UNIVERSITI PUTRA MALAYSIA

PROPERTIES OF RESIN-TREATED OIL PALM WOOD HEATED USING CONVENTIONAL OVEN AND MICROWAVE WITH DIFFERENT DENSIFICATION PARAMETERS

NURUL AZWA BINTI AHMAD

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By

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

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DEDICATION

'Praise be to Allah S.W.T. who created the heavens and the earth, and made the darkness and light' (Al-An'am 1)

All praise to Allah. I am thankful to Allah for giving me peace, good life and success through my parents and family's great prayers. I pray everyone will be blessed continuously by Him and I greatly appreciate their undivided support, patienceandsacrificeswhileI'mpursuingmyprofessionalaim.Inthenameof Allah (Subhanahu WaTaalaa). This thesis is dedicated to:

My Late Father
Almarhum Ahmad Ariffin

May Allah have mercy on his soul and grants him Jannah

My Mother
Khotijah Salleh

My Beloved Husband
Zulkhairi Mokhtar

My Uncle and My Auntie
Zuber Abdul Hamid and Rosnah Safee

My Parents In Law
Mokhtar Abdullah and Asmak Md Noor

My Daughter
Nur Qaireen Alisya Zulkhairi

Nur Qaira Aulia Zulkhairi

All my family members

And

My Supervisor, Associate Professor Dr. Edi Suhaimi Bakar who helped me throughout this journey.

May Allah S.W.T. blesses you and grants you success and Jannah.

Last Quote

“ There is always a hope for them who pray, and there is always a solution for them who work hard”

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

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

A study was undertaken to evaluate the physical and mechanical properties of Oil Palm Wood (OPW) treated with low molecular weight phenol formaldehyde (Lmw-PF) resin. The objectives of the study were to determine the effect of dual combination heating systems (oven heating and microwave heating) with different densification parameters on the weight gain, physical and mechanical properties of the treated OPW.

A preliminary study conducted revealed that the suitable drying by combination oven with temperature 70ºC dried until 80% moisture content (MC) and microwave heating (dried until final MC 50%) used and proceeded for the different densification parameters processes. The samples were densified to 50% densification from the thickness of 40 mm to 20 mm at a temperature of 150ºC for three durations namely 30 minutes, 35 minutes and 40 minutes using 85 bar pressure. Four pressing cycles were applied for each process which consists of one cycle until three cycles with different compressed thickness. The compressed samples were then tested with the formaldehyde emission test, Fourier Transform Infra-Red (FTIR) as well as physical and mechanical tests.

As for physical testing, the data analysis showed that the compression steps and durations did not give significant effect to the densities of the samples. The analysis also showed that the density profile between the different parts (surface and core) of the samples were also insignificant ($p > 0.05$). As for density gain study, the study showed that the mean percentage density gain values ranged from 94% to 116%. The compression duration and step were

found to give significant effect to the density gain of the treated OPW. The weight gain study showed that the mean values range was 12.04% and 21.41% respectively. The mean water absorption values of the compressed samples were between 8.73% and 19.73%. The compression steps and durations gave significantly different to the water absorption rate of the compressed samples at $P<0.05$. The thickness swelling of the control samples was found to be higher than the thickness swelling of the compressed samples. Mixed results were recorded when mean values between compression durations were compared. It was hard to determine which compression duration caused a huge increment of thickness swelling since compression step may have also affected the results.

The formaldehyde emission test showed that the longer compression duration and cycles gave a lower formaldehyde emission rate of the samples. However, the formaldehyde emission mean values for the treated samples were found to be too high when compared with the required FE value (0.1 mg/L) by the American National Standard Institute (ANSI) for indoor applications.

Mechanical properties of the treated and untreated OPW were also assessed. Comparison on the mean values of the Modulus of Rupture (MOR) was made between each compression step and duration. The compression step and the compression duration gave no significant effect to the mean MOR values. On the other hand, the Modulus of Elasticity (MOE) results showed that the compression step gave no significant effect ($p > 0.05$) to the MOE of the OPW samples. Like MOR, the highest mean MOE values came from the samples impregnated with Lwm-PF compressed with compression step C:Thickness 4cm – 3.5cm – 2.5cm – 2cm (3 cycles). The compression duration did not really give significant effect in improving the elasticity of the OPW samples. The compression strength comparison showed that treated OPW performed better than untreated samples. The best mean compression strength value was 88.90N/mm^2obtained from samples treated with Lwm-PF and compressed with compression step C for 40 minutes. The compression step was found to cause insignificant effect to the hardness of the OPW samples. The treated OPW samples were found superior to the control samples. The highest mean hardness value was found from the treated OPW samples compressed with compression C for 35 min.

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

SIFAT-SIFAT KAYU KELAPA SAWIT DIRAWAT MELALUI GABUNGAN PEMANASAN KONVENSIONAL OVEN DAN PEMANASAN MIKROWAVE DENGAN PEMADATAN BERBEZA

Oleh

NURUL AZWA BINTI AHMAD

Jun 2015

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

Satu kajian telah dijalankan untuk menilai sifat-sifat fizikal dan mekanikal Kayu Kelapa Sawit (KKS) dirawat dengan berat molekul rendah fenol formaldehid resin (LMW-PF). Objektif kajian ini ialah:1) untuk menentukan kesan sistem gabungan pemanasan (pemanasan ketuhar dan pemanasan gelombang mikro) dengan parameter pemadatan yang berbeza pada berat KKS dirawat;2) untuk menentukan kesan dua sistem pemanasan gabungan (pemanasan ketuhar dan pemanasan gelombang mikro) dengan parameter pemadatan berbeza pada sifat-sifat fizikal dan mekanikal OPW yang dirawat.

Kajian awal yang dijalankan menunjukkan bahawa pengeringan sesuai melalui kombinasi ketuhar dengan suhu 70ºC dikeringkan sehingga kandungan 80% kelembapan (MC) dan pemanasan gelombang mikro (kering sehingga MC akhir 50%) digunakan dan diteruskan untuk parameter proses pemadatan berbeza. Sampel melalui 50% pemadatan dari ketebalan 40mm hingga 20mm pada suhu 150ºC selama tiga jangka masa iaitu 30 minit,35 minit dan 40 minit menggunakan 85 tekanan bar. Empat kitaran menekan telah digunakan untuk setiap proses yang melibatkan kitaran satu hingga tiga dengan ketebalan pemadatan berbeza.Sampel dimampatkan kemudiannya diuji dengan ujian pelepasan formaldehid,FourierTransformInfra-Merah (FTIR) serta ujian fizikal dan mekanikal.

Bagi ujian fizikal, analisis data menunjukkan bahawa langkah-langkah mampatan dan tempoh tidak memberi kesan yang ketara kepada ketumpatan sampel. Analisis juga menunjukkan bahawa kepadatan profil antara bahagian yang berlainan (permukaan dan teras) daripada sampel juga

tidak ketara (p> 0.05). Bagi ketumpatan keuntungan kajian, kajian menunjukkan bahawa nilai keuntungan ketumpatan purata peratusan adalah di antara 94% hingga 116%. Tempoh mampatan dan langkah didapati memberi kesan kepada pertambahan ketumpatan KKW yang dirawat. Penambahan berat sampel menunjukkan bahawa nilai min berkisar masing-masing adalah 12.04% dan 21.41%. Nilai penyerapan purataair sampel dimampatkan adalah di antara 8.73% dan 19.73%. Langkah-langkah mampatan dan tempoh memberi perubahan ketara berbeza dengan kadar penyerapan air sampel yang dimampatkan pada P <0.05. Bengkak ketebalan sampel kawalan didapati lebih tinggi daripada bengkak ketebalan sampel yang dimampatkan. Hasil yang pelbagai telah direkodkan apabila nilai purata antara jangka mampatan berbeza. Adalah sukar untuk menentukan perimeter yang menyebabkan kenaikan besar bengkak ketebalan apabila langkah mampatan juga boleh mempengaruhi keputusan.

Ujian pelepasan formaldehid menunjukkan bahawa tempoh mampatan yang lebih lama dan kitaran menunjukkan kadar pelepasan formaldehid lebih rendah daripada sampel. Walau bagaimanapun,pelepasan formaldehid nilai purata sampel yang dirawat didapati terlalu tinggi jika dibandingkan dengan nilai FE yang diperlukan (0.1 mg / L) oleh ANSI untuk keperluan dalaman.

Sifat-sifat mekanikal KKW yang dirawat dan tidak dirawat juga telah dinilai. Perbandingan nilai purata Modulus pecah (MOR) telah dibuat antara setiap langkah mampatan dan jangka masa. Langkah mampatan dan tempoh mampatan tidak memberikan kesan yang besar kepada purata nilai MOR. Sebaliknya, Kajian Modulus Keanjalan (MOE) hasil kajian menunjukkan bahawa langkah mampatan tidak memberi sebarang kesan yang signifikan (p> 0.05) kepada MOE sampel KKW. Seperti MOR, nilai purata paling tinggi MOE datang dari sampel dirawat dengan LWM-PF dimampatkan dengan langkah mampatan C: Ketebalan 4cm - 3.5cm - 2.5cm - 2cm (3 kitaran). Tempoh mampatan tidak benar-benar memberi kesan yang besar dalam meningkatkan keanjalan sampel KKW. Kekuatan mampatan perbandingan menunjukkan bahawa KKW yang dirawat memberi keputusan yang lebih baik daripada sampel yang tidak dirawat. Nilai purata mampatan kekuatan yang terbaik adalah 88.90 N / mm² diperolehi daripada sampel dirawat dengan LWM-PF dan dimampatkan dengan langkah mampatan C selama 40 minit. Langkah mampatan didapati menyebabkan kesan yang tidak ketara kepada kekerasan sampel OPW. Sampel OPW dirawat didapati lebih tinggi daripada sampel kawalan. Yang paling tinggi nilai kekerasan min didapati dari sampel OPW dirawat dimampatkan dengan mampatan C selama 35 min.

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

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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;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
Approx	Approximately
C	Celsius
CT	Control Treated
CU	Control Untreated
FE	Formaldehyde Emission
FRIM	Forest Research Institute Malaysia
FTIR	Fourier Transformed Infra-red
KKS	Kayu Kelapa Sawit
LSD	Least significant different
Lmw-PF	Low molecular weight phenol formaldehyde
MC	Moisture content
Min	Minutes
MOE	Modulus of elasticity
MOR	Modulus of rupture
MPOB	Malaysia Palm Oil Board
MS	Malaysia Standard
OPT	Oil palm trunk
OPW	Oil palm wood
PF	Phenol formaldehyde
RH	Relative Humidity
TS	Thickness swelling
UPM	Universiti Putra Malaysia

WA	Water absorption
WPG	Weight percent gain
cm	centimeter
mm	milimeter
M	magnetron
ha	hectares

CHAPTER 1

INTRODUCTION

1.1 Background

Demand for wood has increased in line with population growth, economy and technology development due to its versatility. It is renewable, biodegradable, non-toxic, energy-efficient and environmental-friendly (Anon, 2012). Hence, wood has become a popular raw material for housing and furniture applications due to the properties that it has.

Unfortunately, the increasing demand of natural timbers has exceeded the long- term supply of natural timbers and plantation forests. Timbers need longer time to grow and achieve suitable age, maturity and diameter before it can be harvested. As the timbers grow slowly, the loggers / suppliers need to wait for a long period of time before they could supply the timbers to the market and meet its demand. There is no way for the loggers or suppliers to supply the wood before the required time is met, unless they supply fast-growing timbers. However, normally, fast-growing timbers have inferior properties as compared to slow-growing timbers. In the view of quality demand which keeps rising, supplying fast-growing timbers is not a good option. This surely has caused decrements to the supply of the timbers

The decreasing supply of timbers is also due to several factors such as reduction of forest areas for open mining, industrial plantation and infrastructure development. Another contributor is public awareness on forest preservation that forced the loggers to reduce the exploitation of timbers from the forests. It has been discovered the decrease of natural timber supply has happened since the last two decades and it keeps happening until today.

This situation has given a massive negative impact to wood-based industry as it makes wood manufacturers difficult to find suitable raw materials for their productions (Bakar, 2008). Therefore, any alternatives must be sought, including those from agricultural residues. One of the strategic alternative materials is oil palm residues from oil palm plantations. As one of the most important commercial crops in Malaysia, huge amount of oil palm residues is left underutilized in the field and these, especially the trunk, can be used as wood alternatives (Bakar *et al.,*2005).

The commercial value of oil palm lies mainly in the oil that can be obtained from the mesocarp of the fruit–palm oil and the kernel of the nut–palm kernel oil. The remainders are considerable amount of lignocellulosic residues such as fronds, trunks, and empty fruit bunches. Among these residues, oil palm trunk (OPT) offers the best properties which are comparable to those of wood. The total area under oil palm cultivation is 5,392,235 hectares in Malaysia, where 4,689,321 hectares matured trees and 702,914 hectare immature trees (MPOB, 2014).

It is now needful to conduct continuous research and development to find ways to convert oil palm residues into useful and valuable material. Many researches have proven that OPT can be transformed into value-added products such as plywood, particleboard and laminated veneer lumber (Nordin *et. al*. 2014; Sulaiman *et al.*, 2008). A study has shown that oil palm wood (OPW) from the outer part of the OPT can be used as solid wood (Bakar *et al.,* 2008). Based on those studies and the data of the total current replanting area, it is projected that about 12 million m³ OPW can be produced annually in Malaysia.

Wood from the outer part of the OPT, "outer lumbers", offer the best properties. Yet, this part of lumber still has four main imperfections that need to be improved; i.e. very low in strength, bad in dimensional stability, very low in durability, and very poor in machining characteristic. Therefore, effective methods for properties enhancement need to be sought. By looking at the properties that OPT has, it was reported that impregnation using phenol formaldehyde and followed by compression to produce 'compreg' OPW is one of the best ways to tackle the imperfections of OPT (Bakar *et al.,* 1999). The Modification Impregnation method which consists of drying, impregnation, re- drying, and hot pressing densification has proven to be the effective method to improve the quality of OPW. Using low molecular weight Phenol formaldehyde resin (Lwm-PF), of various concentrations, impregnation times, re-dying conditions, and hot-pressing densification process, the optimum treatment condition of OPW has been disclosed (Bakar *et al.,* 2005). The dimensional stability, strength, durability and the machining characteristic of OPW can be improved significantly. These improved properties as well as good appearance make the treated OPW to be used as a material for production of non-structural components (Bakar *et al.,* 2007). Based on its physical and mechanical properties, (Bakar *et al.,* 2007) revealed that the PF-treated OPW is suitable for internal and non-structural applications.

1.2 Problem Statement

Oil Palm Tree (*Elaeis Guineensis*) has become one of the most valuable commercial crops in Malaysia where it produces significant biomass that can be converted into a value-added product (Sulaiman et. al., 2012). OPT, which felled after 25 years is less expensive and abundantly available where it can be difficult to degrade the trunk due to the higher density variability especially between the inner and the outer part of the trunk. By treating the

OPW with the suitable chemicals such as synthetic or natural polymers in fluid form, it can increase the properties of the OPW and can be a replace the usage of solid wood. There were few methods to increase wood density such as by compressing wood to reduce void volume, impregnating the void volume with suitable chemicals or by using a combination of impregnation and compression (Bustos *et. al*., 2011). Treatments to the OPT with low molecular weight phenol formaldehyde (Lwm-PF) resin can increase the properties and replace the usage of solid wood, but the suitable parameter to be used is still not established yet. Based on the physical and mechanical studies of low molecular weight (600mw) phenol formaldehyde treated Oil Palm Wood (OPW) done by Bakar *et al.* (2007), it was suggested that Lwm-PF-treated OPW can be used fornon-structural and indoor applications.

Unfortunately, the formaldehyde emission of the Lwm-PF-treated OPW was quite high (Amarullah, 2010) and not suitable for indoor applications. Thus, a system needs to be established to increase the properties of the OPW and to control/reduce the formaldehyde emission so that it can be a substitute of solid wood. There are numerous studies on how heat treatment affects the properties of wood (Bekhta *et. al.*, 2009, Bekhta and Niemz 2003, Boonstra and Tjerrdsma 2006, Ozcan *et. al*., 2012). Densification of wood with heat and compression has some advantages over wood with treated by heat without compressed. (Boonstra and Blomberg 2007, Bami and Mohebby 2011). Densification of OPW can increase the density and solve the porous structures that obtain in OPW. However, densifying the treated OPW to achieve best properties by heat and compression seen to be used for different applications. Therefore this research was carried out to obtain more information as well as finding ways on the best properties OPW and formaldehyde emission of Lwm-PF (which was dried with the most efficient drying step and fabricated with the most suitable compression step).However, the hot pressing variables using combination system still not yet optimized. Thus, it is important to know the effect of hot pressing cycles and times on the physical and mechanical properties of the samples that used a combination of oven and microwave method in the heating stage. Manufacturing parameters such as pre-treatment, pressure, temperature, and chemical properties have been found to have an important influence on the properties of compressed wood (Shahbazi *et. al*., 2005; Cai*et. al*., 1992; Hsu *et. al*., 1988; Hillis 1984).

1.3 Objectives

The objective of this study is:

- To determine the effect of dual heating systems (oven heating and microwave heating) with different hot-pressing parameters on the weight percent gain, physical and mechanical properties of the treated OPW.

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