UNIVERSITI PUTRA MALAYSIA

PHYSICO-MECHANICAL PROPERTIES OF KEDONDONG (Canarium spp.) AND BATAI [Paraserianthes falcataria (L.) Nielsen] IMPREGNATED WITH PHENOLIC RESIN AND THEIR RELATIONS TO SORPTION BEHAVIOUR

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By

ARFAH SHAWATI BINTI BONEKA

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillments of the Requirements for the Degree of Master of Science

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DEDICATION

Special dedicated to:

My father

Boneka Bin Halail

and

My mother

Bahara Binti Abdul Hari

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

PHYSICO-MECHANICAL PROPERTIES OF KEDONDONG (*Canarium* spp.) AND BATAI |*Paraserianthes falcataria* (L.) Nielsen| IMPREGNATED WITH PHENOLIC RESIN AND THEIR RELATIONS TO SORPTION BEHAVIOUR

By

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February 2022

Chairman : Sabiha Salim, PhD
Faculty : Forestry and Environment

Kedondong (*Canarium spp.)* and batai (*Paraserianthes falcataria (L.)* Nielsen) hardwood were chosen as the raw materials to improve their dimensional stability and mechanical performances via several scientific treatments that this study undertook. Wood modifications of these two species were conducted with the objective to enhance their low dimensional instability, inferior mechanical strength and high hygroscopicity which limit their commercial utilization. In this study, kedondong and batai samples were impregnated with low-molecular weight phenol formaldehyde (LM_wPF) resin at 15%, 20% and 30% concentrations followed by the curing process at 150 °C for 60 minutes. Weight percent gain (WPG), surface wettability and physical properties like water absorption (WA), thickness swelling (TS), swelling coefficient (SC) and anti-shrink efficiency (ASE) were all monitored by this study. In addition, mechanical strength in terms of their bending and hardness strengths and sorption behaviour of untreated sample against impregnated samples were also individually evaluated. Consequently, results showed that impregnated batai demonstrated better treatability than the kedondong sample. However, impregnated kedondong showed an increase in WPG as the LM_wPF resin concentration increased from 15% to 30%. Surface wettability of impregnated sample for both species showed distinct decrements compared to their untreated samples. The results also showed that the impregnated kedondong decreased significantly in terms of WA, TS and SC while the ASE increased with increment of resin concentration. This trend was similar for impregnated batai. In terms of its mechanical properties, the modulus of rupture (MOR) value of batai between the impregnated sample at 15% resin concentration and the untreated batai sample showed significant difference but there was no significant difference for the kedondong sample. Nevertheless, both the kedondong and batai species showed no significant difference in terms of modulus of elasticity (MOE) and hardness properties. The equilibrium moisture content (EMC) at 95% relative humidity (RH) of the untreated kedondong and batai samples records 19.10% and 21.19% respectively. Meanwhile, for the impregnated kedondong the EMC ranged from 18.14% to 18.43%, and for batai the EMC was recorded at 13.35% - 17.12%. Kedondong and batai samples shows a reduction in EMC up to 11.57% and 58.74%

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respectively after being impregnated with LM_wPF resin. In addition, there was a noticeable difference in the hysteresis loop between the untreated and all impregnated samples for both species. The highest absolute hysteresis (AH) was marked at 80% RH with values at 3.74% and 3.85% for the untreated kedondong and batai, respectively. The AH also showed a marked reduction due to impregnation. Moreover, due to the penetration of LM_wPF resins in wood cells, it had resulted the low hysteresis ratio (HR) when compared to the untreated samples. The projected-fibre saturation point (p-FSP) that was determined by applying the hailwood-horrobin (HH) Model for this study, showed that the impregnated kedondong and batai exhibited lower EMC compared to the untreated samples. Therefore, it could be concluded that the impregnation method with LM_wPF resin increased the bending strength of batai, and enhanced the dimensional stability and reduced the hygroscopicity of kedondong and batai woods.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

SIFAT FIZIKAL DAN MEKANIKAL KEDONDONG (*Canarium* spp.) DAN BATAI [*Paraserianthes falcataria* (L.) Nielsen] DIIMPREGNASI DENGAN RESIN FENOL DAN HUBUNGANNYA DENGAN TINGKAH LAKU SERAPAN

Oleh

ARFAH SHAWATI BINTI BONEKA

Februari 2022

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Kedondong (*Canarium spp.*) dan batai (*Paraserianthes falcataria (L.)* Nielsen) adalah kayu keras yang dipilih sebagai bahan mentah untuk dikaji samada berupaya meningkatkan kestabilan dimensi dan prestasi mekanikalnya. Sifat-sifat kayu kedondong dan batai ditambah baik bagi mempertingkatkan ketidakstabilan dimensinya, kekuatan mekanikal yang rendah dan higroskopisiti tinggi yang membataskan penggunaannya. Dalam kajian ini, sampel kedondong dan batai diimpregnasi dengan fenol formaldehid yang berjisim molekul rendah (LM_wPF) pada kepekatan 15%, 20% dan 30% diikuti dengan pengeringan pada suhu 150 °C selama 60 minit. Penilaian terhadap pertambahan peratus berat (WPG), sifat keterbasahan, sifat fizikal seperti penyerapan air (WA), peratusan pembengkakan ketebalan (TS), pekali pengembangan (SC) dan peratusan keupayaan menentang pengembangan (ASE), sifat mekanikal yang terbahagi kepada kekuatan lenturan dan kekerasan, serta tingkahlaku serapan oleh kayu terimpregnasi tersebut telah dijalankan. Batai menunjukkan kebolehrawatan yang lebih baik berbanding sampel kedondong. Walau bagaimanapun, apabila kepekatan resin meningkat daripada 15% ke 30%, terdapat pertambahan peratus berat bagi sampel kedondong. Sifat keterbasahan sampel yang diimpregnasi menunjukkan penurunan bacaan sudut kontak yang ketara berbanding dengan sampel yang tidak dirawat untuk kedua-dua spesis. Kedondong yang telah diimpregnasi menunjukkan pengurangan yang ketara terhadap peratusan TS, WA dan SC. Manakala, peratusan ASE menaik dengan meningkatnya kepekatan resin. Pola perubahan tersebut juga terjadi pada sampel batai yang diimpregnasi. Dari segi sifat mekanikal, pada nilai modulus kerapuhan (MOR), tiada perbezaan yang signifikan antara kedondong yang telah diimpregnasi dengan yang tidak dirawat dan ada perbezaan yang signifikan antara batai yang telah diimpregnasi dengan yang tidak dirawat. Kedua-dua spesies kedondong dan batai yang telah diimpregnasi dengan yang tidak dirawat menunjukkan tiada perbezaan yang signifikan untuk modulus kelenturan (MOE) dan modulus kerapuhan (MOR). Peratusan EMC pada kelembapan relatif (RH) 95% untuk sampel kedondong dan batai masing masing 19.10% dan 21.19%. Manakala, sampel kedondong dan batai yang telah diimpregnasi

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mencatatkan peratusan EMC masing masing pada purata 18.14% - 18.43% dan 13.35% - 17.12%. Kedondong dan batai masing-masing menunjukkan penurunan maksimum sehingga 11.57% dan 58.74%. Di samping itu, gelung histeresis antara sampel yang tidak dirawat dan setelah diimpregnasi untuk kedua-dua spesies menunjukkan perbezaan yang jelas. Pada RH 80%, histeresis tertinggi (AH) direkodkan dengan nilai 3.74% dan 3.85% untuk spesis kedondong dan batai dan nilainya lebih rendah setelah sampel diimpregnasi. Tambahan lagi, penembusan resin LM_wPF dalam sel-sel kayu menyebabkan penurunan kepada peratusan nisbah histeresis (HR) berbanding dengan kayu yang tidak dirawat. Titik tepu serat yang diunjurkan (p-FSP) telah ditentukan dengan mengaplikasikan model hailwood horrobin (HH). Data menunjukkan bahawa kedondong dan batai yang telah diimpregnasi menghasilkan peratusan EMC yang lebih rendah berbanding dengan sampelnya yang tidak dirawat. Secara kesimpulannya, keputusan kajian ini menunjukkan bahawa kaedah impregnasi dengan resin LM_wPF telah meningkatkan kekuatan batai, serta menambahbaik sifat kedondong dan batai dari segi kestabilan dimensi dan mengurangkan higroskopisiti kayu.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AH	Absolute hysteresis
ANOVA	Analysis of variance
ASE	Anti-swelling efficiency
DVS	Dynamic vapour sorption
EMC	Equilibrium moisture content
FRIM	Forest Research Institute Malaysia
FSP	Fibre saturation point
H-H	Hailwood Horrobin
HR	Hysteresis Ratio
LSD	Least significant difference
LM_wPF	Low molecular weight phenol formaldehyde
LKS	Lesser-known species
MMA	Methyl methacrylate
MC	Moisture content
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
p-FSP	Projected-fibre saturation point
RH	Relative Humidity
SC	Swelling coefficient
TS	Thickness swelling
WA	Water absorption
WPG	Weight percent gain

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Kedondong (*Canarium* spp.) and batai (*Paraserianthes falcataria (L.)* Nielsen) are commercial Malaysian tropical hardwoods that require preservative treatments to enhance their durability. Kedondong is one of the commonly marketed timber species and are widely available for various applications in local sawmills and plywood mills. According to the Forestry Department of Peninsular Malaysia (2016) about 312,283 m^3 of kedondong logs were extracted from forests in Peninsular Malaysia annually. At the same time, about 4,199 m^3 of batai logs were also extracted from Peninsular Malaysia forests (FDPM, 2016). Remarkably, batai is planted in large scale plantations in Sarawak and Sabah and the price of those logs are still competitive. Apart from generating significant economic gains for locals and for rural development, these species are fast growers and are commonly free from major known pests and diseases (Adnan et al., 2021; Hashim et al., 2015). Batai can hit a height of up to 40 m tall and its diameter more than 100 cm enabling it to be cut into sawn timber of different sizes (Orwa et al., 2009).

In terms of structural applications in the construction industry, kedondong and batai have not been fully exploited due to their poor strength which when exposed to humid environment will deteriorate in strengths and durability. Based on the Malaysian Standard MS544: Part 2, kedondong and batai are classified as having a strength group (SG) of only 5 and 7 levels respectively. Hence, they are considered as weak and could be used only for light construction purposes, for instance, for walling works. In addition, these species exhibit inherent limitations such as dimensional instability and low durability (Lembaga Perindustrian Kayu Malaysia, 2010). Therefore, proper treatments to transform them into good construction and building materials for long-term duration should be carried out. This study aims to contribute in this aspect.

Several wood modifications such as acetylation, furfurylation, thermal and impregnation treatments are said to be able to improve wood performance into desired properties (Hill, 2006). As an example, a remarkable improvement on the mechanical properties and dimensional stability of hornbeam wood was reported through acetylation treatment. The acetylated hornbeam wood showed a decrement of about 70% in its equilibrium moisture content (EMC) which caused the reduction in the shrinking and swelling rates by 24-82% (Németh et al., 2020). A study on poplar wood which was chemically modified with the glycidyl methacrylate and vinyl acetate (GMA/VA) solutions had resulted in the enhancement of its physical properties. Its water absorption capability was significantly lower compared to its untreated sample while the anti-swelling efficiency (ASE) reached up to 67.62%.

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Evidently, several studies maintain that impregnation treatment with LM_wPF resin had been identified as a promising method to upgrade low-quality timber and Lignocellulosic material (Ang et al., 2014; Anwar et al, 2011). In fact, a study discovered that a simple production process and equipment to synthesize the LM_wPF has made it a cost-effective treatment method

to improve strength properties, enhance its dimensional stability and increase its resistance towards weathering and moldability (Huang et al., 2013). Furthermore, the high temperature applied during the curing stage also causes the bulking action of LM_wPF resin in the wood cell structure. As stated in Zaidon (2017), curing temperature at 150ºC was the optimum temperature to cured about 12-mm thick of impreg and compreg product and results in a no leaching state when PF treated sample in contact with water.

Researches have revealed that the bulking action of LM_wPF would improve wood physical and mechanical properties, moisture uptake as well as biological durability (Zaidon, 2017; Anwar et al., 2011). In addition, there are other researches that have reported success for enhancing the physical and mechanical properties of wood by LM_wPF impregnation. Nur et al. (2011) found that LM_wPF impregnated jelutong showed improvement in the mechanical and dimensional stability. The impregnated product of oil palm wood with LM_wPF also showed significant increase in the physical and mechanical properties (Khairunnisha et al., 2017) .

In another study, masson pine impregnated with phenol formaldehyde reported that the dimensional stability and wood strength had improved. The swelling and shrinking coefficients percentage were reduced while the anti-swelling and anti-shrinking efficiency showed an increment along with the increasing percentage of resin concentration. The resin impregnation on masson pine wood also contributed to the significant improvement of wood hardness and compressive strength compared to its control sample (Wang et al., 2019).

Phenolic impregnation through the bulking mechanism could reduce wood hygroscopicity as sorption behaviour could affect the dimensional movement. Since wood is hygroscopic, further moisture absorption would result the timber to decay (Engelund et al., 2013). The performance of wood shrinking and swelling, bearing of heavy loads and resistance to deflection is significant for outdoor exposures (Hosseinpourpia et al., 2016). As outdoor condition continuously changes at particular temperature and relative humidity (RH), the selection of unsuitable hardwood species and inefficiency of treatment for exterior usage would cause the products to be easily damaged.

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1.2 Problem Statement and Justification of Study

Enhancement on physico-mechanical properties of wood through impregnation treatment using PF resin had resulted in numerous positive disclosures. PF resin at low molecular weight about 290-480 was identified has significant reduction on wood swelling due to deep penetration of solution into the wood cell wall (Purba et al., 2014). The three different PF resin concentration in the current study was maximize in its solid content with aim to reduce the formaldehyde emission as possible. Study on birch woods revealed that the deposited resin bulked the cell wall resulting in dimensional stabilization. A study outcome shows that the WPG of the sample can reach up to 17.1% at 15% resin concentration with the ASE recorded at an average of 41% (Grinins et al., 2018). In agreement with this, sesenduk also recorded significant improvements on water absorption after impregnation with LM_wPF /nanoclay admixture. It recorded 69.8% to 77.2% reduction in water absorption after impregnation (Nabil et al., 2015).

On the other side, the impregnation treatment with LM_wPF resin offers an excellent improvement on wood strength. Research conducted on sesenduk wood showed that the penetrated and deposited resin in wood cell wall increased its MOE value up to 7721 N/mm^2 compared to its untreated sample that recorded at 3863 N/mm^2 (Nabil et al., 2015). Phenolic treated pine and beech also showed an enhancement in bending strengths with about 21.4% and 29.0%, respectively and its MOR value had reached to almost 18% improvement compared to is untreated sample (Pečnik et al., 2021).

Wood treated with PF resin had successfully reduced its hygroscopicity. This is because the moisture sorption at particular relative humidity (RH) and temperature affected wood dimensional stability and strength significantly. A study on beech veneer treated with MUPF resin had successfully reduced wood moisture content. At 95% RH, untreated sample recorded EMC of up to 25% while phenolic treated sample at 25% and 50% PF resin concentration recorded 17% - 20% (Bicke and Militz, 2014). In addition, another previous study on wood veneer treated with PF resin also showed an apparent low adsorption activity at about 80% RH (Hosseinpourpia et al., 2016).

Hence, this study attempts to seek the potential of kedondong and batai for wider utilization in structural applications in the construction industry. It aims at investigating the effectiveness of treatments to increase their dimensional stability and strength performances. Admittedly, studies on the moisture sorption behaviour of wood that has undergone impregnation treatment with LM_wPF resin are rather limited. As kedondong and batai are expected to be utilized more popularly with appropriate treatment, the investigation to improve the performance of kedondong and batai after being impregnated with LM_wPF resin is worth to be carried out.

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1.3 Aim of The Study

The focus of this research is to improve the performance of kedondong (*Canarium spp*.) and batai *(Paraserianthes falcataria (L.)* Nielsen) using different concentration of LM_wPF resin. In this study, the wood samples were impregnated with low-molecular weight phenol formaldehyde (LM_wPF) resin. The physical and mechanical properties of both the untreated and impregnated samples were evaluated and compared. The sorption behaviour of the samples was characterized and the obtained data was fitted using the hailwood Horrobin (HH) Model.
The specific objectives of this study are:

1. To determine the effect of resin concentration of LM_wPF on weight percent gain (WPG) and wettability of kedondong and batai.
2. To compare the physical and mechanical properties of LMwPF treated and untreated kedondong and batai
3. To assess the adsorption and desorption behaviour of impregnated kedondong and batai by using HH model.

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