Faculty of Resource Science and Technology

Drying Characteristics Variation in Dry Pre-treated Seven and 10-Year-Old of *Acacia mangium*

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

In Sarawak, *Acacia mangium* is the primary species used for commercial forest plantation to reduce timber dependency from the natural forest. The wood has adequate strength, quality and durability for appropriate utilization and end-use. However, the uneven distribution of moisture content and drying defects are the primary problems in converting *Acacia mangium* wood into high-value products. The major cause of those problems is the presence of wet pockets in the dried wood. The objectives of this study were to (1) determine the untreated moisture content and the physical properties of seven and 10-year-old of *A. mangium* wood, (2) determine the effect of pre-treatments on the drying time, occurrence of wet pocket and drying defects in dried *A. mangium* boards, and (3) develop new drying schedules for seven and 10-year-old *A. mangium* board. Trees of seven and 10-year-old *A. mangium* were obtained from a plantation. The felled trees were rough sawn to 50 mm and 400 cm thick and long, respectively. Defects-free quarter and rift-sawn sample boards were selected and subsequently cut to a standard size of 27 mm (thickness) × 150 mm (width) × 690 mm (length). Three pre-treatments experimented were incision, forced air drying and pressure. The average basic wood density of 10-year-old *Acacia mangium* was significantly higher than seven-year-old *A. mangium.* The untreated moisture content of the seven-year-old is greater than the 10-year-old *A. mangium*. Results showed that pressure pre-treatment was the best for both seven and 10- year-old *A. mangium.* All sample boards treated with pressure did not show severe drying defects such as checks, collapse, and honeycombing. Mild schedule was recommended for both seven and 10-year-old *A. mangium*. Although the recommended schedule is not the fastest in terms of drying rate, it can reduce the occurrence of wet pocket and minimize the incidence of drying defects in both ages. The newly developed drying schedule for seven-year-old *A. mangium* indicate that kiln drying begins with an initial dry-bulb temperature of 45 °C, the wet-bulb depression 1.7 °C and the final dry bulb temperature of 70 °C. For 10-year-old *A. mangium* begin with an initial dry-bulb temperature of 48 °C, wet-bulb depression 4.0 °C and the final dry bulb temperature of 71 °C. Application of the new drying schedule on flat sawn sample boards succeed with no severe drying defects. The new drying schedule for 10-year-old *A. mangium* able to reduce the occurrence of wet pocket.

Keywords: *Acacia mangium*, pre-treatment, wet pocket, drying schedule, drying defects

Variasi Ciri Pengeringan Dalam Pra-rawatan Kayu Kering Tujuh dan 10 tahun Acacia mangium

ABSTRAK

Di Sarawak Acacia mangium merupakan spesies utama untuk perladangan hutan komersial seterusnya mengurangkan kebergantungan sunber kayu dari hutan asli. Kayunya mempunyai kekuatan, kualiti dan ketahanan semulajadi yang memuaskan dan sesuai untuk kegunaan dan penghasilan produk. Walau bagaimanapun ketidakseragaman taburan kandungan kelembapan dan kecacatan pengeringan adalah masalah utama dalam menggunakan kayu A. mangium untuk menghasilkan produk yang bernilai tinggi. Faktor utama yang menyebabkan masalah ini adalah kehadiran poket basah dalam papan yang telah dikeringkan. Objektif-objektif kajian ini adalah (1) menentukan purata kandungan kelembapan kayu serta sifat fisikal kayu A. mangium berumur tujuh and 10 tahun, (2) menentukan kesan pra-rawatan terhadap masa pengeringan papan, kejadian poket basah dan kecacatan pengeringan pada papan kering yang telah menjalani pra-rawatan, dan (3) menghasilkan jadual pengeringan baru untuk papan A. mangium berumur tujuh dan 10 tahun. Pokok-pokok A. mangium berumur tujuh dan 10 tahun diperolehi dari sebuah ladang hutan. Semua pokok yang ditebang dipotong masing- masingnya mempunyai ketebalan dan panjang kasar 50 mm dan 400 mm. Papan gergaji potongan suku (quarter-sawn) dan ricih (rift-sawn) yang bebas dari cacat dipilih untuk dijadikan sampel bersaiz 27 mm (tebal) x 150 mm (lebar) x 690 mm (panjang). Tiga pra-rawatan yang diuji ialah insisi, pengeringan paksa udara dan tekanan. Purata ketumpatan kayu asas bagi kayu A. mangium berumur 10 tahun lebih tinggi dari yang berumur tujuh tahun secara signifikan Purata kandungan kelembapan hijau bagi kayu A. mangium berumur tujuh tahun lebih tinggi dari yang berumur 10 tahun secara signifikan. Keputusan menunjukkan penggunaan tekanan sebagai *pra-rawatan adalah yang terbaik untuk tujuh dan 10 tahun A. mangium. Semua sampel papan yang diberi pra-rawatan tekanan tidak menunjukkan kecacatan pengeringan yang teruk. Jadual pengeringan sederhana disyorkan untuk tujuh dan 10 tahun A. mangium. Walaupun jadual yang disyorkan ini tidak dapat mengeringkan kayu dengan cepat, ia boleh mengurangkan pembentukan poket basah dan meminimakan kecacatan pengeringan untuk kedua-dua umur. Jadual pengeringan yang baru dihasilkan untuk kayu tujuh tahun menunjukkan pengeringan tanur dimulakan dengan permulaan suhu bebuli kering 45 °C, rendahan bebuli basah 1.7 °C dan suhu akhir bebuli kering 70 °C untuk A. mangium berumur tujuh tahun. Bagi A. mangium berumur 10 tahun suhu permulaan bebuli kering ialah 48 °C rendahan bebuli basah 4.0 °C dan suhu akhir bebuli kering 71 °C. Aplikasi jadual pengeringan terhadap papan potongan tangen (flat-sawn) tidak menghasilkan kecacatan pengeringan yang teruk. Jadual pengeringan yang baru bagi A. mangium berumur 10 tahun adalah berkesan untuk mengurangkan kehadiran poket basah*

Kata kunci: *Acacia mangium, pra-rawatan, poket basah, jadual pengeringan, kecacatan pengeringan*

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LIST OF ABBREVIATIONS

A.mangium	*Acacia mangium*
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
cm	Centimetre
DBT	Dry Bulb Temperature
DST	Drying Schedule Test
EMC	Equilibrium Moisture Content
FSP	Fibre Saturation Point
GMC	Green Moisture Content
RH	Relative Humidity
Hrs	Hours
MC	Moisture Content
MC_i	Initial Moisture Content
MC_f	Final Moisture Content
m	Meter
mm	Millimetre
QDT	Quick Drying Test
SG	Specific Gravity
WBD	Wet Bulb Depression
WBT	Wet Bulb Temperature

CHAPTER 1

INTRODUCTION

1.1 Study Background

Acacia mangium is a commercial plantation species planted widely in Southeast Asia. Its ability to tolerate and adapt to adverse climate and condition make it preferable to be planted on a large scale. At least 2.6 million hectares of *A. mangium* plantations were established in Southeast Asia (Nambiar & Harwood, 2014). As of June 2019, Sarawak has established 452,760.45 ha of forest plantations, of which 69% are planted with *A. mangium* (Forest Department Sarawak, 2019). The total production of logs from all planted forests in Sarawak in 2019 was 1,664,305 m^3 (Forest Department Sarawak, 2019). In Sarawak, *A. mangium* is widely used for commercial reforestation programmes to reduce timber dependency from the natural forest and sustain natural forests.

Initially, *A. mangium* was planted for pulp and paper due to its trait in producing a good quality pulp and high pulping ability. However, over time, new breeds of *A. mangium* will be available and might have superior characteristics in term of wood quality, which can be utilized as the primary timber source for the local wood-based industry especially furniture. The delicate appearance, grain orientation, and colour of the wood itself increased the wood aesthetic value and suitable for converting a high-value products at a premium price. The wood has acceptable strength, quality and durability if it utilized properly and managed appropriately.

Wood drying is the most crucial process in timber manufacturing. Timber can be drying by using air drying, but it is time-consuming. Kiln drying used to dry timber in this modern era to accelerate drying. However, kiln drying must be adequately monitored especially the setting of the kiln dry itself. Extreme drying setting and rapid drying time can reduce the end quality of the wood by developing drying defects such as cracking, checking and case hardening (Kettula, 2015).

Acacia mangium is known as a hard to dry plantation tree species due to its refractory properties. Zafhian et al. (2020) stated that the conventional method for drying *A. mangium* is very demanding to achieve a consistent result in drying *A. mangium* wood. Drying is the detrimental stage of wood processing for *A. mangium.* Error in wood drying of *A. mangium* will influence the dimensional stability, finishing process, glueing ability and workability (Tenorio & Moya, 2011). Dimension instability in *A. mangium* wood occurred due to the variations in the distribution of moisture content (MC) in a single board attributed to the presence of the wet pocket. Wet pockets likely to occur in the quarter and rift sawing grain pattern of the wood and double rift sawing grains pattern of the wood (Tenorio & Moya 2011; Gan et al., 2015).

A wet pocket is defined as a particular area in heartwood with adversely huge MC (Watanabe et al., 2010). The presence of wet pockets can be detected after drying by observing the area with dark brown colour. The area with wet pockets normally has a darker colour than the normal area of the wood without wet pockets. The moisture content of wet pockets in *A. mangium* ranged from 12 to 76% and average at 25% (Tenorio et al., 2012). It is also likely that these areas will collapse, split and check during drying.

It was suggested that wet pockets in heartwood are related to the presence of bacteria (Lihra et al., 2000). Vessels also can be clogged and blocked by bacteria and tyloses, respectively and restricting the flow of water in the wood (Sun et al., 2006). Wet pockets in *Gmelina arborea* was attributed to anaerobic type bacteria (Moya & Muṅoz, 2008).

There are some techniques or methods reportedly able to reduce wet pockets and final moisture content (MC_f). For instance, hot water bath and microwave pre-treatments of *A. mangium* boards can relieve the occurrence of wet pockets (Gan et al., 2015). However, this method might not be feasible in a commercial setting due to establishing large water bath and microwave facilities. Pre-drying using airflow velocity 100 rpm in room temperature condition (21 °C and RH 52%) before kiln drying of alpine fir, hemlock and western red cedar partially reduce moisture content differences between wet pockets and normal wood (Warren et al., 1995).

Moya et al. (2009) reported that wood with wet pocket have low permeability. Thus, it will slow down the drying and contribute to uneven MC_f. Air pressure pre-treatment, known as micro explosion pre-treatment, is a new technology that was introduced to treat and improve the permeability of the Poplar wood. Before this, steam pre-treatment is reported effective in improving the permeability of the wood and reduced the drying period but steam pre-treatment is cost and times consuming as it requires a long cycle of the process (Ma et al., 2015). Both of these pre-treatments are similar to each other and able to weaken and break down the bordered pit pairs in the wood to reach the wet pockets area and improve the permeability of the wood (Ma et al., 2015).

Another pre-treatment method introduced by Zhao et al. (2015) is by modifying the wood treatment and preservation method known as the wood compression method. This wood compression method was used to force out the air inside the wood. During wood drying, this compression method can help in improving the permeability of the wood. Two types of wood compression methods introduced are tangential and radial compression described in Zhao et al. (2015). Through wood compression, the thin-walled tyloses can be broken down thus the permeability of the wood by rupturing the pit in the wood the improves the flow of the water through the wood layer (He at el., 2017).

Sorting of lumber before kiln drying can alleviate wet pockets and reduce the chance of over-drying of lumber. Apart from that, sorting of lumber can avert the under or over-drying and low timber quality. Separating *Vochysia guatemalensis* boards according to the distance from the pith, vertical parts of tree, heartwood and sapwood reduced moisture content variability, which produced improved dried timber quality (Moya et al., 2011).

Tenorio and Moya (2011) have modified their first drying schedule to reduce the moisture content of the *A. mangium* wood. Their study showed there was still a lack of uniformity of the moisture content due to the presence of the wet pockets. A mild drying schedule is recommended to consider the refractory nature of *A. mangium* wood and its tendency to show honeycomb in kiln-dried boards (Tan, 2014).

Thus, it is crucial to determine the right temperature and drying condition for *A. mangium* wood by manipulating the current drying schedule to avoid irregular and excessive wood shrinkage. Apart from minimizing the occurrence of the wet pockets within and between the sections of the board after drying, the data will be helpful for both utilization of the *A. mangium* in Sarawak and the determination of the suitable condition in obtaining lumber with lower and uniform MC. All the drying process need to be well under control to prevent any drying defects, uneven moisture distribution and wet pocket in *A. mangium.*

1.2 Problem Statement

Acacia mangium accounts for 67% of the forest plantation area planted in Sarawak, with the estimated current productivity of about 180 m^3/ha for a 12-year cycle. It was anticipated at least 3 million m^3 of the log would be produced annually in the coming year. Initially, the resource from the early planting of the *A. mangium* was only targeted for the fibre industry. However, if the sawn timber thickness of the *A. mangium* more than 31 mm (1 1/4 inch) can be obtained from the lower portion of the *A. mangium*, these logs may produce value-added products, such as furniture. However, it must be economically dried before processing.

The current empirical practice of drying *A. mangium* is air drying for about a month before kiln drying at conventional temperature for another month. This practice aimed to ensure the *A. mangium* boards dried evenly and dimensionally stable during the service. However, this practice cannot be pertained especially for small timber industry due to limited space available in the mills for air drying. Besides, air drying was time-consuming and not economical for the industry. Drying too fast, the *A. mangium* boards were hampered with collapse, causing irregular; excessive shrinkage and consequently forming wet pocket within the sections of the board. The boards have irregular surface and thickness but are dimensionally unstable due to a considerable variation in moisture content. Sawn timber boards with these characteristics would be unsuitable for indoor joinery as well as the furniture industry. Thus, it is important to find ways to accelerate the drying of *A. mangium* boards so that they can be utilized as raw material for many other products apart from the fibre industry.

1.3 Objectives

The main aims of this study were to assess the effect of pre-treatment of *A. mangium* wood on the moisture content after drying and develop a drying schedule. The specific objectives were to: -

i. determine the untreated moisture content and physical properties of seven and 10-year-old *A. mangium*.

ii. determine the effects of pre-treatments on the drying rate, occurrence of the wet pocket and drying defects in dried pre-treated *A. mangium* boards; and

iii. develop a new drying schedule for seven and 10-year-old *A. mangium* based on Quick Drying Test (QDT).

1.4 Chapter Summary

Due to the uneven distribution of wet pockets and large variation of MC value in single boards of *A. mangium*, the utilization of *A. mangium was* limited to chips and fibre products. Its inherent and refractory properties make it difficult to be converted to furniture, joinery and construction materials. Quarter and rift sawing grains patterns of *A. mangium*, especially at the lower part of the logs, have a high incidence of wet pockets. The lower part of *A. mangium* log consists of high percentages of heartwood and have low permeability. It has the potential to be converted to high-end value products if the incident of wet pockets and uneven distribution of MC can be reduced and eliminated. Thus, a proper drying schedule and process must be implemented. The main aims of this study were to assess the effect of pre-treatment *of A. mangium* wood on the moisture content and the physical properties of seven and 10-years-old *A. mangium*; effects of pre-treatments on drying of *A. mangium* and develop a drying schedule for both seven and 10-year-old *A. mangium.*