UNIVERSITI PUTRA MALAYSIA

PERFORMANCE OF OIL PALM WOOD IMPREGNATED WITH PHENOLIC RESIN AT DIFFERENT CONCENTRATIONS AND EXTENDED SOAKING PERIODS

PUTERI NUR KHAIRUNNISHA BINTI ISMAIL

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By

PUTERI NUR KHAIRUNNISHA BINTI ISMAIL

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

March 2015

DEDICATION

Special dedicated to:

My supervisor committees
ASSOC. PROF. DR. EDI SUHAIMI BAKAR
DR. RASMINA HALIS

My Father
ISMAIL BIN NOSI

My Mother
RAJA KHAIZON BINTI RAJA KAMARUZAMAN

and

My Sisters and Brother
PUTERI NUR ILY AMALINA BINTI ISMAIL
MEGAT NAQIUDDIN LUTFIE BIN ISMAIL
PUTERI NUR SYAHEEDA BINTI ISMAIL

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

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March 2015

Chairman : Associate Professor Edi Suhaimi Bakar, PhD.
Faculty : Forestry

Wood from oil palm (*Elaeis guineensis* Jacq.) trunk has not yet been optimally utilized because of several imperfections in their properties. It was reported that the oil palm wood (OPW), even from the best outer-part, has four main imperfections, which are very low in strength (class III-V), very low in durability (class V), low in dimensional stability, and very poor in machining behavior. Considering these imperfections in properties, the properties of OPW should be improved before it can be utilized. Resin impregnation treatment has been considered as an effective method in overcoming the shortfalls of OPW mentioned above. The process of the treatment includes drying, impregnation, heating and densification. However, in this treatment, the resin used is not expected to penetrate and bulked into OPW cell walls. The soaking method has been used as a method for treating wood. It was reported that low molecular weight resin penetrates well into swollen cell walls that occurred by soaking method. Therefore, the impregnation and soaking process using low molecular weight phenol formaldehyde (Lmw-PF) were carried out in this study. The process consists of drying, impregnation, soaking process, semi-curing resin and curing to produce *impreg* OPW. Study was undertaken to determine the effect of soaking process and resin concentration on polymer loading and performance of *impreg* OPW which had been treated with Lmw-PF resin. The polygon sawing pattern was used to prepare the materials in this study. After drying to 15% MC, the lumber samples were impregnated under vacuum (80 mmHg) and continued with 30 min under pressure (120 psi) with resin concentration 10, 15 and 20%. After impregnation, the samples were soaked in a container contained with the same resin concentration for 6, 12, 18 and 24 h to allow soaking process. Then, the samples were re-dried in an oven set at a temperature of 70°C until 70% MC, before finally being fully cured in an oven at a temperature of 150°C for ±3 h.

In general, the results from samples with soaking process (soaking periods at 6, 12, 18 and 24 h) were better than those without soaking process (soaking period 0 h). In terms of physical properties, the soaking periods and resin concentrations had a significant effect and had increment 4 times of density

gain, 32.98% of weight percent gain, and 2 times cell wall penetration. The dimensional stability also give significantly effect to the *impreg* OPW. Both water absorption and thickness swelling had reduction on soaking periods and resin concentrations with 7.37% and 5.08% respectively. Meanwhile, in terms of mechanical properties, it was found that the soaking periods and resin concentrations gave significant effects and had increment 1.5 times of MOE, 2 times MOR, 2 times of compression strength parallel to the grain, 42.25% of hardness and 34% of shear strength parallel to the grain. The physical and mechanical properties of *impreg* OPW were positively correlated with polymer loading, whilst water absorption and thickness swelling were negatively correlated with polymer loading for *impreg* OPW.

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

PRESTASI KELAPA SAWIT KAYU IMPREGNASI DENGAN FENOLIK RESIN PADA KEPEKATAN BERBEZA DAN DILANJUTKAN TEMPOH RENDAMAN

Oleh

PUTERI NUR KHAIRUNNISHA BINTI ISMAIL

Mac 2015

Pengerusi : Professor Madya Edi Suhaimi Bakar, PhD
Fakulti : Perhutanan

Kayu dari kelapa sawit (*Elaeis guineensis* Jacq.) belum dioptimumkan kerana beberapa ketidaksempurnaan pada sifat kayu. Dilaporkan bahawa kayu kelapa sawit (OPW), walaupun yang terbaik dari luar-bahagian, mempunyai empat ketidaksempurnaan utama, iaitu yang amat rendah kekuatan (kelas III-V), yang sangat rendah ketahanan (kelas V), dimensi kestabilan yang rendah, dan sangat buruk dalam pemesinan. Oleh sebab ketidaksempurnaan ini, sifat-sifat OPW perlu diperbaiki sebelum boleh digunakan. Rawatan resin impregnasi telah dianggap sebagai kaedah yang berkesan untuk mengatasi masalah kekurangan OPW. Proses rawatan adalah termasuk pengeringan, impregnasi, pengeringan separa dan pemadatan. Walau bagaimanapun dengan kaedah rawatan ini, resin yang digunakan tidak dijangka akan menembusi dan berkumpul ke dalam dinding sel OPW. Kaedah rendaman telah digunakan sebagai satu kaedah untuk merawat kayu. Dilaporkan bahawa molekul formaldehid berat fenol rendah dapat menembusi ke dalam dinding sel bengkak yang berlaku dengan kaedah rendaman. Oleh itu, impregnasi dan rendaman menggunakan molekul formaldehid berat fenol formaldehyde rendah (Lmw-PF) telah digunakan dalam kajian ini. Proses ini terdiri daripada pengeringan, impregnasi, rendaman, pengeringan separa dan pengeringan penuh untuk menghasilkan *impreg* OPW. Kajian telah dijalankan untuk menentukan kesan rendaman dan kepekatan resin pada muatan polimer dan prestasi *impreg* OPW yang telah dirawat dengan Lmw-PF resin. Kaedah poligon menggergaji telah digunakan untuk menyediakan bahan-bahan dalam kajian ini. Selepas dikeringkan sehingga 15% MC, sampel kayu telah dirawat dengan vakum (80 mmHg) dan diteruskan sehingga 30 min di bawah tekanan (120 psi) dengan kepekatan resin 10, 15 dan 20%. Selepas impregnasi, sampel telah direndam di dalam bekas yang terkandung dengan resin yang sama untuk tempoh 6, 12, 18 dan 24 j untuk proses rendaman. Kemudian, sampel telah dikeringkan semula dalam ketuhar ditetapkan pada suhu 70 °C sehingga 70% MC, dan akhirnya pengeringan sepenuhnya dalam ketuhar pada suhu 150 °C selama ± 3 j.

Secara umum, keputusan daripada sampel dengan rendaman (tempoh merendam pada 6, 12, 18 dan 24 j) adalah lebih baik daripada sampel yang tidak direndam (tempoh rendaman 0 j). Bagi ciri fizikal, tempoh rendaman dan kepekatan resin dipengaruhi ketara dan mempunyai kenaikan iaitu 4 kali peratusan kenaikan ketumpatan, 32.98% daripada peratus berat pertambahan (WPG), 2 kali penembusan dinding sel. Kestabilan dimensi juga memberikan kesan ketara kepada *impreg* OPW. Kedua-dua penyerapan air dan pembengkakan ketebalan ini mempunyai pengurangan dalam tempoh rendaman dan kepekatan resin dengan masing-masing 7.37% dan 5.08%. Sementara itu untuk sifat mekanik, didapati bahawa tempoh rendaman dan kepekatan resin memberi kesan yang penting dan mempunyai kenaikan 1.5 kali daripada MOE, 2 kali MOR, 2 kali kekuatan mampatan selari dengan ira, 42.25% daripada kekerasan dan 34% kekuatan ricih yang selari dengan ira. Sifat-sifat fizikal dan mekanikal *impreg* OPW dengan muatan polimer telah memberi kesan positif kepada sifat OPW, manakala penyerapan air dan pembengkakan ketebalan memberi kesan negatif apabila dikaitkan dengan muatan polimer untuk *impreg* OPW.

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I certify that a Thesis Examination Committee met on 31 March 2015 to conduct the final examination of Puteri Nur Khairunnisha binti Ismail on her thesis entitled "Performance of Oil Palm Wood Impregnated with Phenolic Resin at Different Concentrations and Extended Soaking Periods" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Jegatheswaran a/l Ratnasingam, PhD
Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Zaidon bin Ashaari, PhD
Professor
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

H'ng Paik San, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

Abdul Khalil bin Shawkataly, PhD
Professor
Universiti Sains Malaysia
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17 June 2015

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

Edi Suhaimi bin Bakar, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Rasmina binti Halis, PhD
Senior Lecturer
Faculty of Forestry
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision
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Signature: ______________________

Name of Chairman of Supervisory Committee: **Assoc. Professor Dr. Edi Suhaimi bin Bakar**

Signature: ______________________

Name of Member of Supervisory Committee: **Dr. Rasmina binti Halis**

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
C	Celsius
$CS_{\parallel}$	Compression strength parallel to the grain
CWP	Cell wall penetration
DG	Density gain
EFB	Empty fruit bunches
FRIM	Forest Research Institute Malaysia
HS	Hardness strength
LSD	Least significant different
Lmw-PF	Low molecular weight phenol formaldehyde
MC	Moisture content
MDF	Medium density fiberboard
MOR	Modulus of rupture
MOE	Modulus of elasticity
MPOB	Malaysia Palm Oil Board
OPF	Oil palm fronds
OPT	Oil palm trunk
OPW	Oil palm wood
PF	Phenol formaldehyde
R&D	Research and development
SAS	Statistical analysis system
UF	Urea formaldehyde
UPM	Universiti Putra Malaysia
TS	Thickness swelling
WA	Water absorption
WL	Weight loss
WPG	Weight percent gain

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In 2013, sawn timber from Peninsular Malaysia was a major contributor to the export of wood based products. Sawn timber accounted for 37% of export of volume (549,521 m^3), with a much higher value compared to other wood products (Maskayu MTIB, 2014). The majority of the species of wood converted to sawn timber has high strength and high durability such as Chengal, Balau, Merbau and more. However, these species are categorized as slow growing trees and the availability of these species is now severely restricted. Thus, a solution must be sought to solve this problem.

Related to the difficulty in obtaining sources to produce sawn timber, the use of non-conventional materials such as industrial waste and agriculture waste was proposed. Palm oil is the largest agricultural product in Malaysia and Malaysia is the second largest palm oil producer in the world behind Indonesia (USDA FAS, 2014). In 2013, Malaysia had approximately 5.2 million hectares of oil palm plantation (MPOB, 2014). The vast plantation area implies that Malaysia also produces a large amount of agricultural waste from oil palm. This large amount of agricultural waste from oil palm has been suggested as alternative materials for substituted sawn timber, especially the trunks from replanting activities.

The average age for oil palm replanting is approximately 25-30 years. Every year in Malaysia, there were 40 million tons residual oil palm biomass waste from oil palm tree (Baharuddin *et al.*, 2009). This was indicated that oil palm had produced al large quantity of agriculture residues. The oil production of palm is only about 10% of the total biomass produced in oil palm plantations. The rest of the biomass are lignocellulosic materials which consist of oil palm fronds (OPF), oil palm trunks (OPT) and empty fruit bunches (EFB) (Bakar *et al.,* 2008a). There is a potential to use these materials such as an alternative wood material, plywood manufacture, produced composite wood, produced biofuel, especially from the OPTs (Bakar *et al.,* 2008b). However, the OPT needs to be improved because of several limitations in their properties.

It was reported that the quality of OPW can be enhanced through several chemical treatments such as bulking treatment, internal coating cross-linking and wood modifications (Hill, 2006). There have been many studies done to enhance the quality of OPW by bulking treatment with Lmw-PF resin. Impregnation with Lmw-PF resin (molecular weight 600) followed by densification had increased the mechanical and physical properties Of OPW (Faizatul *et al.,* 2010; Abdul Khalil *et al.*, 2012a; Khairunnisha *et al.,* 2014). Impregnation with 15% Lmw-PF densification also increase the durability of OPW (Bakar *et al.,* 2013a), improved the quality of machining (Chong *et al.,* 2010) and reduce the level of formaldehyde emission (Amarullah *et al.*, 2010). Thus, with such characteristics along its good appearance, the treated OPW can be used for high-grade furniture and housing materials (Bakar *et al.*, 2007a). However, there is a possibility to further enhance the quality of OPW using the diffusion method instead of just the impregnation modification.

Impregnation modification can define as any method that results in in filling of the wood substance with an inert material. Researchers have several methods in impregnation modification involves treating wood/lignocellulosic material with monomer solution that diffuses into the cell wall, followed by subsequent polymerization. These were proofed by studies of (Stamm and Beacheler, 1960; Rowell and Banks, 1985; Aizat *et al.*, 2014, Ang *et al.*, 2014; Zaidon *et al.*, 2014). The properties were enhanced due to the bulking of the cell wall impregnation. The common synthetic resin for treatment used are phenol formaldehyde, melamine urea formaldehyde, methylolated melamine and formaldehye, urea formaldehyde, dimethyloodihydroxethyeneurea and polypropylene (Hill, 2006). The Lmw-PF resin, with the molecular weight is below 1000 has been most successful and most reported to improve the dimensional stability of composite products.

Hunt and Garratt (1967) reported that the theory of diffusion states that chemicals will move from zones of higher concentration (treating solution) to those with lower concentrations (water in the wood). Therefore, wood and waterbone chemicals are used for diffusion treatments. This diffusion method typically involves soaking wood in solutions, but theoretically can extend to use of pastres and wraps to deliver chemicals into wood. In addition, Hill (2006) also had mentioned the resin penetration into cell walls occurred by diffusion process. If so, the soaking method can be considered as an effective method for treating OPW.

1.2 Problem Statement and Justification

The wood of OPT, oil palm wood (OPW), has not been optimally utilized because of several imperfections in their properties. The outer part of OPT has the best properties of OPW. It was reported that even the best outer-part OPW has four main imperfections, which are; (i) very low in strength, (ii) very poor in durability, (iii) bad in dimensional stability, and (iv) very poor in machining behavior (Bakar *et al.,* 2006). Considering these problems, there were needed a proper treatment to improve the quality of OPW.

There was a good solution to enhance the quality OPW which was by the impregnation treatment with synthetic resin such as phenol formaldehyde (Bakar *et al.*, 2013). Theoretically, the resin used in the impregnation method was bulked and penetrated into cell lumens (Rowell, 2005). It is expected that better improvement of the material will be achieved if the resin penetrates into cell walls. The penetration resin into cell wall occurred by extended soaking periods and different resin concentrations. Deka and Saikia (2000) stated that most of resin were penetrates in cell wall when the volume treated samples were nearly equal to volume polymer added

In this study, the oil palm wood impregnated with phenolic resin at different concentrations and extended soaking periods with Lmw-PF resin was employed to improve the properties of OPW. The increasing of extended soaking periods and different resin concentrations were enhanced the properties of OPW. Thus, the treatment OPW within these variables were affected the properties OPW. There were selected the extended soaking periods (6, 12, 18 and 24 h) and different resin concentrations (10, 15 and 20%) to determine the performance of OPW impregnated with Lmw-PF resin. In addition, the treated OPW is targeted for indoor application such as flooring and furniture.

1.3 Objectives

This study attempts to study the extension of soaking activity in the impregnation process on the physical and mechanical properties of OPW impregnated with Lmw-PF resin.

The specific objectives of the study were:

- To determine the effects of resin concentrations and soaking period on polymer resin and durability OPW impregnated with Lmw-PF
- To investigate the effects of the treated enhancement on physical and mechanical properties of the *impreg* OPW.
- To optimize of soaking periods and resin concentrations on the properties of *impreg* OPW

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