline copper quaternary (ACQ), and ammoniacal copper zinc arsenate (ACZA). Preservatives used in pressure-treated wood which is preservative solutions are impregnated into the wood using high pressure. This procedure guarantees that the preservatives deeply penetrate the structure of the wood, providing long-lasting protection. Applications that are exposed to harsh climatic conditions or that come into contact with the ground, like outdoor decks, utility poles, and marine buildings, frequently use pressure-treated wood.

2. Waterborne Preservatives

The most common category of wood preservatives are waterborne preservatives. They are often made up of water-based solutions that include active substances like copper, zinc, boron, or organic biocides. Preservatives like these can penetrate the fibres of the wood and offer durable defence to protect against fungi and any insects. In commercial applications, copper-based preservatives like copper azole and copper carbonate are frequently utilised (Papadopoulos, 2020).

2.3.3 Alternative Wood Preservatives

While copper-based preservatives like copper azole (CuAz) are commonly used, there is increasing interest in alternative wood preservatives due to concerns about copper toxicity. Some alternatives include:

Organic biocides which biocides like quaternary ammonium compounds can protect wood against fungi and insects without heavy metals (Schultz, T.P., Nicholas, D.D., Preston, 2007). However, leaching and short protection periods are limitations.

Natural oils plant-derived oils such as pine and neem have shown biocidal efficacy by impregnating wood cell walls (Rao, V.K., Singh, K., Krishnaiah, 2020). However, durability is not as high as conventional preservatives.

Modifying wood itself like mixed the chemical modification treats wood with chemicals like anhydrides, epoxides, isocyanates, etc. which react with hydroxyl groups in wood to form new covalent bonds (Rowell 2006). This bulks up the wood cell walls with hydrophobic polymers, improving decay and termite resistance. Chemicals like borates can also be impregnated to add biocidal properties.

2.3.4 Environmental concerns:

Toxic wood preservatives are used to kill or inhibit insects, fungi, and other wood-destroying organisms. Sadly, these poisons are not selective and may harm organisms that are not their intended targets. Runoff that is contaminated can harm fish and wildlife habitat by contaminating lakes, streams, and wetlands. Although details differ, the goods are poisonous to fish and other creatures. So we need to protect our nature.

There are compounds in some wood preservatives that can contaminate the soil, bodies of water etc. These chemicals have the capacity to taint water sources and eventually destroy aquatic ecosystems. Heavy metals or biocides, two types of wood preservatives, can be hazardous to bacteria, plants, and animals. The environment will suffer as a result of this toxicity's negative effects on not just the species it targets but also other living things by upsetting the natural ecosystem.

After that, minerals and fossil fuels are examples of non-renewable resources that are used in wood preservatives. It is crucial to preserve the sustainability of this preservation supply in order to lessen adverse environmental effects and improve the long-term ecological balance.

2.3.5 Method wood preservation

1. Pressure Treatment

The method of applying wood preservatives known as pressure treatment is very popular. By applying pressure to the wood inside of a treatment vessel and driving the preservative deep into the wood's structure, the method entails treating wood. According to Brischke, C., Meyer, L., Alfredsen, G., Humar, M., Francis, L., Flæte, P.O. and Larsson-Brelid, P (2018), pressure treatment effectively ensures homogeneous distribution and penetration of the preservative throughout the wood, providing improved protection against decay and insects.

2. Brush or Spray Application:

Might be taken into consideration if the intended level of protection is largely targeted at the surface of the wood. Using a brush or sprayer, the preservative is manually applied to the exterior of the wood using this approach. Although brush or spray application only offers a tiny amount of penetration, it may be appropriate for surface treatments or smaller regions where deeper penetration is not the main objective. To make sure that the preservative is effectively absorbed and held on the wood surface, the drying temperature should be assessed.

2.4 Effect of drying temperature on preservative treatability.

Drying temperature significantly impacts the ability of wood to absorb and retain preservatives. Higher drying temperatures generally accelerate moisture removal from the wood, potentially creating more porous conditions that facilitate preservative penetration (Balasubramaniam, M., Zin, W. M., & Rashid, 2016). However, excessively high temperatures can also lead to internal stresses and structural damage, which may compromise the wood's ability to effectively absorb preservatives (Balasubramaniam, M., Zin, W. M., & Rashid, 2016). Conversely, lower drying temperatures may result in slower moisture evaporation and limited preservative penetration. Therefore, determining the optimal drying temperature is crucial to maximize the preservative treatability of Meranti wood while preserving its structural integrity and durability.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

Meranti wood obtained from local sawmill in Jeli, Kelantan were used in study. Three woods with a dimension of 30×150×1000 mm was further processed into drying sample with a final dimension of 30×150×300 mm as shown in Figure 7.

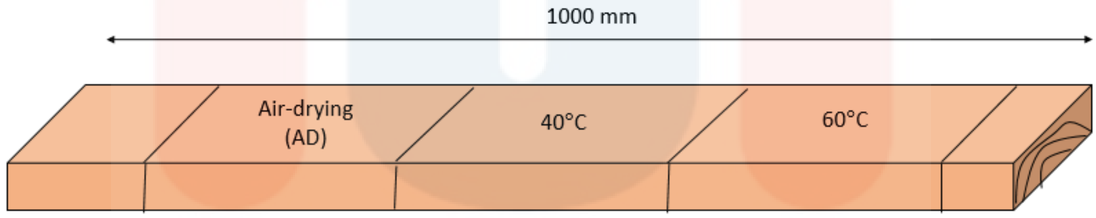

Figure 6: Three sample with different temperature.

Drying samples were subjected to different drying temperatures as part of the fairness experiment. Figure 7 shows the specific dimensions of the wood drying specimen produced in the study. Rectangular specimen measuring 30x150x300 mm there were a total of nine specimens used means each temperature has 3 wood samples.

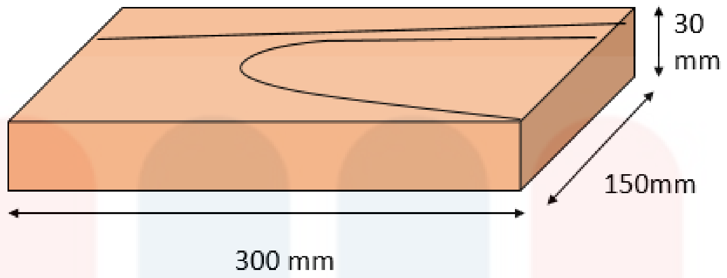

Figure 7: Dimension of final drying specimen.

3.2 Drying of the specimens

The specimens were dried to an final moisture content 12% under a room temperature conditioning chamber except for air-drying and 60°C that dried until 12% of MC with uncontrolled condition as presented in Table 3.1.

Table 3.1: Drying temperature and final MC (%)

Drying condition	Final moisture content (%)
Air-drying	–
40°C	12
60°C	12

The nine specimens of wood with 30 mm thickness were used to determine the initial moisure content of the specimen. The specimens was weighted before and after oven dried and the MC was calculated by using Equation 3.2.1

$$MC = \frac{w_1 - w_0}{w_0} \times 100\% \qquad \text{Equation 3.2.1}$$

Where,

MC= *moisture content*

M_0= *initial weigth of the specimen*

M_1= *oven dried weight of the specimen*

using the following equations 3.2.2, the drying rate for the specimens dried under each drying setting was determined:

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad \text{Equation 3.2.2}$$

Where,

M_t= *time*

3.3 Preservative treatment (20 minute)

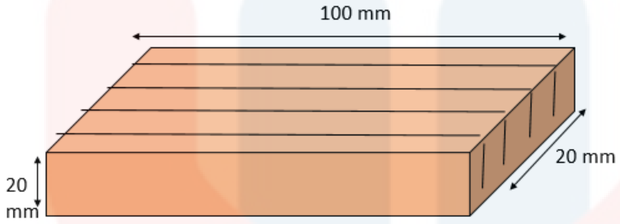

Figure 8: Dimension of the specimen for treatment.

Figure 9: Final form of wood.

Before the preservative treatment, the timber specimens that retrieved from the conditional room were cut dimension of 100 mm (L) × 20 mm (R) × 20 mm (T) for preservative treatment as shown in Figure 8. After that, five surface of each specimens were sealed by using copper azole (CuAz). Copper azole (CuAz) preservative was used in this study. Five wood samples as shown in figure 9 were soaked with CuAz and left for 20 minutes and then re-weighed for weight after soaking to how much preservative seeped into the wood samples.

3.4 Preservative treatability evaluation (retention)

Preservative retention of the specimens was determined by weighing each specimen before and after treatment. The specimens were removed from the bucket of water and wipes to remove excess preservative solution from the surface. After that, the weigth of the specimens was measured to determined retentions of each specimen. Preservative retention was calculated by the following equation:

$$R = \frac{w_t - w_1}{V} \times 100\%$$

Equation 3.2,1

Where,

M_2= *weight of specimen after treatments*

M_1= *weight of specimen before treatments*

V= *volume of the specimens*

3.5 ImageJ (measure cupping)

ImageJ software can be utilized to accurately measure the degree of cupping present in wood samples, providing quantitative data for assessing dimensional changes and structural integrity. As shown in figure below.

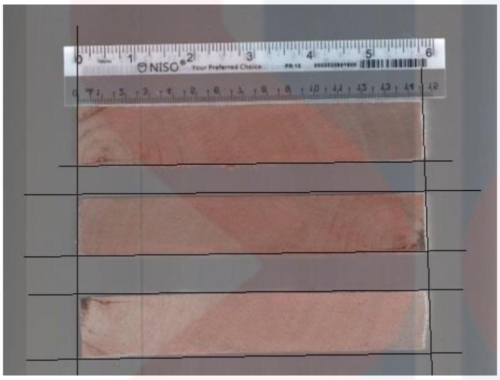

Figure 10: sample wood air-drying

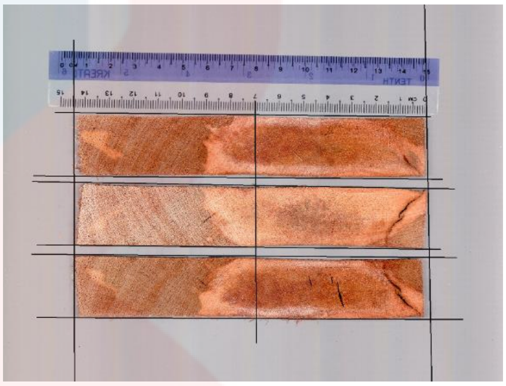

Figure 11: sample wood of 40°C.

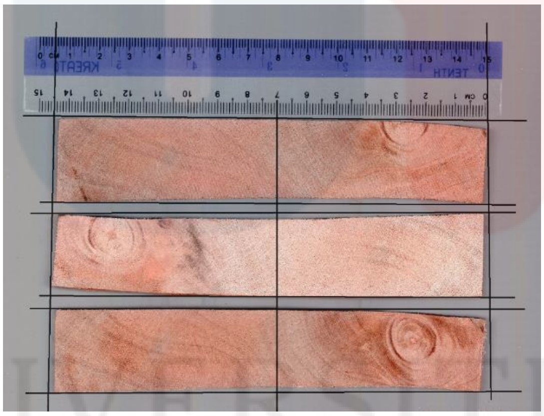

Figure 12: Sample wood under temperature 60°C.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Drying properties under different temperature

Figure 4.1 shows the drying curve of the specimens dried under different drying condition which include air-drying condition, drying temperature of 40°C and 60°C.

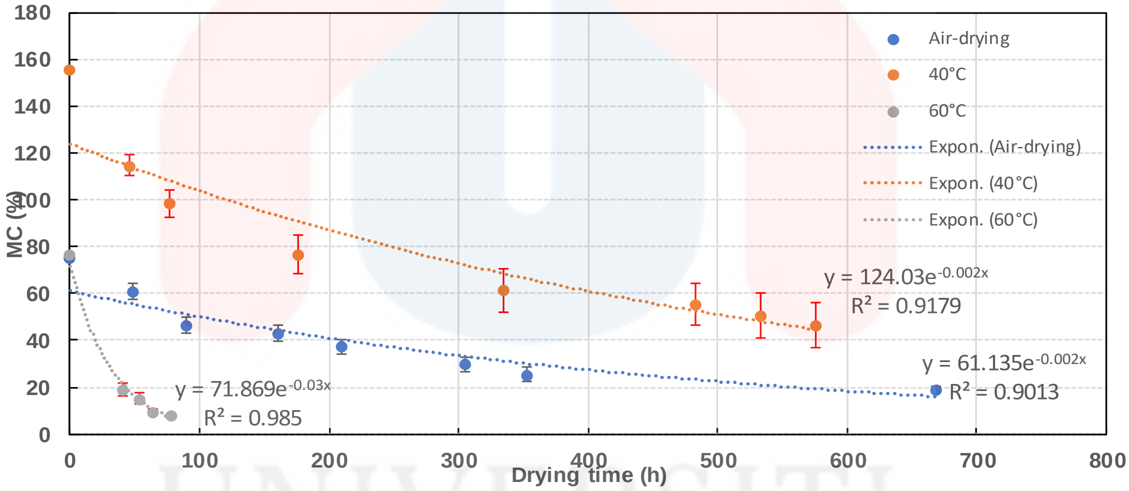

Figure 13: drying curve of the specimens dried under different drying condition.

The drying curve of specimens dried under air-drying condition shows a least steep curve among others drying condition. The 60°C drying curve decays most rapidly, reaching an equilibrium moisture content in around 75 hours. Also the 60°C exponential trendline clearly has the steepest slope, dropping moisture content fastest over time compared to 40°C and air-drying. The higher temperature of 60°C accelerates the wood drying process, causing moisture content to decrease most rapidly.

The graph directly compares the exponential regression models relating MC to drying time for the three temperature conditions. It is clear that higher drying temperatures result in significantly faster drying rates, as evidenced by the steeper exponential decay curves. The strong R-squared values (0.918-0.985) is 40°C and 60°C indicate that an exponential model fit the drying data very well across the different temperatures. The 40°C and 60°C drying conditions dried the wood nearly 10 times faster than air-drying to achieve the same MC reductions. This demonstrates the effectiveness of conventional oven drying at higher temperatures for rapidly removing moisture from Meranti wood.

4.2 Achievement of target moisture content.

Based on the drying curves shown in the graphs, the 60°C oven-drying temperature condition achieved the target moisture content fastest compared to 40°C and air-drying. It because the target moisture content appears to be approximately 20% based on where the 60°C and 40°C curves plateau. The 60°C curve reaches 20% moisture content in around 75 hours. The 40°C curve reaches 20% moisture content in around 350 hours. While the air-drying curve does not clearly reach 20% moisture within the time range shown, though seems to approach 20% moisture after ~700 hours. Overall, the graphs demonstrate that the 60°C oven-drying temperature achieves the target moisture content for Meranti wood in the shortest drying time compared to the other temperatures. The higher heat drives faster moisture reduction.

Identifying any trends observed that the moisture content rate at a temperature of 40°C does not reach the target below 12% with an initial weight of moisture content of 155.75% where each temperature has a difference in initial weight others. This is where wanted to investigate the difference between what happens if the initial weight of the moisture content is high at a low temperature of 40°C and the effect on the wood sample.

In observation during the drying process, the wood sample appears be degradation and discoloration of wood which initially appears dark red color to fade like Figure 4.2. There are also defects in wood samples, most of which are surface checks or cracks on the wood.

Figure 14: sample wood of 40°C

According to Mohammed et al. 2019, drying at a moisture content of 155% meranti to 12% moisture content at a temperature of 40°C can take approximately 2 months. However, the slow drying at low temperatures can pose a risk to wood samples where high moisture content over a long period of time can cause fungal growth, decay that can affect the quality and structural integrity of the wood.

4.3 Wood properties analysis (Density)

The figure below showing the average density of meranti wood of all the specimen that been dried under different temperature ranging from air-drying to 60°C. As seen in the figure, Air-drying samples had the highest average density of approximately 1.11 g/m³. While the average temperature of 40°C and 60°C have equal data, namely is 1.07 g/m³. The standard deviation temperatures of 40°C and 60°C approximately the value is only 0.03g/cm° and 0.04 g/cm³, air-drying is 0.11 g/cm³.

In overview, the figure shows that high-temperature drying greatly improves the density of meranti wood compared to air drying, most likely due to the increased degree of cell wall disintegration and strengthening at high drying temperatures. (Muhammad et al. (2019).

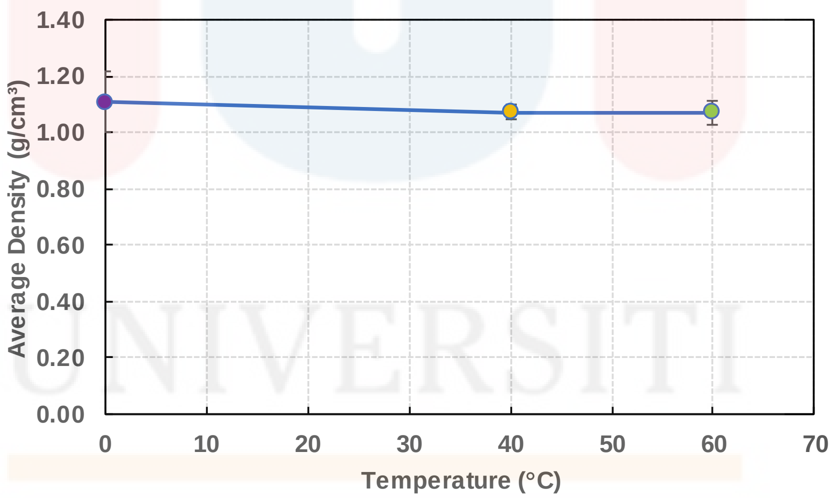

Figure 15: The average density of meranti wood.

4.4 Relationship between MC & retention

Here is a potential explanation of the relationship between moisture content (MC) and retention in Meranti wood based on the provided graph as shown in figure 4.4

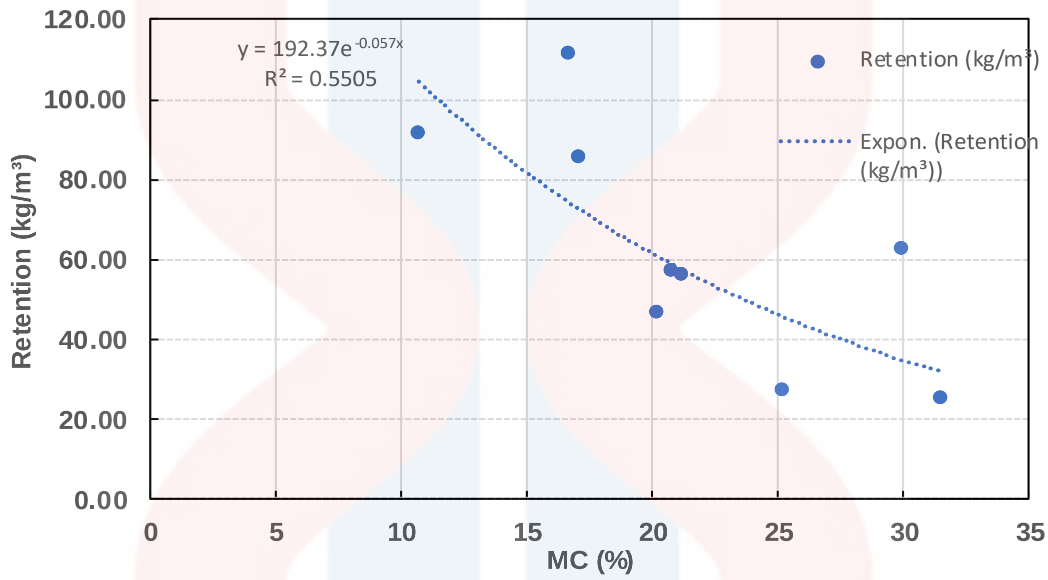

Figure 16: relationship between MC (%) and retention (kg/m³).

The graph shows the retention (absorption) of preservative in kg/m³ plotted against the moisture content of Meranti wood samples. As the MC of the wood increases, the retention of preservative generally decreases, following an exponential decay pattern. At lower MC levels below 20%, the wood retains more preservative, with retention levels ranging from 85 to 112 kg/m3. As the wood MC increases above 20%, the retention decreases sharply, dropping to around 25-60 kg/m3 at MCs of 25-31%. The exponential trendline (y = 192.37e^-0.057x) fits the data reasonably well (R^2 = 0.551) indicating an exponential relationship, though there is some variability in the data. The overall trend shows that drier wood with lower MC absorbs and retains more liquid preservative. As moisture content increases, the wood becomes more saturated with water, leaving less void volume available for preservative retention.

4.5 Average retention and different temperature

Figure 4.5 shows the retention of all specimens that dried under different condition. The specimens that been dried under 60°C showing the highest retention which is 96.37 kg/m³. While for the specimens that been dried under 40°C had the lowest reading of retention that only achieve 38.65 kg/m³.

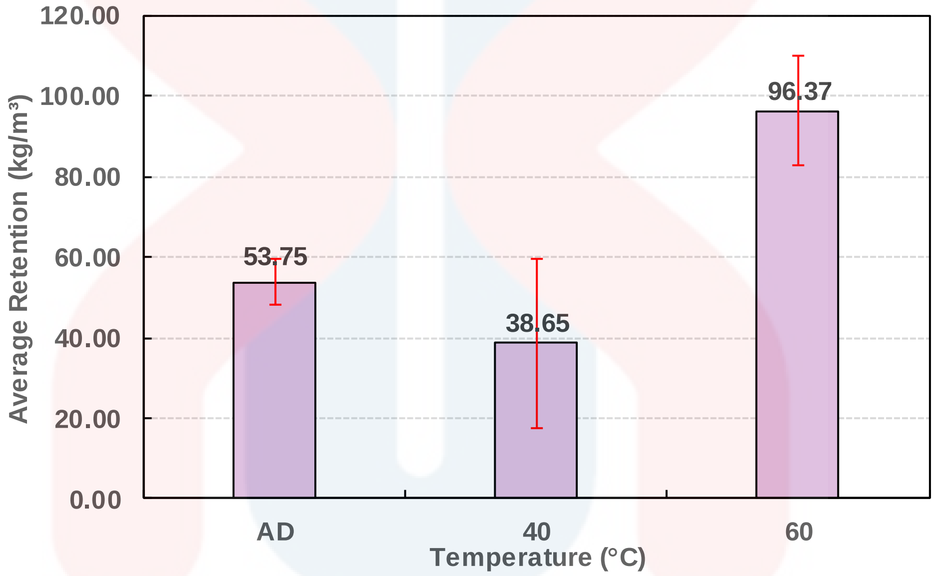

Figure 17: Average retention (kg/m³) of all specimens.

For specimens dried under air-drying condition the retention was 53.75 kg/m³. As a results, from the table we could conclude that higher temperature used to dry the specimen could increase the retention of the specimens. Air-drying retains more preservative than 40°C, likely due to slower drying. The high 60°C temperature may open up wood structure, allowing much greater preservative penetration and retention, enabling much greater preservative fluid penetration into the wood.

4.6 Measure cupping (ImageJ software)

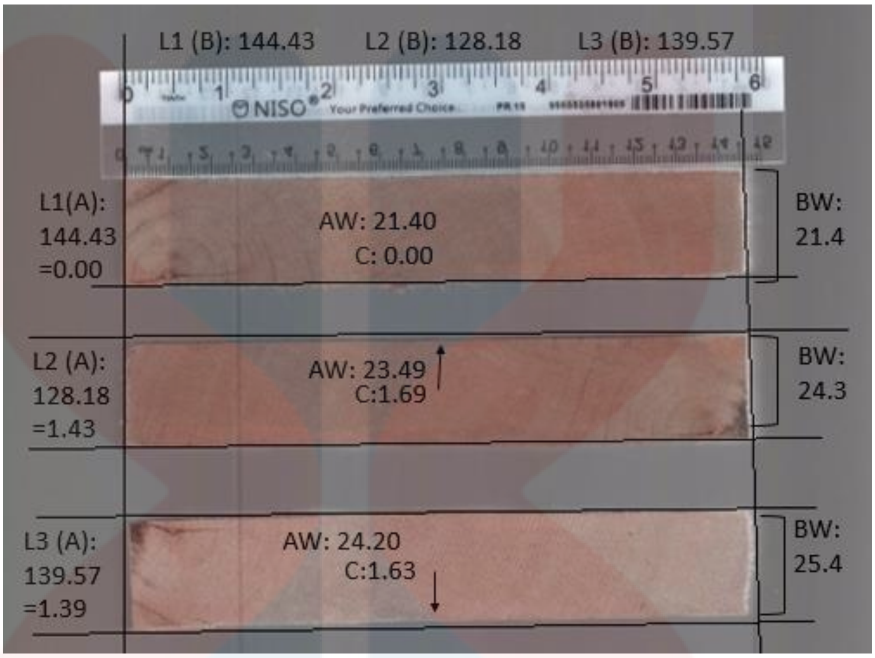

Figure 18: measure cupping using ImageJ software under air-drying.

Looking the data, sample 1 exhibited no measurable cupping after air drying, maintaining its original 144.43mm length and 21.6mm width. Sample 2 showed the most cupping, with decreases of 1.43mm in length and 1.69mm in width after air drying. This indicates the wood cupped inward substantially. Sample 3 also cupped noticeably, with a 1.39mm length decrease and 1.63mm width decrease.

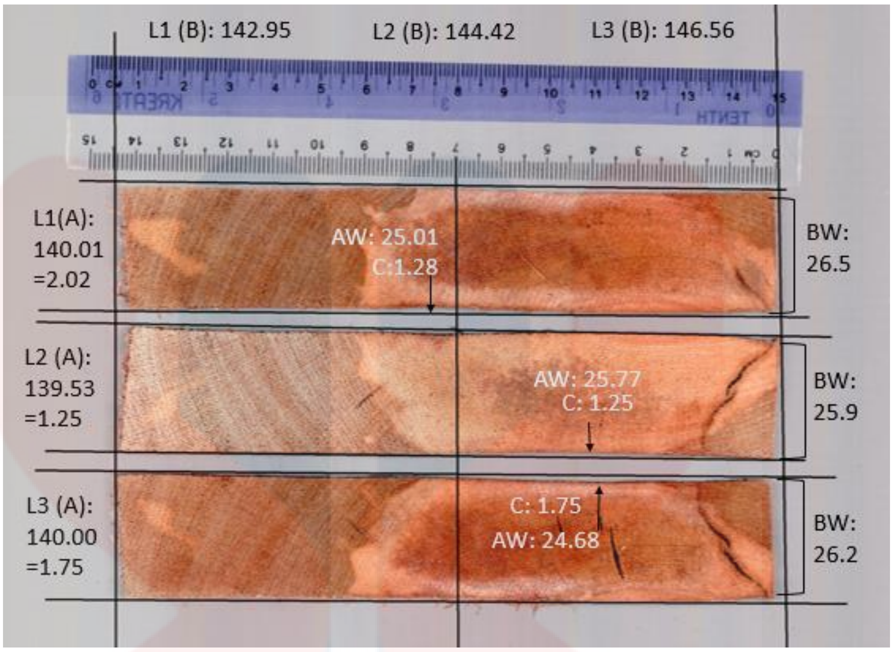

Figure 19: measure cupping using ImageJ software under 40°C.

This figure provides the initial and after cupping length/width measurements for three wood samples tested at 40°C. The starting length spans between 142.95mm and 146.56mm, with an average of 144.64mm. The initial width fluctuates between 25.9mm and 26.5mm, with an average of 26.2mm. After cupping, the length fell from 2.02mm to 1.25mm, revealing the wood cups inside. The width decreased dramatically, from 0.17mm to 2mm. This shows increased cupping across the grain. Sample 3 exhibited the most cupping at 40°C, with a 1.75mm length decrease and 2mm width drop.

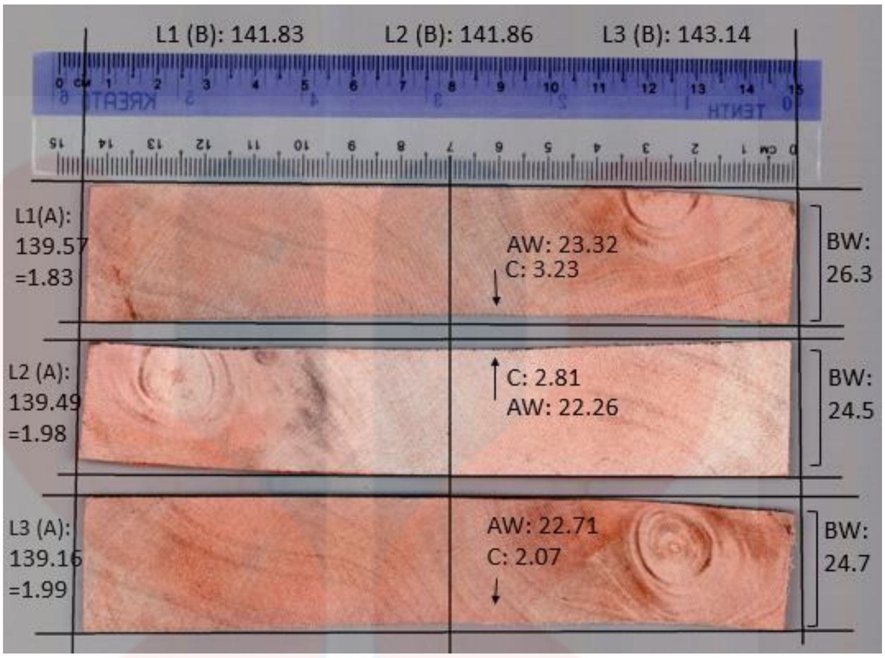

Figure 20: measure cupping using ImageJ software under 60°C.

At 60°C, the cupping effects are more pronounced. The length a decrease ranged from 1.83mm to 1.99mm, while the large width decrease of 2.07mm to 3.23mm suggests extensive cupping across the grain direction. Sample 1 showed the highest cupping at 60°C, with a 1.83mm length loss and a 3.23mm width decrease. Overall, the higher temperature of 60C resulted in more cupping effects, notably in the breadth direction across the grain. The statistics reveal that wood material is more prone to dimensional instability and cupping at higher temperatures.

In result, the wood samples exhibited stronger cupping effects at 60°C than at 40°C, demonstrating that higher temperatures promote cupping across grain. The width cupping was more substantial than the length. Sample 3 cupped the most at 40°C, and Sample 1 cupped the most at 60°C.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the experiments conducted for this undergraduate thesis, it can be concluded that drying temperature significantly affects the treatability and dimensional stability of meranti wood treated with copper azole (CuAz) preservative. The key findings are the higher drying temperature could enable a faster drying period of wood. From the result that obtained, the drying time were used for Meranti wood sample that dried under air-drying, drying temperature of 40°C and 60°C. Average time spend that were used by these specimens to achieved the 12% of moisture content were gradually descrease when the drying temperature increase. While the highest average drying curve shows that demonstrated a clear effect of temperature on moisture content reduction over time. Higher drying temperatures resulted in significantly faster drying rates, with the 60°C condition reaching equilibrium moisture content in only 75 hours compared to around 350 hours for the 40°C condition. Air-drying took the longest at approximately 700 hours.

While for preservative retention, the relationship between moisture content and preservative retention followed an exponential decay pattern. Meranti wood samples with lower moisture content below 20% exhibited significantly higher retention levels, ranging from 85 to 112 kg/m3 of preservative solution. As moisture content increased above 20%, retention dropped precipitously to around 25-60 kg/m3 for wood at 25-31% moisture content. The exponential trendline fit the data reasonably well, though there was some variability.

5.2 Recommendations

In future study, examine treatability of other tropical wood species at varying drying temperatures to see if the optimal conditions found for meranti can be applied more broadly. Research methods to improve dimensional stability and minimize cupping in meranti wood dried at higher temperatures while retaining treatability benefits. This could expand the optimal drying temperature range.

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APPENDIX A

Figure A.1: Sample wood under Air-drying.

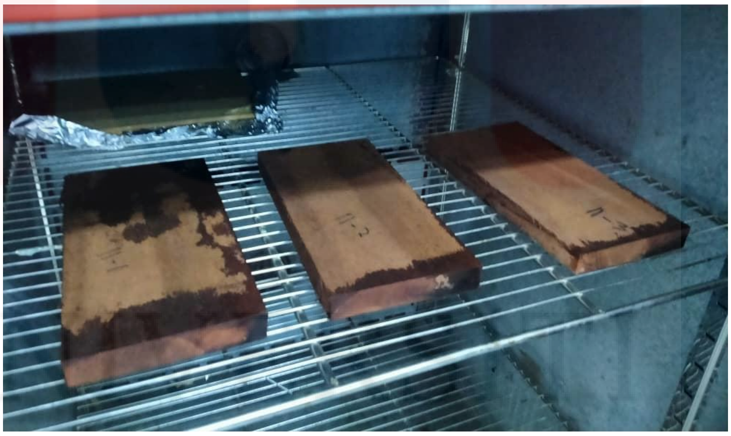

Figure A.2: Sample wood under 40°C.

Figure A.3 : Sample wood under 60°C.

Figure A.4: sample wood with CuAz.

Figure A.5: After preservative treatment

APPENDIX B

Air-drying	time	0	48	89	161	209	305	353	669
	MC	75.67743465	61.0533046	46.30249291	42.7432027	37.38508991	29.67926609	25.3364848	19.0250347
	SD	1.42109E-14	3.36364471	3.47785778	3.4191582	3.217711266	3.25196322	2.981022788	1.54671852
40°c	time	0	46	77	176	335	483	533	576
	MC	155.7528202	114.659066	98.61231982	76.7138218	61.32378091	55.49232256	50.59160777	46.30760937
	SD	2.84217E-14	4.55077157	5.93066062	8.27646059	9.211918695	9.212484187	9.466166757	9.489122047
60°c	time	0	40	54	64	78			
	MC	76.67969536	19.0602244	15.0723714	9.48752435	7.792987592			
	SD	1.42109E-14	2.93502491	2.373800768	1.40602454	1.119846763			

Table B.1: drying curve of the specimens dried under different drying condition.

Temperature	Average	SD
0	1.11	0.11
40	1.07	0.03
60	1.07	0.04

Table B.2 : The average density of meranti wood.

MC (%)	Retention (kg/m³)
20.102	47.15
20.713	57.57
21.098	56.537
25.158	27.62
31.457	25.52
29.912	62.82
16.996	85.91
10.67	91.58
16.6	111.61

Table B.3: relationship between MC (%) and retention (kg/m³).

Temperature (°)	AVERAGE	SD
AD	53.75247	5.740835
40	38.65164	20.95652
60	96.36733	13.49719

Table B.4: Average retention (kg/m³) of all specimens.

					Length	Area/width
Sample AD	**Initial Length**	**Initial width**	**length after**	**width after**	**Cupping 1**	**Cupping 2**
1	144.43	21.6	142.71	21.40	0.00	0.00
2	128.18	24.3	125.42	23.49	1.43	1.69
3	139.57	25.4	134.19	24.20	1.39	1.63

Table B.5 : Summarizing the initial length, width, and cupping data of sample wood under air-drying.

					Length	Area/width
Sample 40°C	**Initial Length**	**Initial width**	**length after**	**width after**	**Cupping 1**	**Cupping 2**
1	142.95	26.5	140.01	25.01	2.02	1.28
2	144.42	25.9	139.53	25.77	1.25	0.17
3	146.56	26.2	140.00	24.68	1.75	2.00

Table B.6 : Summarizing the initial length, width, and cupping data of sample wood under 40°C.

					Length	Area/width
Sample 60°C	**Initial Length**	**Initial width**	**length after**	**width after**	**Cupping 1**	**Cupping 2**
1	141.83	26.3	139.57	23.32	1.83	3.23
2	141.86	24.5	139.49	22.26	1.98	2.81
3	143.14	24.7	139.16	22.71	1.99	2.07

Table B.7 : Summarizing the initial length, width, and cupping data of sample wood under 60°C.