FABRICATION OF NOVEL PARTICLEBOARDS FROM OIL PALM FROND BLENDED WITH EMPTY FRUIT BUNCH AND TREATED WITH PRESERVATIVE AGAINST TERMITE

WAHIDA BINTI AMAT FADZIL

MASTER OF ENGINEERING（CHEMICAL）

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : WAHIDA BINTI AMAT FADZIL

Date of Birth : 28 OCTOBER 1988

Title : FABRICATION OF NOVEL PARTICLEBOARDS FROM OIL PALM FROND BLENDED WITH EMPTY FRUIT BUNCH AND TREATED WITH PRESERVATIVE AGAINST TERMITE

Academic Session : 2016/2017

I declare that this thesis is classified as:

☐	CONFIDENTIAL	(Contains confidential information under the Official Secret Act 1997)*
☐	RESTRICTED	(Contains restricted information as specified by the organization where research was done)*
☑	OPEN ACCESS	I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

_______________________ (Student's Signature)

_______________________ (Supervisor's Signature)

881028-11-5436
Date:

Assoc. Prof. Dr. Ghazi Faisal Najmuldeen
Date:

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Engineering in Chemical Engineering.

____

(Supervisor's Signature)

Full Name : ASSOC. PROF. DR. GHAZI FAISAL NAJMULDEEN

Position : SENIOR LECTURER

Date :

____

(Co-supervisor's Signature)

Full Name : ASSOC. PROF. DR. ARUN GUPTA

Position : SENIOR LECTURER

Date :

____

(Co-supervisor's Signature)

Full Name : DR. SURIATI BINTI GHAZALI

Position : SENIOR LECTURER

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for the quotations and summaries which have been duly acknowledge. The thesis has not been accepted for any degree and is not concurrently submitted for the award for any other degree.

____

(Student's Signature)

Name : WAHIDA BINTI AMAT FADZIL

ID Number : MKC13005

Date :

DEDICATION

Dedicated especially to my:

Mentors

Family

Friends

Thank you for all of your supports along the way.

FABRICATION OF NOVEL PARTICLEBOARDS FROM OIL PALM FROND BLENDED WITH EMPTY FRUIT BUNCH AND TREATED WITH PRESERVATIVE AGAINST TERMITE

WAHIDA BINTI AMAT FADZIL

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Master of Engineering

Faculty of Chemical and Natural Resources Engineering

UNIVERSITI MALAYSIA PAHANG

FEBRUARY 2017

ACKNOWLEDGEMENTS

I am grateful to Allah swt for the good health and wellbeing that were necessary to complete this research and dissertation. I wish to express my sincere to my supervisor, Assoc. Prof. Dr. Ghazi Faisal Najmuldeen, for the support, for his patience, motivations and immerse knowledge. I wish to express my sincere thanks to co-supervisor, who are giving comments and suggestions about this project.

I am thankful you my fellow friends for the friendship and spiritual support whenever I was in need. Last but not least, I am grateful to my parents, brothers and sister for supporting me throughout this journey.

ABSTRAK

Kekurangan sumber hutan telah meningkatkan kesedaran dikalangan pengeluar komposit berasaskan kayu untuk mencari sumber alternatif untuk bahan mentah yang digunakan dalam penghasilan komposit. Pada masa kini, penyelidikan dan pembangunan berkaitan sisa kelapa sawit sedang dijalankan dan didapati sisa sawit adalah alternatif yang boleh digunakan untuk mengatasi masalah kekurangan sumber kayu. Dalam kajian ini, papan serpai telah berjaya dihasilkan daripada campuran hancuran pelepah kelapa sawit (OPF) dan gentian daripada tandan kosong kelapa sawit (EFB). Eksperimen berdasarkan reka bentuk Box-Behnken telah dijalankan untuk menentukan kesan suhu tekanan, masa tekanan dan nisbah gentian tandan kosong kelapa sawit ke atas sifat papan serpai yang diperbuat daripada hancuran pelepah kelapa sawit. Tiga tahap telah ditetapkan untuk setiap pembolehubah dimanipulasi. Pemboleh ubah bergerak balas terdiri daripada modulus kepecahan (MOR), modulus keanjalan (MOE), ikatan dalaman (IB), keserapan air (WA) dan pembengkakkan ketebalan (TS) dianalisa menggunakan perisian Design Expert. Simulasi model dan pengoptimuman turut dilaksanakan. Analisa statistik menunjukkan semua pembolehubah mempunyai kesan yang ketara ke atas sifat papan serpai. Parameter optimum untuk maksimum MOR, MOE, IB dan minimum WA dan TS diperolehi pada; suhu 185.6°C, masa 5.70 minit dan nisbah gentian tandan kosong kelapa sawit 30.4%. Papan partikel optimum hasil campuran pelepah dan hampas tandan kosong telah dirawat dengan menggunakan cypermthrin berkepekatan (0.5, 1.0 dan 1.5% w/v) dan minyak semambu berkepekatan (5, 10 dan 15% v/v) untuk meningkatkan rintangan papan partikel terhadap anai-anai. Rintangan papan partikel terhadap anai-anai telah dinilai melalui dua cara iaitu, kaedah ujian makmal dan juga ujian lapangan. Penemuan daripada dua ujian tersebut menunjukkan papan partikel yang dirawat menggunakan cypermethrin dan minyak semambu mampu meningkatkan kerintangan papan partikel terhadap anai-anai.

ABSTRACT

The shortage of forest resources has triggered an increase in awareness among the wood based product industry to find alternative supply of raw materials for composites production. Currently, oil palm biomass is undergoing research and development and appears to be the feasible alternative to the wood shortage problem. In this research, novel blend particleboards made of oil palm fronds (OPF) particles and empty fruit bunch (EFB) fibre were successfully fabricated. A Box-Behnken experimental design was carried out to determine the effects of pressing temperature, pressing time and EFB/OPF ratio on the properties of the OPF particleboards. Three levels were employed for each variable. The responses are modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding (IB), water absorption (WA) and thickness swelling (TS) of fabricated particleboards were analysed using Design Expert Software. Model simulation and numerical optimisation were also carried out. The statistical analysis showed that all the variables have significant effects on the properties of particleboards. The optimised parameters for maximum MOR, MOE and IB, and minimum WA and TS determined were found to be: press temperature, 186 °C; press time, 5.70 min; and EFB/OPF ratio, 30.4%. A treatment of optimised OPF-EFB particleboards with various concentrations of cypermethrin (0.5, 1.0 and 1.5% w/v) and neem oil solution (5, 10 and 15% v/v) has been used to improve the resistance of fabricated particleboard against termite. Termite resistance of particleboards sample was evaluated in two ways; laboratory test and field test. The finding from both tests revealed that the OPF-EFB particleboards treated with cypermethrin and neem oil has improved the resistance of particleboards against termite.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

y	Predicted response
β_0	Constant coefficient
$\beta_j,\beta_{jj},\beta_{ij}$	Regression coefficient
X_j, X_i	Coded independent variables
e_i	Error
N	Number of experiment
f	Number of factor
C_0	Number of centre points
W_{OD}	Oven dried weight
W_w	Wet weight
MC	Moisture content
W_1	Oven dried weight
W_2	Weight of residue, Oven dried weight
A	Linear effect for press temperature
B	Linear effect for press time
C	Linear effect for EFB/OPF ratio
AB	Interaction effect for press temperature and time
AC	Interaction effect for press temperature and EFB/OPF ratio
BC	Interaction effect for press time and EFB/OPF ratio
A^2	Quadratic effect for press temperature
B^2	Quadratic effect for press time
C^2	Quadratic effect for EFB/OPF ratio
R_1	Modulus of rupture
R_2	Modulus of elasticity
R_3	Internal bonding
R_4	Thickness swelling
R_5	Water absorption
T_1	Initial thickness of sample before immersion
T_2	Final thickness after immersion

P_m	Static bending load is
L	Specimen's length
b	Specimen's width
t	Specimen's thickness
P'	Maximum rupture load
R^2	Coefficient of determination
R_{adj}^2	Adjusted coefficient of determination
R_{pred}^2	Predicted coefficient of determination
G	Weight of the treatment solution absorbed by the block
C	Preservative amount in 100 g or 100 ml of the treatment solution
V	Volume of the block
M_1	Number of termites alive at the beginning of the test
M_2	Number of termites alive at the end of the test
NA	Not available
NS	Not specific
M-S	Commercial grade
M-1	Commercial grade
PBU	Underlayment grade
W_T	Total weight
$W_{R(solid)}$	Solid weight of resin
$W_{H(solid)}$	Solid weight of hardener
$W_{P(solid)}$	Solid weight of OPF particles or EFB fibres
W_R	Measured weight of resin
W_H	Measured weight of hardener

LIST OF ABBREVIATIONS

2FI	Two factorial interaction model
ANOVA	Analysis of Variance
ANSI	American National Standard Institute
ASTM	American Testing for Testing and Materials
AWPA	American Wood Protection Association
BJC	Builders' joinery and carpentry
CCD	Central composite design
CPO	Crude palm oil
CV	Coefficient of variation
DM	Dry matter
EC	Emulsifier concentrate
EFB	Empty fruit bunch
FFB	Fresh fruit bunch
FRIM	Forest Research Institute Malaysia
GCMS	Gas Spectrometer Mass Spectrometer
HDF	High density fibreboard
IB	Internal bonding
IC	Isocyanate
LOF	Lack of fit
MC	Moisture of content
MDF	Medium density fibreboard
MF	Melamine formed-formaldehyde
MF	Mesocarp fibres
MNSB	Malaysian National Biomass Strategy
MOE	Modulus of elasticity
MOR	Modulus of rupture
MPOB	Malaysian Palm Oil Berhad
MTIB	Malaysian Timber Industry Board
MUF	Melamine urea formaldehyde

NH_4Cl	Ammonium chloride
OFAT	One Factor at Time
OPF	Oil palm fronds
OPT	Oil palm trunks
OSB	Oriented strand board
PF	Phenol formaldehyde
PKO	Palm kernel oil
PKS	Palm kernel shells
PMDI	Polymeric dipenyl methane diisocyanate
RSM	Response Surface Methodology
TS	Thickness swelling
UF	Urea formaldehyde
WA	Water absorption capacity

CHAPTER 1

INTRODUCTION

1.1 Research Background

The nature provides humans with sources needed for life, such as energy for heat, mobility and electricity, woods for building and shelter construction, furniture, paper and as well as foods, lands and pure water. Unfortunately, global human population growth has caused the demand for the consumption of natural resources is constantly on the rise. Since the forest provides us with most of the resources, but most of the forests are being cut down and burned. Exploitation of hardwood to build houses and making furniture are responsible for deforestation. The environmental problems caused by overexploitation of natural resources for higher standard living are already clear. Industrial logging of the forest is destroying the habitats of animal and plant species, climate change, fresh water and oxygen reserves are depleting (Muilerman & Blonk, 2001). Thus, sustainable development of natural resources and waste is needed to prevent the extinction of these resources.

Sustainable development is socio-ecological process characterised by the fulfilment of human needs while maintaining the natural environment. Switching from natural wood to other alternatives will decrease the demand for wood. Using solid wood to manufacture various types of wood products has caused the forest reserves to diminish in an alarming way and increasing cost of the raw materials. When the Malaysian government restricted the logging activities, rubber wood emerged as an alternative resource of timber in the wood industry. Latex tapping of rubber trees starts in the fifth to seventh year after planting and continues for 20 to 30 years. At the age of 20 to 30 years, the latex production is uneconomic and the trees will be cut and the new replantation is done (Kiyono et al., 2014). The utilization of rubber wood in the making furniture, sawn timber and wood based panels began in the 1980s (Tekle, 2014). The rubber wood is well known as the most important timber used in the furniture industry due to its machining properties, acceptable durability, pleasant appearance and ease finishing. Approximately, 80% of wood based furniture is produced using rubber wood (Zakaria, Merous, & Ahmad, 2014). However, the rubber wood which is planted for its latex tapping and wood harvesting is also facing declining supply problems. The rubber wood logs price has increased up to RM160 per tonne in 2015 (MTIB, 2015a) from RM135 in 2011 (Juliana, Paridah, & Anwar, 2012) due to high demand of rubber wood.

According to a survey conducted by Ratnasingam & Jalil, (2011), the wood products manufacturers are very concerned about the seasonality supply of rubber wood and the increasing price of the materials. The causes for this problem are the declining rubber tree cultivation area in Malaysia due to the low latex price in the market. The large plantation group in Malaysia; KL Kepong, Golden Hope and Guthrie are slowly converting from rubber plantation to oil palm tree plantation. The area of rubber tree cultivation has shrunk from 1.9 million hectares in 1990 to 1 million hectares in 2010 (Ratnasingam, Ioraș, & Wenming, 2011). It is proved that, the production of rubber wood logs showed a descending trend through the time. Thus, to ensure a long term supply of furniture raw materials, changing to renewable biomass could be a way to overcome this problem.

Utilization of renewable resources instead of depreciating resources can reduce the dependence of furniture and composite industry on natural solid wood. It is an effort in addressing the goals of sustainable developments. The building materials should be green, reusable and obtained from local sources, including rapid renewable plants like palm fronds, bamboo, coral stone (Haggag & Elmasry, 2011). Renewable raw materials include all agricultural and forest raw materials such as starch from cereals, oils from oilseed crops, cellulose from wood and straw, fibres from fibres plants and sugars from sugar beet (Jering et al., 2010).

Malaysia has vast amounts of untapped natural fibre materials available from the agricultural plantation area. These fibrous biomass materials range from rice husk, coconut coir and oil palm biomass. Oil palm trees are the most important crop in Malaysia. In 2015, the total oil palm plantation area was 5.4 million hectares. The oil palm trees bear fruits at the age of two to three years and have an economic life of approximately 25 to 30 years. Then, the trees will be removed for replanting. Along its life, oil palm trees will produce six types of oil palm biomass; oil palm fronds (OPF), empty fruit bunch (EFB) fibre and oil palm trunk (OPT), palm kernel shell, mesocarp fibres and palm mill effluent. It is estimated about 80 million dry tonnes of oil palm biomass was generated in 2010. The number is expected to continually increase up to 100 million dry tonnes by 2020 as stated in Malaysian National Biomass Strategy 2020 (MNBS 2020, 2011). The biomass volume is kept on rising due to the expansion of agricultural land and will lead to environmental problems if they are not handled wisely.

Many researchers are focusing on converting biomass residue into wide varieties of products as well as application of technologies in producing wood based composite products. These products are manufactured by binding the plant fibre strands, particles or veneers with adhesive through certain methods. The wood based products can be classified into two categories which are structural and non-structural wood products. Structural products include plywood, strand lumber and veneer lumber products while non-structural are particleboards and fibreboards. Currently, Malaysia wood manufacturers produce both structural and non-structural products for domestic and international market (Osman, 2015). Current wood based composite market shows positive trends and expected to continually grow in the coming years. In the third quarter of 2015, the wood based industry recorded total export earnings of RM14.13 billion and the total import value is RM2.2 billion (MTIB, 2015b). The demand is driven by the population growth, increases in household numbers and construction materials.

1.2 Problem Statement

In wood-based industries, the shortage of wood as a raw material has recently become a great concern. Wood-based industries are now facing a problem with the supply of raw materials, not only from natural forests, but also from rubber plantations. Shortage of wood as a raw material has forced wood-based industries to find alternative local raw materials. Currently, oil palm biomass is undergoing research and development and appears to be the most viable alternative. This work examines the conversion of oil palm fronds and oil palm empty fruit bunches into new particleboards and analyses its properties. Oil palm frond is especially promising, as it can be utilised as a value added product as well as in future wood-based industries.

Oil palm empty fruit bunch and oil palm mesocarp fibers are two important types of fibrous materials left in the palm oil mill. Among the different natural fibers, EFB fibres appear to be promising materials because of the high tensile strength and toughness of oil palm fibre. Therefore any composite comprising of EFB fibres will exhibit the above desirable properties of the individual constituents (Jacob et al., 2004). Currently, there is no information on the physical and mechanical properties of particleboard made from oil palm frond and empty fruit bunches. Therefore, this study seeks to determine the physical and mechanical properties of the hybrid particleboards. A better understanding will help to develop productive uses for oil palm frond and empty fruit bunch, mitigating environmental problems from waste biomass while also developing an alternative material to wood.

Wood and wood based composites are important both residential and non-residential building construction. Many types of solid wood are relatively easily deteriorated by a variety of organisms, including fungi, termites, bores and also weathering. These biological degradations are developed with time and leads to products damage and huge financially loss. However, wood based composite have received more attention than solid wood due to changes in building design and protective practice (Morrell, 2002). The termites will damage the wood based composites by feeding the lignocellulosic component. This study is crucial since the termite attacking the wood based product is a common problem in Malaysia causing high economical loses. It is uneconomic to replace the damage products. It will reduce the life span, structural ability and its appearance. Thus, in order to increase the life span of the particleboards, treatment with preservative material is necessary.

1.3 Research Objectives

- To fabricate particleboards from mixed oil palm fronds and empty fruit bunch.
- To characterize physical and mechanical properties of fabricated particleboards and compare with the standard.
- To optimise the fabrication process parameter of particleboards using Response Surface Method (RSM).
- To treat and test the fabricated particleboards with anti-termite preservative materials.

1.4 Research Scopes

To achieve all the objectives of this research, all following shall be followed:

- Collection oil palm frond (OPF) and empty fruit bunch (EFB) fibres and processing into desired size.
- Fabrication of particleboards from OPF particles and EFB fibres using urea formaldehyde resin through hot press method.
- The variable factors include are EFB fibres ratio to OPF particles (0 to 40%), hot pressing temperature (150 to 190 °C) and hot pressing time (3 to 7 minutes).
- The physical and mechanical properties of the fabricated particleboards were characterized and analysed in order to identify the optimum conditions.
- Comparison of the properties of the particleboards with the ANSI A-208. 1-1999 Standard.
- The treatment of the optimised fabricated particleboards using anti-termite solution using vacuum impregnation treatment method.
- Biodegradation studies on untreated and treated particleboards against termite through 4 weeks laboratory test and field test were conducted.
- The weight loss, visual rating examination and termite mortality of samples after the test were evaluated.

1.5 Research Significances

This study aims to use oil palm biomass (OPF and EFB) as a source to replace the diminishing rubber wood to produce particleboards. It is a way to promote the use of low cost and renewable resources. The increased level of accumulated OPF and EFB in the plantation area is leading to a very bad environment impact. Finding a method to utilize these sources will save the environment and solve the environmental problems due to disposal of the biomass. Another concern in the utilization of lignocellulosic material in making panels is to increase the durability and resistance of wood based boards from biological degradation of termites.

Assessing the positive impact of the increased utilization of oil palm biomass has been a concern to the Malaysian Government with a launched of National Biomass Policy 2020. Furthermore, this study is important both to expand fundamental knowledge and enhance industrial applications of particleboards manufacturing. The information obtained will be a very useful guide for future activities in relatives to any oil palm biomass research and development.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter is a bibliographic review of past studies regarding to lignocellulosic biomass, oil palm biomass and their application in production wood based composites. Oil palm biomass was chosen because oil palm industry is the main contributor of biomass resources in Malaysia. This chapter also describes the detailed practices for the particleboards manufacturing process along with the review of variables affecting the particleboards properties and optimised method to be applied in particleboards manufacturing process. Termite resistance testing methods also were included. All the information and data gathered are very useful to be applied in Chapter 3.

2.2 Agricultural Residue – Sources of Lignocellulosic Biomass

The concern over the fossil fuel process, environmental pollution, global warming issues have initiated interest in the use of renewable materials. An alternative for this issue is promoting the use of biomass as raw material resources for various products and applications.

2.2.1 Introduction to Lignocellulosic Biomass

Biomass is the biological material with no or low profit that derived from living organisms. The biomass sources include the conventional product and waste from agricultural, forestry, animal waste and effluent sludge. The biomass categorization is shown in Figure 2.1.

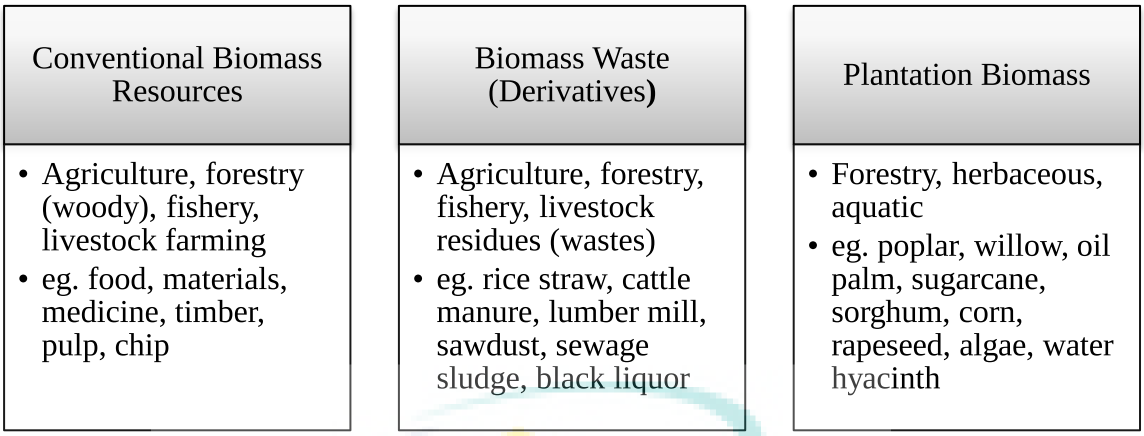

Figure 2.1 Biomass categorization in term of use and application.
Source: Yokoyama & Matsumura (2002)

Agricultural residue may be defined in a broad sense as those parts of any tree which are not utilized to manufacture valuable products. The character of the residue may vary from whole standing trees to logging residue to waste produced from the plantation crops. The agricultural crop residues are produced in billions of tons around the world. These residues are abundant, inexpensive and readily available sources of lignocellulosic biomass. Lignocellulosic biomass are composed of a complex composite of two structural carbohydrates, which are cellulose (38 – 50%) and hemicellulose (23 – 32%), phenolic lignin (15 – 25%) and small amounts of extractive and ash (Kamm, Gerhardt, & Dautzenberg, 2013). The composition of these components varies from one plant species to another depends on the plant age, environment and development growth. Table 2.1 shows the composition of cellulose, hemicellulose and lignin in several lignocellulose sources. These components have the potential to create bonding between particles without using any synthetic resin. When heat and pressure is applied to an insoluble and infusible polymeric substances, the natural sugar within the lignocellulosic material are chemically transformed through the hydrolysis of cellulose, hemicellulose and soften the lignin. The sugars eventually act as bonding agent and strengthen the reconstituted composite product with high physical and mechanical properties, thus improving the properties of the boards. It can be observed that, oil palm biomass have higher cellulose content compared to other biomass. Thus higher content of cellulose and hemicellulos create more bonds especially in making binderless particleboards.

Table 2.1 Percentage composition of lignocellulose component in various lignoocellulosic materials

Materials	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Wheat straw	29 – 35	26 – 32	16 – 21
Hardwood	40 – 55	24-40	18 – 25
Softwood	45 – 50	25-35	25 – 35
Nut shells	25 – 30	25 – 30	30 – 40
Grasses	25 – 40	25 – 50	10 – 30
OPF	33.2 – 57	33.40	15 – 23.7
EFB	29 – 37	22	18 – 23
Rice straw	32.1	24	18

Source: Anwar, Gulfraz, & Irshad, (2014) and UNEP, (2012)

Cellulose is a highly stable glucose polymer linked by β-1,4 glycosidic bonds. It is a polymer made of repeating glucose molecules attached end to end. This linear polymer is consisting of cellubiose which is a glucose-glucose dimer. Klemm et al., (2005) reported that wood pulp cellulose has typical chain lengths between 300 to 1700 units. The second component of lignocellulose materials is hemicellulose, which also known as polyose (Balat, Balat, & Öz, 2008). It presents along with cellulose in almost cell plant walls. Generally, it is a short and highly branched polymer of five-carbon sugars (xylose and arabinose) and six-carbon sugars (galactose, glucose and mannose) (Lee et al., 2007).

Lignin is an amorphous molecule having both aliphatic and aromatic site that makes plants woody. It is derived from phenylpropane; a six-carbon benzene ring that attached to a straight chain of three carbon atoms. The lignin will fill up the gaps between the long thin fibres in the cell wall and bind them together. Lignin can act as copolymer in urea formaldehyde and phenol formaldehyde because its structure is similar to those resins. This component plays important role in the wet forming board process. Figures 2.2 – 2.4 illustrate the molecular structure of cellulose, hemicelluloses and lignin components respectively.

Another common components exist in lignocellulosic biomass are protein, organic compounds such as glycerides, alkaloids, pigments and waxes. The metal elements such as Na, Fe, K, P, Mg, Si and Al also can be found depends on the feedstock type (Yokoyama & Matsumura, 2008). These components account for a lower proportion compared to the main components.

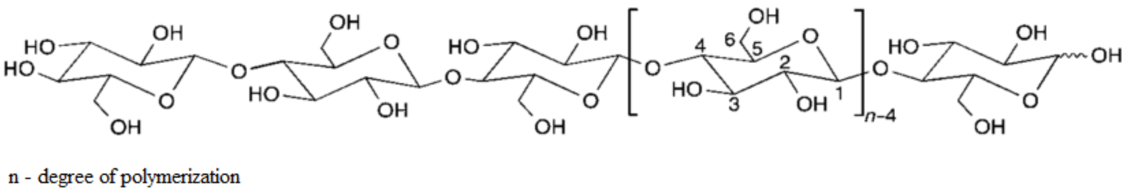

Figure 2.2 Molecular structure of cellulose.
Source: Klemm et al., (2005)

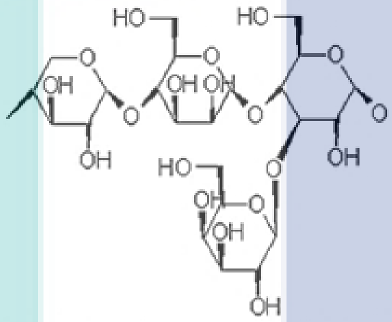

Figure 2.3 Molecular structure of hemicellulose.
Source: Lee et al., (2007)

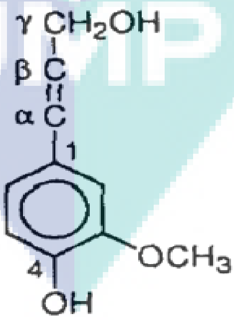

Figure 2.4 Molecular structure of lignin.
Source: Anwar et al., (2014)

Table 2.2 presents the data of total area harvested for world primary crop production, their residue and distribution of the crops in different continents. It shows that, oil palm, rice and coconut are the primary crops in Asia. Table 2.2 also shows the agricultural residue production for different continents. For Asia, the data displayed are the total for three sub-regions; Eastern, Southern and Southeast Asia. The sugarcane residue is largely produced in South Asia, oil palm residue is largely produced in South-Eastern Asian countries (including Malaysia, Indonesia and Thailand) and residues from rice production are produced in all three sub-regions of Asia (Bakker, 2013). According to Malik (2012), most Southeast Asian countries are top producer of agricultural products such as rice, sugar, sugar cane, coconut, palm oil and rubber. These countries have a potential of accumulating unwanted biomass from oil palm trees, sugarcane, rice and including all others up to 206.68 million tonnes per year. These agricultural crops produced 30 million cubic metres of wood residues, 27 million tonnes of oil palm residue and 19 million tonnes of rice husk residue which can be used to generate approximately 41000 MW of power (Parnphumeesup & Kerr, 2011and Malik, 2012).

Historically, biomass had been used in many ways such as a source of household fuel, ancient tools, food sources, textiles and building material. Agricultural residues are also used to provide feeds and bedding for animals. In a high yielding rice growing area, cultivars produce about 6 – 7 ton/hectare of paddy straws. The farmers tend to burn these crops residues because the straw is not needed to protect the soils against winds and water erosion in wet and flat field (Smil, 1999). Consequently, this undesirable practice will lead to environmental problems and community health effects.

Instead of burning, these residues can be used to make industrial and commercially viable products. Lignocellulosic residue can be converted into bio-energy; (biofuel or bio-ethanol), fine chemicals (pharmaceutical ingredients), enzyme production and cheap energy sources for microbial fermentation (Anwar et al., 2014). Microcrystalline and nanocrystalline also can be isolated from cellulose material (Keshk & Haija, 2011 and Lee et al., 2014). These residues can be used to manufacture reconstituted product such as paper, particleboards and hardboards (Nemli & Kalaycioglu, 2001). Utilization of lignocellulose material to produce composites will be discussed in section 2.4.3. Conversion of the lignocellulosic feedstock into various valuable products will reduce the dependence on the fossil fuel, and the most important is saving the environment since they are derived from low cost and abundant feedstock.

2.2.2 Oil Palm Plantation Biomass

Oil palm trees may grow up to sixty feet and more in height. The trunks are wrapped in fronds which give them a rather rough appearance. The trees will start bearing fruit after 30 months of field planting and will continue to be economically productive for the next 20 to 30 years. Each palm tree can produce between eight to 15 fresh fruit bunch (FFB) weighing about 15 to 25 kg each depending on the planting conditions and age. Each FFB contains about 1000 to 1300 fruitlets and each fruitlet consists of fibrous mesocarp layer, shell and kernel (Teoh, 2002). Along its live, oil palm tree will produce plenty of biomass from the plantation area and mill site.

2.2.2.1 Oil Palm Tree Lignocellulosic Biomass

Along its life, oil palm trees will produce six types of oil palm biomass. The OPF are available from plantation site since they are regularly cut during harvesting of FFB and pruning of the palm trees, while the trunk is generated during replanting activities. In the mills, EFB remains after the removal of the fruitlets from the bunch. Mesocarp fibres (MF) and palm kernel shells (PKS) are recovered during the extraction of crude palm oil (CPO) and palm kernel oil (PKO), respectively. Besides, palm oil mill effluent (POME) is obtained as an effluent at the final stages of CPO processing.

The oil palm tree biomass are lignocellulosic materials which contains three major components; cellulose, hemicellulose and lignin (Hashim et al., 2011 and Abdul Khalil et al., 2012). Typically, oil palm biomass contains 50% cellulose, 25% hemicellulose and 25% lignin in their cell wall (Alam et al., 2009). Chemical composition of main oil palm biomass in comparison with rubber wood is presented in Table 2.3.

Table 2.2 Distribution of main crops produced in the world by region, and associated agricultural residue production in 2008

Crop	World production crop a Million ton	Total area harvested Million ha	Agri. Residue production b Million ton	Percentage distribution of main crops according to region (%)				
				Africa	America	Asia	Europe	Oceania
Rice	689	156	849	4	5	91	1	0
Maize	827	161	843	7	53	29	11	0
Wheat	683	223	581	3	17	40	36	3
Sugar cane	1734	24	677	5	52	41	0	2
Soybeans	96	231	491	1	86	12	1	0
Barley	155	56	132	3	13	11	68	0
Oil palm fruit	214	15	70	8	5	86	0	0
Coconut	60	12	33	3	9	83	0	4
Sunflower seed	36	25	31	4	19	16	61	0
Cassava	232	19	16	52	15	33	0	0
Coffee beans	8	11	15	11	61	28	0	7

a Crop production in million ton fresh weight (total weight crop including moisture) harvest, as reported by FAO

b Residue production in million ton dry weight basis, based on residue to crop ratio

Source: Bakker (2013)

Table 2.3 Chemical composition of main oil palm biomass and rubber wood

Composition	OPF [a] (%)	OPT [b] (%)	EFB [b] (%)	Rubber wood [c] (%)
Lignin	15–23.7	18–23	13–37	16–17.6
Holocellulose	66.6–83	42–45	68–86	56–60
α-cellulose	33.2–57	29–37	43–65	36–43
Hot water solubility	12.4	-	17.2	6.7–6.8
Alcohol-benzene solubility	4.56	-	4.1	4–4.8
Ash	0.71–2.3	2–3	1–6	0.7–0.85

Source:

[a] Abdul Khalil et al., (2006); Wan Rosli et al., (2007) and Hashim et al., (2011)

[b] Abdul Khalil et al., (2012)

[c] Junaida, Suhaimi, Amran, & Wan Rosli, (2012)

Table 2.4 shows the general utilization of different part of the oil palm biomass. Most of the oil palm biomass is disposed within the system for mulching, use as organic fertiliser and also for energy production in the mill. The rest of the utilized biomass is probably being wasted away or burned. Accumulated of oil palm residue will lead to severe problems in the disposal site since open burning is often no longer allowed. Open burning or simply abandon the biomass away is a great loss of energy since these biomass have significant energy content (Hassan et al., 2013). To date, the MNBS 2020 lays the foundation for Malaysia to capitalise on biomass by channelling it into higher value downstream uses.

Table 2.4 Level of utilization of oil palm biomass residue in Malaysia

Biomass	Percentage utilization (%)	Method of utilization
Pruned fronds	95	Mulching in plantations
Trunks and fronds at replanting	80	Left to be degraded in the fields as mulch to the newly planted tree
Mesocarp fibres	90	Fuel
PKS	90	Fuel
POME	35	Nutrient source and organic fertilizer
EFB	65	Left to be degraded in the fields as mulch

Source: UNEP, (2012)

2.2.2.2 Availability of Oil Palm Biomass

The three largest producers of palm crude oil are Malaysia, Thailand and Indonesia, who together account about 85% of the world palm oil production (Sulaiman et al., 2011 and Abdul Khalil et al., 2012). As December 2014, the total of oil palm plated area in Malaysia is approximately about 5.4 million hectares (MPOC, 2015). This large plantation area is a tremendous opportunity in supplying massive amounts of biomass. The amount of oil palm residues from plantation and mill sites in Malaysia from 2008 to 2012 are presented in Figures 2.5 and 2.6.

Figures 2.5 and 2.6 demonstrate that the OPF are the most abundant residue from oil palm plantation area compared to the others. It is reported that, the fronds average generation rate during pruning activities is 9.8 tons-dry/hectare-plantation/years and 15 tons-dry/hectare-plantation/years during replanting activities (Aljuboori, 2013). The estimated amount of mill residues generally depends on the amount of FFB processed. In the palm oil milling process, a ton of FFB will produce about 0.22 ton EFB (Ng et al., 2011).

Besides the massive amount of available sources, another advantage of oil palm residue is their low cost. Their cost is listed in Table 2.5. The cost acknowledged involves the substitution cost, harvesting cost, collection cost, pre-processing cost and transportation cost. In the wood based product manufacturing process, the raw material cost as much as 40% of the total manufacturing cost (Andre, Young, & Zaretzki, 2010). The raw material cost represents the largest cost out of total manufacturing cost. Thus, utilization of the waste is one of the alternative ways to reduce the manufacturing cost in the industry.

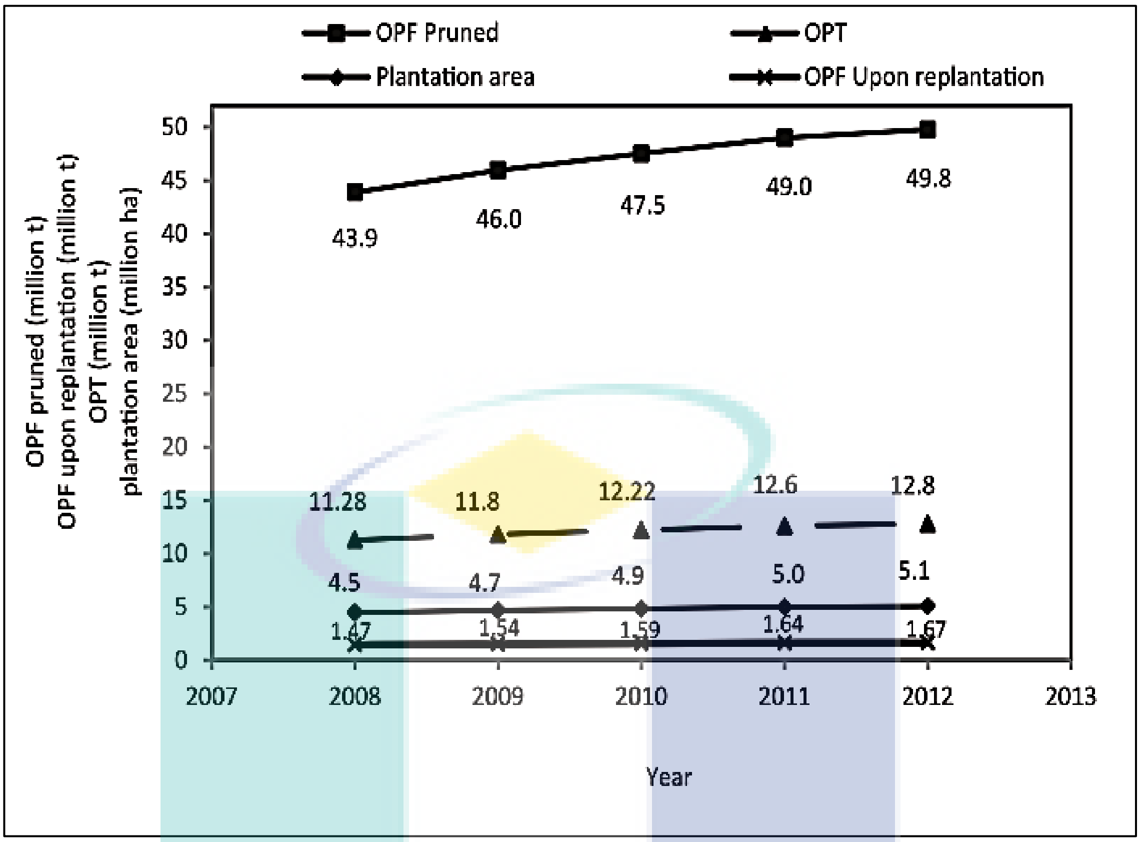

Figure 2.5 Amount of oil palm biomass residue generated from plantation
Source: Aljuboori (2013)

Table 2.5 Cost per tonne of oil palm dry biomass

Oil palm biomass part	Cost (RM)
OPF	150.00
OPT	220.00
EFB	140.00
PKS	130.00

Source: MNBS 2020, (2011)

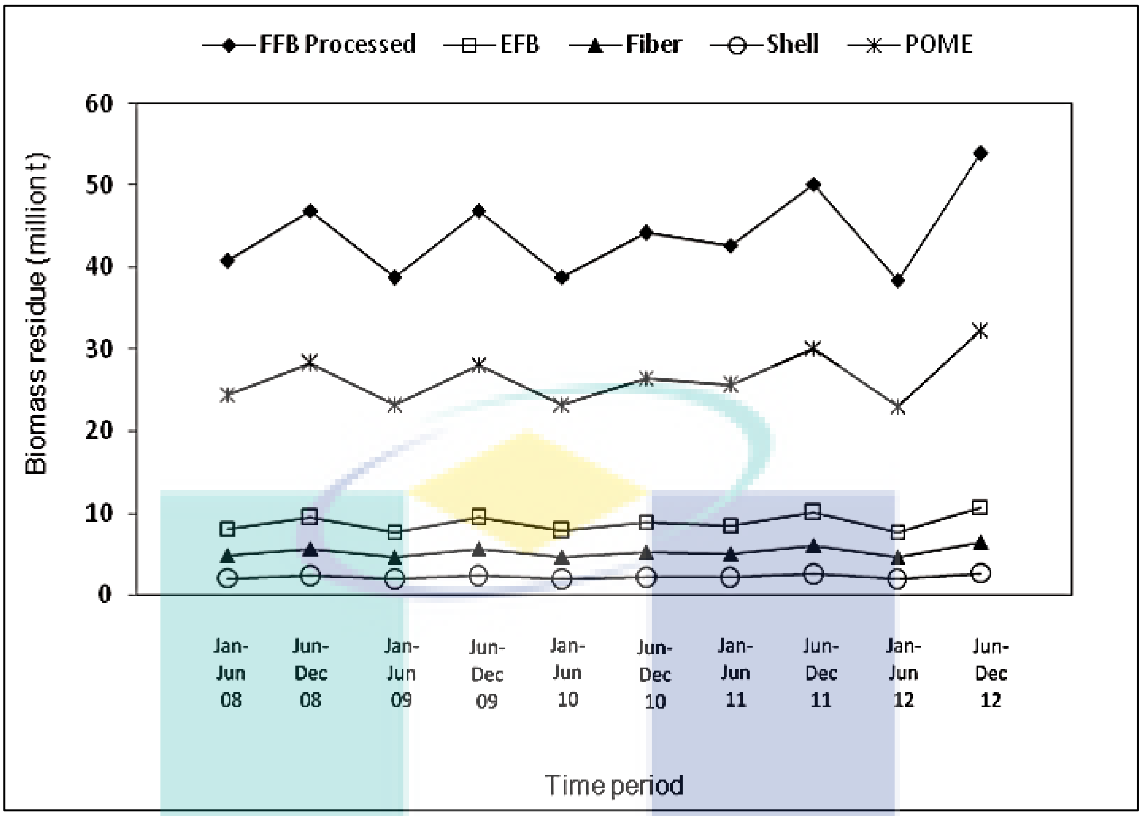

Figure 2.6 Amount of oil palm biomass generated from mill site.
Source: Aljuboori (2013)

2.2.2.3 Oil Palm Fronds (OPF)

OPF consisting of leaflets and petioles is the most abundant biomass residues in oil palm plantation. The average density of fronds is about 700 kg/m^3 with the weight of each frond is between 15 and 20 kg depending on the age and condition of the palm tree (Hassan et al., 2013). The fronds are rich in nitrogen, high content of crude protein and dry matter which considered a good source for ruminant feed.

These literatures affirm the potential utilization of OPF through experimental works into several categories. The fresh cut fronds are suitable as a roughage feed source for ruminants (Ishida & Abu Hassan, 1997 and Wong & Wan Zahari, 2011). Furthermore, OPF also suitable to be used as raw material for pulp and fibre due to high content of α-cellulose and holocellulose (Wan Rosli et al., 2007; Wan Rosli & Law, 2011 and Wang et al., 2012).

Numerous researches had been conducted in the recent past to develop various types of composites using fronds and characterized them in term of physical, mechanical, thermal and sound absorption coefficient. Ibrahim et al., (2012) stated that characteristic of OPF fibre are better compared to OPT and EFB fibres since it do not contain unwanted elements like parenchyma and residual oil which are disadvantageous to the composite strength. All the studies were focussed on the behaviour of the composites to different loading; static, impact, flexural and also product dimensional stability but there are no available data focussing on biological test of the fronds composite.

OPF particleboards have been successfully developed by Laemsak & Okuma, (1996). Then, Sihabut & Laemsak (2010a; 2010b) continued their study on development of thermal and sound insulation fibreboard from OPF through wet forming process. The boards produced exhibit low thermal conductivity which offering of being good insulators. OPF fibreboards generally showed a better sound absorption capacity compared to the absorbing materials in commercial use.

Production of medium density fibreboard (MDF) using OPF and was conducted by Ibrahim et al., (2012). There were also studies explore the manufacturing of binderless fibreboard and particleboards from OPF (Hashim et al., 2011; 2012). The properties of binderless particleboard panels manufactured from of bark, leaves, fronds, mid-parts and core-parts of the trunks were compared. It was found that, the boards made from core-parts trunks and fronds have acceptable strength properties compared to bark and leave fibreboards. However, all developed particleboards had poor dimensional stability properties. This is expected due to the hygroscopic properties of lignocellulosic materials. They tend to absorb water from surrounding easily.

There was a study investigated the productions of composite panels from OPF and rubber woods (Ibrahim et al., 2012), but there are no available data on production of particleboards from a combination of OPF particles with EFB fibres. Therefore, this study is attempting to fabricate particleboards by incorporating EFB fibres as reinforcement materials into OPF particles and characterize the properties of the particleboards produced.

2.2.2.4 Empty Fruit Bunches Fibres (EFB)

The most popular residue used for products development is the oil palm EFB which is a renewable resource. In the past decades, a large number of interesting applications of EFB have accelerated. EFB mulching gives improvement in soil structure due to better aeration thus increase water holding capacity. EFB pulp is suitable to be used in paper making due to its lignocellulosic properties (Tanaka et al., 2004 and Wan Rosli & Law, 2011). EFB also can be used as one of the renewable energy resources (Kerdsuwan & Laohalidanond, 2010). These renewable energy sources not only limited for heating and power generation but also for liquid transportation fuel production. Another commercial product can be obtained from EFB is fibres strands. The fibres are extracted from EFB either through the decortation process (Zulkifli et al., 2009) or retting process (Shinoj et al., 2011). The available retting processes are mechanical retting using hammering, chemical retting by boiling the EFB with chemicals, steam retting and also water/microbial retting. Then, the fibres can be further used to produce pellet, bricket or applied in composite manufacturing.

The growing interest of EFB fibres in making composite had been reported in many research papers. Production of MDF from EFB fibre was investigated by Ramli, Shaler, & Jamaludin, (2002). Potential of hybrid MDF manufactured from EFB fibres blended with rubber wood also have been investigated by Abdul Khalil et al., (2010a). The developed hybrid MDF exhibited better physical and mechanical properties. Same finding also was observed in incorporating of EFB fibres and OPT veneer into plywood (Abdul Khalil et al., 2010b). The hybrid plywood demonstrated better bending strength, screw withdrawal and shear strength. In fact, the hybridisation two or more different particles and materials does improve the composite properties (Barros Filho et al., 2011; Dixit & Verma, 2012).

Incorporating of oil palm fibre into various polymeric matrices for making composite had been reported. Effects of fibre loading, size and treatment on physical, mechanical, thermal properties of composite produced were inspected. EFB fibres appear to be a promising reinforcement material because of its toughness. It also has similarities to coir fibres (Shinoj et al., 2011). Its porous surface morphology is useful for better mechanical interlocking with matrix resin for composite fabrication. Therefore, any composite comprising EFB fibre will exhibit the toughness properties (Jacob et al., 2004). Table 2.6 displays the physical properties of EFB fibres compare to other natural fibres.

Table 2.6 Physical and mechanical properties of natural fibres

Fibre	Diameter (μm)	Density (kg/m^3)	Tensile strength (MPa)	Young Modulus (MPa)	Elongation at break (%)	Microfibrillar angle (°)
EFB	150–500	700–1550	248	6700	14	46
Sisal	120–140	1450	530-630	17–22	20–25	37
Pineapple	20–80	1440	239.46	17.4	0–1.6	14–18
Coir	100–450	1150	131-175	4–6	40–150	39–49
Sisal	50–300	1450	530-640	9.4–22	3–7	10–22
Jute	200	1470	239.46	17.4	1.16	8.10

Source: Jacob et al., 2004; Satyanarayana, Arizaga, & Wypych, 2009 and Chand et al., 1988

2.3 Malaysian Wood Based Industry

The furniture industry in Malaysia has come a long way from the beginning as a traditional and domestic cottage based production in the 1980s to a technologically advanced billion Ringgit today. The industry has gained international acceptance due to its capacity to produce high quality products. Malaysia is currently the 8th largest exporter globally and the third largest Asian exporters of furniture products to over 160 countries (Zainal et al., 2015).

Malaysian wood-based industry is divided into four major sub sectors which are sawn timber, veneer, panel products (plywood, fibreboards, particleboards and mouldings) and builders' joinery and carpentry (BJC) sectors (doors, flooring parquet and furniture components) (Zakaria et al., 2014). The Malaysian government has set up initiatives to moving away from the primary and commodity products towards the production of engineered wood products from other materials such as bamboo, rattan, kenaf, oil palm fibres (Harun et al., 2014). The development of wood based industry also is supported by stable manufacturing activities, research and development of product design, marketing and promotion and also government policies. The export value of different wood products for January to August 2015 is illustrated in Figure 2.7.

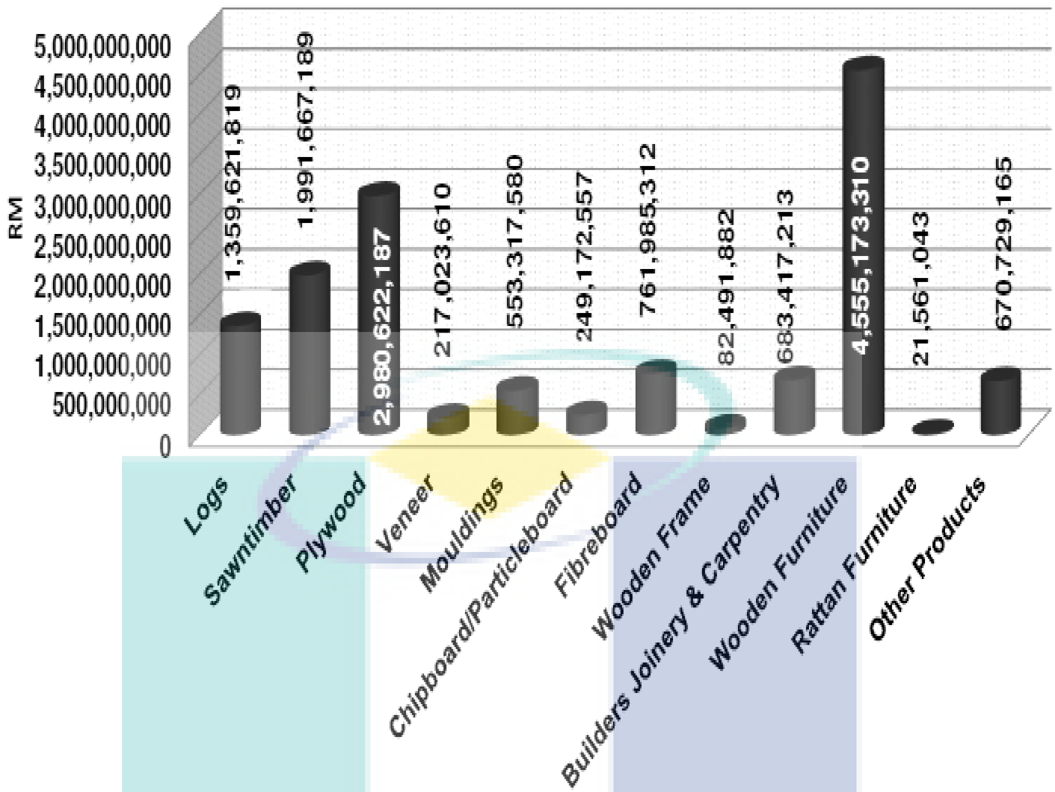

Figure 2.7 Malaysia export value by type of wood products of Jan – August 2015
Source: MTIB, (2015b)

The export earnings for 8 months are RM14.13 billion. It is the revenues from the export of wooden furniture (32%); plywood (21%); sawn timber (14%); logs (9%); fibreboard (6%); BCJ (5%); mouldings (4%), particleboards (2%); wooden frame (1%); veneer (1%) and other timber products (5%). Particleboards market is predicted to climb over the forecast period due to the expected growth in the furniture production and residential construction (RISI, 2015). The export of particleboards products by destination is shown in Figure 2.8. It shows that Asian countries are the largest regional market for Malaysia's particleboards exports. Based on the export earning, the future of particleboards market look very bright and promising.

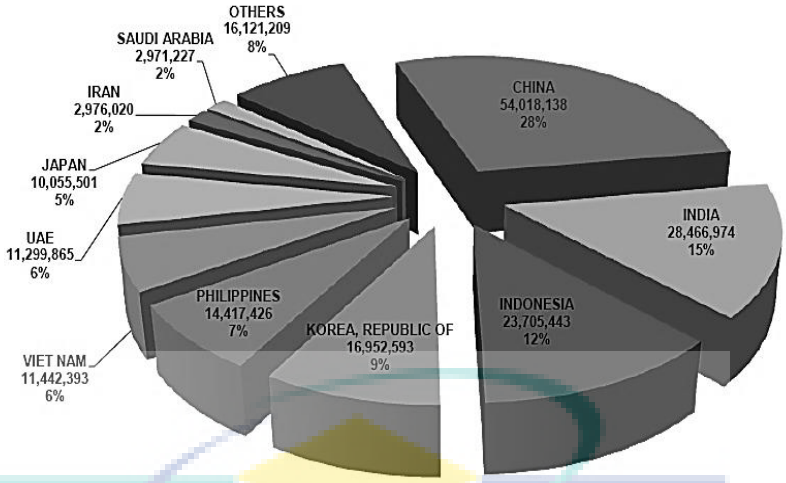

Figure 2.8 Export of Malaysian particleboards products by destinations in Jan – April 2015.

Source: (MTIB, 2015b)

2.4 Wood Based Composites

Wood based composite products can be classified into four groups; veneer based material (plywood, laminated veneer lumber); composite material (fibreboard, hardboard, particleboard, oriented strand board (OSB), flakebaord and waferbaord; laminates (overlaid materials, laminated wood non-wood composites) and wood non-wood composites such as wood fibre-polymer composites (Stark, Cai, & Carll, 2010). Particleboards by far are the most produced product and followed by MDF (BAT, 2014). The wood based composite products are composed of various size and geometry wood materials such as particles, fibres, strips, wood flakes, sawdust, veneers, pulp, lumbers and their combinations (Porter, 2012). These wood elements will go through resin application, forming and pressing process.

Figure 2.9 shows the classification of wood composites in term of material used, manufacturing process, density and specific gravity. The selections of wood elements, adhesive and processing techniques are contributed to the product performance. Table 2.7 shows the typical densities and mechanical properties required by various manufactured boards. It shows that each composite has different required mechanical properties due to their different raw material sources, geometrical, structures, manufacturing process and applications.

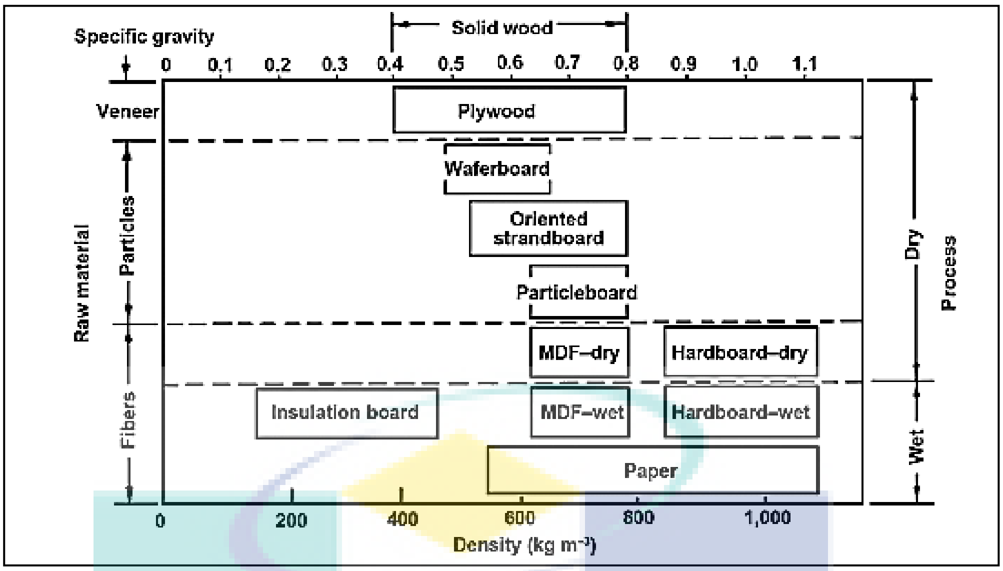

Figure 2.9 Classification of wood composites panels by particles size, density and its process.

Source: Suchsland & Woodson (1986)

Table 2.7 Typical properties of wood composites

Wood composite	Density (kg/m^3)	Elastic Modulus (GPa)	Bending Strength (MPa)	Tensile Strength (MPa)
Spruce plywood	≈500	6.9-13	21-48	6.9-13
OSB	≈500	4.8-8.3	21-28	6.9-10.3
High density fibreboard (HDF)	850-1100	2.8-5.5	31	15
Particleboards	500-750	2-4	15-25	-
Kraft linerboard	600-800	2.8-4.1	NA	25

Source: Rowell (2012)

Wood based products are used for a number of structural and non-structural applications ranging from panels for interior covering purposes to exterior uses, in furniture and as support structures in many different types of buildings. Wood based products have become important as a substitute for the solid woods over the decade years. The main advantages are it will help in conserving the tropical forest and also economical alternatives particularly to the furniture industry. Compare to the solid wood, wood composite can provide better uniform properties because reduction of wood into small uniform particles, fibres or flakes. Wood composites also can be manufactured with targeted properties by controlling the properties of the wood element and production process used. Application of certain additives could improve the resistance of wood composite against weather and biological attack or degradation.

2.4.1 Particleboards

Particleboards sometimes called chipboards are non-structural panels developed in 1950 to utilize wood industrial residue from production of plywood and softwood lumber. Particleboards can be manufactured from numerous particles; fine, flake or chips and chemical agents; resins or additives may be added and is formed and bonded together under heat and pressure in a hot press. The glue spreading, drying, forming and hot pressing is called dry process. Theoretically, the particleboards can be made from any lignocellulosic materials that provide high mechanical resistance and pre-established specific weight, since the chemical structure of lignocellulosic material is similar to the wood structure (Rowell et al., 2000).

Particleboards are made of either single, three or multi layered symmetrical structure. In a single layered particleboard, the geometry and dimension of the particle is uniform along the board thickness direction while in the multi layered particleboard, the fine particles will be used to form two outer surface layers of the board and rough particle in the core layer. Particularly, a graduated structure particleboard is produced with fine particle on the surface, rough particle in the core and largest particle forms the centre layer (Hua, 2002).

Figure 2.10 shows the particles size gradations in a particleboard.

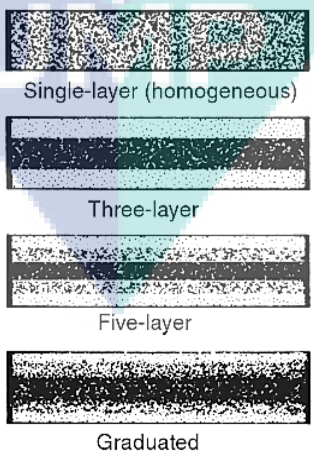

Figure 2.10 Particle size gradation in single and multi-layered particleboards. Source: Shmulsky & Jones (2011)

Particleboards generally falls into two products categories, industrial used for making cabinets, furniture, tables, countertops and underlayment used in floor construction. Compare to solid wood, particleboards are available at lower selling price, available in large flat sheet and can be decorated with many kinds of overlays. However, particleboard is not as strong as solid wood and fibreboards. The particleboards also tend to get damaged due to moisture and humidity. Besides, the particleboards are quite low on strength compared to other engineered composites and only suitable to hold low load. Instead of these weaknesses, the properties of particleboards could be improved with laminating, sealing, doubling, bracing and adding reinforcement materials to the boards.

2.4.2 Fibreboards

Fibreboards are produced from wood sources that have been shredded into a fibrous state and press into a uniform sheet form. Fibreboards can be manufactured using wet-forming or dry-forming process (Berglund & Rowell, 2005). In wet forming process, pulp is produced and board is formed in a same way as paper (Ormondroyd & Stefanowski, 2015). In this process, lignin will serve as the adhesive to bond the fibres. Depending on the pressing degree and density of the final products, the products are termed softboard, mediumboard or hardboard (Panel Guide, 2014). In the dry process, wood fibres are not pulped and they are bonded together using synthetic resin. The resulting products are generally referred as MDF.

The wide range of board types within the fibreboards means that have a wide range of properties and end uses. Porter (2012) summarized the end use of fibreboards in his book. These panels are suitable for interior or/and exterior applications. The wet boards are suitable for lining wall and ceiling, floor underlays, cladding, joinery fitments and etc. MDF are widely used in making furniture, cabinets, wall linings and partitions, window boards and notice boards.

2.4.3 Manufactured Composites from Lignocellulosic Biomass

In the past few years, there were a large number of studies on developing different varieties of composite panels using low cost and abundant agricultural biomass. Some of the related literatures are listed in Table 2.8. All the studies proved that all of these agricultural residues are feasible to be used as raw materials for making composite panels. There are many more agricultural residues that are available to be utilized. Industry must be prepared to take advantage of the residues and utilize them in the best way.

Various processing parameters affecting the properties of the composite panels have been focussed. The variables include target density, press condition; time, temperature and pressure, resins; type and amount, maturity of materials and pre-treatment of material. All of the factors have significant effects on the physical and mechanical properties of the composites. The physical properties include the density, moisture content, water absorption capacity (WA), thickness swelling (TS) while the important mechanical properties are modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB). Thus, the selection of material and experimental design play important roles in order to meet desired structural, design and marketable properties.

Table 2.8 Structural composite from various agricultural wastes

Agricultural waste	Type of composite developed	References
Bagasse	Binderless particleboard	Widyorini et al., (2005)
	Hybrid MDF	Holt et al., (2012)
	MDF	Doosthoseini et al., (2013)
	Particleboard	Iswanto et al., 2014)
Coconut coir fibre	Insulating particleboard	(Khedari et al., 2003; Zulkifli et al., 2010)
Durian peel	Insulating particleboard	Khedari et al., (2003)
Oil palm biomass	MDF	Ramli et al., (2002)
	Hybrid plywood	Abdul Khalil et al., (2010b)
	Compress board	Mat Rasat et al., (2011)
	Binderless particleboard	Hashim et al., (2011)
	Particleboard	Jumhuri et al., (2014)
Palm dates	Particleboard	Ashori & Nourbakhsh, (2008)
	Binderless particleboard	Saadaoui et al., 2013)
Rice husks	MDF	Ayrilmis et al., (2011)
Sugarcane bagasse	Binderless particleboard	Widyorini, (2005)
	Hybrid particleboard	Barros Filho, (2011)
Sun flower stalk	Particleboard	Guler et al., (2006)
	Fibreboard	Evon et al., (2012)
Waste tea leave	Particleboard	Yalinkilic et al., (1998)
Watermelon peels	Particleboard	Idirs et al., (2011)
Wheat straw	MDF	Mo et al., (2003)
	Hybrid particleboard	Zhang & Hu, (2014)

2.5 Particleboards Manufacturing Process

This section outlines the methodology of the particleboards manufacturing process. Most of particleboards are formed into panels at certain required thickness. Chemical additive such as binders are applied for adhesion and development of physical and mechanical properties of particleboard. Particleboards production involves several stages (Figure 2.11) which includes preparation of materials, particle drying and screening, followed by gluing and mat forming, pressing and board finishing.

The first step in particleboards manufacturing process is preparation of materials. The materials can be derived from a multiple sources such as solid wood residues, low grade residue; sawdust and hogged milled waste and agricultural residue. A standard particleboard plant used a combination of hogs, chippers, hemmer mills, ring flakers, ring mills and attrition mills to break the large pieces of wood into small particles. Reducing lignocellulosic materials to particles requires less energy compared to reducing the same materials into fibres. To generates fibre from lignocellulosic materials, steam is required in the fibre refiner to soften the raw material (Youngquist, 1999). This process is called defibration. Consequently, particleboards are less strong than fibreboards because the fibrous nature of lignocellulosic is not well exploited.

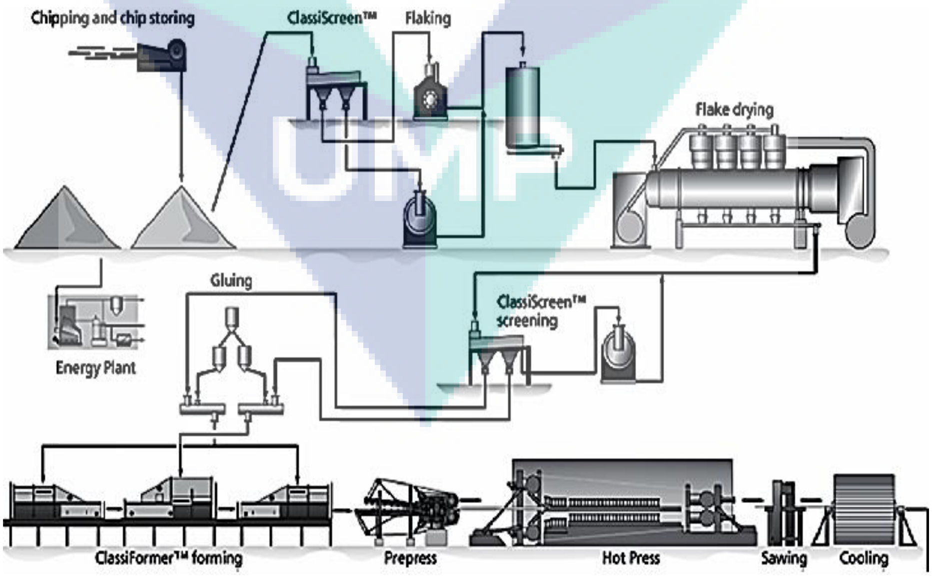

Figure 2.11 The main process stations in particleboards production line.
Source: Thoeman, Irle, & Sernek, (2010)

The second step in particleboards manufacturing process is particle drying and screening. Youngquist (1999) stated that, the raw materials usually arrive at the plant at high moisture content ranging from 10 to 200%. For bonding purpose between the particles and resins, the furnish moisture content should be in the range of 4 to 8%. The screening process is used to segregate the particles according to size and grading the furnish either for face or core layers. Oversized particles can adversely affect the properties of the final product because of internal flaws in the particle. To obtain good properties particleboards, manufactures ideally use a homogenous material with a high degree of slenderness, no oversize particle, no splinters and no dust. However, the small size particles improve the surface quality and bonding strength (Thoeman et al., 2010). Oversize particles will be recycled for further size reduction and the dust will be screened out.

Then, the particles will be mechanically blended with the resins, wax and other additives. After that, the blended furnish is formed into single or multiple layers of loose mat and the thickness is depending on the targeted thickness of the final product. Based on the weight of dry resins solid and weight of oven dry particles, the resins content can be in the range of 4 to 10%. To manufacture multiple layers of particleboards, the resin content of the outer layer is slightly higher than the core layer. The frequently used resins in particleboards manufacturing are urea formaldehyde (UF), phenol formaldehyde (PF), melamine formed-formaldehyde (MF). These resins are thermosetting resins which are cross-linked while heating, and cannot go back to their original chemical structures while cooling. Type and amount of the resin used depends on panel types; exterior or interior, particle size and hot press conditions.

Blending process may either take place in large vats at slow speed or on a small blender with rapid mixing and short blends times. The resins should be quickly cured in the press but also must have excess pot-life of 20 to 30 minutes, so that the resins do not harden before the press process. To achieve high ratios of pot-life to high temperature gel time, latent hardener is mixed with the resin (Irle et al., 2012). Adding the hardener into the resin would assist the transition of liquid resin into solid state in the hot press process. The most popular hardener used is ammonium chloride (NH_4Cl).

Then, the blended particles are formed into an even and consistent mat and ready to be pre-pressed in order to reduce the mat thickness prior to hot pressing. The step purpose is to eliminate the voids in the mat, compressed to wood structure and to ensure retention of the consolidated mat upon release of the pressure. Pre-press provides increased strength and density and also reduce the spring back of particleboards (Berglund & Rowell, 2005). Then, the mats are ready to be pressed in the hot press machine to produce consolidated panels.

Hot press is the process in which the particles and resin furnish is cured under certain temperature, pressure and time. The hot press process consolidates the particles mat to the desired thickness and polymerises the binder system between individual particles. Theoretically, during hot pressing process heat is transferred from the press platens to the centre of the board until the centre temperature approach the target temperature. At the same time, heat and water are lost through the edges of the particleboards due to escape of water vapour as shown in Figure 2.12. Generally, the pressure applied during hot press is in the range of 1.37 to 3.43 MPa (Youngquist, 1999).

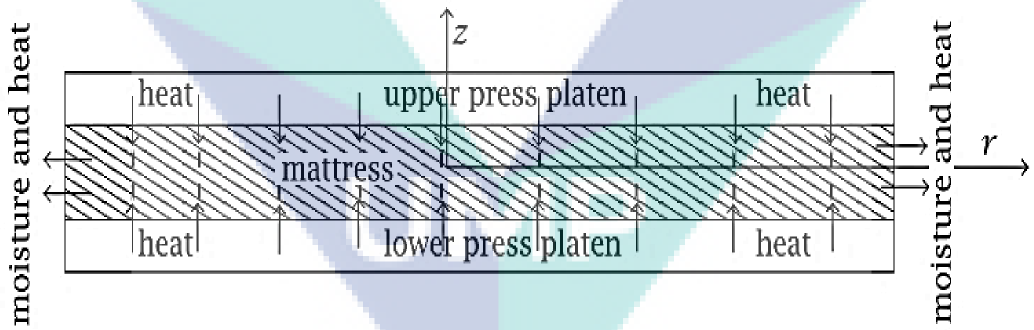

Figure 2.12 Hot press process description.
Source: Nigro & Storti, (2001)

Rowell, (2012) explained that, the surface heating cause the surface layer to squash more readily than the core part. As a result, particleboard with higher density surfaces and less density in the core layer is produced. This phenomenon refers to the vertical density profile (VDP). The VDP is closely related to the pressing variables and mat configuration. Cai et al., (2006) explained that, although the hot press stress applied to the mat during hot pressing is always same through the thickness, the mat consolidation is different due to gradient of heat transfer, moisture movement and resin curing. The different mat consolidation resulting in uneven density distribution through the thickness direction. This can be seen in the example of VDP through the thickness of the boards (Figure 2.13). A board with higher density surface also will have better bending strength, make the surfaces scratch resistance and less prone to absorb paints applied to the surface.

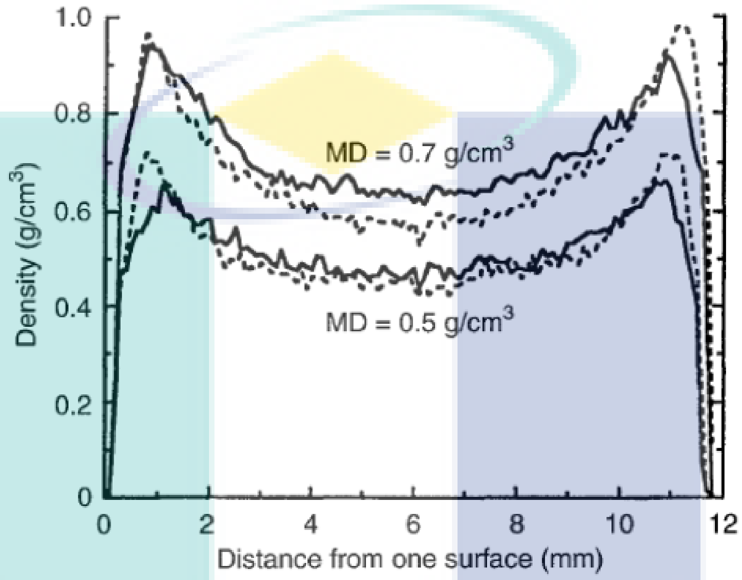

Figure 2.13   Example of vertical density profile in pressed boards.
Adapted from Wong (2012)

After pressing, the particleboards are conditioned to avoid degradation of resins before undergoing trimming process. Trimming saws are used to cut the particleboards into desired length and width and also to square the edges.

2.6 Factors Affecting Particleboards Properties

The manufacture of particleboards is a complex because there is always a number of factor influencing the properties and performance of the products. The factors that influence the physical and mechanical properties of the particleboards are type and board density, size of particles, moisture content of materials, type and amount of binding agents, press variables; temperature, time, pressure and also curing conditions. The interactions of these factors make the whole manufacturing process become more complicated. The factors will be discussed through next section.

2.6.1 Particleboard Density

Density is a measurement of particle compactness in a board and it is dependent on the density of the wood and pressure applied during pressing. Higher board density is accomplished by increasing the weight of the material in the mat or the compression of the mat or by both factors. Thus, target density of final products can be controlled by adjusting these two factors.

Many articles have reported that the density have significant effects on physical and mechanical properties of particleboards. Increasing the panel density improve the mechanical performance (Cai et al., 2006 and Sumardi et al., 2007). Laemsak & Okuma (1996) produced three different densities fronds particleboards (500, 700 and 900 kg/m^3). The results proved that MOR and MOE values are increased linearly with the density. The particleboards with densities above than 700 kg/m^3 have superior properties and meet the requirement of Type 18 particleboards as specified by JIS 5908-1994. The panel surface roughness also was improved as the density increased (Akbulut & Ayrilmis, 2006). Jun et al., (2008) studied for the production of boards from rubber wood at higher densities. However, this study showed that when the density was higher than 1000 kg/m^3, the mechanical property values were dropped due to fibre damage. Investigation of low density effect (350, 450 and 550 kg/m^3) on kenaf particleboards proved that only 550 kg/m^3 kenaf particleboards have achieved the minimum requirement of British Standards (Jani & Izran, 2013).

2.6.2 Effect of Pressing Conditions

Hot press operation is extremely important in the manufacturing of particleboards. Hot pressing parameters such as platen temperature, pressing time, closing time and opening time play an important role to obtain good properties of particleboards. Wong (2012) explained that the hot press process will consolidate the particle mats to meet the desired density or thickness and polymerised the resin used. Therefore, the amount and condition of the material in the mat, together with the pressing technique will determine the final board density. The target particleboards thickness is attained by using stopper.

Temperature is a crucial factor controlling the resins activity in particleboards manufacturing as it is related to the curing process. The platen temperature must be sufficient to prevent the board surfaces from being degraded, thus curing process is accomplished by lengthening the press time (Wong, 2012). Press time is the period when the upper plate first touches the panel mats until the opening of plates. The press time should be short but it has to be sufficient for the resin to fully cure and consolidate the panels.

Lynam (1959) found that longer press cycle at lower temperature was desirable. In this condition, less water is evaporated to the surroundings and the remaining water remaining was uniformly distributed in the finished board. However, Lehman et al., (1973) preferred shorter pressing time at higher press temperature. The high temperature allows faster heat transfer and shifts the maximum density region towards the core. It will improve the internal bonding and bending strength. Thus, optimisation is needed in order to determine adequate temperature and time to ensure the core reaches a sufficient temperature to allow the resin fully cured.

There were reported studies about the effect of press parameters on the particleboards properties. Using high press temperature between 170 to 190 °C but using short press time (180 s) to produce particleboards is presented by Papadopoulos, (2006). The UF bonded board's properties were significantly improved when the temperature is increased. An optimisation study on high press temperature (160 to 180 °C) and time (180 to 420 s) was conducted by Jun et al., (2008) to produce UF bonded panels from wood particle mixed with rubber crumbs. The properties of panels improved when press temperature and time were increased. When the press time is short, the transfiguration of wood particle was not sufficient. Thus, the materials and resins could not achieve sufficient contacts and leads to poor panel's properties.

When the lower press temperature is approached, longer press cycle is needed. Iswanto et al., (2014) produced sorghum particleboards using UF resin at rather low temperatures (120 and 130 °C) and pressed for 8 and 10 minutes. Particleboards produced at 130 °C and 10 minutes have better mechanical properties but poor dimensional stability. Elevated temperature of furnish is needed to plasticise wood fibres and flakes respectively, as well as to cure the resins (Steffen et al., 1999). It can be concluded that the press cycle duration, temperature and pressure are important variables affecting the quality of final products.

2.6.3 Resin and Adhesive

Resin is an important and sometimes costly constituent which often controls the properties of particleboards. Different types of resins are used in the industry and each resin has its advantages. Resin type and levels are crucial factor affecting the final properties of the finished products. Table 2.9 shows the application levels for different types of resin for different panels and Table 2.10 shows the properties of common resins, their strength properties and uses.

Approximately, 1 million metric tons of UF are produced annually. Almost 70% of this resin is used in making various composite industries. 61% of the UF is used in making particleboards; fibreboards 27%, hardwood plywood 5% and 7% for bonding in laminating adhesive (Corner, 1996). UF is suitable for indoor application. During the curing process, UF resins form three dimensional networks that are no longer thermo formable and insoluble. The curing of UF has to be done in an acidic environment and better curing can be reached at lower pH. The acidic condition can be achieved by adding direct acid or latent hardener. Ammonium sulphate (NH_4SO_2) or ammonium chloride (NH_4Cl) is widely used as a latent acid in particleboards manufacturing. The suggested amount ratio of hardener to resin is 1 to 10% (Rowell, 2012). The hardener will react with the free formaldehyde in the resin to generate acid condition. The speed of reaction depends on the amount of free formaldehyde and hardener, which is dependent on temperature and time (Wong, 2012).

Advantages of UF resins include lower curing temperatures and ease of use under a variety of curing conditions but have less moisture resistance. UF by virtue of its lower unit cost, excellent cohesion and adhesion, lack of colour in the finished product, easy handling and shorter press cycle time remains the dominant binder system for particleboards. In fact, UF resin is not suitable at higher relative humidity and at elevated temperatures, since the amino linkage is susceptible to hydrolysis compared to PF and methylene dipenyl diisocyanate (MDI) bonded (Ilias, 2006). However, the effect of resins on production cost is one of the main concerns because the resin cost is a part of the manufacturing expense of particleboards makes UF remains the dominant binder system for particleboards.

Table 2.9 Typical resins additive levels for different panel types

Panels	Resin	Level (%)
Particleboards	Urea Formaldehyde	4 – 10
	Phenol formaldehyde	6 – 8
	Methylene Diphenyl Dilsocyanate (MDI)	2 – 6
OSB	Phenol formaldehyde (PF)	6 – 8
	Methylene Diphenyl Dilsocyanate (MDI)	2 – 6
MDF	Urea Formaldehyde (UF)	6 – 14
	Melamine Urea Formaldehyde (MUF)	8 – 12
	Methylene Diphenyl Dilsocyanate (MDI)	4 – 10

Source: Ressel (2008)

Table 2.10 Type of adhesive, working and strength properties and typical uses

Type	Form and colour	Preparation and application	Strength properties	Typical uses
UF	Powder and liquid forms, may be blended with melamine or other more durable resins; white to tan resin with colourless bond line	Powder mixed with water, hardener, filler, and extender by user; some formulations cure at room temperatures, others require hot pressing at about 120 °C for plywood and 210 °C for fibreboard and particleboard; curable with high-frequency heating	High dry and wet strength; moderately durable under damp atmospheres; moderate to low resistance to temperatures in excess of 50 °C	Hardwood plywood, furniture; MDF; particleboard; underlayment; flush doors; furniture cores
MF and MUF	Powder with blended catalyst; may be blended up to 40% with urea; white to tan; colourless bond line	Dissolved in water; cured in hot press with platens at 120 to 150 °C and lower internal temperatures; particularly suited for fast curing in high-frequency presses	High dry and wet strength; very resistant to water and damp atmospheres	Primary adhesive for durable bonds in hardwood plywood; end-jointing and edge-gluing of lumber; and scarf joining softwood plywood.
IC	Liquid containing monomers and oligomers of methylene diphenyl diisocyanate; light brown	Applied directly by spray; reactive with water; requires high temperature and high pressure for best bond development in flake boards	High dry and wet strength; very resistant to water and damp atmosphere	Flake boards; particleboard, strand- wood products
PF	Liquid, powder, and dry film; dark red bond line	Liquid blended with extenders and fillers by user; film inserted directly between laminates; liquid or powder applied directly to flakes in composites; all formulations cured in hot press at 120 to 150 °C and up to 200 °C in flake boards	High dry and wet strength; very resistant to water and damp atmospheres; more resistant than wood to high temperatures and chemical aging	Exterior softwood plywood, flake board, hardboard, and low emission particleboard

Source: Frihart & Hunt (2010)

2.6.4 Raw Material Properties

A variety of wood species and agricultural biomass are used as raw material in particleboards industries. Generally, particleboards consist of 90% of lignocellulosic material on a dry weight basis and the rest of it is adhesive. It is believed that the properties of raw mat have a significantly effect on physical and mechanical properties of boards produced.

Rathke et al., (2012) compared the properties of single layer particleboards manufactured from five different wood particles; spruce, recovered particles, willow, locust and poplar. Poplar and willow particleboards exhibited the best mechanical properties due to the low density of raw material while boards using recovered particles had poor performance due to high density. The previous study by Kowaluk et al., (2011) proved that lower density willow particleboards had better properties than black locust panels. Hashim et al., (2011) completed an investigation of binderless particleboards using leaves, bark, mid and core trunk and fronds of oil palm biomass. It was found that the entire oil palm tree could be utilized for particleboard and different part particleboards resulting different properties. Bark and leaves boards have poor IB and MOR compared to the particleboards produced from the fronds and trunks. It was attributed by the chemical component composition of the biomass.

The influence of chemical components; cellulose, lignin, sugar, starch on OPT binderless particleboards was evaluated through physical, mechanical and chemical properties (Lamaming et al., 2013). The sugars contribute to self-bonding mechanism in binderless particleboards. Lamaming et al., (2014) furthered the study on manufacturing binderless OPT particleboards using young and old trunks. It was found that the age of trunk affected the properties of boards manufactured. Saadaoui et al., (2013) investigated the possibilities of using four by-products of date palm tree; leaflets, rachis, leaf sheath and fibrillum to produce self-bonded particleboards. Based on this four type material, the most promising by-products are the fibrillum and leaflets. It is due to the high lignin and protein content that will lead to better IB and WA capacity properties.

Furthermore, the recent studies explored the potential of incorporating two or more lignocellulosic materials to developed hybrid particleboards. The reason behind mixing two or more materials is to achieve synergistic performance, complement material properties and sustain the supply chain of raw material (Jawaid & Abdul Khalil, 2011). The properties of weak fibres or particles in the hybrid could be enhanced, as well as the overall performance of composites. Ghalehno et al., (2010) produced three layers particleboards from wood particles as well as using this material in combination with reed particles. Particleboards made with 100% wood particles did meet standard but mixing this material with reed on equal weight basis produced poor WA and TS properties. 60% of wood particles – 40% of reed particleboards exhibited optimum properties of particleboards. Zhang & Hu, (2014) produced single layer particleboards incorporating rice straw particles and coir fibres and pressed at 130 °C for 20 minutes using PMDI and PF resin. Addition of coir fibres shows significant increase in IB but adverse effect in MOR, MOE, and dimensional stability. Thickness swelling decreased as fibres content increased, reflecting lower hygroscopicity of coir fibres.

Materials acidity also plays important role in determining the suitability of materials for particleboards. A chemically induced effect can occur if the materials have acidic behaviour which might cause acceleration in the adhesive hardening process based on poly-condensation resins (Paridah et al., 2009). Different species show great differences in pH value. Akyüz et al., (2010) investigated the effect of particles acidity on the properties of wood particleboards using urea formaldehyde. The acidity of the particles is measured in extract solution made from particles flour and boiling process. The application of UF resins favours acidic condition for fastening resins.

The moisture content and drying process of raw material also could influence the pH of the dried materials (Latibari et al., 2012). The moisture content is used as a medium of heat transfer from the surface to the core layer during hot press and assist resin curing at the same time. The moisture content of materials is dependent on the type of resin to be added either dry or in solution form. Since liquid resin will be used in this study, the material should be dried to about 2 to 7% moisture content (Youngquist, 1999) .

The quality of furnish in particleboards manufacturing is controlled by species, parts, maturity, moisture content, density, extractive, acidity and machinability. The review of literatures has identified the basic process of particleboards productions, processing parameters which affect the final product properties and basic properties required for particleboards. All the factors previously discussed were the factors that have the potential to affect the properties of final products. The properties required are MOR, MOE, IB, WA and TS.

2.7 Particleboards Standard

American National Standard (ANSI A208.1) classifies particleboards by its density and strength covers physical and mechanical properties and dimensional stability as well as formaldehyde emission level. Mechanical properties of all fabricated particleboards is compared to the requirement for the commercial and underlayment use based on American Standard – ANSI A208.1. Since this standard not specify the requirement for WA and TS value for commercial and underlayment use, the requirement for furniture is used for comparison as stated by Schneider, Chui, & Ganev, (1996). Table 2.11 classified the typical or target property values for ANSI A.208.1 and industrial requirement.

Table 2.11 ANSI A208.1 Standard and industry recommended values for particleboards

Use	Grade	MOR (MPa)	MOE (MPa)	IB (MPa)	TS-24hr (%)	WA-24hr (%)
Commercial	M-1	11	1725	0.4	NS	NS
	M-S	12.5	1900	0.4	NS	NS
Underlayment	PBU	11	1725	0.4	NS	NS
* Recommended value	Furniture	NS	NS	0.4	25	60

Source: American National Standard (ANSI A208.1) and *Schneider, Chui, & Ganev, (1996); Li et al., (2009)
NS – Not Specify

2.8 Biocide Treatment for Wood Based Composite

2.8.1 Introduction

Wood and wood based composites are important both residential and non-residential building construction. Many types of solid wood are relatively easily deteriorated by a variety of organisms, including fungi, termites, bores and also weathering. These biological degradations are developed with time and leads to products damage and huge financially loss. However, wood based composite have received more attention than solid wood due to changes in building design and protective practice (Morrell, 2002). The composites show a greater resistance to biological degradation agent but they are still susceptible to biological attack (Curling & Murphy, 1999). In most cases, the wood based products perform well as long as they are used in dry conditions, but they are increasingly used where they are likely to become wet and will ultimately deteriorate. The wood based products can be used for many years if properly preserved. A number of protective methods using preservative or insecticide allow composites to perform more reliably under conditions that suitable for bio-deterioration.

2.8.2 Termite Attacks

Termites are one of the damaging pests in the tropics and can cause huge problems in agriculture, forestry and housing. They have a wide range of distributions, throughout different habitats of tropical, subtropical and temperate world regions (Gubrel, 2008). Tascioglu et al., (2013) stated that termite damage start earlier compared to fungal attack and the effect is severe. It will attack the wood and start to build their colony and used wood as their foods. They can attack above ground and also remain under the ground (Usta et al., 2009). Termite infestations can become established under concrete slab, garage floors, porches and patios in homes. They usually work their way above ground to reach wood or any other cellulose sources.

Subterranean termites can cause damage on wood composites produced from non-durable wood species (Kartal & Green, 2003). This species feed on cellulosic materials like papers, woods, dried plants, furniture as well as structural wood. Ngee et al., (2004) stated that the cost of termite control in Malaysia was estimated about USD 10 – 12 million in 2003 and the repair cost could be three to four times higher. This cost encountered for termite damage in forestry, agricultural and urban setting. Therefore, it is important to increase the resistance of the wood based products against termite by using various types of chemicals and treatment methods.

2.8.3 Wood Preservative Materials

Chemical treatment measures is the most important and most widely used to reduce the infestation of termites. Several termiticides containing active ingredients such as bifenthrin, chlorfenapyr, cypermethrin, fipronil, imidacloprid and permethrin are registered for termite control around the world under various brand names (Verma, Sharma, & Prasad, 2009). Many types of chemical compounds have been applied successfully to wood composites. Some common wood composites and their standard preservatives materials can be seen in Table 2.12.

Table 2.12 Common wood composites and their preservative

Composite type	**Treatment chemical**
Plywood	Ammoniacal Copper Arsenate, Ammoniacal Copper Zinc Arsenate, propiconazole, tebuconazole, permethrin,
Oriented Strand board	Zinc borate, copper complex, copper, cypermethrin or permethrin, IPBC plus chlorpyrifos or permethrin
Particleboard	Fire retardant, permethrin
MDF	Fire retardant, zinc borate, boric acid
Hardboard	Fire retardant
Wood plastic composites	Zinc borate

Source: Kirkpatrick & Barnes, (2006)

Bifenthrin, cypermethrin, deltamethrin and permethrin are a member of the pyrethroid class which are analogues of the naturally occurring pyrethrums, which is used to form a barrier to repel or kill termites. The pyrethroids kill termites by affecting the salt balance (sodium channels) in their nerve cells (Kirkpatrick & Barnes, 2006). Synthetic pyrethroid has been used to preserve the wood based products against and it was very effective to increase the durability of wood composites against termites attack (Su et al., 1993; Kirkpatrick & Barnes, 2006 and Zaidon et al., 2008).

Plant-derived natural products are promising replacements to the preservative chemicals. Natural extract do not pollute the environment and are not harmful to the beneficial animals or the people. Repellency and toxicity of essential oils from vetiver grass, cassia leaf, clove bud, cedarwood, Eucalyptus globules, Eucalyptus citrodera, lemon grass, and geranium against Formosan subterranean termites was reported (Zhu et al., 2001).

Neem oil is natural insecticide formulations that have toxicity effects on subterranean termite (Grace & Yates, 1992). In the present study, neem oil extract from various neem tree parts has been found to be able to protect wood samples from termites (Sotannde, 2011). The neem tree is a native to tropical and semi-tropical regionswith origin in Europe and later domesticated in Asia. It is extensively found in India and Indonesia (Liauw et al., 2008). It is a tree in the mahogany family with broad dark stems and widely spread branches. It grows above 20 m and produces evergreen leaves with white fragrant flowers and fruits. All parts of neem tree (the leaves, twigs, and oil from the nuts) are used both industrially and medicinally. Neem oil is widely used as insecticides, lubricant, drugs for variety of diseases (Ragasa et al., 1997 and Awolu, Obafaye, & Ayodele, 2013). Neem oil is generally light to dark brown, bitter and has a strong odour. It comprises mainly triglycerides and large amounts of triterpenoid compounds, which are responsible for the bitter taste (Schmutterer, 2002). It also contains azadirachtin, meliantriol, salannin, nimbin and nimbidin (National Research Council, 1992).

There is no available study about termite resistance of particleboards made from oil palm fronds (OPF) particles blended with empty fruit bunch fibres (EFB). This study is aimed to examine an experiment of enhancing the termite resistance of OPF-EFB particleboards treated with cypermethrin and neem oil.

2.8.4 Wood Protection Methods

Wood based composite offer complexities and opportunities not found in the solid wood preserving industry. Ross et al., (2003) stated that the advantage of the wood composites is they can be successfully protected by treatments with insecticides and it has been a standard practice in Hawaii and Japan for a number of years. Besides the adhesive and resins used in the composite manufacturing process, preservative (fungicide and/or insecticide) may be added to protect these products from biological degradation.

Gardner et al., (2003) have summarized four systems and treatment processes that can be used in the preservation of composites. They are use of pre-treated wood, use of wood species with high resistance against termite, in-process preservative treatment and post-process. During the in-process treatment, the preservative material is incorporated with the wood materials during the manufacturing process. Gardner et al., (2003) favoured the in-process treatment to be applied in the making wood composite due to less cost, homogeneous distribution of the preservative during blending and the physical properties of the products can be easily monitored. The strategies include in the post manufacture treatments are incorporating the active materials into the composite through pressure or vacuum treatment, surface coatings (brush, spray or dip) and direct placement of active material rods in the products.

In a study conducted by Humar, Žlindra, & Pohleven, (2007), it is found that higher uptake of preservative solution was measured at vacuum impregnation compared to brushing and soaking technique. The uptake of the preservative solution was significantly affected by concentration of the active ingredient. The composition of the preservative solution did not have significant influence on the amount of retained biocide. Ross et al., (2003) believed that surface treatments (immersion or spray application) are suitable for engineered wood composites because they are easy to apply and a very cost effective. However, Razak et al., (2003) who performed in-ground termite test upon bamboo stakes reported that the treatment technique proved not to be the critical factor in influencing the performance of the stakes.

2.9 Standard Method for Evaluation Termite Resistance

Historically, an established testing method for a new treated wood often requires 5 to 15 years of testing before market entry. However, to reduce the long testing period, proper testing methods that provide appropriate data were developed (Ross et al., 2003).

There are two types of testing methods used to determine wood resistance against termites which are laboratory and field test.

2.9.1 Laboratory Evaluation for Termite Resistance

The duration of the laboratory test is normally approximately 4 weeks. The most methodology standards used are AWPA E1-97, AWPA E1-09 and ASTM D334. In the test, the sample will be placed in a container or jar (Figure 2.14) and exposed to 200 to 400 termites under control conditions. The soil material, humidity and temperature should be constant.

Figure 2.14 Sample test jar with wood sample.
Source: Suhasman, Hadi, & Santoso, (2013)

2.9.2 Field Evaluation of Termite Resistance

Generally, the field efficacy test requires much longer testing period compared to the lab. The testing may require a 3 to 15 years testing period in order to develop sufficient information on the treatment efficacy and durability (Ross et al., 2003). The testing period can be many years but there were studies applied this method for short periods exposure; 28 days (Wong et al., 1998), 32 days (Ncube et al., 2012) and 60 days (Peralta et al., 2004). The area must be identified as an infested area with termites. Based on the standards, the treated and control samples are placed in the infested area and examine periodically to determine the efficacy. The field test is divided into two; in ground and above ground test. The well recognizes standards for in-ground field test (Figure 2.15) are AWPA E7-93, ASTM D 1758-74, JIS K157:2004 and EN 252: 1989. In ground field test, the control and treated stakes will be inserted into the ground closed to termite hill. In above ground test (Figure 2.16), specimens will be laid directly on the soil in an area known with termite attack

.

Figure 2.15 Installation of stakes in-ground efficacy test.
Source: Hadi, Massijaya, & Arinana, (2016)

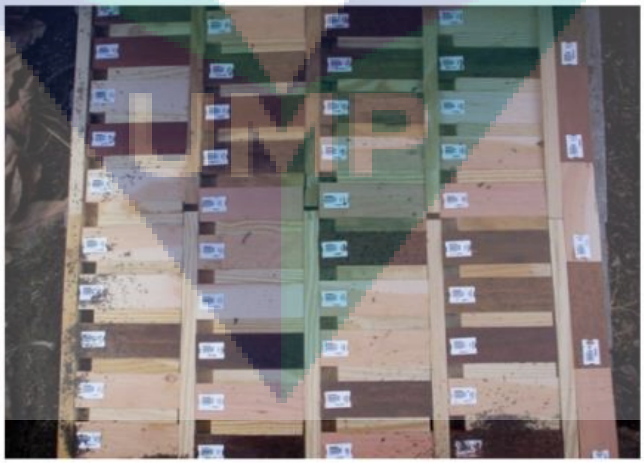

Figure 2.16 Example of specimen installation above the ground efficacy test.
Source: Morrell (2010)

After the test period is completed, the test specimens will be disassembled from the container or grounds. Then, the specimens will be evaluated using a visual rating system and measure the mass loss in order to determine the termite degradation. The AWPA evaluating rating from 0 to 10 is described in Table 2.13.

Table 2.13 AWPA rating system for termite degradation

Rating	Description
10	Sound, suspicion of decay permitted
9	Trace decay to 3% of cross section
8	Decay from 3 to 10% of cross section
7	Decay from 10 to 30% of cross section
6	Decay from 30 to 50% of cross section
4	Decay from 50 to 75% cross section
0	Failure, disintegration of sample

2.10 Design of Experiments (DOE)

2.10.1 Introduction to DOE

Traditionally, One Factor at a Time (OFAT) experiment is used to examine or develop a process or products. In OFAT, only one factor varies at a time while other factors are fixed. However, when two or more factors are studied, application of design of experiments (DOE) is more efficient. Zitrom, (1999); Tsai, Tong, & Wang, (2010) and Wahid & Nadir, (2013) summarized the advantages of design of experiment (DOE) over OFAT method. DOE allows the researchers to study a large number of factors in a small experimental runs, thus it requires less time and materials. It also uses statistical method to develop the best factor and its level setting in order to optimise a design or process. The statistical analysis of the data can be performed using software analysis package such as Design Expert and Minitab.

DOE and its analysis revolve around the understanding of the relationship between a number of independent variables and dependent variables. The detail about DOE is discussed in Hotwire, (2008) and NIST/SEMATECH, (2012). In DOE, independent variables are called factors and dependent variables are called responses. Factor is experimental variable that is thought to influence the response such as temperature; pressure; time and etc. An experiment with a series of test is called runs in which changes are made in factor in order to identify the reasons for changes in the response. Different factor values of an experiment are called levels. Each experiment may involve a combination of the levels of the factors. Each of the levels combination is termed as treatment. In a single factor experiment, each level of the factor is referred as a treatment and in the experiments involved with many factors; each combination of the levels of the factors is referred as a treatment.

The number of treatments is determined on the basis of the number of factor levels being investigated in the experimental work. For example, if two factors (A and B) is to be performed, with A having *x* levels and B having y levels, *xy* treatment combinations can possibly be run and the experiment is a *xy* factorial design. If all *xy* treatment combinations are run, the experiment is a full factorial. If only some of the *xy* treatment combination, then the experiment is called a fractional factorial. It can be seen that, the size of an experiment escalates as the number of factor or factors level increased.

There are four broad categories of experimental design which classified base on the objective of the design. They are comparative design, screening design, response surface and regression modelling. The first design is comparative design. This design referred to the experiment that has only one factor to be investigated. Generally, the goal of the experiment is to make a conclusion about one important factor in the presence of another factor. This design is also used to choose between alternatives for initial comparison or confirmatory comparison. It is applicable to determine whether that factor is significant or not towards the response at different levels. Secondly, in a screening experimental design, the experimental objective is to screen out the few important main factors from less important factors. This design is suitable when two or more quantitative factors or including qualitative factors.

The third design is response surface. This design can be applied to achieve one or more of the following objectives; maximize or minimize the response, hit a target or reduce a variation by locating a region where the process is easier to manage. This design allows the estimation of interaction and also quadratic effects. It also will obtain the shape of investigated response surface. Due to this reason, this design is termed as response surface methodology (RSM) design. Response surface is a response to the values of one or more factors. The surface is a plot of two or three dimensions of the function that is fitted to the experimental data (Hibbert, 2012). The regression modelling is used to estimate a precise model and quantify the dependence of response variable on process input. The most common DOE techniques are stated below. Furthermore, the selection guide of DOE is summarised as in Table 2.14.

- General full factorial design
- Two-level full factorial design
- Two-level fractional factorial design
- Plackett-Burman
- Response surface method (RSM) design

Table 2.14 Design of experiment selection guideline

Number of factors	Objective		
	Comparative design	**Screening design**	**Response surface design**
1	One factor	-	-
2 to 4	Randomized block design	Full factorial Fractional factorial	Central composite Box Behnken
5 and more	Randomized block design	Fractional factorial Placket Burman	Screen process first to reduce number of factors

Source: NIST/SEMATECH, (2012)

2.10.2 Response Surface Methodology Design (RSM)

Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for developing, improving and optimisation of a product or process in which the response is influenced by several variables and the objective is to optimise the response. Myers, Montgomery, & Anderson-Cook, (2009) point out that, in the aspect of statistical, RSM is used as a method in identifying the connection of each variables and response variables while projecting design of experiments. RSM defines the effect of the independent variables, alone or combination variables of a process. To analyse the effect of the independent variables, this experimental methodology builds a mathematical model which describes the process based on observation data.

The obtained model facilitates to search for optimum process response and is validated through experimental works. The model used in RSM is generally a full quadratic equation or the diminished form of quadratic equation. A quadratic model, which also includes linear model is given as Eq. (2.1), where *y* is the predicted response, β_0 is constant coefficient, $\beta_{j's}$, $\beta_{jj's}$ and $\beta_{ij's}$ are regression coefficient for linear, quadratic and interaction term, respectively, X_j and X_i are coded independent variables and ei is the error.

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_j^2 + \sum \sum_{i<j=2}^{k} \beta_{ij} X_i X_j + e_i \qquad (2.1)$$

The application of RSM in optimisation is aimed to reduce the cost of experimental work and expensive analysis method. The common designs used in RSM are central composite design (CCD), Box-Behnken and Doehelrt design (Heyden & Dejaegher, 2009 and Mourabet et al., 2014). The CCD is the frequently used design. This design contains a two level full factorial design (2^f experiments), a star/axial design point (2*f* experiments) and centre point. Thus, the required number of experiment by CCD to examine the variable factor is expressed in Eq. (2.2) where N is number of experiment run, *f* is number of factor and C_0 is number of centre points. The experiment of the full factorial design is situated at level -1 and +1, star design point at level –α or +α and centre point situated at level 0.

$$N = 2^f + 2f + C_0 \qquad (2.2)$$

Box-Behnken design is an incomplete three level factorial design that built by combining two level factorial design with incomplete block design in a particular manner. This design was introduced in order to limit the sample size as the number of parameters grows. The sample size is kept to a value which is sufficient for the estimation of coefficient in a second degree least square approximating polynomial. In this design, the number of experiments required to examine the factors is calculated using Eq. (2.3). This design is rotatable or near rotatable and does not require factorial or extreme point. The factors will be evaluated at three levels (-1, 0 and +1).

$$N = 2f(f-1) + C_0 \qquad (2.3)$$

The centre point (C_0) is used to evaluate the reproducibility and experimental error of the data. Typically, the centre point of the design is repeated, often four times or more. This gives an adequate estimate of the variation of the response and provides the number of degrees of freedom needed for an adequate statistical test of the model. The C_0 will affect the number of experiment. For example, in Box-Behnken design with three factors, if only one centre point is selected, the number of experiment run require is 13. Three and five centre points will generate 15 and 17 run of experiments, respectively. Thus, in this research, Box-Behnken is chosen over CCD design because it requires fewer treatment combinations than CCD in case involving 3 or more factors. Islam et al., (2012) agreed that this design is a second order polynomial design that required few numbers of experiments, more efficient and easier to arrange as well as interpret in comparison to others and it avoids extreme treatment combinations. In Box-Behnken Design, major and interaction effects can be easily evaluated. The major effect refers to the effect caused by the varied factor, while the interaction effect is related to the case in which the effect of one factor is dependent on another factor (Razzaghi-Asl et al., 2012)

2.10.3 Statistical Analysis

After all response is obtained from the experimental works, RSM will generate mathematical models (Eq. 2.1) to describe the process based on the experimental data. Then, Analysis of Variance (ANOVA) is used to analyse the models, response and variable factors.

ANOVA is essential to test the adequacy and the significance of the model (Mourabet et al., 2014). It is necessary to examine the fitted model to ensure it provides an adequate approximation to the system. Proceeding with exploration and optimisation of a fitted response surface will likely give poor result unless the model provides an adequate fit (Myers et al., 2009). The model should have $p - value < 0.05$ in order to prove that a model is significant. Lack of fit (LOF) also can be used to determine adequacy of a model fit. LOF is the variation of the data around the fitted model. The LOF compares the residual error to the pure error from relocated design points. In this study, 5 centre points were used to calculate the pure error. The non-significant LOF (*p –value* > 0.05) proved that the model is valid for an experiment. If the model does not fit the data well, LOF will be significant.

Karim et al., (2014) mentioned that, the quality of the models was further verified by observing the coefficient of determination (R^2), standard deviation and coefficient of variation (CV). R^2 is a measure of the amount of reduction in the variability of response obtained by using all the variables in the model. The range of R^2 is between 0 and 1. The experimental R^2 should be close to the adjusted R^2. If the R^2 and R_{adj}^2 are differ dramatically, there are chances that non-significant terms have been included in the model. The R_{pred}^2 also should be close to R_{adj}^2 in order to make it in reasonable agreement with the R_{adj}^2. Moreover, the standard deviation and CV indicates a high degree of precision and reflect the reproducibility of the model. The signal to noise ratio is determined in terms of adequate precision. A ratio greater than 4 is desirable.

2.11 Optimisation Study

When the appropriate models have been established, the responses can be optimised simultaneously. In mathematical concept, optimisation is defined as a way of selecting the best factor/s or effect/s from a set of available parameters. The optimisation module in Design-Expert searches for a combination of factor levels that simultaneously satisfy the requirements placed on each of the responses and factors. Optimisation of one response or multiple responses can be performed either graphically, numerically or using the point prediction mode. In this study, numerical optimisation is selected to determine an optimum condition.

In numerical optimisation, the goals for each factor and response can be selected. The possible input for optimisation that can be selected either in range, maximum, minimum, target, none (for responses) and is set to as establish an optimised output value for a given set of conditions. A minimum and a maximum level must be provided for each parameter included in the optimization. The numerical optimization will optimize any combination of one or more goals. Three dimensional surface, contours and perturbation plots of the desirability function at each optimum can be used to explore the function in the factor space.

Table 2.15 shows the lists of optimisation study that related to the production of wood based composites. Most of these studies choose Box-Behnken design over others because it less number of experimental runs and suitable to build quadratic response surface.

Table 2.15 Previous optimisation study in the production of wood based composites

Study	Design	References
Optimisation of board density, pressing time and pressing temperature variables in wood-rubber composite panel manufacturing.	Box-Behnken	Jun et al., (2008)
Optimisation of flake thickness, moisture content and press temperature in production of particleboards.	Box–Behnken	Islam, Alam, & Hannan, (2012)
Optimising resin consumption, pressing time and density of mixes of hardwood sawmill residue and custom flaked. Softwood	Two level fractional factorial	Wong, (2012)
Optimisation of manufacturing parameter (steaming time, press; temperature, time and pressure) for compressed lumber from OPT	CCD	Salim et al., (2012)
Optimisation of steaming temperature, steaming time, hot pressing temperature and hot pressing time in binderless OPT particleboard	CCD	Wan Nadhari et al., (2013)
Optimisation the effect of additives (Si-Al molar ratio, Si amount and Si-Al amount) in the preparation of Kraft ultra-low density fibreboard	Box-Behnken	Chen, Xie, & Niu, (2015)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this project, lab scaled particleboards incorporating of OPF particles and EFB fibres were developed. This chapter presents the detail descriptions of the materials, equipment and procedures used to fabricate oil palm biomass particleboards. The selection of the materials and experimental procedures were selected based on literature review discussed in Chapter 2. The majority of the experimental works was conducted in the FKKSA laboratory. This chapter also discusses the characterization procedures, data analysis and optimisations steps in order to study the effect of the manufacturing variables on particleboards performance.

Then, the optimised particleboards undergo a treatment process with preservative materials and followed by termite resistance testing. All of the experimental work was carried out according to the experimental flowchart (Figure 3.1).

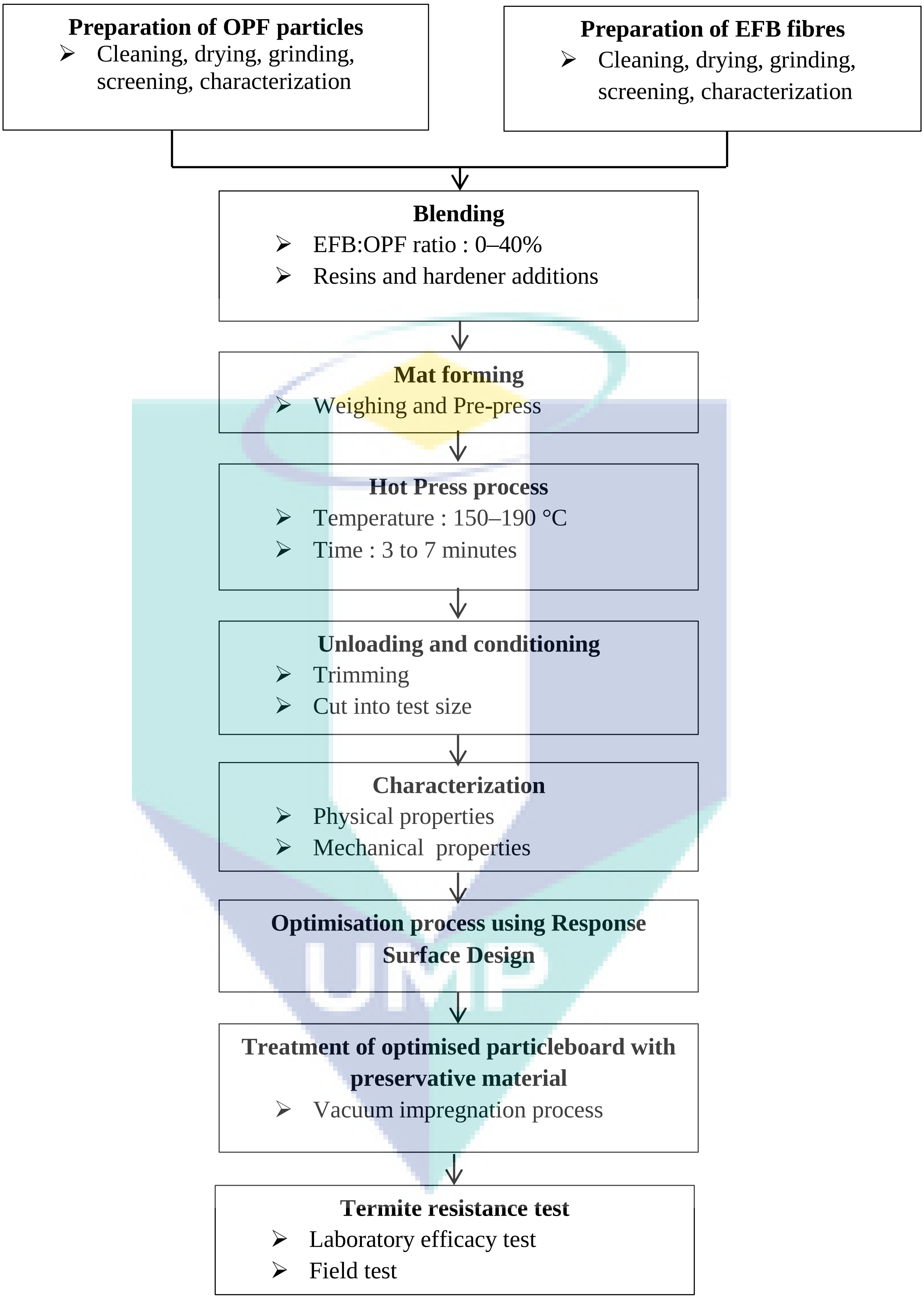

Figure 3.1 Experimental flow

3.2 Materials

The fresh fronds were obtained from private oil palm plantation in Felda Lepar Hilir, Kuantan, Malaysia. The matured fronds were selected from approximately 12 – 15 years old palm trees. The EFB fibres strands were acquired from Malaysian Palm Oil Berhad (MPOB). The UF resin was selected as the bonding agent for the particleboards production and NH_4Cl was used as the hardener. The industrial water soluble UF resins were supplied from Malayan Adhesive & Chemicals Sdn. Bhd. with measured properties tabulated in Table 3.1. The resin used in this study was a low formaldehyde grade resin (E1-grade). The other chemicals used in the experimental work are listed in Table 3.2.

Table 3.1 Characteristic of urea formaldehyde

Properties	
Solid content (%)	65
Viscosity at 30 °C (Pa.s)	2.01
pH at 30 °C	8.59
Free formaldehyde 30 °C (%)	0.38

Table 3.2 List of chemicals used in the experimental works

Chemical	**Supplier**	**Purity (%)**
Ammonium chloride (NH_4Cl)	Sigma Aldrich	> 99
Sodium chlorite ($NaClO_2$)	Sigma Aldrich	80
Sodium hydroxide (NaOH)	Sigma Aldrich	> 97
Methanol	Sigma Aldrich	99
Acetic acid ($C_2H_2O_4$)	Merck	98
Sulphuric acid (H_2SO_4).	Merck	98
Cypermethrin (1.5% w/v)	BASF	92
Cypermethrin EC (5% w/v)	IMASPRO Biotech	92.1
Pure Neem oil	NOW Food	98

3.3 Preparation of Materials

Preparation of raw materials entirely depends on the suitability of the materials for the specific process. In this research, the fronds and EFB fibres were processed separately to produce particles or fibres of the desired sizes.

3.3.1 Oil Palm Fronds Particles

The collected fronds were cut into 250–300 mm long and were spread under the sun drying for 8 hours. The sun drying technique was adopted from Köse et al., (2011). It is necessary to remove moisture content of the fresh fronds. Then, the petiole and leaflets were removed from the fronds before slicing them longitudinally with thickness ranged from 10–15 mm. The fronds were rinsed with water to gum off and remove any dirt. After the cleaning, they were dried in the oven at 105 °C to achieve 10% moisture content. The moisture content should not be either too high or too low. The high moisture content cause uneven pressing of the panels and the drier material consuming more resin in the hot pressing process (BAT, 2014). Next, the dried fronds were ground using a feed grinder - SIMA- FG 400 x 200 (Figure 3.2) to obtain particles with 5–10 mm approximately. The particles undergo a screening process to separate dust and fine particles. Figure 3.3 shows the fresh fronds, dried fronds and its particles.

Figure 3.2 Feed grinder machine

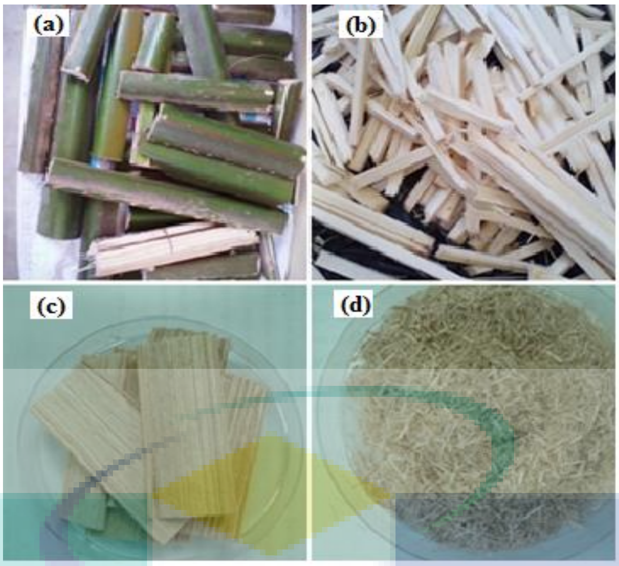

Figure 3.3 Oil palm fronds; (a) Fresh fronds; (b) Sliced fresh fronds; (c) dried fronds after drying process and (d) fronds particles

3.3.2 Empty Fruit Bunch Fibres

Any dirt and unwanted substances from the collected EFB strand were removed. The EFB fibres were oven dried at 103 °C in order to achieve the moisture content of 10 – 11%. Next, the strands were ground using the feed grinder (Figure 3.2) to obtain short fibre length (Figure 3.4). The grounded EFB fibres were screened to separate dust and fine particles. 5 – 20 mm length of EFB fibres was used in this study. Prior to use, all the materials were placed in the sealed plastic bag.

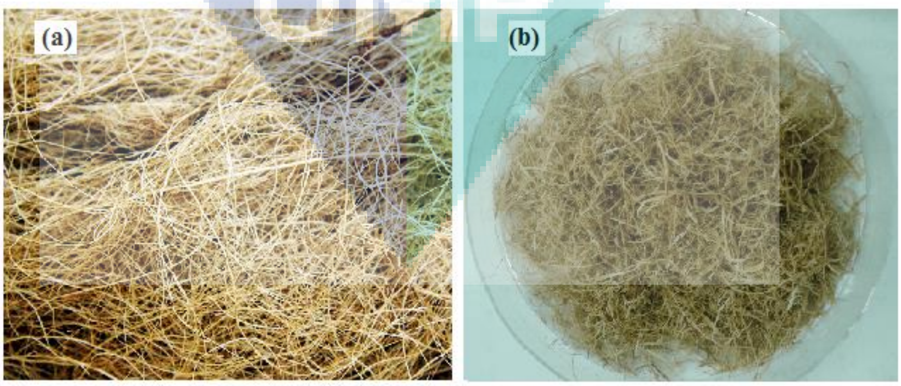

Figure 3.4 EFB fibres (a) before grinding; (b) after grinding process

3.4 Characterization of OPF Particles and EFB Fibres

The OPF particles and EFB fibres were characterized in term of moisture content (MC) and their chemical composition. Chemical analysis method was used to quantify the holocellulose, cellulose and lignin components in OPF particles and EFB fibres.

3.4.1 Moisture Content of OPF Particles and EFB Fibres

MC is defined as the weight of water as expressed as percentage of oven dried weight of sample. The determination of MC was conducted using oven dried method in principle to TAPPI Test Method T264 om-88. 10 g of fresh OPF was oven dried at 105 °C until the weight is constant. The Eq. (3.1) was used to calculate the MC value, where W_w is weight sample with water (g) and W_{OD} is oven dried weight (g). Because the denominator is the dried weight, the MC value could be more than 100%. This calculation is generally used as standard for wood based materials (Baeza & Freer, 2000). The MC determination procedures were repeated using 10 g of EFB fibres

$$\text{Moisture Content, MC (\%)} = \frac{W_W - W_{OD}}{W_{OD}} \times 100 \qquad (3.1)$$

3.4.2 Determination of Holocellulose Content of OPF Particles and EFB Fibres

Holocellulose is obtained from wood by using delignification methods by applying either oxidizing agents or acidic or basic solutions at high temperature. Once the lignin is removed from the lignocellulosic substance, the residue is called holocellulose which consist of hemicellulose and cellulose (Vuorinen & Alen, 2013).

The method used to extract the holocellulose is based on Browning method (Browning, 1967). To a 2.5 g of oven dry OPF particles sample, 80 ml of distilled water, 1 g $NaClO_2$ and 0.5 ml $C_2H_2O_4$ were added in a 250 ml conical flask. The mixture was heated in a water bath at 70 °C. 1 g of $NaClO_2$ and 0.5 ml $C_2H_2O_4$ was consecutively added to the flask for every hour for next 5 hours. The changing colour of the samples from light brown to white was observed. After 6 hours, the samples were cooled, filtered and rinsed with tap water. The filtered samples were dried at 103 °C for 24 hours. The weight of dried samples was measured. The holocellulose content was calculated as a percentage of non-extracted residues using equation Eq. (3.2) where W_1 is oven dried weight sample (g) and W_2 is weight of holocellulose residue (g). The hocellulose determination procedures were repeated using 2.5 g of oven dried EFB fibres.

$$\text{Holocellulose Content (\%)} = \frac{W_2}{W_1} \times 100 \tag{3.2}$$

3.4.3 Determination of Cellulose Content of OPF Particles and EFB Fibres

One g of oven dried OPF holocellulose obtained in section 3.4.2 was placed into a 250 ml conical flask and followed by addition of 5 ml of 17.5% NaOH solution. The flask was then placed in 20 °C water bath. After 5 minutes, 2.5 ml of 17.5% NaOH solution was added to the mixture two times at five minutes intervals and left for 30 minutes. Then, 16.5 ml of distilled water was added to the mixture. After 1 hour, the samples were filtered and washed with 8.3% NaOH solution. The washing process is continued using tap water. The alkali cellulose was continuously washed with 10% $C_2H_2O_4$ for 5 minutes to neutralize the cellulose. Finally, the cellulose was filtered, washed and rinsed again with distilled water. The cellulose was dried in an oven at 103 °C until constant weight. The percentage of α-cellulose in OPF particles was calculated using Eq. (3.3) where W_1 is oven dried weight holocellulose sample (g) and W_2 is weight of cellulose residue (g). The cellulose determination procedures were repeated using 1 g of oven dried EFB holocellulose.

$$\alpha\text{-cellulose Content (\%)} = \frac{W_2}{W_1} \times 100 \tag{3.3}$$

3.4.4 Determination of Lignin Content

Lignin content was determined using acid hydrolysis method (Klason lignin) based on TAPPI T222 om-83. In this method, carbohydrates (cellulose and hemicellulose) was destroyed by concentrated acid and leaving the lignin floating in the acid. To 1 g of OPF oven dried sample, 15 ml of 72% H_2SO_4 were added in a 250 conical flask. The mixture was placed in 30 °C water bath for 1 hour. At this state, black liquor is formed. The mixture was then diluted with 250 ml of 3% H_2SO_4 and placed in an autoclave for 1 hour. The lignin was filtered and oven dried at 103 °C for 12 hours. The percentage of lignin content in OPF particles was measured using Eq. (3.4) where W_1 oven dry sample weight before acid analysis (g) and W_2 the dry weight residue after acid hydrolysis (g). The procedures to determine lignin content were repeated using 1 g of oven dried EFB fibres.

$$\text{Lignin Content (\%)} = \frac{W_2}{W_1} \times 100 \tag{3.4}$$

3.5 Particleboards Manufacturing Procedures

The experimental procedures were set up based on three steps; grinding the materials, blending and pressing. The grinding process was discussed in the Section 3.3. In this research, single OPF particles-EFB fibres particleboards with a targeted density of 750 kg/m^3 were manufactured. The detail calculation of mix proportion of OPF particles, EFB fibres, urea formaldehyde and hardener was adapted from Wong (2012). The target board properties are clearly stated below:

Target density	=	750 kg/m^3
Particleboards area	=	200 × 200 mm^2
Thickness	=	6 mm
Total weight (W_T)	=	20 × 20 × 0.6 cm^3 × 0.75 g/cm^3
		180 g

Total weight (W_T) is the combination of the weights of the solid resin, hardener and dry wood residue, the equation for total weight can also be expressed as in Eq. (3.5).Where $W_{R(solid)}$ is solid weight of resin (g), $W_{H(solid)}$ is solid weight of hardener (g) and $W_{P(solid)}$ is solid weight of OPF particles or EFB fibres.

$$W_T = W_{R(solid)} + W_{H(solid)} + W_P \tag{3.5}$$

Taking into consideration the solid percentage of each material Eq. (3.5) is presented as in Eq. (3.6),

$$W_T = 0.65W_R + 0.2W_H + W_P \tag{3.6}$$

Where, W_R is measured weight of resin (g) and W_H is measured weight of hardener (g) Dividing Eq. (3.6) by W_P and simplified to obtain Eq. (3.7)

$$\frac{W_T}{W_P} = 0.65\frac{W_R}{W_P} + 0.2\frac{W_H}{W_P} + 1$$

$$W_P = \frac{W_T}{0.65\frac{W_R}{W_P} + 0.2\frac{W_H}{W_P} + 1} \tag{3.7}$$

W_R/W_P is ratio of resin solid weight to OPF or fibres EFB weight, thus

$$\frac{W_R}{W_P} = \frac{10\%}{100\%} = 0.1 \tag{3.8}$$

W_H/W_P is the solid weight ratio of hardener and OPF particles and EFB fibres, but the solid weight of hardener is based on the solid weight of resin. Therefore, W_R/W_P should be inserted into Eq. (3.7) and the resulting equation expressed as Eq. (3.9).

$$W_P = \frac{W_T}{0.65\frac{W_R}{W_P} + 0.2(\frac{W_H}{W_R} \times \frac{W_R}{W_P}) + 1} \tag{3.9}$$

Solid weight ratio of hardener and OPF particles and EFB fibres is presented in Eq.(3.10)

$$\frac{0.25W_H}{0.65W_R} = \frac{1\%}{100\%}$$

$$\frac{W_H}{W_R} = 2.6x10^{-2} \tag{3.10}$$

The weight of wood residues, W_P can be easily calculated using Eq. (3.9). Then, W_R, $W_{R(solid)}$, $W_{H(solid)}$ and W_H were calculated using Eq. (3.8), Eq. (3.5) and Eq. (3.6), respectively. Thus, the value of W_P, W_H and W_H required are 169 g, 16.9 g and 0.015 g, respectively.

The oven dried particles and fibres were weighed and loaded into a blender machine (Figure 3.5) to obtain uniform distribution of the resins on the particles and fibre. Prior to use in the particleboards production, UF was mixed with 20% NH_4Cl aqueous solution (Antonovic et al., 2010). The UF-NH_4Cl mixture was sprayed using a single pneumatic spray gun on the mixture during rotation. The adhesive application on furnish mixture took 10 minutes. The blender was left to run for an additional 5 minutes to ensure the wood particles and fibres were evenly coated with resins.

The mixture was then formed into a mat on a on a metal plate, using a 20 cm square metal forming box (Figure 3.6). The particleboards thickness was controlled by using two rectangular 6 mm metal stops. Then, the formed mat was loaded on a single opening hot press machine - Lotus Scientific, LS-22025 – 25 Ton Hydraulic hot press (Figure 3.7) at different manufacturing variables (temperature and time). The hot press pressure was maintained at 2.7 N/mm^2. Three replications boards were made for each experimental condition. All subsequent experiments were performed with this processing method. After pressing process, the finished boards were allowed to cool at room temperature for a week. It removes the formaldehyde trapped inside the boards (Laemlaksakul, 2010). Then, 5 mm were trimmed along the rough edges using an electrical cutter (FH-103), (Figure 3.8) to obtained 200 × 195 mm^2 particleboards.

Figure 3.5 The blender machine

Figure 3.6 The mat forming after blending process

Figure 3.7 Hot press machine

Figure 3.8 The electrical cutter

3.6 Preliminary Assessment of Processing Conditions

At first stage, a trial experiments were made to compare the properties of the fabricated OPF and the particleboards made of 70% OPF particles and 30% EFB fibres (denoted as 70% OPF : 30% EFB). Both particleboards were pressed at 150 °C for 5 minutes, with a target density of 750 kg/m^3 but with reduced UF resin level, which is 10% to the dry weight of material. The hot press parameters were adapted from Laemsak and Okuma, 1996. The study suggested that, press temperature an time, 150 °C for 5 minutes was adequate to produced strong particleboards. The panels were characterized and yield the physical and mechanical properties.

After reviewing the first trial experimental result, in order to improve the quality of the fabricated particleboards, another series of OPF and OPF-EFB particleboards were made with increased press temperature to 180 °C. The press time, UF resin level and target density of the particleboard were maintained at 5 minutes, 10% and 750 kg/m^3, respectively. The experiments also were repeated at 180 °C with shorter press time. Shorter press time is favourable in the industry since it will reduce the production cost. The properties of new particleboards were also investigated with the same testing methods.

Based on the preliminary study, in order to determine the optimum parameter in the fabrication process of particleboards made from OPF and EFB fibre, response surface methodology was employed to analyse the effect of hot press temperature (150–190 °C); press time (3–7 minutes) and EFB blending ratio (0–40%) on particleboards MOR, MOE, IB, WA and TS values.

3.7 Box-Behnken - Response Surface Methodology

3.7.1 Introduction

Based on the literatures, it is obvious that Response Surface Methodology design (RSM) is a practiced statistical tool for optimisation of manufacturing process and at the same time, reducing the number of costly experiments and able to evaluate the interactions between the parameter. The field of RSM covers three aspects which consist of; the experimental strategy for exploring the independent variables or factors, empirical statistical modelling to develop the relationship between the response and factors, and optimisation method for finding the levels or values of the variables that produce desirable values of the response (Myers et al., 2009).

3.7.2 Box-Behnken Experimental Design

The objective of this study was to produce mixed particleboards from OPF particles and EFB fibres and to establish the optimum condition for making these particleboards using RSM. After the preliminary study, a Box-Behnken design of RSM in Design-Expert 7.01 software was selected to construct experimental design order and optimise the manufacturing variables of the particleboards production. This method allows establishing statistical relationship between the experimental variables and response which the optimal experimental conditions could be predicted for achieving the optimal boards properties (Jun et al., 2008). The effect of operating factors; hot pressing temperature, hot pressing time and blending ratio of EFB fibres to OPF particles were evaluated to the physical and mechanical properties of the produced particleboards. The operating variables were varied within the desired ranges to obtain the optimum values are tabulated in Table 3.4. The experimental levels for each variable were selected based on the literature review and preliminary study. The target density of the particleboard was maintained at 750 kg/m^3.

Table 3.3 Factors and corresponding levels for Box-Behnken design

Factor	**Unit**	**ID**	**Level**		
			-1 (Low)	**0 (Medium)**	**+1 (High)**
Press temperature	°C	A	150	170	190
Press time	min	B	3	5	7
EFB blending ratio	%	C	0	20	40

In this study, the C_0 was set to 5 and based on the Eq. (2.3), 17 experiments were required to evaluate the three independent factors on the responses. The centre point was run five times to allow for a more uniform estimate of the prediction variance over the entire design space. The experimental work order was done according to run order as shown in Table 3.4. The responses are denoted as; R_1 – modulus of rupture (MPa), R_2

– modulus of elasticity (MPa), R_3 – internal bonding (MPa), R_4 – thickness swelling (%) and R_5 – water absorption (%).

Table 3.4 Three factors Box Behnken experimental design matrix in term of actual and coded factors

Standard order	Experimental run order	Actual factors level			Coded factors levels		
		A Temperature (°C)	B Time (min)	C Ratio (%)	A Temperature (°C)	B Time (min)	C Ratio (%)
1	10	150	3	20	-1	-1	0
2	3	190	3	20	+1	-1	0
3	7	150	7	20	-1	+1	0
4	1	190	7	20	+1	+1	0
5	13	150	5	0	-1	0	-1
6	15	190	5	0	+1	+1	-1
7	17	150	5	40	-1	0	+1
8	11	190	5	40	+1	0	+1
9	6	170	3	0	0	-1	-1
10	9	170	7	0	0	+1	-1
11	16	170	3	40	0	-1	+1
12	2	170	7	40	0	+1	+1
13	12	170	5	20	0	0	0
14	4	170	5	20	0	0	0
15	14	170	5	20	0	0	0
16	8	170	5	20	0	0	0
17	5	170	5	20	0	0	0

3.8 Physical Properties Testing

In this study, the dimensional stability; WA and TS were the physical properties measured for each particleboard. These properties were carried out following the ASTM D1037-1999.

3.8.1 Water Absorption (WA)

WA is a test to check for sample resistance to the moisture. It is calculated as the amount of water absorbed by a submerged sample of particleboards. WA was measured on three conditioned 50 mm square specimens from each particleboard. The samples were dried in oven at 80 ˚C for 2 hours and then are allowed to cool to room temperature. The WA was determined using Eq. (3.11) where W_1 is initial weight of sample before immersion (g) and W_2 is final weight after immersion (g). Samples were weighed and the weight of the samples was determined before and after removing from water after 24 hours immersion. After the samples were removed from water bath, they were gently blotted with tissue to remove excess water on the surface and the weight of the samples was recorded.

$$\text{WA (\%)} = \frac{W_2 - W_1}{W_2} \times 100 \quad (3.11)$$

3.8.2 Thickness Swelling (TS)

The TS test was used to measure the swelling of the samples after immersion in water. TS value was calculated using Eq. (3.12) where T_1 is initial thickness of sample before immersion (mm) and T_2 is final thickness after immersion (mm). TS value was measured on three conditioned 50 mm square specimens from each particleboard. Before the samples were soaked into the water, the thickness of every sample was measured. The thickness of specimen was measured at four point midway along each side at 10 mm from the edge (Figure 3.10). After 24 hours, the samples were taken out and drained for 10 minutes before the thickness value for the four points of the samples was measured.

$$\text{TS (\%)} = \frac{T_2 - T_1}{T_2} \times 100 \quad (3.12)$$

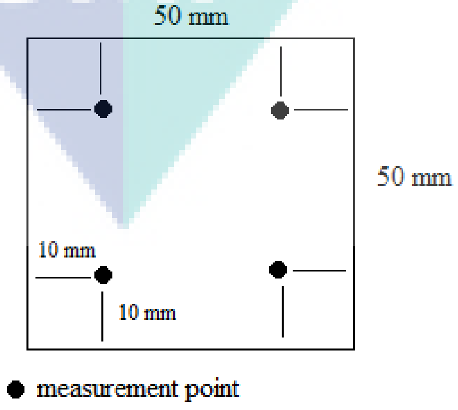

Figure 3.9 Points of TS measurement

Figure 3.10 Water absorption and thickness swelling test

3.9 Mechanical Properties Testing

Mechanical properties testing (MOR, MOE and IB) of the particleboards was done accordance to ASTM D1037-1999 using Shimadzu Universal Testing Machine.

Figure 3.11 Universal testing machine

3.9.1 Modulus of Rupture (MOR)

MOR is used in the bending test to quantify the stress require to cause sample failure. To measure the MOR properties, a specimen with a specific cross section area and length was subjected to increasing force until it breaks. During this test, load is applied in the middle of a rectangular test piece that is supported by its ends. The force at the point of breaking was used to measure the MOR.

The test piece is required with a width of not less than 50 mm and a length of 24 times the nominal thickness. Thus, the particleboards were cut into 144 × 50 × 6 mm^3 rectangular specimens for the measurement of MOR. For each particleboard, two specimens were obtained for the measurement of MOR. The testing was carried out by placing the test piece on parallel metal rollers (Figure 3.12). Then, load was applied to the centre of the test piece at a constant rate of 10 mm/min. Once the sample failure occurred, the maximum load was recorded for further calculation. The MOR values were calculated using Eq. (3.13) where Pm is static bending load (N), L is specimen's length (mm), b is specimen's width (mm) and t is specimen's thickness (mm).

$$\text{MOR (MPa)} = \frac{3P_m L}{2bt^2} \tag{3.13}$$

Figure 3.12 Bending strength (MOR and MOE) test

3.9.2 Modulus of Elasticity (MOE)

The MOE values were calculated together with MOR because it came from the same bending test. Eq. (3.14) was used to calculate MOE values where the values of maximum stress and strain were obtained during MOR test.

$$\text{MOE (MPa)} = \frac{\text{Maximum Stress}}{\text{Maximum Strain}} \tag{3.14}$$

3.9.3 Internal Bonding (IB)

IB is the strength of the bond between the wood particles and fibres in the particleboards. The IB test determined the resistance of tension perpendicular to the test piece by submitting the latter to a uniformly distributed tensile force until it breaks. The resistance of the sample is determined by the maximum load in the relation to the surface of the test piece. The IB values were determined using three specimens of 50 × 50 mm^2 for each particleboard. The test piece was glued to two metal grips (Figure 3.13) and then conditioned for 24 hours to fully cure the glue. After curing, the grips were placed in the universal testing machine and the load needed for breaking was applied. The load was applied at steady speed of 10 mm/min. Once the break happened, the maximum load sustained by the test piece was recorded. The maximum load was used to calculate the IB value using Eq. (3.15), where P' is the maximum rupture load (N), *L* and b are the length and width of the test specimen (mm), respectively.

$$\text{IB (MPa)} = \frac{P'}{bL} \tag{3.15}$$

Figure 3.13 Internal bonding test

3.10 Development of Model and Analysis of Variance (ANOVA)

In the practical application of RSM, it is necessary to develop an approximating model for the true response surface based on observed data from the experimental work (Carley, Kamneva, & Reminga, 2004). The selected model for each response obtained from the Design Expert Software was considered based on three criteria below as stated by Salim et al., (2012);

- The sequential model sum of square was in the highest order polynomial with the highest F value and low probability value, $p - value < 0.05$
- The models should not aliased based on the sequential model sum of squares.
- The model should have the value of lack of fit test insignificant with a low value F value and highest probability value, $p - value > 0.05$
- The model should have the highest value of adjusted R^2 and predicted R^2 than other models.
- Then, the experimental results obtained were examined by analysis of variance (ANOVA).

3.11 Process Variables Optimisation

The goal of optimisation in this experiment was to find the optimum manufacturing variables in getting the desired response of maximum MOR, MOE and IB, minimize TS and WA of particleboards. In this study, the hot press conditions variables were set to 'minimize' goals while for blending ratio, it was set to 'in range' goals in order to achieve the objectives for optimisation. The limits of the input variables range were set based on the initial level experimental design.

Since this study will compare the mechanical properties of the particleboards to the requirement stated in ANSI A208.1-1999, the minimum response limit for MOR, MOE and IB were set to 11, 1725 and 0.4, respectively. For WA and TS, the maximum limits were set to 60 and 25% based on requirement stated by Schneider, Chui, & Ganev, (1996).

3.12 Verification Experiments for Developed Models

The adequacy of the developed models of the responses was verified by conducting a confirmatory experiment of fabricating OPF-EFB particleboards under the suggested optimised manufacturing conditions. A solution was given by the software to determine the optimum condition for fabricating OPF-EFB particleboards was listed in Table 3.5. Under the selected optimised manufacturing conditions; a confirmatory experiment of fabricating particleboards, was performed to evaluate the accuracy of the optimisation procedure by comparing the predicted response with the experimental response result.

Table 3.5 A solution suggested by Design Expert Software

Factor			Predicted response				
Temp. (°C)	**Time (min)**	**EFF/OPF Ratio (%)**	**MOR (MPa)**	**MOE (MPa)**	**IB (MPa)**	**WA (%)**	**TS (%)**
185.60	5.70	30.38	14.10	1896.37	0.5824	59.15	20.11

3.13 Treatment Process

The OPF-EFB particleboards obtained from optimum conditions were used to test the possibility in the preservations of the fabricated particleboards. In this study, vacuum impregnation treatment was used to treat the particleboards specimens. The impregnation procedure was operated in accordance to ASTM-D1413 (1999).

3.13.1 Preparation of Test Samples

The samples with dimension of 25 × 25 × 6 mm^3 were randomly cut from the optimised particleboard. A total of 35 specimens for OPF-EFB particleboards and 5 specimens of rubber wood were prepared. Before undergoing treatment process, the samples were oven dried at a temperature of 103 °C for two hours to remove moisture content. After removing the samples from the oven and cooled down, the samples were weighed and the initial weight (W_1) was recorded. The oven dried samples were kept in a desiccator until impregnation process.

3.13.2 Preparation of Preservative Solutions

For termite laboratory test, cypermethrin (1.5% w/v) and neem oil solution were used to treat optimised OPF-EFB particleboards samples. The treatment solutions were prepared a day before the impregnation process to obtain homogenous mixture. The concentrations of cypermethrin were varied at 0.5, 1 and 1.5% w/v. Deionized water was used to dilute the cypermethrin solution. The concentrations of neem oil were varied at 5, 10 and 15% v/v, and acetone was used to dilute the neem oil. For termite field evaluation test, emulsifier concentrates cypermethrin (5% w/v) was used to treat the OPF-EFB particleboards samples.

3.13.3 Vacuum Impregnation Treatment Procedures

Vacuum impregnation method was used to treat the specimens in accordance with ASTM-D1413 (1999). The equipment was assembled practically the same to Figure 3.14. For each treatment, a specimen was placed in a beaker and then it is placed into a desiccator of the impregnation apparatus. The desiccator was attached to a vacuum pump in order to create a vacuum condition. The desiccator was evacuated for 30 minutes and 100 ml active materials solution from solution flask was delivered into the beaker under vacuum condition and followed by 60 minutes diffusions under vacuum. After the holding time, the container containing the sample was removed from the desiccator. The sample was taken from the solution and wiped off lightly using tissue paper to remove access solution. The specimens were conditioned at room temperature until constant weight was obtained to ensure all solvent had dissipated before being subjected to termite tests. The treated specimens were weighed (W_2) to determine solution uptake. Retention of materials was calculated using Eq. (1) where G (g) is the weight of the treatment solution absorbed by the block (g), C is the preservative amount in 100 g or 100 ml of the treatment solution (%) and V is the volume of the block (cm^3). The treated specimens were stored at room temperature until the specimen weight is constant before the subsequent termite resistance test.

$$R(kg/m^3) = \frac{GC}{V} \times 100 \tag{3.16}$$

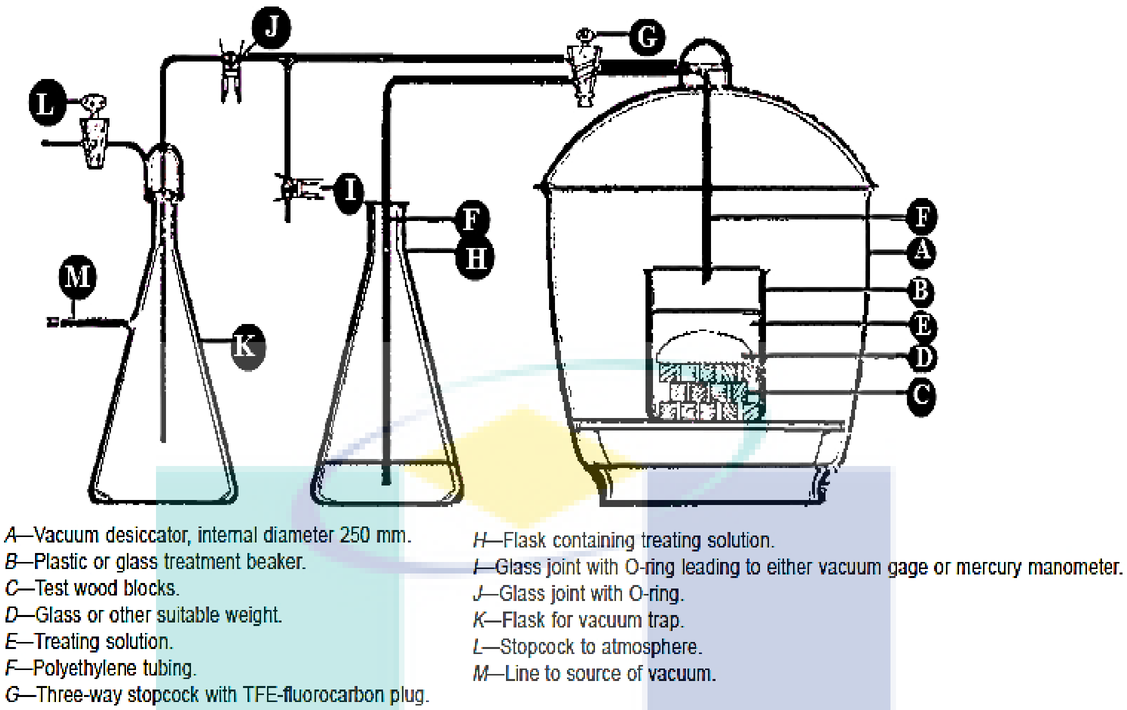

Figure 3.14 Apparatus for vacuum impregnation.

Source: ASTM-D1413 (1999)

3.14 No-choice Laboratory Evaluation of Termite Resistance

The treated and untreated specimens with a dimension of 25 × 25 × 6 mm^3 were were sent to Wood Entomology Laboratory, FRIM, Kepong to undergo termite laboratory efficacy tests. In this test, the method used was no choice FRIM In-House Method PK (A4) modified based on ASTM D3345 and AWPA E1 (1999) (Standard methods for laboratory evaluation to determine resistance to subterranean termite). The initial weight (W_1) of the specimen was measured and placed at the bottom of the jar test and filled with sand. Approximately, 400 subterranean termites (Coptotermes gestroi.) were introduced into each jar. The jars were loosely covered and kept at room temperature for 28 days. In FRIM, solid wood from rubber wood were tested for comparison. Five specimens for each particleboard and rubber wood were assayed against subterranean termites.

The activities of the termites were observed weekly. At the end of the bioassay period, OPF-EFB board samples and rubber wood were removed from the containers, cleaned, oven dried until constant weight (W_2) was obtained. The resistance of samples against termite attacks was calculated based on the percentage of weight loss using Eq. (3.17).

$$\text{Weight Loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad (3.17)$$

Termite mortality also was calculated at the end of the test period. It was calculated using Eq. (3.18), where M_1 is the number of termites alive at the beginning of the test and M_2 is the number of termites alive at the end of the test. It was count based on the number of termite died out of 400 total termites in the jar. The ratings of the termite mortality percentage are classified as: 99.1 – 100%; complete, 66.1 – 99%; heavy, 33.1 – 66%; moderate and 0 – 33%; slightly.

$$\text{Termite Mortality} = \frac{M_1 - M_2}{M_1} \times 100 \quad (3.18)$$

In addition, the appearance each specimen was examined and visually rated using AWPA E7 (2010) – a standard rating system as described in Table 2.13.

3.15 Field Evaluation of Termite Resistance – In Ground Contact Method

The performance of OPF-EFB particleboards treated against termite attacks were evaluated in field trials. The field (in-ground method) was adapted based on AWPA E7 (Standard method of evaluating wood preservative by field test) and several literatures (Pan & Wang, 2015; Nicholas & Freeman, 2000; Peralta et al, 2004; Tascioglu et al., 2013).

Prior exposure in the field test, the stakes with a dimension of 170 × 25 × 6 mm^3 long were cut from optimised particleboards. The stakes were weighed after drying in oven at 103 °C for 2 hours (Pan & Wang, 2015). Afterwards, the impregnation treatment process of the samples was repeated with cypermethrin 5% w/v. A stake was placed in the container and engaged to the desiccator. 100 ml of the active solution was transferred from the solution flask into the container containing the stake. The stake was taken from the solution and wiped off lightly using tissue paper to remove access solution. The stakes were dried at room temperature until constant final weight (W_2) was obtained. To determine the presence of the active materials inside the treated wood samples, they were evaluated using GCMS analysis. The method will be discussed in section 3.16.

In order to compare the performance of treated stakes, untreated stakes also were included as control. Five replicates test stakes of treated and untreated were used in the field trial against termites. The site for field test was in agricultural land located in Terengganu having a hot and humid climate through the year with annual rainfall of 2000 mm and means daily temperature of 32 °C and means annual temperature of 26.7 °C.

The treated and untreated samples stakes were installed at the test plot by inserting vertically into the ground to a depth of 140 mm with 200 mm apart in order to natural infestation by subterranean termites for an exposure of 4 weeks (Figure 3.16). Figure 3.16 shows termite test array samples map. The samples were covered with insulating materials to avoid rainfall and maintained high humidity (Peters, Bailleres, & Fitzgerald, 2014). The stakes were removed carefully from the field using a dull blade after first, second, third and fourth week exposure. The stakes were cleaned; oven dried and reweighed (W_2). The extent of termite damage was determined by calculating sample weight loss according to Eq. (3.17). Each sample also was visually rated according to AWPA E7 – a standard rating system as described in Table 2.13.

Figure 3.15 Installation of the stakes into the ground during the field test

C	T	C	T
T	C	T	C
C	T	C	T
T	C	T	C
C	T	C	T
T	C	T	C
C	T	C	T
T	C	T	C
C	T	C	T
T	C	T	C

harvested after 1st week
harvested after 2nd week
harvested after 3rd week
harvested after 4th week

C - control/untreated samples
T - treated samples

Figure 3.16 Specimen map for in-ground test

3.16 Gas Spectrometer Mass Spectrometer (GCMS) Analysis

GCMS analysis was done in order to determine the presence of the active materials inside the particleboards after the treatment process. To begin with, a 20 × 20 × 6 mm^3 board sample was crushed into small particles before mixing with 100 ml GC grade methanol for two hours. The mixture was continued shaking for every 15 minutes to ensure the active materials dissolved in methanol. After that, the solution was filtered using filter paper for two times to remove any wood pieces from the solution. Then, 0.5 ml of the filtered solution was transferred into a vial for further analysis.

Sample of preservative solution was diluted in methanol and analysed using GCMS for comparison. 0.5 ml of the cypermethrin concentrated solution was diluted with methanol which was made up to 100 ml in a volumetric flask. Then, 1.0 ml of the diluted solution was transferred into a 2.0 ml vial. The samples were injected into a GC (Agilent 5975 Inert/N MSD) comprising an auto sampler and gas chromatography to a mass spectrometer instrument employing the following conditions; silica capillary column, helium gas was used as the carrier gas at a constant flow of 30 ml/min, injection volume of 1.5 µl, column temperature 250 °C, injection port temperature 260 °C and temperature detector 280 °C.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter consists of three main parts presents the results from the studies on the fabrication of mixed oil palm fronds particles (OPF) and empty fruit bunch fibres (EFB) particleboards. The first part will discuss the results from a preliminary study on the fabrication of OPF-EFB particleboards. Part two will discuss the result of OPF-EFB particleboards optimisation by RSM using Design Expert Software. In part three, the results of termite test of the treatment of particleboards will be discussed.

4.2 Properties of OPF Particles and EFB Fibres

A quantitative analysis was applied to determine the moisture content and percentage of the lignocellulosic element of OPF particles and EFB fibres. This is for the identification of the raw material factors which is likely having an influence on the particleboards quality. Using Eq. (3.1), the average moisture of content (MC) of the OPF was found to be 81.2% and for EFB was found to be 10.8%. It is accepted that the MC value for OPF is higher compared to the EFB fibres since it was determined using fresh OPF while the EFB used was from readily processed sources.

Table 4.1 shows the percentage of lignocellulosic element in the OPF particles and EFB fibres. Data from the previous researchers also are included for comparison. As expected, the average percentage composition obtained of the three components is comparable with the data in previous studies. A slight difference is noticed in cellulose content for EFB fibres. The lignocellulosic element fraction of agricultural residue might be different and is not easily quantified because it depends on the testing effect, plant age, weather effect, soil, crop rotation, slops of the land and the farming practice (Kim & Dale, 2004 and Abdul Khalil et al., 2012).

Table 4.1 Composition of lignocellulose component in OPF particles and EFB fibres

	Sample	Composition (%)		
		Holocellulose	Cellulose	Lignin
Experimental	OPF	65.6	36	12.8
	EFB	77.6	41.2	19.1
Literature	OPF [a]	66 – 83	33.2 – 57	15 – 23.7
	EFB [b]	68 – 86	43 – 65	13 – 37

Source: [a] Abdul Khalil et al., (2006); Wan Rosli et al., (2007) and Hashim et al., (2011); [b] Abdul Khalil et al., (2008)

4.3 Preliminary Assessment on OPF-EFB Particleboards Fabrication

A trial experiments were run to compare the properties of OPF particleboards and the blended particleboards made from 70% OPF particles and 30% EFB fibres Particleboards have been fabricated at two different hot press temperatures (150 and 180 °C) and two different press times (3 and 5 minutes). At first trial, the particleboards were pressed at 150 for 5 minutes using 10% resin. The particleboards were characterized and the physical and mechanical properties are given in Table 4.2.

From Table 4.2, it is observed that blended particleboards (OPF-EFB) have better bending properties (MOR and MOE) and bonding properties compared to OPF particleboards. It might be affected by the variation properties of the raw materials (EFB fibres and OPF particles). Generally, fibre are stronger than the particles because in the defibration process, the fibrous nature of lignocellulosic material is well exploited (Youngquist, 1999). The particles and fibres also would form hybrid structure, in which particles-particles, fibre-fibre and particles-fibre could occur by the resin (Zhang & Hu, 2014).

Table 4.2 Properties of experimental particleboards at 150 °C, 5 minutes, 10% UF

Particleboards	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)	WA (%)
OPF	10.2	1330	0.30	27.5	88.4
70% OPF : 30% EFB	11.5	1597	0.33	26.1	85.7
OPF (Laemsak & Okuma, 1996)	12	1960	0.85	13	NA

However, the physical and mechanical properties of OPF and OPF-EFB particleboards fabricated in this study are lower compared to the results reported by Laemsak & Okuma, (1996). It is probably due to the origin of fronds and particles geometry. In the study conducted by Laemsak & Okuma, (1996), the OPF used was from Thailand and smaller size of OPF particles (0.2 – 1.3 cm) was used. The fronds also may have a different composition of the lignocellulosic elements. Thus, another series of OPF and OPF-EFB particleboards were made at higher temperature (180 °C) at two different press time (3 and 5 minutes). The physical and mechanical properties of particleboards fabricated at 180 °C are shown in Table 4.3.

Table 4.3 Properties of experimental particleboards at 180 °C, 3 and 5 minutes and 10% UF

Particleboards	Press time	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)	WA (%)
100% OPF	5	11.2	1714	0.42	23.8	67.1
70% OPF : 30% EFB	5	15.5	1840	0.64	22.5	70
100% OPF	3	10.6	1549	0.37	23.1	82.9
70% OPF : 30% EFB	3	12.4	1609	0.47	24.2	76.0

It can be observed that from Table 4.3, the mechanical properties of OPF and OPF-EFB particleboards pressed at 180 °C for 5 minutes are superior compared to the particleboards compressed at 150 °C. The value of MOR, MOE and IB for mixed particleboards (70% OPF: 30% EFB) is higher compared to the particleboards made of 100% OPF particles. It is proved that at this hot pressed condition, the UF resin is fully cured and able to consolidate the boards. Reducing the press time from five minutes to three minutes caused the decrease in mechanical properties (MOR, MOE and IB) and poor dimensional stability (WA and TS). It is closely related to the pre-curing of UF resin. When the press time is too short, the compaction of wood particles is inadequate to enable sufficient contact between particles and adhesive (Wong, 2012). In comparison to study conducted by Laemsak and Okuma, (1996), only MOR value of the OPF-EFB has surpassed the reported properties. This can be related to the difference in UF resin level used. Laemsak and Okuma, (1996) used 12% of UF resin based on oven dried OPF particles. In comparison to ANSI A208.1 standard and industrial recommended value (Table 3.8), the OPF-EFB particleboards pressed at 180 °C, 5 minutes have achieved the minimum requirement in term of MOR, MOE, IB and TS value.

In can be concluded that, mixing OPF particles and EFB fibres together could enhance the particleboards properties rather than using OPF particles only. The EFB fibres are expected to act as reinforcement in the OPF particleboards. As reported previously, EFB fibres had been used as reinforcement materials in various composites (Sreekala et al., 2000 and Shinoj et al., 2011). In the second experimental trial, it is observed that the physical and mechanical properties of the OPF and OPF-EFB particleboards were improved as the magnitude of the temperature and time are increased. The improvement was related to the resin curing process. It is believed that, if either temperature or time is extended, the particleboards physical and mechanical properties could be enhanced.

4.4 Physical and Mechanical Properties – Response Variable

The design matrix and corresponding results for the RSM experiments for the fabricated particleboards with three suggested factors (hot press temperature, time and EFB/OPF ratio) are summarised in Table 4.4. Each of the response variables were analysed separately using Design Expert software to obtain the regression models and afterwards, the interactions between the experimental factors were analysed. The results were also analysed and evaluated statistically in order to obtain suitable model for each properties. Results for the characterization of the produced particleboards is explained through Section 4.5, 4.6 and 4.7.

Table 4.4 Box-Behnken experimental matrix and measured experimental responses

		Factor A	Factor B	Factor C					
Std. order	**Run order**	**Temp. (°C)**	**Time (min)**	**EFB/OPF ratio (%)**	**MOR (MPa)**	**MOE (MPa)**	**IB (MPa)**	**WA (%)**	**TS (%)**
1	10	150	3	20	9.36	1130	0.242	98.6	33.1
2	3	190	3	20	13.2	1751	0.498	60.9	19.2
3	7	150	7	20	11.9	1541	0.423	76.1	19.6
4	1	190	7	20	12.3	1693	0.491	58.7	19.2
5	13	150	5	0	11	1319	0.345	90.3	27.5
6	15	190	5	0	14	1877	0.451	64.3	18.5
7	17	150	5	40	12.9	1677	0.376	85.4	26.5
8	11	190	5	40	14.2	1836	0.548	58.7	19.6
9	6	170	3	0	12.4	1608	0.450	78.8	26.3
10	9	170	7	0	14.9	1701	0.509	66.7	22.2
11	16	170	3	40	14.2	1843	0.487	78.3	25.4
12	2	170	7	40	15.2	1973	0.617	64.4	19.9
13	12	170	5	20	14.4	1861	0.565	70.4	23.7
14	4	170	5	20	14.6	1891	0.580	67.1	21.3
15	14	170	5	20	14.4	1862	0.595	65.9	27.3
16	8	170	5	20	14.1	1791	0.602	68.4	22.6
17	5	170	5	20	14.3	1857	0.570	69.9	22.8

4.5 Development of Regression Model

To analyse the effect of the factors on responses, RSM generates mathematical models which describe the process based on experimental data. The model used in RSM is generally a full quadratic equation or the diminished form of quadratic equation. From the analysis, quadratic models were chosen for MOR, MOE, IB and WA, and for TS properties, a second order two factorial interaction model (2FI) was selected. All these models have the highest order polynomial, were not aliased, have insignificant lack of fit (LOF) and maximize R_{pred}^2 and R_{adj}^2. In each model, the coefficient relationship of the variables to the response was calculated and evaluated statistically using RSM - Design Expert Software based on the regression equation and experimental data. The individual model was combined by RSM in order to get the optimum model.

The suggested mathematical models in terms of coded factors for all responses were given in the Eq. (4.1– 4.5) and in terms of actual factors; the models are shown in Eq. (4.6–4.10), respectively. The models representing the response are denoted as R_1 (MOR), R_2 (MOE), R_3 (IB), R_4 (WA) and R_5 (TS) as a function of hot press temperature (A), hot press time (B) and EFB/OPF ratio (C). The models can be used to predict the response (MOR, MOE, IB, WA and TS) for various combinations of parameters (temperature, time and ratio). The coefficient of linear terms of A, B and C shows the single effect of the factors for OPF based particleboards production. The coefficient of two multiplied factors; AB, AC and BC depict the interaction effects on the responses while second order terms related to A^2, B^2 and C^2 were representing the quadratic effect. The positive value before the coefficient in the model represents an effect that favours the optimisation while a negative value indicates an inverse relationship between the factor and the response (Mourabet et al., 2014).

Mathematical models in term of coded factor;

$$R_1 = +14.4 + 1.07A + 0.65B + 0.53C - 0.86AB - 0.46AC - 0.38BC - 1.9A^2 - 0.75B^2 + 0.59C^2 \quad (4.1)$$

$$R_2 = +1852 + 196A + 94.4 + 90.4C - 102AB - 99.8AC + 34.3BC - 194A^2 - 115B^2 + 18.8C^2 \quad (4.2)$$

$$R_3 = +0.58 + 0.075A + 0.045B + 0.034C - 0.047AB + 0.016AC + 0.018BC - 0.13A^2 - 0.042B^2 - 0.025C^2 \quad (4.3)$$

$$R_4 = +68.3 - 13.5A - 6.34B - 1.68C + 5.07AB - 0.19AC - 0.46BC + 3.95A^2 + 1.31B^2 + 2.43C^2 \quad (4.4)$$

$$R_5 = +23.2 - 3.78A - 2.87B - 0.39C + 3.35AB + 0.5AC - 0.34BC \quad (4.5)$$

Mathematical models in term of actual factors;

$$MOR = -163 + 1.82 * Temperature + 6.04 * Time + 0.21 * Blending\ ratio - 0.022 * Temperature * Time - 0.001 * Temperature * Blending\ ratio - 0.010 * Time * Blending\ ratio - 0.005 * Temperature^2 - 0.186 * \quad (4.6)$$

$\text{Time}^2 + 0.001 * \text{Blending ratio}^2$

MOE = $-17792 + 192 * \text{Temperature} + 752 * \text{Time} + 40.8 * \text{Blending ratio} - 2.56 * \text{Temperature} * \text{Time} - 0.25 * \text{Temperature} * \text{Blending ratio} + 0.86 * \text{Time} * \text{Blending ratio} - 0.49 * \text{Temperature}^2 - 28.7 * \text{Time}^2 + 0.047 * \text{Blending ratio}^2$ (4.7)

IB = $-10.5 + 0.117 * \text{Temperature} + 0.318 * \text{Time} - 0.005 * \text{Blending ratio} - 0.001 * \text{Temperature} * \text{Time} + 0.00004 * \text{Temperature} * \text{Blending ratio} + 0.0004 * \text{Time} * \text{Blending ratio} - 0.0003 * \text{Temperature}^2 - 0.01 * \text{Time}^2 - 0.00006 * \text{Blending ratio}^2$ (4.8)

WA = $+602 - 4.66 * \text{Temperature} - 27.8 * \text{Time} - 0.189 * \text{Blending ratio} + 0.127 * \text{Temperature} * \text{Time} - 0.0005 * \text{Temperature} * \text{Blending ratio} - 0.0115 * \text{Time} * \text{Blending ratio} + 0.01 * \text{Temperature}^2 + 0.328 * \text{Time}^2 + 0.006 * \text{Blending ratio}^2$ (4.9)

TS = $+138 - 0.63 * \text{Temperature} - 15.5 * \text{Time} - 0.192 * \text{Blending ratio} + 0.084 * \text{Temperature} * \text{Time} + 0.001 * \text{Temperature} * \text{Blending ratio} - 0.008 * \text{Time} * \text{Blending ratio}$ (4.10)

The response values obtained from Eq. (4.1 – 4.5) are called predicted values and the actual response values obtained from the experiment are called observed or actual values. The predicted and observed values are shown in Appendix A. The predicted values for all responses were closed to the experimental values and it is proved by the model regression coefficient of determination values (R^2). All the models had large R^2 which almost near 1. It indicates a good fit between the predicted and experimental values. The plot for actual values versus predicted values for each response are shown in Figures 4.1 – 4.5. The value points were classified into colour by standard order as tabulated in Table 3.4. It can be observed that most of the predicted and actual response points for all plots were lie in 45° lines. This indicates a good response to the model.

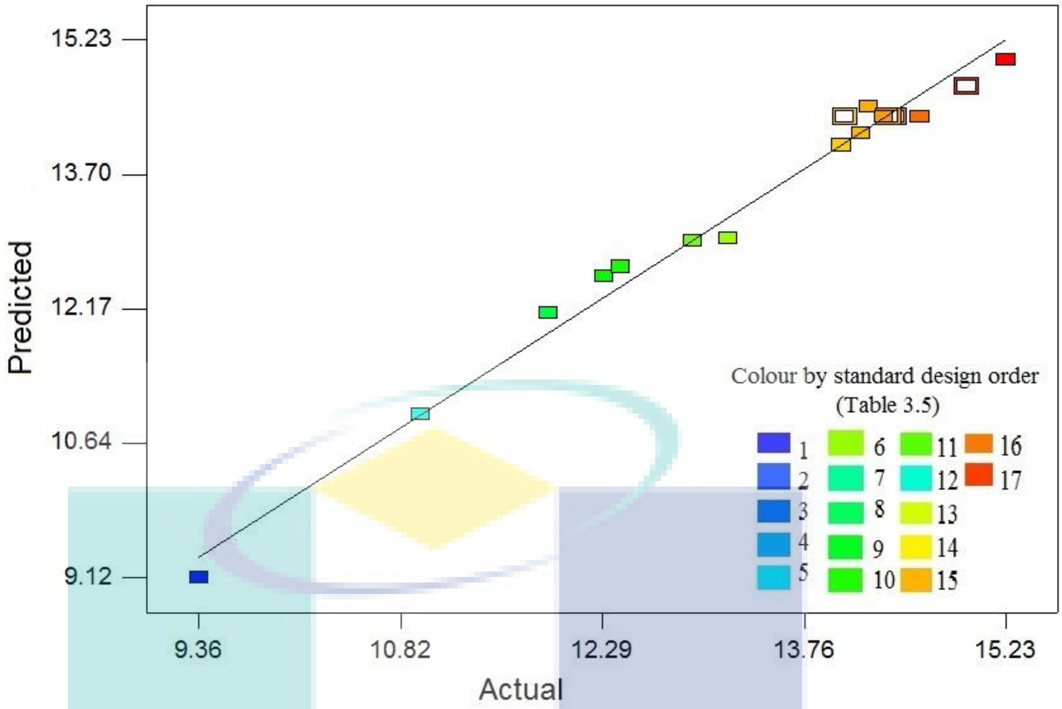

Figure 4.1 Predicted versus actual values of modulus of rupture (MOR)

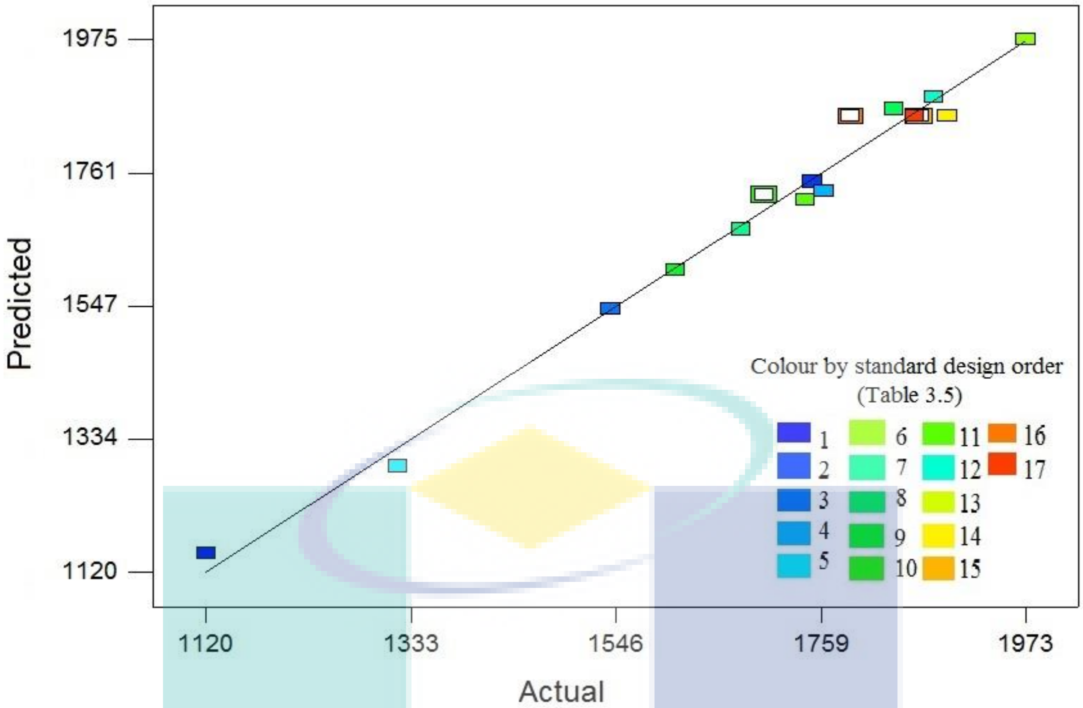

Figure 4.2 Predicted versus actual values of modulus of elasticity (MOE)

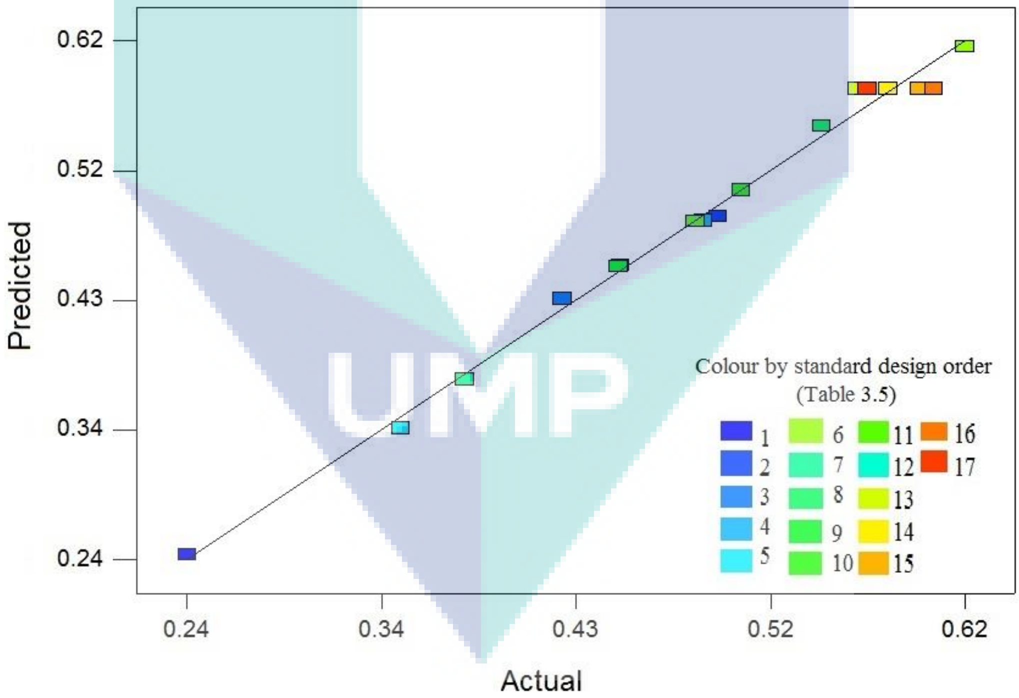

Figure 4.3 Predicted versus actual values of internal bonding (IB)

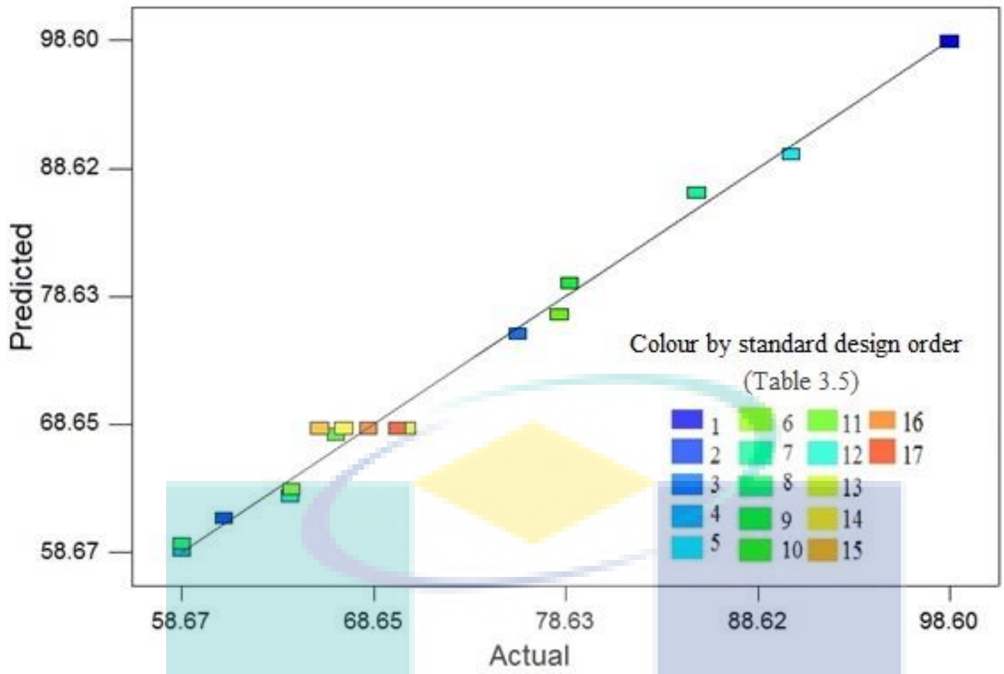

Figure 4.4 Predicted versus actual values of water absorption (WA)

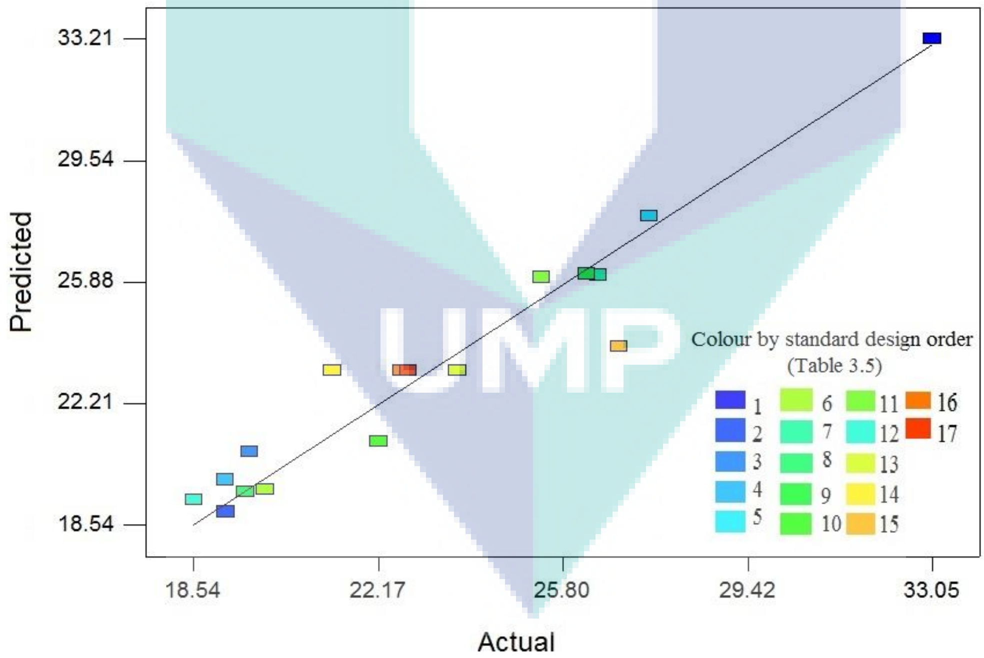

Figure 4.5 Predicted versus actual values of thickness swelling (TS)

4.6 ANOVA Analysis

The linear effects (A, B and C), interaction effects (AB, AC and BC); and quadratic effects (A^2, B^2 and C^2) of the independent variables; hot press temperature (A), hot press time (B) and EFB blending ratio (C) on the responses; MOR, MOE, IB, WA and IB obtained by analysis of variance (ANOVA) were presented in Table 4.5 – 4.9, respectively. Lack of fit (LOF) test result, corresponding R^2 of the polynomial response surface model, standard deviation, coefficient variation (CV) and adequate precision were also included. The *p – value* indicates the level of significance of the variable. If *p – value* < 0.05 for any variable with respect to any particleboards property, that variable has a significant effect on the particleboards properties with 95% significance level. ANOVA table for MOR is shown in Table 4.5.

As shown in Table 4.5, model *F – value* of 50.4 implies that the MOR model is significant as the *p – value* < 0.05. There is less than 0.1% chance that a "Model *F – value*" this large could occur due to noise. The lack of fit *F – value* of 3.79 is not significant relative to the pure error as the *p – value* is > 0.05. There is a 11.5% chance that the LOF *F – value* could occur due to noise. The non-significant value of lack of fit proved that the model was valid for this experiment. The R^2 of the MOR model was 0.985. It implies that 98.5% of the variations of the MOR is explained by the independent variables and also means that the model does not only explain about 1.5% of the variations.

For MOE, ANOVA table is shown in Table 4.6. The model *F – value* of 46.6 implies that the MOE model is significant as the *p – value* is < 0.05. There is less than 0.1% chance that a "Model *F – value*" this large could occur due to noise. The lack of fit *F – value* of 1.71 is not significant as the *p – value* is > 0.05. There is a 30.2% chance that the LOF *F – value* could occur due to noise. The R^2 of the MOE model was 0.984. It implies that 98.5% of the variations of the MOE is explained by the independent variables and also means that the model does not only explain about 1.6% of the variations.

Table 4.5 ANOVA and lack of fit test of response surface quadratic model for MOR

Sources	Sum of square	df	Mean square	*F – value*	*p – value*
Model	38.5	9	4.27	50.4	< 0.001
A- Press Temperature	9.11	1	9.11	108	< 0.001
B- Press Time	3.33	1	3.33	39.3	< 0.001
C- EFB/OPF Ratio	2.22	1	2.22	26.2	0.001
AB	2.97	1	2.97	35	< 0.001
AC	0.85	1	0.85	10	0.016
BC	0.58	1	0.58	6.83	0.035
A^2	15.5	1	15.5	183.3	< 0.001
B^2	2.34	1	2.34	27.6	0.001
C^2	1.48	1	1.48	17.5	0.004
Residual	0.59	7	0.085		
Lack of Fit	0.44	3	0.150	3.79	0.115
Pure Error	0.15	4	0.039		
Correlation Total	39	16			
R^2	0.985		Std. Dev.	0.29	
Adjusted R^2	0.965		Adeq. Precision	26.3	
Predicted R^2	0.814		CV (%)	2.18	

df – Degree of freedom; Std. Dev. – Standard Deviation; Adeq. Precision – Adequate precision ; CV – coefficient of variation

Table 4.6 ANOVA and lack of fit test of response surface quadratic model for MOE

Sources	Sum of square	df	Mean square	*F – value*	*p – value*
Model	755600	9	83960	46.6	< 0.001
A- Press Temperature	277800	1	277800	154	< 0.001
B- Press Time	41355	1	41355	23.0	0.002
C-EFB/OPF Ratio	84629	1	84629	47.0	< 0.001
AB	54955	1	54955	30.5	< 0.001
AC	39892	1	39892	22.1	0.002
BC	345	1	345	0.19	0.675
A^2	192800	1	192800	107	< 0.001
B^2	50918	1	50918	28.3	0.001
C^2	6324	1	6324	3.51	0.103
Residual	12610	7	1801		
Lack of Fit	7085	3	2362	1.71	0.302
Pure Error	5525	4	1381		
Correlation Total	768200	16			
R^2	0.984		Std. Dev.	42.4	
Adjusted R^2	0.963		Adeq. Precision	25	
Predicted R^2	0.841		CV (%)	2.47	

Table 4.7 presents the ANOVA for IB strength. As shown in Table 4.7, model *F – value* of 96.4 implies that the IB model is significant as the *p – value* is < 0.05. There is less than 0.1% chance that a "Model *F – value*" this large could occur due to noise. The lack of fit *F – value* of 0.44 is not significant as the *p – value* is > 0.05. There is a 73.9% chance that the LOF *F – value* could occur due to noise. The R^2 of the IB model was 0.992. It implies that 99.2% of the variations of the IB is explained by the independent variables and also means that the model does not only explain about 0.8% of the variations.

ANOVA table for WA are shown in Table 4.8. The model F – value of 69.3 implies that the WA model is significant as the *p – value* is < 0.05. There is less than 0.1% chance that a "Model *F – value*" this large could occur due to noise. The lack of fit *F – value* of 0.78 is not significant as the *p – value* is > 0.05. There is a 56.4% chance that the LOF *F – value* could occur due to noise. The R^2 of the WA model was 98.9. It implies that 98.9% of the variations of the WA is explained by the independent variables and also means that the model does not only explain about 1.1% of the variations.

Table 4.7 ANOVA and lack of fit test of response surface quadratic model for IB

Sources	**Sum of square**	**df**	**Mean square**	***F – value***	***p – value***
Model	0.17	9	0.018	96.4	< 0.001
A- Press Temperature	0.045	1	0.045	238	< 0.001
B- Press Time	0.016	1	0.016	86.4	< 0.001
C- EFB/OPF Ratio	0.009	1	0.009	48.9	< 0.001
AB	0.009	1	0.009	46.4	< 0.001
AC	0.001	1	0.001	5.71	0.048
BC	0.001	1	0.001	6.61	0.037
A^2	0.068	1	0.068	358	< 0.001
B^2	0.007	1	0.007	38.2	< 0.001
C^2	0.003	1	0.003	13.9	< 0.001
Residual	0.001	7	< 0.001		
Lack of Fit	< 0.001	3	< 0.001	0.44	0.739
Pure Error	0.001	4	< 0.001		
Correlation Total	0.17	16			
R^2	0.992		Std. Dev.	0.14	
Adjusted R^2	0.982		Adeq. Precision	34.7	
Predicted R^2	0.959		CV (%)	2.81	

Table 4.8 ANOVA and lack of fit test of response surface quadratic model for WA

Sources	Sum of square	df	Mean square	*F – value*	*p – value*
Model	2011	9	223	69.3	< 0.001
A- Press Temperature	1457	1	1457	451	< 0.001
B- Press Time	322	1	322	99.7	< 0.001
C-EFB/OPF Ratio	22.5	1	22.5	6.98	0.033
AB	103	1	103	31.8	< 0.001
AC	0.14	1	0.14	0.044	0.840
BC	0.84	1	0.84	0.26	0.625
A^2	65.7	1	65.7	20.4	0.003
B^2	7.23	1	7.23	2.24	0.178
C^2	24.8	1	24.8	7.68	0.028
Residual	22.6	7	3.23		
Lack of Fit	8.34	3	2.78	0.78	0.564
Pure Error	14.3	4	3.56		
Correlation Total	2034	16			
R^2	0.989		Std. Dev.	1.8	
Adjusted R^2	0.975		Adeq. Precision	18.794	
Predicted R^2	0.801		CV (%)	2.50	

Table 4.9 presents the ANOVA for TS property. As shown in Table 4.9, the model *F – value* of 14.6 implies that the TS model is significant as the *p – value* is < 0.05. There is less than 0.1% chance that a “Model *F – value*” this large could occur due to noise. The lack of fit *F – value* of 0.16 is not significant as the *p – value* is > 0.05. The non-significant value of lack of fit proved that the model was valid for this experiment. There is a 97.4% chance that the LOF *F – value* could occur due to noise. The R^2 of the TS model was 0.898. It implies that 89.8% of the variations of the TS is explained by the independent variables and also means that the model does not only explain about 10.2% of the variations. The R^2 also closed to the R_{adj}^2. The R_{pred}^2 is in reasonable agreement with the R_{adj}^2.

Table 4.9 ANOVA and lack of fit test of response surface 2FI model for TS

Sources	Sum of square	df	Mean square	F – value	*p – value*
Model	228	6	37.92	14.6	< 0.001
A-Temperature	114	1	114	44.0	< 0.001
B-Time	65.8	1	65.76	25.4	< 0.001
C-Ratio	1.21	1	1.21	0.46	0.511
AB	44.9	1	44.91	17.3	0.002
AC	1.02	1	1.02	0.39	0.545
BC	0.45	1	0.45	0.17	0.686
Residual	25.9	10	2.59		
Lack of Fit	5.13	6	0.86	0.16	0.974
Pure Error	20.8	4	5.2		
Correlation Total	253	16			
R^2	0.898		Std. Dev.	1.61	
Adjusted R^2	0.836		Adeq. Precision	13.8	
Predicted R^2	0.812		CV (%)	6.94	

In conclusion from the ANOVA for all responses, press temperature was found to have the greatest effect on the MOR, MOE, IB, WA and TS by showing the highest sum of square value; 9.11, 277800, 0.045, 14567 and 114, respectively. The linear term of press time had second significant effect on all responses and followed by the EFB fibres ratio. The interaction temperature and time (AB) was more pronounced than the other two interactions (AC and BC) relative to the particleboards the physical and mechanical properties, respectively. From the obtained statistical models, it may be inferred that the Box-Behnken design was adequate to predict the particleboards properties within the range of variables studied. All developed mathematical models have high experimental R^2 value, the R^2 also closed to the R_{adj}^2, the R_{pred}^2 is in reasonable agreement with the R_{adj}^2, significant *F – value*, an insignificant LOF, low standard deviation and CV as well the adequate precision value is more than four. The low CV and standard deviation values proved the adequacy of the model.

4.7 Effect of Experiment Factors on Each Response

The three dimensional (3D) response surfaces represent the regression equations for each response will be presented to visualize the relationship between response and experimental factors and also the interaction between factors.

4.7.1 Factors Affecting Modulus of Rupture (MOR)

The MOR is a measure of specimen's strength before rupture by quantifying the stress required to cause the failure to the particleboards samples. The results obtained for MOR characterization are shown in Table 4.4. The average MOR ranged from 9.34 – 15.2 MPa. ANOVA table for MOR is shown in Table 4.5. The one factor plot and interaction plots represent the effects of different variables on MOR are shown in Figure 4.6 and 4.7, respectively. From Table 4.5, all factors (press temperature, press time and EFB blending ratio) were found to be statically significant on MOR at a confidence level of 95%.

At all hot press temperature and time level, all MOR have exceeded the minimum requirement of 11 MPa for general purpose grade except two boards pressed at 150 °C for 3 and 5 minutes. Poor MOR values at minimum press temperature and time may be attributed to the insufficient heat and time required to produce consolidated panels. UF resin is not fully cures if the pressing conditions do not reach the necessary curing conditions (Wong, 2012).

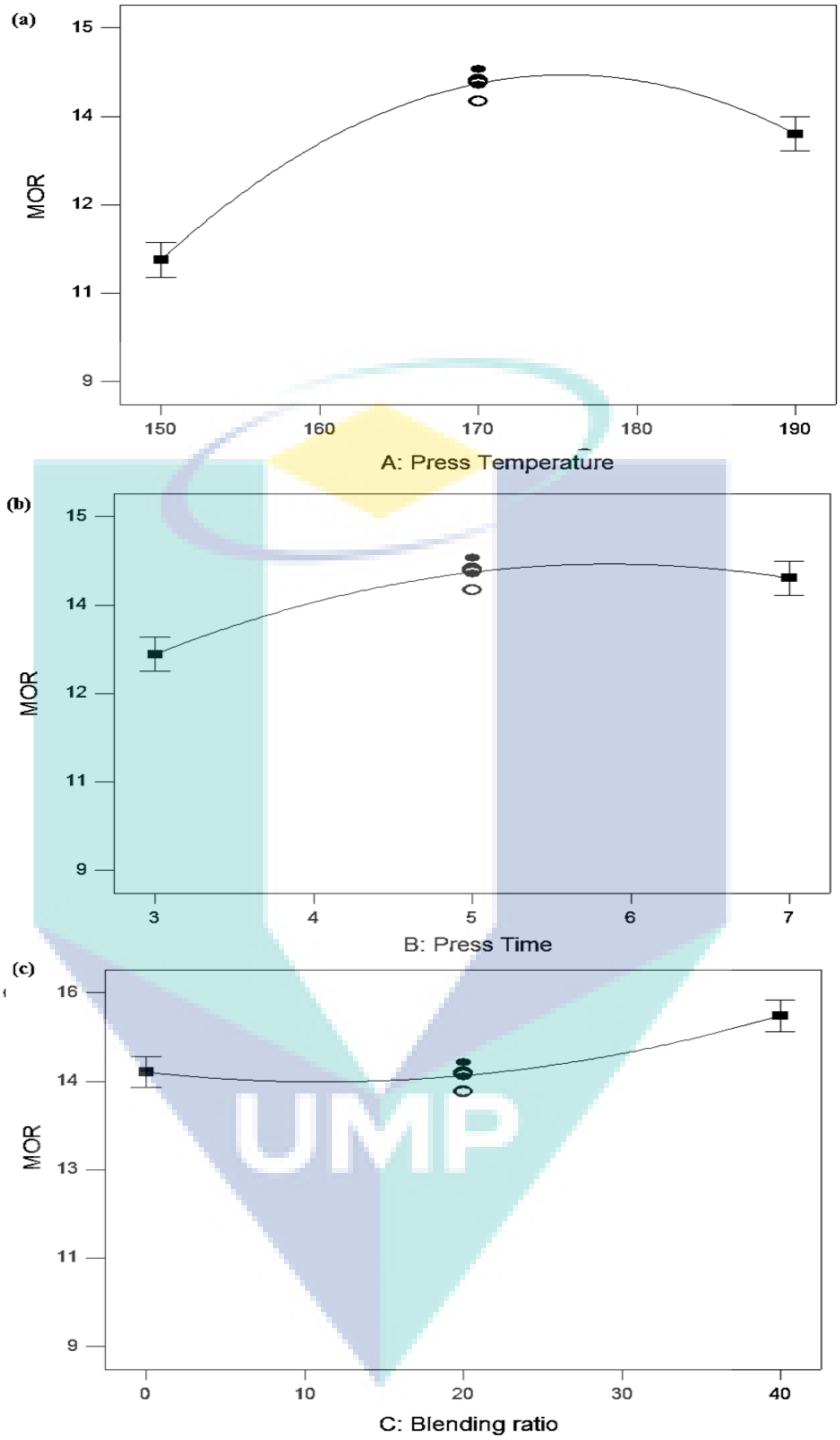

Figure 4.6 One factor plot for MOR between (a) press temperature; (b) press temperature and (c) EFB ratio

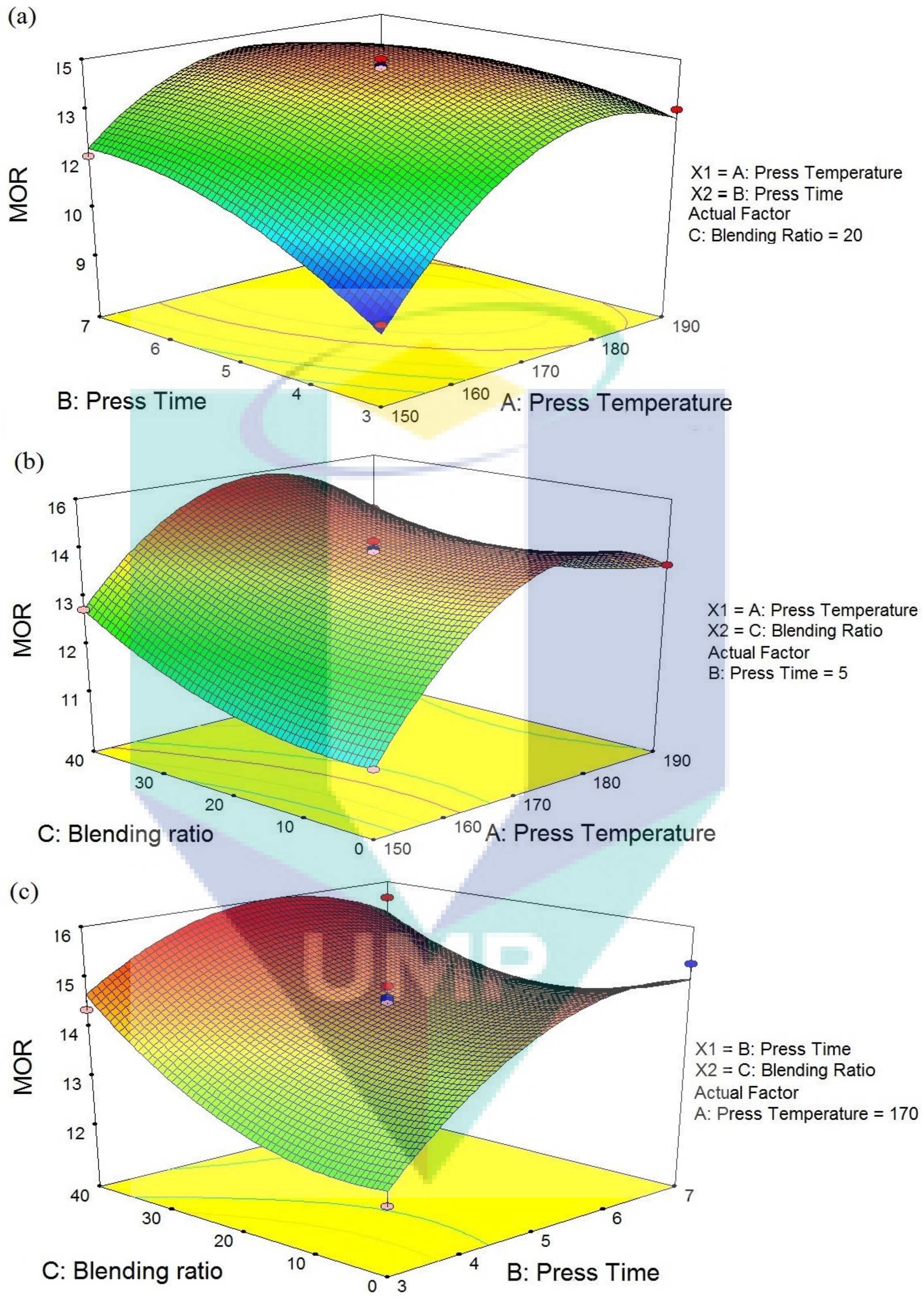

Figure 4.7 Response surface plot for MOR between (a) press temperature and time; (b) press temperature and EFB ratio; (c) press time and EFB ratio

The red area in the statistical plot (Figure 4.7) indicates the region where the response is higher and blue is lower response. From Figure 4.7a, the average MOR values are rapidly increased when hot press temperature was raised from 150 to 175 °C. It was expected due to the increase of contact area between the resin and OPF particles and EFB fibres. The adhesive viscosity becomes low at high temperature and it will increase the contact area between the particles, fibres and resins. As the results, it improves the particleboards bending properties. The similar results trend has been reported in previous studies (Nemli & Kalaycioglu, 2001; Nemli, 2002 and Iswanto el al., 2014). In Figure 4.7a, when the press temperature is in the range of 180 to 190 °C, a slightly decrease in MOR values were noticed. It is might be due to the thermal decomposition of UF resin and raw materials. When the particleboards were pressed at 190°C, the finished particleboards colour become darker and the burnt smell is noticed. It is clear that appreciable loss in MOR eventually occurs from any extended hot pressing parameters, with bending strength being the most effected properties (Winandy & Krzysik, 2007). Maximum press temperature and time may lead to the embrittlement of the particleboards surface and thus reduce the bending properties (Mahdavi et al., 2012). The reduction of MOR against high press temperature and long press time also were reported by Jun et al., (2008) and Yang et al., (2014).

The statistical surface in Figure 4.6a also shows that at low press temperature, longer pressing time enhances MOR. In the hot press process, the centre of particleboards always be at the lowest temperature, thus it needs sufficient press time to reach a significant temperature to allow the resin to fully cure. At short press time, press temperature has a positive influence on the bending strength but at longer pressing time, this influence becomes negative. Based on Table 4.5 and Figure 4.6a, it is proved that pressing temperature and time significantly influence the MOR properties as heat and time are provided in the resin curing.

From Table 4.5, the EFB fibre ratio was statistically significant to the MOR as the *p-value* < 0.05. As shown in Table 4.4, it was found the particleboards made of 60% OPF particles and 40% EFB fibre exhibited the highest MOR (std. order 12). The interaction between EFB fibres ratio and press temperature and time are further shown in Figure 4.6b and 4.6c, respectively. The MOR of particleboards pressed at temperatures above than 170 °C with and addition of more than 20% EFB fibres has achieved the requirement stated by ANSI A208.1. The presence of EFB fibres produced reinforcement effect in the OPF-EFB particleboards. The sufficient stress might have been transferred to the EFB fibres to enable the EFB fibres to be fractured, thus resulting higher bending properties (Abdul Khalil et al., 2010a). Similar results also were reported on the production of blended particleboards from coconut coir fibres and durian peel particles Khedari et al., (2003); coconut coir fibres and rice straw Zhang & Hu, (2014).

4.7.2 Factors Affecting Modulus of Elasticity (MOE)

MOE measure the stiffness or resistance to bending when stress is applied to a material. MOE was measured together with MOR because they came from the same bending assay. Generally, MOE and MOR are affected by similar processing variables (Wong, 2012). The results of the MOE characterization are shown in Table 4.4. The average MOE values ranged from 1129 – 1973 MPa. Out of 17 particleboards, ten of them have achieved the ANSI A208.1 requirement of 1725 MPa. ANOVA table for MOE is shown in Table 4.6. Similar to MOR, all factors also were found to be statically significant on MOE at a confidence level of 95%. The one factor plot and interaction plots represent the effects of different variables on MOE are shown in Figure 4.8 and 4.9, respectively. It can be observed that, the shape of MOE statistical plots seems to be similar to MOR (Figure 4.7).

Figure 4.7a shows the relationship between press temperature and time on MOE, where the EFB fibre ratio was fixed at 20%. At the shortest press time (3 minutes) and lowest press temperatures 150 °C), the MOE values are relatively poor. As discussed earlier, it may be attributed to the insufficient heat and time to produce consolidated panels. The MOE value increases as the temperature changed from 150 to 180 °C. Thereafter, MOE value starts to reduce due to elevation of press temperature and extension of press time. The loss of water in the OPF particles and EFB fibres cell at maximum press temperature and time might be a cause to the reduction of MOE value

(Jun et al., 2008). As a result, wood particles or fibres become fragile and easily damage resulting poor particleboards stiffness. It is observed that both press temperature and time are inversely correlated to the MOE values. At higher press temperature, shorter press time is needed to produce strong particleboards. Similar finding about the effect of press temperature and time on MOE were reported by Jun et al., (2008) and Yang et al., (2014). Both press temperature and times are related to each other and have to be controlled carefully to ensure the particleboards attain enough heat to cure the resin without damaging the boards. As these two factors contribute to MOR and MOE, adequate temperature and time is essential to achieve optimal bending strength.

From Table 4.4, MOE values for OPF-EFB particleboards were higher than those boards comprising 100% OPF particles. This confirms that the presence of EFB fibres improved the elasticity properties. As can be seen in Figure 4.7b and 4.7c, the MOE exhibited a similar trend to MOR (Figure 4.9b and 4.9c). It seems that MOE values are varying proportionally to the increase in the EFB fibre ratio. Therefore, incorporation of EFB fibres in the OPF particleboards structure enhances the bending strength of the particleboards.

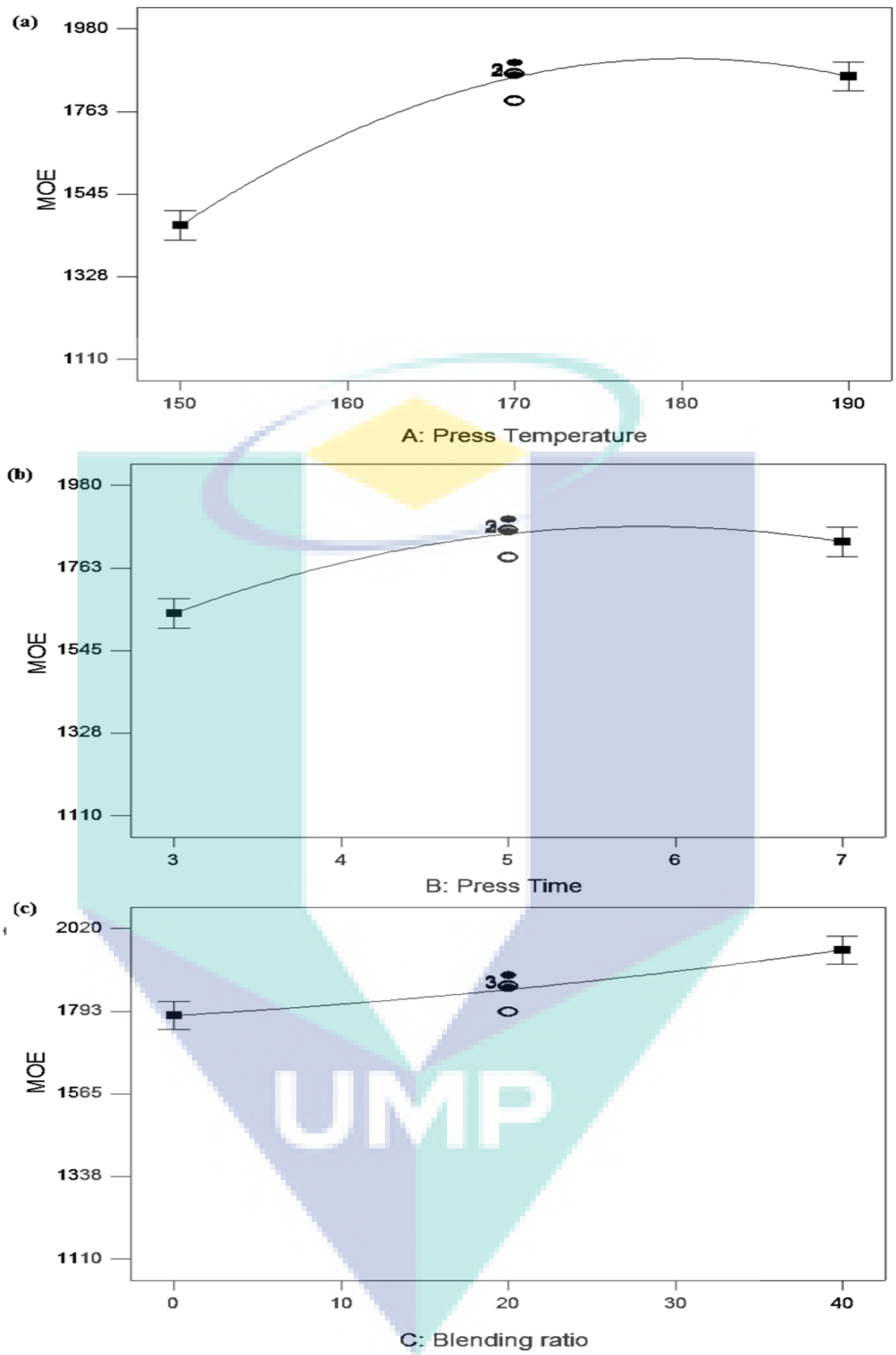

Figure 4.8 One factor plot for MOE between (a) press temperature; (b) press temperature and (c) EFB ratio

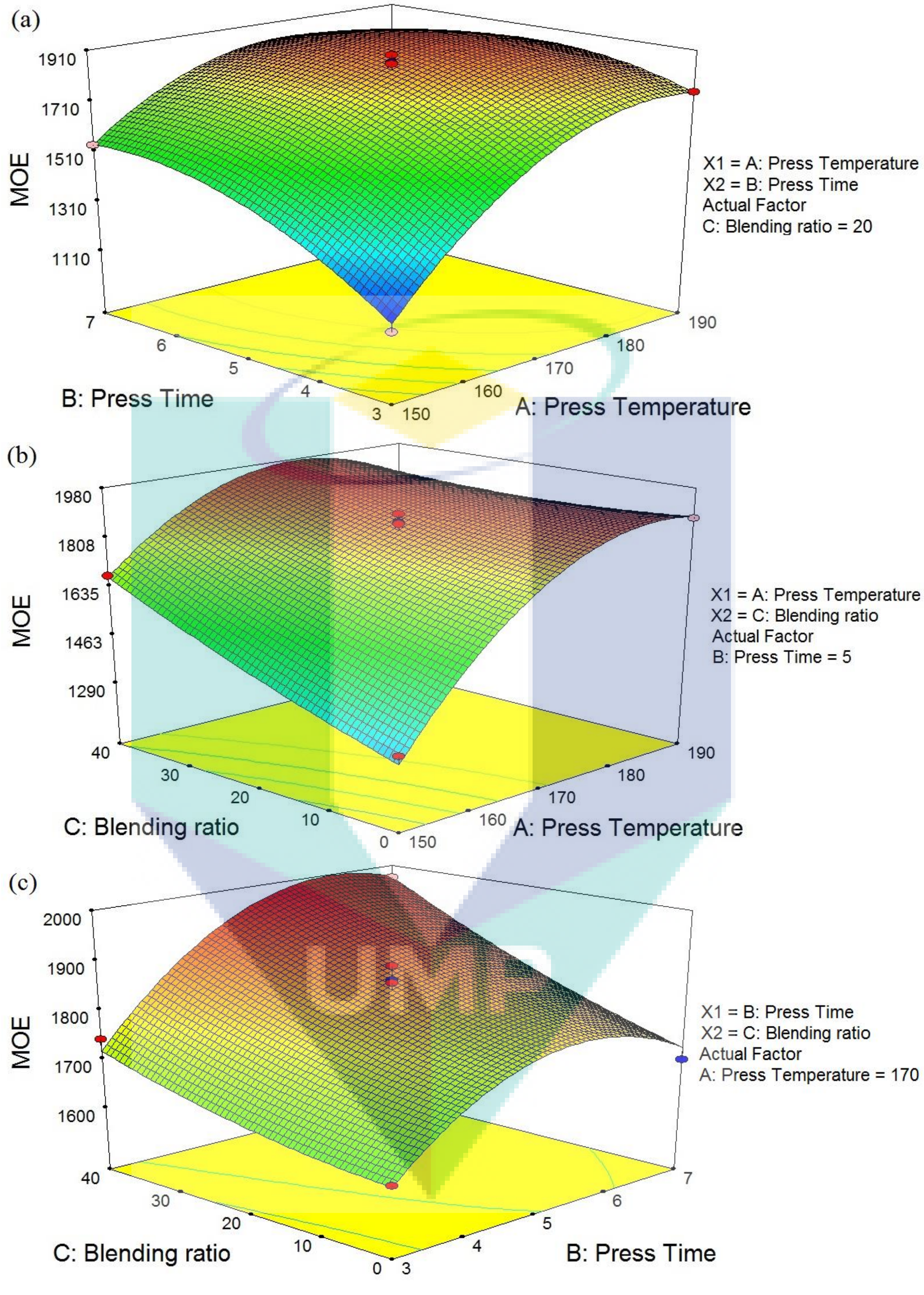

Figure 4.9 Response surface plot for MOE between (a) press temperature and time; (b) press temperature and EFB ratio; (c) press time and EFB ratio

4.7.3 Factors Affecting Internal Bonding (IB)

Internal bond strength is the strength of the bond between the particles and fibres and adhesive in the panels. The IB strength was measured using an equation related to the breaking load of perpendicular tensile strength to the particleboards. Average values of IB strength are shown in Table 4.4. The average IB ranged from 0.24 – 0.62 MPa. The IB at all factor's level meet the minimum requirement of 0.4 MPa except three boards pressed at 150 °C for 3 and 5 minutes. ANOVA table for IB is shown in Table 4.7. Similar to bending properties, all factors are statically significance on IB at a confidence level of 95%. The one factor plot and interaction plots represent the effects of different variables on IB are shown in Figure 4.10 and 4.11, respectively.

Similar to MOR and MOR discussed earlier, press temperature and time have a similar effect on IB strength. It can be observed that Figure 4.11a represents the interactions between press temperature and time on IB strength has a similar shape to statistical plot shown in Figure 4.7a and 4.9a. At minimum press temperature and time, the IB value was relatively low. When the magnitude of these two variables is further increase, the IB value also was found to improve and meet ANSI A208.1 requirement. This explained that, sufficient time is required to transfer the heat for the resin to fully cure and form stronger bond between the particles and fibres. Similarly to MOR and MOE, the particleboards bonding strength also starts to decrease when the press temperature and time increased to maximum levels. It is due to the degradation and decomposition of UF resin at high temperature. Compared to the damage of particles and fibres, the effect of UF decomposition is considerably greater on the panel strength (Kollmann, Kuenzi, & Stamm, 2012). Similar trend on IB strength results against hot press variables were reported by Eroğlu et al., (2001) and Yang et al., (2014).

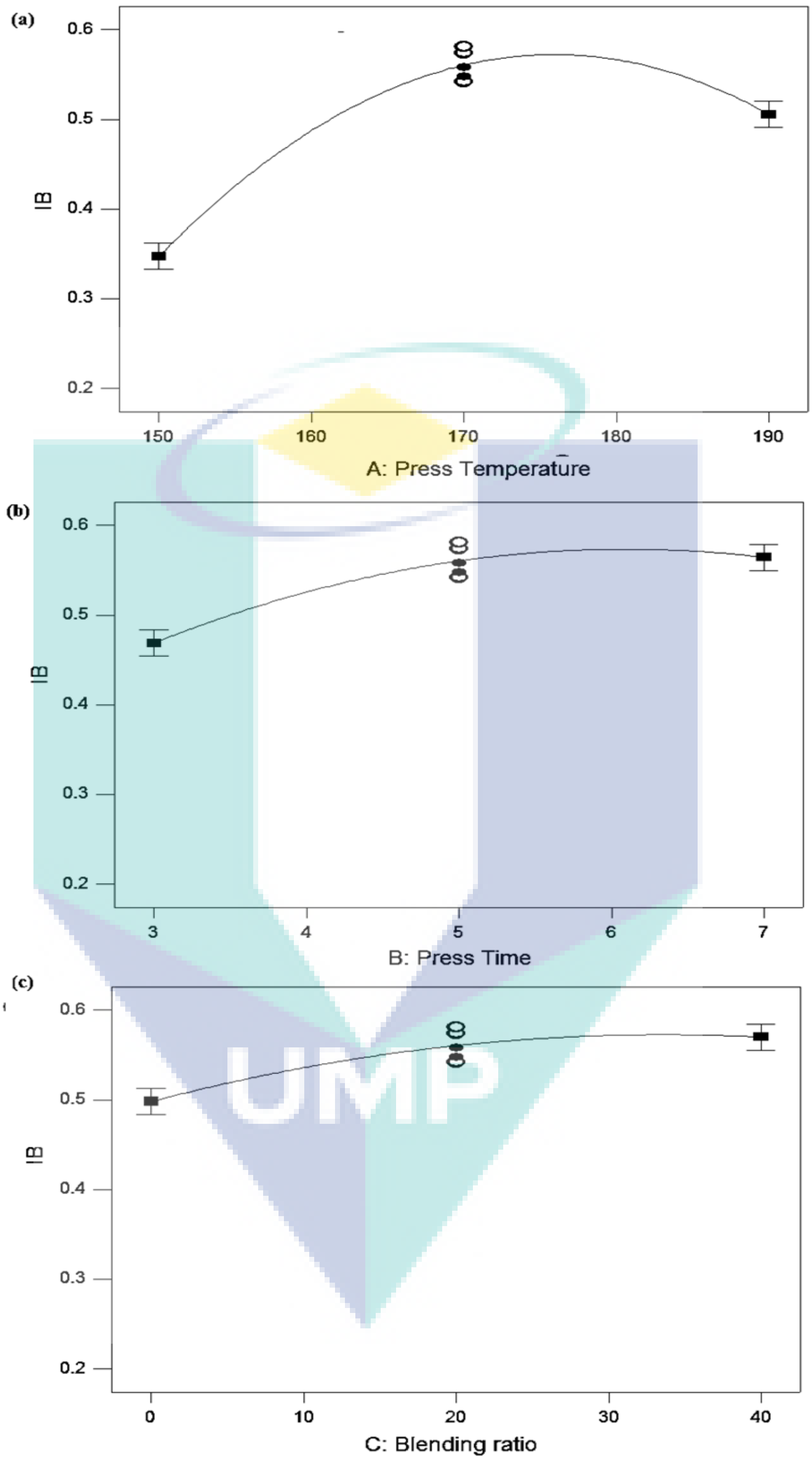

Figure 4.10 One factor plot for IB between (a) press temperature; (b) press temperature and (c) EFB ratio

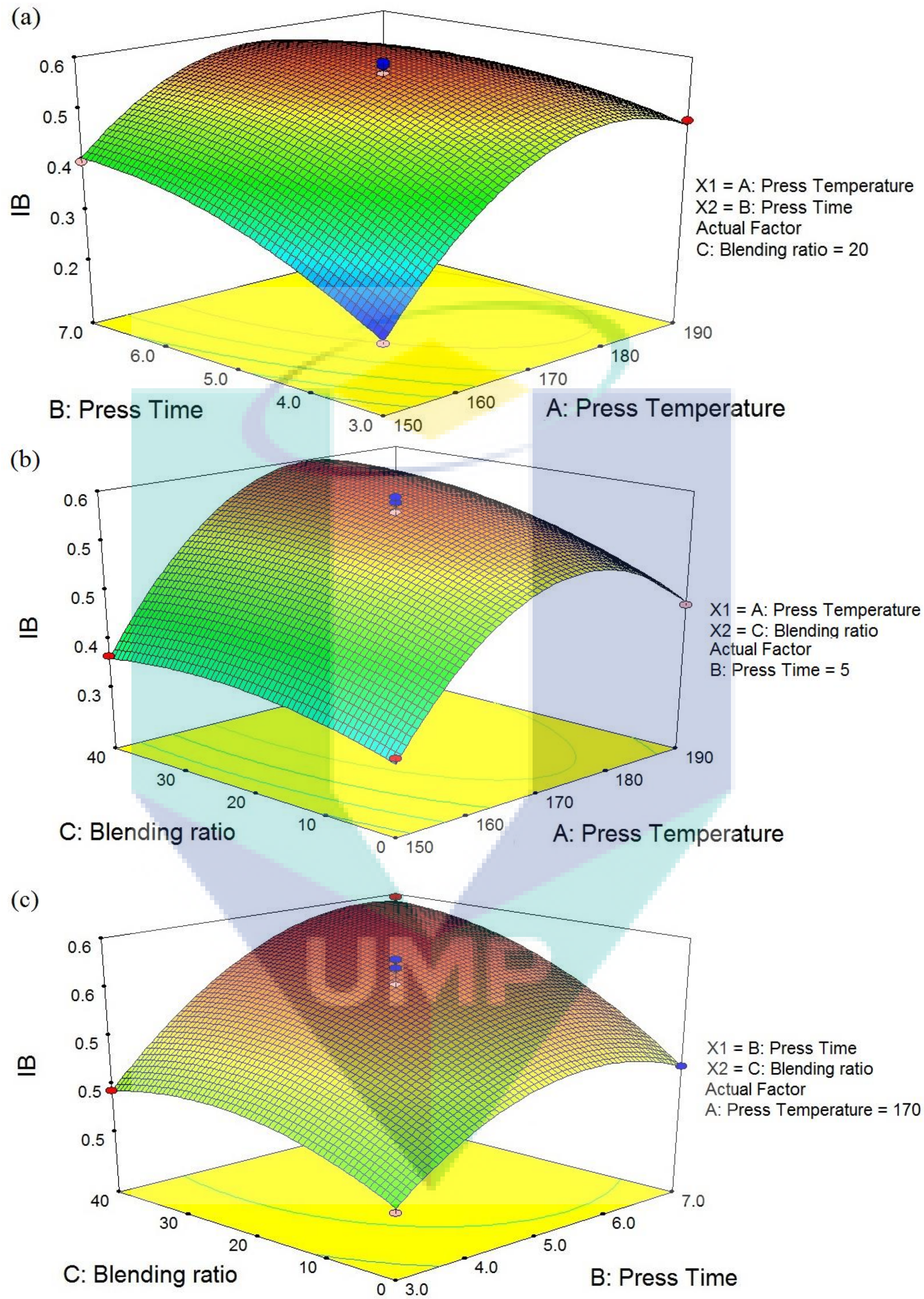

Figure 4.11 Interaction and 3D response surface plot for IB between (a) press temperature and time; (b) press temperature and EFB ratio; (c) press time and EFB ratio

Similar to the bending properties, addition of EFB fibres into OPF particles also has a significant effect on bonding strength. From Table 4.4, admixtures boards have higher IB values compared to 100% OPF particleboards. Figure 4.8b and Figure 4.8c show that as the EFB fibre ratio increase, the IB values also gradually increase. This is respected to the varying properties of the raw materials (EFB fibres and OPF particles) and the ratios. Generally, the particles and fibres would form hybrid structure, in which particles–particles, fibre–fibre and particles–fibre could occur by the resin (Zhang & Hu, 2014). The fibre–fibre bonds and fibre–particles formed would cause the OPF–EFB particleboards to have better bonding strength compared to OPF particleboards which only formed from particles–particles bonds. The higher IB of admixture particleboards than particleboards produced from OPF indicates that a good bonding between the EFB fibres and OPF particles.

4.7.4 Factors Affecting Water Absorption (WA)

WA is the amount of water absorbed by a submerged sample of particleboards in water. It is a test to determine the resistance of fabricated particleboards to the moisture. The aim is to obtain lower WA values. Results for the WA capacity test are shown in Table 4.4. The average WA values of all particleboards were relatively higher, ranging from 58 to 98% after 24 hour water immersion. There are several reasons that resulting poor WA properties. It is expected due to the hygroscopic effect of oil palm biomass which it tends to easily absorb water from surrounding (Nurhazwani et al., 2016). No addition of hydrophobic substance during the particleboards making also could be a reason for high water uptake. However, the WA obtained from this study has a lower value compared to the UF bonded OPT particleboards (Jumhuri et al., 2014).

The experimental results show that only mixed particleboards compressed at 190 °C for 5 and 7 minutes have achieved the minimum requirement for WA capacity. When a sample is immersed in water, the capillarity action conducts the water molecules into the samples and fills in the voids in the composite (Ahmed and Vijayarangan, 2007). The directly absorbed water will break the cross-links between the particles, fibres and resin (Abdul Khalil et al., 2010a). This is responsible for the dimensional change of lignocellulosic composites.

ANOVA table for WA is shown in Table 4.8. Based on ANOVA, only two factors (press temperature and time) were found to be statistically significant on WA at a confidence level of 95%. The one factor plot and interaction plots represent the effects of different variables on WA are shown in Figure 4.12 and 4.13, respectively. The twisted net pattern of effect press temperature and time on WA also were reported by Wan Nadhari et al., (2013).

The modelled surface (Figure 4.13a) shows that lower WA values were obtained for particleboards produced at high press temperature and long press duration. It provides sufficient time and heat for the particleboards surface to become more compact by removing the void space inside the boards. As a result, during water submersion, the surface restricts the entry of water molecules into the pores (Wan Nadhari et al., 2013).

Based on WA ANOVA results (Table 4.8), blending the EFB fibres into OPF particles does not have any significant effect on the particleboards WA values at a confidence level of 95%. From statistical plot (Figures 4.13b and 4.13c), when the EFB fibre content was increased from 0 to 40%, there was no significant change in WA values. The higher WA values might be due to the hygroscopic properties of OPF particles and EFB fibres (Tran, 2011 and Saadaoui et al., 2013).

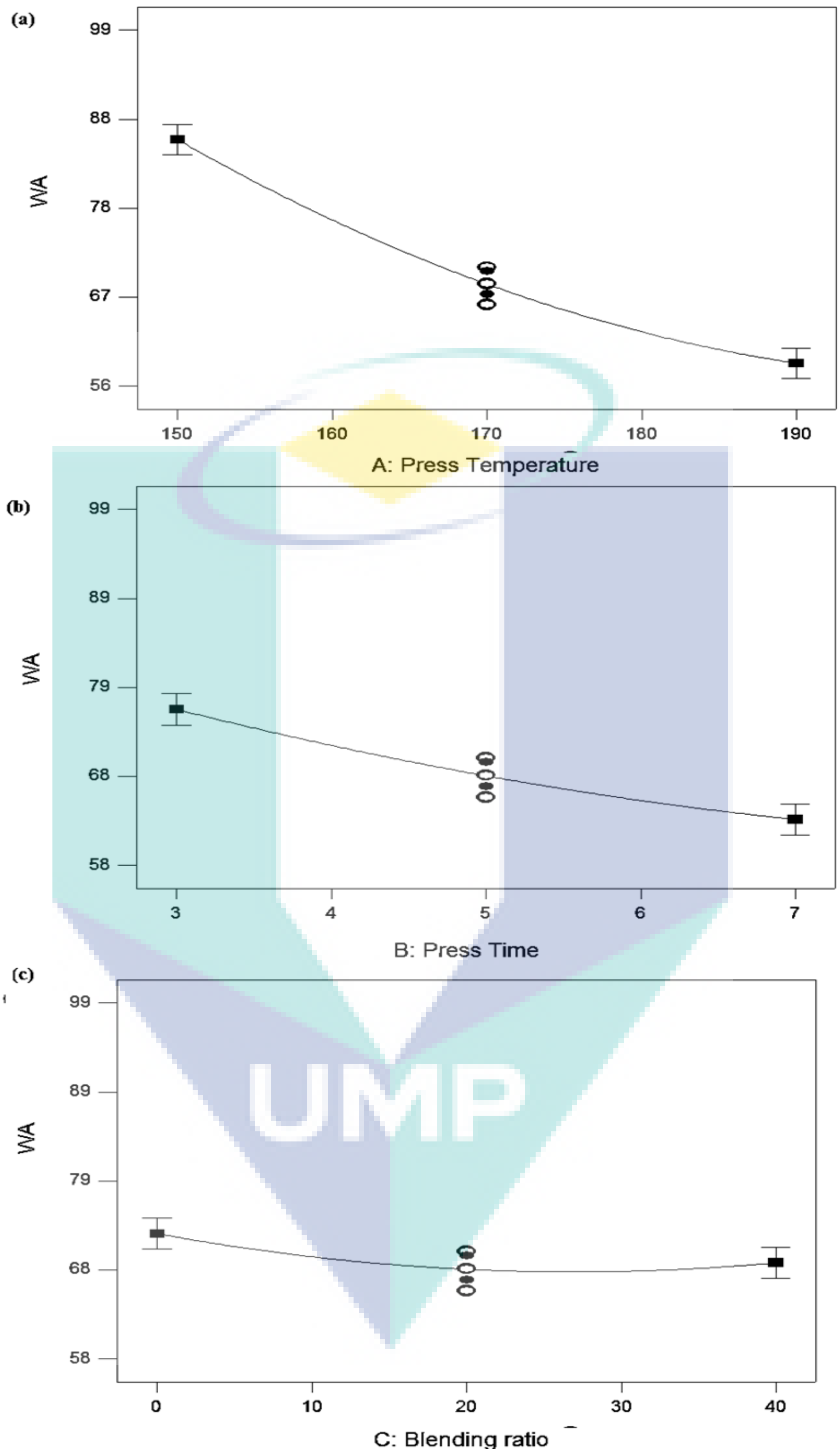

Figure 4.12 One factor plot for WA between (a) press temperature; (b) press temperature and (c) EFB ratio

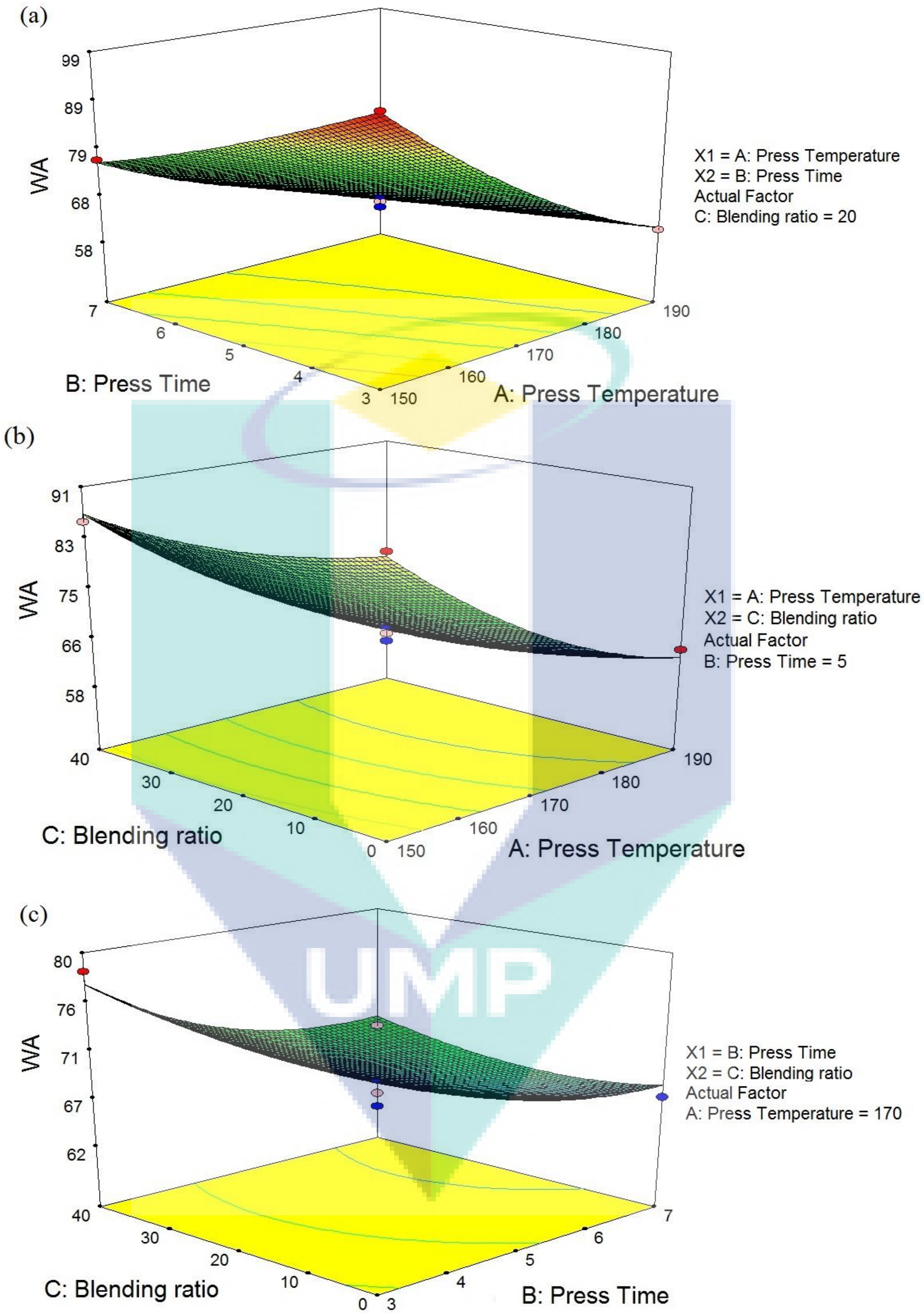

Figure 4.13 Response surface plot for WA between (a) press temperature and time; (b) press temperature and EFB ratio; (c) press time and EFB ratio

4.7.5 Factors Affecting Thickness Swelling (TS)

TS is a measurement of the thickness increase (%) of the materials after 24 hour submersion in water. Results for TS test are shown in Table 4.4. The average TS ranged from 19 to 33%. The least TS rate is obtained from OPF-EFB particleboards pressed at 190 °C for 5 minutes and 20% EFB/OPF ratio. According to industrial requirement, maximum TS required is 25% (Schneider, Chui, & Ganev, 1996). All particleboards met this requirement except the OPF-EFB particleboard pressed at 150°C, 3 minutes.

ANOVA table for TS is shown in Table 4.9. Similar to WA, the most significance parameters affecting TS are press temperature and time. The one factor plot and interaction plots represent the effects of different variables on TS are shown in Figure 4.14 and 4.15, respectively. Figure 4.15a represents the interactions between press temperature and time for TS. The combination of high press temperature and time is good as it decreases the TS values. The reduction of TS could be related to the thermal degradation of hemicellulose content in OPF particles and EFB fibres at high press temperature and longer press period (Ayrilmis et al., 2011). When a lignocellulosic material is subjected to heat, the degradation of hemicellulose is more severe compared to the degradation of cellulose and lignin (Pan et al., 2010). The decomposition of hemicellulose significantly reduces the amount of hydroxyl group, so it will increase the dimensional stability of the panel (Mohebby & Ilbeighi, 2007).

Based on ANOVA results (Table 4.9), blending the EFB fibres into OPF particles also does not have any significant effect on the particleboards TS values at a confidence level of 95%. Figures 4.15b and 4.15c show that when EFB fibre content was increased from 0 to 40%, there was no significant change in TS values. It could be related to the high content of cellulose and hemicellulose in the raw materials (Tran, 2011 and Saadaoui et al., 2013). Moreover, UF resin also contributes to higher TS due to its low dimensional stability and moisture resistance. UF bonded boards are less stable and tend to spring back when exposed to high moisture conditions (Nurhazwani et al., 2016). The UF resin was invented to be used for indoor furniture application, thus it was expected that the UF bonded

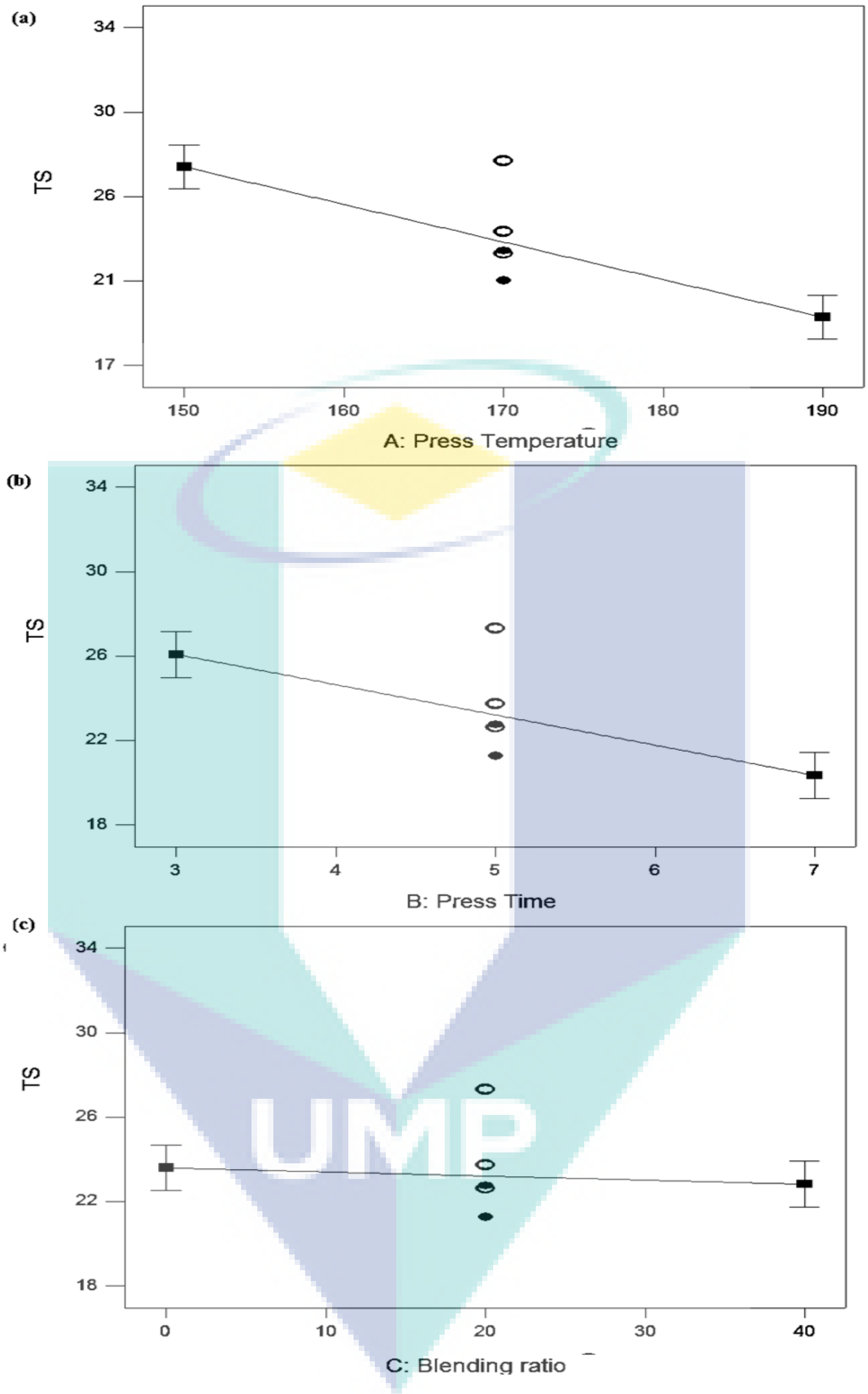

Figure 4.14 One factor plot for WA between (a) press temperature; (b) press temperature and (c) EFB ratio

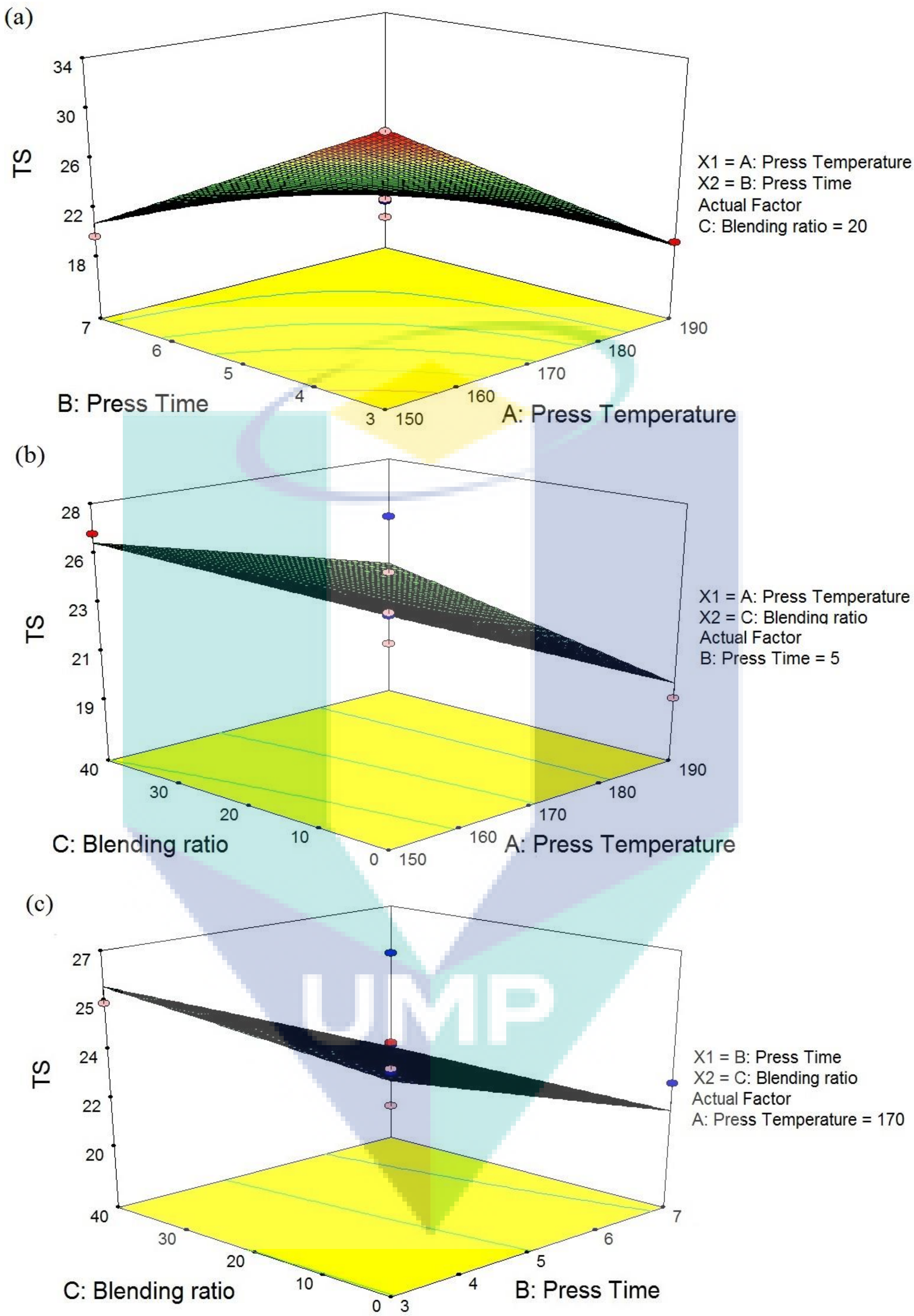

Figure 4.15 Response surface plot for TS between (a) press temperature and time; (b) press temperature and EFB ratio; (c) press time and EFB ratio

4.8 Process Variables Optimisation and Validation Run

After multiple regression analysis and ANOVA test for the developed models related to the physical and mechanical properties, a numerical optimisation procedure was performed in order to obtain the optimal levels of three factors. The goal of optimisation in this experiment was to find the optimum manufacturing variables for getting high; MOR, MOE and IB, low TS and WA of particleboards. Under the optimised manufacturing conditions; pressing temperature, time and EFB fibres blending ratio; 186 °C, 5.70 min and 30.4%, respectively, a confirmatory experiment was performed to evaluate the accuracy of the optimisation procedure by comparing the predicted response with the experimental response result. The predicted and obtained results were tabulated Table 4.10. It was found that, the predicted and experimentally values have acceptable difference. Under the optimised conditions, the MOR, MOE and IB values obtained are 14 MPa, 1870 MPa and 0.556 MPa, respectively. These reading meet the requirement of ANSI A208.1. The TS and WA were 58.5% and 21% gave satisfactory result and achieved the requirement by the furniture industry.

Table 4.10 Predicted and experimental result of optimum conditions

	MOR (MPa)	**MOE (MPa)**	**IB (MPa)**	**WA (%)**	**TS (%)**
Predicted OPF-EFB	14.1	1896	0.583	59.2	20.1
Experimental OPF-EFB	14	1870	0.556	58.5	21
ANSI A208.1 (Commercial grade)	11	1725	0.4	-	-
*Furniture grade	-	-	0.4	60	25

*Adapterd from: Schneider, Chui, & Ganev, (1996) and Li et al., (2009)

4.9 Termite Test Durability Assessment

The resistance of treated OPF-EFB particleboards samples to attack by termites was investigated under no-choice laboratory and short term field bioassay technique. Laboratory studies were conducted in FRIM laboratory. Field studies were conducted in an agricultural land, Terengganu.

4.9.1 No-choice Laboratory Test

The results of the accelerated laboratory test of treated and untreated OPF-EFB particleboards against subterranean termite compared to rubber wood in accordance to FRIM In-House Method PK are shown in

Table 4.11. The results include the sample weight loss, sample rating and termite mortality.

Weight losses in the specimens exposed to the termites are shown in

Table 4.11. The weight loss for all OPF-EFB particleboards test samples, including rubber wood samples proved that there were termites feeding activity during the rest. Weight loss of all treated and untreated OPF-EFB particleboards samples showed almost double to the rubber wood sample weight loss. It is expected due to higher cellulose content in the oil palm biomass compared to rubber wood (Junaida et al., 2012). The rubber woods have a tight grain structure compare to OPE-EFB boards sample.

Table 4.11 Evaluation for durability of treated and untreated OPF-EFB particleboards against subterranean termite compared to the untreated rubber wood during no-choice laboratory test.

Sample	Retention (kg/m^3)	Weight loss [a] (%)	Visual rating [a, b]	Termite mortality [a, c] (%)
Untreated OPF –EFB	-	27.5 (4.69)	6.2 (1.3)	96.8 (2.29)
Cypermethrin – 0.5% w/v	0.10	27 (2.10)	6.8 (0.45)	91.8 (3.73)
Cypermethrin – 1% w/v	0.36	25.4 (3.47)	6.8 (1.30)	90 (9.04)
Cypermethrin – 1.5% w/v	0.62	19.6 (4.58)	7.8 (2.1)	97.5 (5.95)
Neem oil – 5% v/v	1.98	24.7 (1.87)	7.1 (0.70)	97.4 (5.84)
Neem oil – 10% v/v	8.93	24.1 (2.53)	7.3 (1.3)	96.3 (8.93)
Neem oil – 15% v/v	19.4	23.8 (3.47)	8.1 (1.34)	89.4 (7.90)
Untreated Rubber wood	-	13.6 (2.11)	7.4 (0.55)	93.9 (5.80)

a Each value represents the means of 5 replicates. Value in parentheses is standard deviation.
b Termite attack visual rating scales is based on AWPA (Table 2.13)
c Termite mortality is based on the number of termite died out of 400 total termites in the jar after 4 weeks.

As can be seen in

Table 4.11, treatment of OPF-EFB boards samples with cypermethrin and neem oil solution resulted in decrease weight loss compared to untreated OPF-EFB board samples. The average weight loss of untreated samples was 27.5%. It was found that the lowest weight loss obtained from samples treated with cypermethrin is 19.6% and neem oil 23.8%. The efficacy of cypermethrin in decreasing weight loss started to be noticeable at concentrations more that 1% w/v. For neem oil treated samples, it was observed there is no significance difference in weight loss at three different concentrations (5, 10 and 15%). The weight loss (23.8 - 24.78%) for samples treated with neem oil extract is comparable to the reported value (24.2%) in a previous study conducted by Sotannde et al., (2011). The study suggested the combination of neem oil extracted from seed, bark and leaf is more effective against termite attack. However, the results obtained are very contrast compared to the result oreported by Venmalar & Nagaveni, (2005). The difference in result might be due to the different wood used in the bioassay and the treatment process used.

Regarding to the weight loss result for the untreated OPF-EFB particleboards, the value of 27.5% was comparable to another previous study that reported the weight loss of untreated oil palm biomass composite against termites. 25.2% for untreated EFB particleboards (Zaidon et al., 2008) and 24% and 61.9% for untreated OPT composite (Dungani et al., 2013 and Abdullah, 2013).

The visual rating was done by estimating the extent of the specimen damage after four weeks exposure to the termites. The visual observation results are shown in Table 4.12. It is observed that the average visual of untreated samples were rated as 6.2. It was found that the lowest rating obtained from samples treated with cypermethrin was

6.8 and the highest rating 7.8 was obtained for boards treated with 1.5% w/v concentration. For boards samples treated with neem oil solution, the rating ranged from 7.1 to 8.1. The visual rating for samples treated with neem oil at concentration 15% v/v is the best compared to other treated samples. It was found that the impregnation of OPF-EFB particleboards samples with the neem oil-acetone mixture did not cause swelling on the sample surface. The effect of termite attack on OPF-EFB boards and rubber wood specimens after four week test are shown in Figures 4.16–4.23. Among the OPF-EFB particleboards samples, the untreated samples have a darker colour after the exposure period.

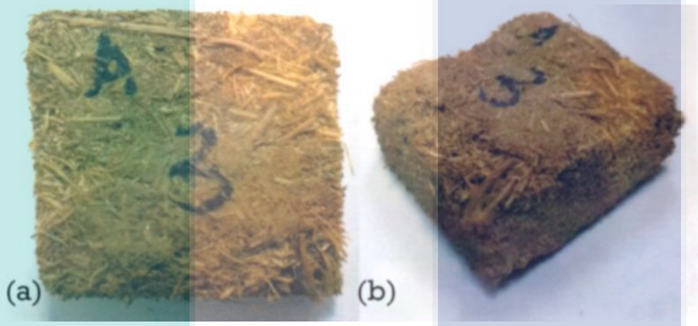

Figure 4.16 OPF-EFB particleboards samples treated with 0.5% w/v cypermethrin; (a) front view and (b) side view

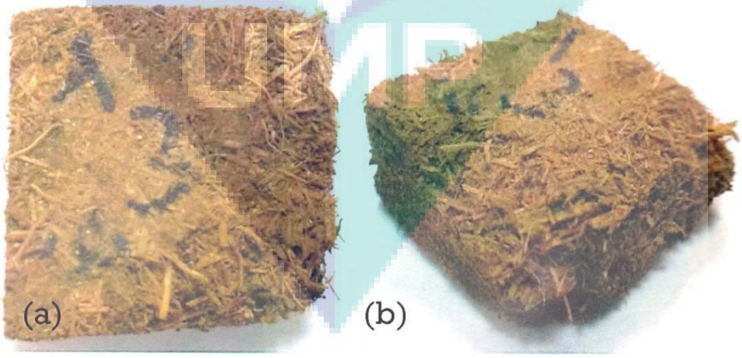

Figure 4.17 OPF-EFB particleboards samples treated with 1.0% w/v cypermethrin; (a) front view and (b) side view

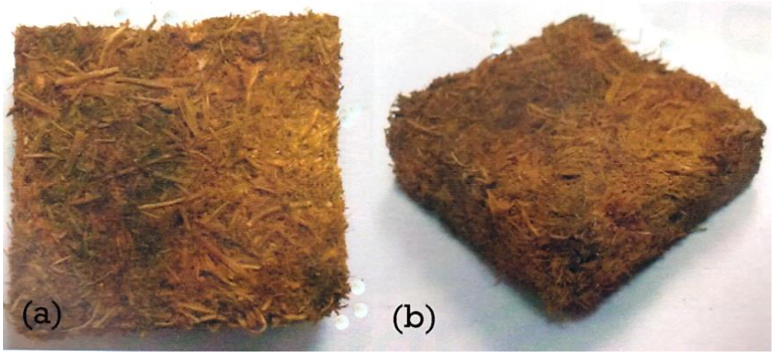

Figure 4.18 OPF-EFB particleboards samples treated with 1.5% w/v cypermethrin; (a) front view and (b) side view

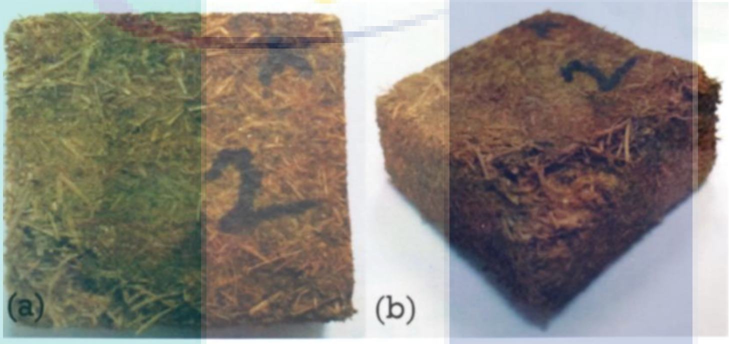

Figure 4.19 OPF-EFB particleboards samples treated with 5% v/v neem; (a) front view and (b) side view

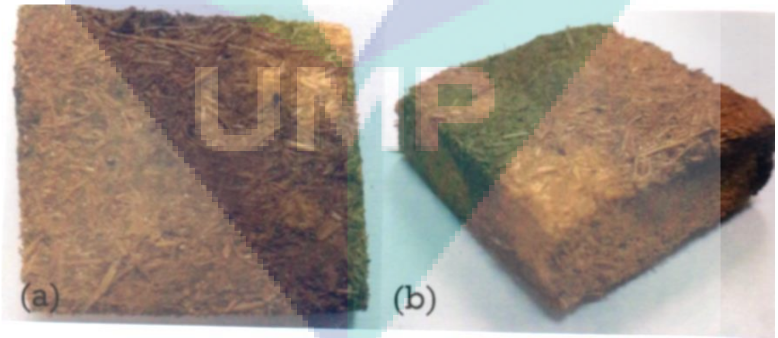

Figure 4.20 OPF-EFB particleboards samples treated with 10% v/v neem; (a) front view and (b) side view

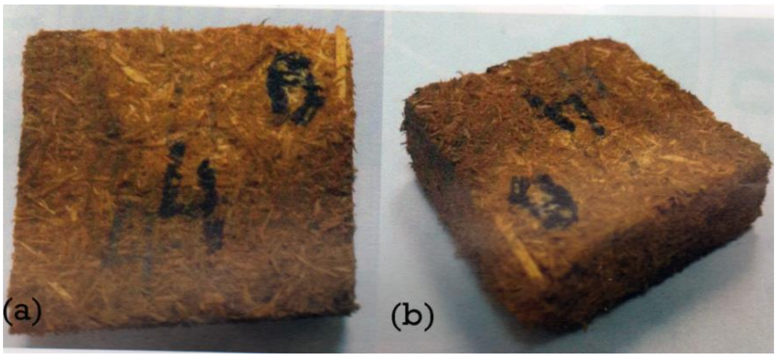

Figure 4.21 OPF-EFB particleboards samples treated with 15% v/v neem; (a) front view and (b) side view

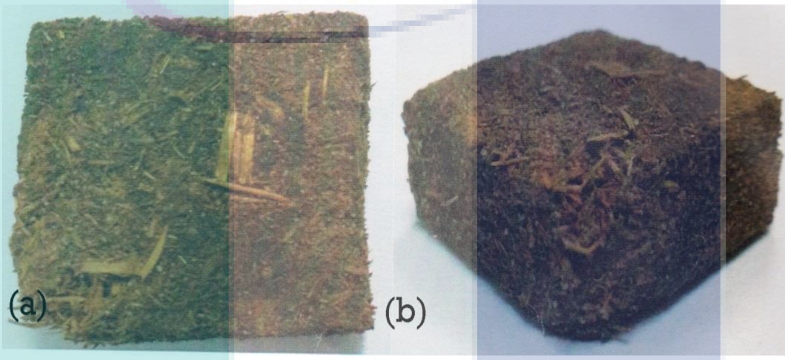

Figure 4.22 Untreated OPF-EFB particleboards samples; (a) front view and (b) side view

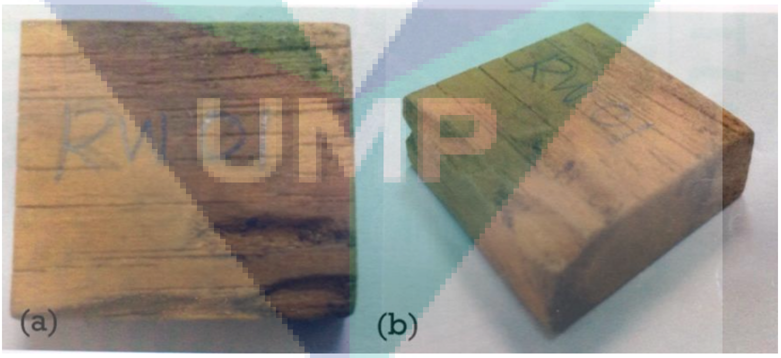

Figure 4.23 Untreated rubber wood samples; (a) front view and (b) side view

The termite mortality results from the laboratory test are shown in

Table 4.11. It was found that, the termites started to die after first week exposure. It was found that, the mortality for all samples is high ranging between 89 to

97.5%. The mortality of termites in the jar containing boards samples treated with 1.5% w/v cypermethrin was the highest compared to other samples. Based on the termite mortality values, cypermethrin and neem oil appear to be toxic to the termites. The untreated OPF-EFB samples also have high termite mortality. It might be due to the toxic effect of the urea formaldehyde towards the termite after consuming the untreated sample (Dungani et al., 2013 and Abdullah, 2013). In a no-choice bioassay, the termites tend to feed upon the treated or untreated samples when there are no food sources resulting high weight loss, poor visual rating and high mortality. In a no-choice bioassay, the termites often behaved like cannibals toward the treated or untreated samples (Nandika, 1998; Dungani et al., 2013 and Abdullah, 2013).

Based on the weight loss, visual rating and termite mortality values in

Table 4.11, the treated and untreated OPF-EFB particleboards samples suffered moderate to severe termite attacks. The unsatisfactory results could be attributed to the insufficient concentration levels of cypermethrin and neem oil used in the treatment process. It is believed that the active material on the particleboard surface might be lost during the handling process.

4.9.2 Field Evaluation for Termite Resistance

After reviewing the no-choice laboratory result in Table 4.11, the OPF-EFB particleboards treated with 1.5% w/v cypermethrin have the highest resistance against termites. The samples show average weight loss, good visual rating and high termite mortality. However, the concentration with 1.5% cypermethrin used is not sufficient to protect the particleboards in a no-choice bioassay. The amount of weight loss is still high. Thus, to work with a choice bioassay, a trial field test using OPF-EFB particleboards treated with 5% w/v cypermthrin is decided.

4.9.2.1 Gas Spectrometer Mass Spectrometer (GCMS) Analysis

A GC-MS method was used to confirm the presence of synthetic cypermethrin in the treated particleboards. GCMS chromatogram of the cypermethrin solution and extract of cypermethrin treated particleboards are given in Figures 4.24 and 4.25. Analysis of the cypermethrin and extract from treated particleboard indicates that there was cypermthrin presence at retention time of 40 until 46. The other constituents present in the chromatogram are classified as solvent. From Figure 20, there was missing peak at the retention of 36 to 40. The missing constituents were identified as inert solvents. They might be evaporated during the sample drying after the treatment process. The comparison between chromatogram in Figures 4.19 and 4.20 proved that the cypermethrin are presented in the treated particleboards after drying process.

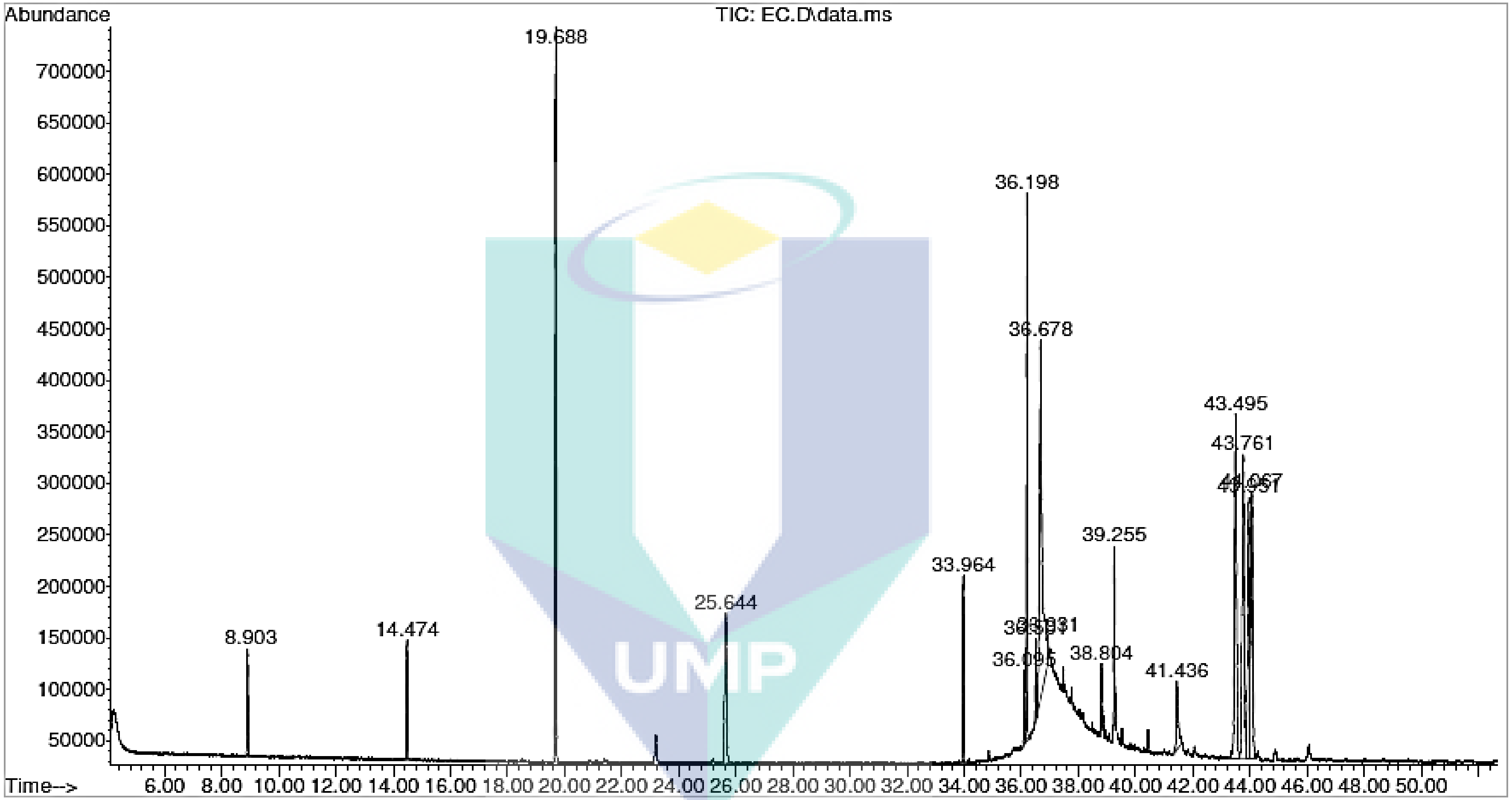

Figure 4.24 The mass spectrum analysis for cypermethrin solution

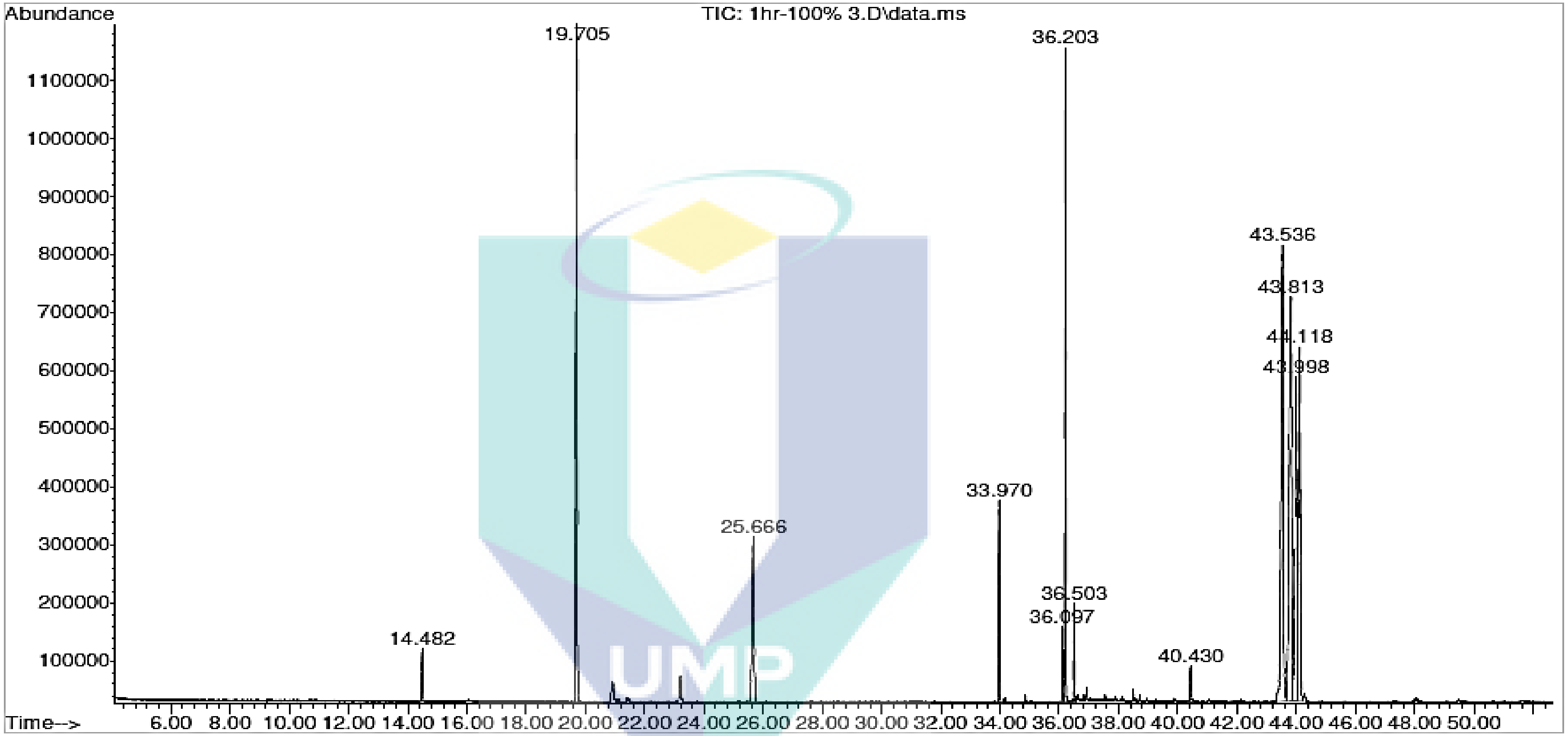

Figure 4.25 The mass spectrum analysis for extract of treated particleboards

4.9.2.2 Field Exposure Test

The severity of in-ground termite test was determined by weight loss and visual rating of untreated and cypermethrin treated OPF-EFB particleboards. The results are presented in Table 4.13. It should be pointed out that the data is based on the short term study. Regarding to data variability, it was due to non-uniform termite attack within the samples. It was found that, the installed stakes located near to termite mound were subjected to higher degree of termite attacks. The same observation of data also was reported by Scouse, (2013).

Table 4.12 Average percentage weight loss and visual rating of untreated and treated OPF-EFB stakes after 1st, 2nd, 3rd and 4th week exposure

Week	Untreated OPF-EFB		OPF-EFB Cypermethrin – 5% w/v	
	Weight loss (%)	**Visual rating**	**Weight loss (%)**	**Visual rating**
1	5.12 (1.34)	7.2 (0.45)	1.4 (0.68)	8.4 (0.89)
2	7.02 (1.16)	6.4 (0.55)	1.8 (1.51)	7.8 (0.83)
3	11.5 (0.54)	6.6 (0.54)	6.56 (1.30)	7.2 (0.84)
4	17 (0.92)	6.2 (1.79)	10.2 (0.19)	7.0 (1.73)

Each value represents the means of 5 replicates. Value in parentheses is standard deviation.

The weight loss measured in the test is a proof of the termite foraging activity. From Table 4.12, it was found that treated OPF-EFB particleboards stakes had a lower weight loss compared to untreated stakes. This is consistent with the results from the laboratory test (section 4.9.1). Weight loss of untreated OPF-EFB board stakes were approximately 5.12, 7.02, 11.5 and 17% after one, two, three and four weeks' in-ground exposure, respectively. Weight loss of cypemethrin treated stakes were only 1.4, 1.8, 6.56 and 10.2% after one, two, three and four weeks, respectively. Weight loss for all stakes were noticed after the stakes was collected after first week exposure. The stakes weight loss continuously increased as the exposure period was extended until the fourth week. The weight loss rate for the treated stakes did not differ significantly until three weeks after the experiments was started. Probably, some of the cypermthrin might be leached into the soil due to high humidity from surrounding and resulting termite attack on particleboards. Other factors contribute to degradation of treated wood in in-ground contact are wood structure, soil factors and climate condition; humidity, temperature and rainfall (Chirenje et al., 2004).

Based on weight loss after 28 days of field exposure, the untreated OPF-EFB particleboards was rated as moderately durable, while the cypermethrin treated was rated as slight to moderately durable using the AWPA damage rating system. The visual observation of termite attack was made on the untreated and treated stakes. The stakes were rated individually and the average ratings are shown in Table 4.12. After four weeks, the untreated stakes were classified into 6.2 levels of durability while treated stakes were classified into 7th levels according to AWPA rate as shown in Table 2.13. The effect of termite attack on OPF-EFB board stakes after four weeks in-ground test are shown in Figures 4.26 and 4.27.

Over the time, the sample colour became darker and there are existences of mould growth on the OPF-EFB stakes. It is probably promoted by the humid conditions. It is reported that the preservative treated wood also could be affected by wood mould (Shupe, 2012). The mould growth do not significantly reduce the wood strength but caused commercial loss due to discolouration of wood surface (Arias, 2009). Future work should therefore incorporate the termiticide with moulds inhibitor to prevent the particleboards against termite and moulds.

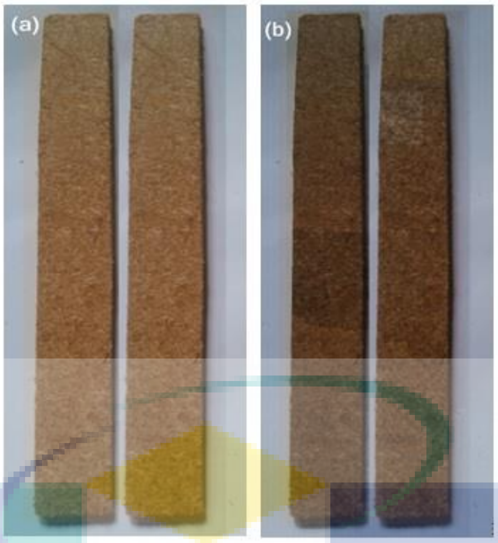

Figure 4.26 OPF-EFB stakes before the field test (a) untreated stakes; (b) treated stakes

Figure 4.27 Treated (T) and untreated (NT) OPF-EFB PB particleboards stakes after (a) 1^{st} week; (b) 2^{nd} week; (c) 3^{rd} week; (d) 4^{th} week exposure

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis covers four main objectives which are the fabrication of OPF-EFB particleboards, characterization of physical and mechanical properties, optimisation of particleboards fabrication process and the treatment and optimised OPF-EFB particleboards with cypermethrin and neem oil.

Particleboards made from blending OPF particles and EFB fibres were successfully fabricated through hot pressing process. All factors (press temperature, press time and EFB blending ratio) were found to be statically significant on particleboards MOR, MOE, IB, WA and TS. The optimised processing parameters to obtain maximum MOR, MOE, IB and minimum WA and TS were determined as follows; press temperature, 185.6 °C, press time, 5.70 min and EFB/OPF ratio 30.38%. The optimum MOR, MOE, IB, WA and TS were 14.10 MPa, 1896.11 MPa, 0.853 MPa, 59.15% and 20.11%, respectively is obtained from Design Expert software. The optimization value obtained is based on the input values of conditions variables. The blending ratio was set to ‘minimize’ goals while for press temperature and time, it was set to ‘in range’ goals in order to achieve the objectives for optimisation. The limits of the input variables range were set based on the initial level experimental design. All the optimum OPF-EFB properties met the requirement stated by ANSI A208.1 and industrial standard. The results from the validation experiment were found to be good with predicted optimum response by Box-Behnken design. RSM has been proved to be adequate for the design and optimisation of the process parameters of OPF-EFB particleboards production. It can be co[illegible]d that, through a reasonable selection of hot press parameters (temperature and time) and EFB fibres ratio, the properties of OPF-EFB particleboards were better compared to OPF particleboards.

In the laboratory no-choice termite test, OPF-EFB particleboards durability against termite was directly related to cypermethrinand neem oil concentration. The samples treated with 1.5% w/v concentrations has minimum weight loss and better visual rating compared to other samples. For the preliminary field test, based on weight loss after 28 days of field exposure, the untreated OPF-EFB particleboards was rated as moderate durable, while the cypermethrin treated was rated as slight to moderate durable using the AWPA damage rating system. The finding from the laboratory and field termite test revealed that, the treatment of OPF-EFB using cypermethrin and neem oil can improve the resistance against termite.

5.2 Recommendation

Based on the results obtained in this study, several recommendations in the future study are suggested to be explored. Only three factors were used in the experimental design to observe their effects on the physical and mechanical properties of fabricated particleboards. Another factor can be further investigated such as particle geometry, adhesive level and particleboards layers to widen the applicability of the model developed. In order to improve the dimensional stability of OPF-EFB particleboards, application of paraffin or wax during blending process is recommended.

REFERENCES

Abdul Khalil, H.P.S., Jawaid, M., Hassan, A., Paridah, M.T., & Zaidon, A. (2012). Oil palm biomass fibres and recent advancement in oil palm biomass fibres based hybrid biocomposites. *Composites and Their Applications*,187–220.

Abdul Khalil, H.P.S., Nur Firdaus, M.Y., Anis, M., & Ridzuan, R. (2008). The effect of storage time and humidity on mechanical and physical properties of medium density fiberboard (MDF) from oil palm empty fruit bunch and rubberwood. *Polymer-Plastics Technology and Engineering*, *47*, 37–41.

Abdul Khalil, H.P.S., Nur Firdaus, M.Y., Jawaid, M., Anis, M., Ridzuan, R., & Mohamed, A.R. (2010a). Development and material properties of new hybrid medium density fibreboard from empty fruit bunch and rubberwood. *Materials and Design*, *31*, 4229–4236.

Abdul Khalil, H.P.S., Nurul Fazita, M.R., Bhat, A.H., Jawaid, M., & Nik Fuad, N.A. (2010b). Development and material properties of new hybrid plywood from oil palm biomass. *Materials and Design Design*, *31*, 417–424.

Abdul Khalil, H.P.S., Siti Alwani, M., & Mohd Omar, A.K. (2006). Distribution , and cell wall structure of malaysian plant waste fibers. *BioResources*, *1*, 220–232.

Abdul Khalil, H.P.S., Siti Alwani, M., Ridzuan, R., Kamarudin, H., & Khairul, A. (2008). Chemical composition, morphological characteristics, and cell wall structure of malaysian oil palm fibers. *Polymer-Plastics Technology and Engineering*, *47*(3), 273–280.

Abdullah, C.K. (2013). Termite and borer resistance of oil palm wood treated with phenol formaldehyde resin. *Journal of Industrial Research and Technology*, *3*(1), 41–46.

Ahmed, K.S., & Vijayarangan, S. (2007). Experimental characterisation of woven jute-fibre reinforced isolatic polyester composites. *Journal of Applied Polymer Science, 104* (40), 2650-2662.

Akbulut, T., & Ayrilmis, N. (2006). Effect of compression wood on surface roughness and surface absorption of medium density fiberboard. S*ilva Fennica*, *40* (1), 161–167.

Akyüz, K.C., Nemli, G., Baharoğlu, M., & Zekoviç, E. (2010). Effects of acidity of the particles and amount of hardener on the physical and mechanical properties of particleboard composite bonded with urea formaldehyde. *International Journal of Adhesion and Adhesives*, *30*, 166–169.

Alam, M.Z., Mamun, A.A., Qudsieh, Y.I., Muyibi, S. A., Salleh, H. M., & Omar., N. M. (2009). Solid state bioconversion of oil palm empty fruit bunches for cellulase enzyme production using a rotary drum bioreactor. *Biochemical Engineering Journal,46*(1), 61–64.

Aljuboori, A.H.R. (2013). Oil palm biomass residue in malaysia : availability and sustainability. *Internal Journal of Biomass & Renewables, 2*(1), 13–18.

Andre, N., Young, T., & Zaretzki, P. (2010). Real time process modelling of wood composite panels. *International Conference on Processing Technologies for the Forest and Biobased Products Industrie*, p. 33.

ANSI A 208.1 (1999). American National Standard for general purpose particleboard. Leesburg, VA: Composite Panel Association.

Antonovic, A., Jambrekovic, V., Kljak, J., Spanic, N., & Medved, S. (2010). Influence of urea-formaldehyde resin modification with liquefied wood on particleboard properties. *Drvna Industrija*, *61*(1), 5–14.

Anwar, Z., Gulfraz, M., & Irshad, M. (2014). Agro-industrial lignocellulosic biomass a key to unlock the future bio-energy: A brief review. *Journal of Radiation Research and Applied Sciences*, *7*(2), 163–173.

Arias, C.M. (2009). *Binderless fiberboard p roduction from cynara cardunculus and vitis vinifera*. Universitat rovira i virgili tarragona.

Ashori, A., & Nourbakhsh, A. (2008). Effect of press cycle time and resin content on physical and mechanical properties of particleboard panels made from the underutilized low-quality raw materials. *Industrial Crops and Products*, *28*, 225–230.

ASTM D 1037. (1999). *Standard test methods for evaluating properties of wood-based fibre and particle panel materials static tests of timbers*, Philadelphia: American Society for Testing Materials.

ASTM D 1413. (1999). *Standard Test Method for Wood Preservatives by Laboratory Soil-Block Cultures*, Philadelphia: American Society for Testing Materials.

AWPA E1. (1999). *Standard method for laboratory evaluation to determine resistance to subterranean termite*, Woodstock: American Wood Preserver's Association.

AWPA E7. (2010). *Standard method of evaluating wood preservatives by field tests with stakes,* Birmingham, Alabama: American Wood Preserver's Association.

Awolu, O.O., Obafaye, R.O., & Ayodele, B.S. (2013). Optimization of solvent extraction of oil from meem (Azadirachta indica) and its characterizations. *Journal of Scientific Research & Reports*, *2*(1), 304–314.

Ayrilmis, N., Jarusombuti, S., Fueangvivat, V., & Bauchongkol, P. (2011). Effects of thermal treatment of rubberwood fibres on physical and mechanical properties of medium density fibreboard. *Tropical Forest Science*, *23*(1), 10–16.

Baeza, J., & Freer, J. (2000). *Wood and Cellulosic Chemistry*. 2nd ed. United States of America: Marcell Dekker, Inc.

Bakker, R.R.C. (2013). Availability of lignocellulosic feedstocks for lactic acid production. Food and Baverage Research, Report 1391. Wageningen.

Balat, M., Balat, H., & Öz, C. (2008). Progress in bioethanol processing. *Energy and Combustion Science*, *34*(5), 551–573.

Barros Filho, R.M., Mendes, L.M., Novack, K.M., Aprelini, L.O., & Botaro, V.R. (2011). Hybrid chipboard panels based on sugarcane bagasse, urea formaldehyde and melamine formaldehyde resin. *Industrial Crops and Products*, *33*(2), 369–373.

BAT. (2014). Production of Wood – based Panels (Report). Seville, Spain.

Berglund, L., & Rowell, R.M. (2005). *Handbook of Wood Chemistry and Wood Composite*, CRC Press LLC.

Browning, B.L. (1967). *Methods of wood chemistry*. Vol. 2. New York.

Cai, Z., Wu, Q., Lee, J.N., & Hiziroglu, S. (2004). Influence of board density , mat construction , and chip type on performance of particleboard made from eastern redcedar. *Forest Products Journal*, *54*(12), 226–232.

Cai, Z., Muehl, J.H., & Winandy, J.E. (2006). Effects of panel density and mat moisture content on processing medium density fiberboard. *Forest Products Journal*, *56*(10), 20–25.

Carley, K.M., Kamneva, N.Y., & Reminga, J. (2004). *Response Surface Methodology*, CASOS Technical Report, CMU-ISRI-04-136. Carnegie Mellon University.

Chand, N., Tiwary, R.K., & Rohatgi, P.K. (1988). Resource structure properties of natural cellulosic fibres - an annonated bibliography. *Materials and Science*, *23*, 381–387.

Chen, T., Xie, Y., & Niu, M. (2015). Optimizing preparation conditions of ultra-low-density fiberboard by response surface methodology. *Wood and Fiber Scienc*, *47*(3), 1–9.

Chirenje, T., Ma, L.Q., Szulczewski, M., Hendry, K., & Clark, C. (2004). Retention of As, Cu, and Cr leached from CCA-treated wood products in select Florida soils. *Environmental impacts of preservative-treated wood conference*, pp. 45–56.

Corner, A.H. (1996). *Urea-formaldehyde adhesive resins chemistry of urea-formaldehyde*, 8.

Curling, S.F., & Murphy, R.J., (1999). The effect of artificial ageing on the durability of wood-based board materials against basidiomycete decay fungi. *Wood Science and Technology*, *33*, 245–257.

Dixit, S., & Verma, P. (2012). The effect of hybridization on mechanical behaviour of coir / sisal / jute fibres reinforced polyester composite material. *Chemical Sciences*, *2*(6), 91–93.

Doosthoseini, K., Hosseinabadi, Z., & Moradpour, P. (2013). Oxidative activation of bagasse fibers surfaces in medium density fiberboard manufacturing. *Drvna Industrija*, *64*(3), 239–245.

Dungani, R., Nazrul Islam, M., Abdul Khalil, H.P.S., Hartati, S., Abdullah, C.K., Dewi, M., & Hadiyane, A. (2013). Termite resistance study of oil palm trunk lumber (optl) impregnated with oil palm shell meal and phenol-formaldehyde resin. *BioResources*, *8*(4), 4937–4950.

Eroğlu, H., İstek, A., & Usta, M. (2001). Medium density fiberboard (MDF) manufacturing from wheat straw (triticum aestivum l .) and straw wood mixture. Engineering Science, 7(2), 305–311.

Evon, P., Vandenbossche, V., & Rigal, L. (2012). Manufacturing of renewable and biodegradable fiberboards from cake generated during biorefinery of sunflower whole plant in twin-screw extruder: Influence of thermo-pressing conditions. *Polymer Degradation and Stability*, *97*(10), 1940–1947.

Frihart, C.R., & Hunt, C.G. (2010). *Wood handbook—Wood as an engineering material*. Madison, United States Department of Agriculture Forest Service.

Gardner, D.J., Tascioglu, C & Wålinder, M.E. (2003). Wood composite protection. In: Wood Deterioration and Preservation: Advances in Our Changing World. American Chemical Society, Washington D.C., 399-419.

Ghalehno, M.D., Madhoushi, M., Tabarsa, T., & Nazerian, M. (2010). The manufacture of particleboards using mixture of reed (surface layer) and commercial species (middle layer). *European Journal of Wood and Wood Products*, *69*(3), 341–344.

Grace, J.K. & Yates, J.R. (1992). Behavioural effects of a neem insecticide on Coptotermes formosanus (Isoptera: Rhinotermitidae). *Tropical Pest Management*, *38*, 176–180.

Gubrel, S.S.O. (2008). Laboratory evaluations of some termiticides against subterranean termite (Technical Report). Universiti sains malaysia.

Guler, C., Bektas, I., & Kalaycioglu, H. (2006). The experimental particleboard manufacture from sunflower stalks (Helianthus annuus L.) and calabrian pine (Pinus brutia Ten). *Forest Products*, *56*(4), 56–60.

Hadi, Y.S., Massijaya, M.Y., & Arinana, A. (2016). Subterranean termite resistance of polystyrene-treated wood from three tropical wood species. *Insects*, *7*(3), 6–11.

Haggag, M.A., & Elmasry, S.K. (2011). *Sustainable Development and Planning* WIT Press.

Harun, Z., Zaki, P.H., Ismail, M.H., Khairil, M., & Awang, W. (2014). Trend of timber products export in malaysia. *International Conference on Busines, Management & Corporate Social Resposibility (ICBMCSR' 14),* pp. 45–49.

Hashim, R., Wan Nadhari, W.N.A., Sulaiman, O., Kawamura, F., Hiziroglu, S., Sato, M.,Tanaka, R. (2011). Characterization of raw materials and manufactured binderless particleboard from oil palm biomass. *Materials and Design*, *32*, 246–254.

Hashim, R., Wan Nadhari, W.N.A., Sulaiman, O., Sato, M., Hiziroglu, S., Kawamura, F., Tanaka, R. (2012). Properties of binderless particleboard panels manufactured from oil palm biomass. *BioResources*, *7*(1), 1352–1365.

Hassan, S., Kee, L.S., & Al-Kayiem, H.H. (2013). Experimental study of palm oil mill effluent and oil palm frond waste mixture as an alternative biomass fuel. *Engineering Scince and Technology*, *8*(6), 703–712.

Heyden, V., & Dejaegher, B. (2009, May). Response surface designs part 1 — types and properties. *LCGC*, *22*(5), 1–4.

Hibbert, D.B. (2012). Experimental design in chromatography: A tutorial review. *Journal of Chromatography B*, *2*(13), 39.

Holt, G., Chow, P., Wanjura, J.D., Pelletier, M.G., Coffelt, T., & Nakayama, F.S. (2012). Termite resistance of biobased composition boards made from cotton byproducts and guayule bagasse. *Industrial Crops and Products*, *36*(1), 508–512.

Hotwire, R. (2008). Introduction to design of experiments - DOE Types. *http://www.weibull.com/hotwire/issue85/relbasics85.htm*.

Hua, Y. (2002). *Handbook of Polymer Blends and Composites*.1st ed., Vol. 1. Shropshire, United Kingdom: Rapra Technology Limited.

Humar, M., Žlindra, D., & Pohleven, F. (2007). Influence of wood species, treatment method and biocides concentration on leaching of copper–ethanolamine preservatives. *Building and Environment*, *42*(2), 578–583.

Ibrahim, Z., Abdul Aziz, A., Mokhtar, A., Ramli, R., & Mamat, R. (2012). Production of medium density fibreboard (mdf) from oil palm fronds and its admixture. *MPOB Infromation Series, MPOB TT No*(601).

Idirs, U.D., Aigbodion, V.S., Gadzama, R.M., & Abdullahi, J. (2011). Eco-friendly (watermelon peels) alternatives to wood-based particleboard composites. *Pacific Journal of Science and Technology*, *12*(2), 112–119.

Ilias, K. (2006). New trends in wood adhesive technology. *6th Panhellenic Polymer Conference*, p. 13.

Irle, M.A., Barbu, M.C., Reh, R., Berglan, L., & Rowell, R.M. (2012). *Handbook of wood chemistry and wood composite.* 2nd ed. Boca Raton: CRC Press,.

Ishida, M., & Abu Hassan, O. (1997). Utilization of oil palm frond as cattle feed. *JARQ*, *3*(1), 41–47.

Islam, A., Alam, R., & Hannan, O. (2012). Multiresponse optimization based on statistical response surface methodology and desirability function for the production of particleboard. *Composites Part B*, *43*(3), 861–868.

Iswanto, A.H., Azhar, I., Susilowati, A., & Susilowati, S. (2014). Effect of resin type, pressing temperature and time on particleboard properties made from sorghum bagasse. *Agriculture, Forestry and Fisheries*, *3*(2), 62.

Jacob, M., Thomas, S., & Varughese, K.T. (2004). Mechanical properties of sisal/oil palm hybrid fiber reinforced natural rubber composites. *Composites Science and Technology*, *64*(7-8), 955–965.

Jani, S.M., & Izran, K. (2013). Mechanical and physical properties of urea-formaldehyde bonded kenaf core particle boards. *Tropical Agricultural and Food Science*, *41*(2), 341–347.

Jawaid, M., & Abdul Khalil, H.P.S. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydrate Polymer*, *86*(1), 2011.

Jering, A., Günther, J., Raschka, A., Carus, M., Piotrowski, S., & Scholz, L. (2010). *Use of renewable raw materials with special emphasis on chemical industry*. European Topic Centre on Sustainable Consumption and Production, ETC/SCP report 1/ 2010, German Federal Environmental Agency.

Juliana, A.H., Paridah, M.T., & Anwar, U.M.K. (2012). Properties of three-layer particleboards made from kenaf (Hibiscus cannabinus L.) and rubberwood (Hevea brasiliensis). *Materials & Design*, *40*, 59–63.

Jumhuri, N., Hashim, R., Sulaiman, O., Wan Nadhari, W.N.A., Salleh, K. M., Khalid, I., Razali, M.Z. (2014). Effect of treated particles on the properties of particleboard made from oil palm trunk. *Materials & Design*, *64*, 769–774.

Jun, Z., Xiang-Ming, W., Jian-Min, C., & Kai, Z. (2008). Optimization of processing variables in wood-rubber composite panel manufacturing technology. *Bioresource Technology*, *99*(7), 2384–2391.

Junaida, A.Z., Suhaimi, M., Amran, S., & Wan Rosli, W.D. (2012). Chemical properties of juvenile latex timber clone rubberwood trees. *The Malaysian Journal of Analytical Science*, *16*(3), 228–234.

Kamm, B., Gerhardt, M., & Dautzenberg, G. (2013). *New and Future Developments in Catalysis: Catalytic Biomass Conversion,* Vol. 5. Waltham, USA: Elsevier Ltd.

Karim, Z., Chowdhury, Z.Z., Bee, S., Hamid, A., & Ali, E. (2014). Statistical optimization for acid hydrolysis of microcrystalline cellulose and its physiochemical characterization by using metal ion catalyst. *Materials*, *7*, 6982–6999.

Kartal, S.N., & Green, F. (2003). Decay and termite resistance of medium density fiberboard (MDF) made from different wood species. *Internal Journal of Biomass & Renewables, 51*, 29–35.

Kerdsuwan, S., & Laohalidanond, K. (2010). *Renewable energy from palm oil empty fruit bunch*. Department of Mechanical and Aerospace Engineering, University of Technology North Bangkok.

Keshk, S.M.A.S., & Haija, M.A. (2011). A new method for producing microcrystalline cellulose from Gluconacetobacter xylinus and kenaf. *Carbohydrate Polymers*, *84*(4), 1301–1305.

Khedari, J., Charoenvai, S., & Hirunlabh, J. (2003). New insulating particleboards from durian peel and coconut coir. *Building and Environment*, *38*(3), 435–441.

Kim, S., & Dale, B.E. (2004). Biomass and bioenergy, *4*(4), 361–375.

Kirkpatrick, J.W., & Barnes, H.M. (2006). *Biocide Treatments for Wood Composites.* International Research Group on Wood Protection. 37th Annual Meeting, IRG/WP 06-40323, Tromso, Norway.

Kiyono, Y., Furuya, N., Fujita, N., Sato, T., Matsumoto, M., Bounthabandid, S., & Sanonty, S. (2014). Can converting slash-and-burn agricultural fields into rubber tree (Hevea brasiliensis) plantations provide climate change mitigation? A case study in northern Laos. *Bulletin of FFPRI*, *13*(3), 79–88.

Klemm, D., Heublein, B., Fink, H.P., & Bohn, A. (2005). Cellulose: fascinating biopolymer and sustainable raw material. *Angewandte Chemie (International Ed. in English)*, *44*(22), 3358–3393.

Kollmann, F.F.P., Kuenzi, E.W., & Stamm, A.J. (2012). *Principle of Wood Scince and TEchnology: II Wood Based Materials*. 1st ed. Springer Scince & Business Media.

Köse, C., Terzi, E., Büyüksarı, Ü., Avcı, E., Ayrılmış, N., Kartal, N., & Imamura, Y. (2011). Particleboard and MDF panels made from a mixture of wood and pinecones : resistance to decay fungi. *BioResources*, *6*(2), 2045–2054.

Kowaluk, G., Fuczek, D., Beer, P., & Grzeskiewicz, M. (2011). Influnce of the raw materials and production parameters on chosen standard properties for furniture panels of biocomposites from fibrous chips. *BioResources*, *6*(3), 3004–3018.

Laemlaksakul, V. (2010). Physical and mechanical properties of particleboard from bamboo waste. *World Academy of Science, Engineering and Technology*, *4*(4), 488–492.

Laemsak, N., & Okuma, M. (1996). Development of boards made from oil palm frond I.: manufacture & fundamental properties of oil palm frond particleboard. FORTROP'96 : Tropical Forestry in the 21st century .

Lamaming, J., Hashim, R., Sulaiman, O., Sugimoto, T., Sato, M., & Hiziroglu, S. (2014). Measurement of some properties of binderless particleboards made from young and old oil palm trunks. *Measurement*, *47*, 813–819.

Lamaming, J., Sulaiman, O., Sugimoto, T., Hashim, R., Said, N., & Sato, M. (2013). Influence of chemical components of oil palm on properties of binderless particleboard. *BioResources*, *8*(3), 3358–3371.

Latibari, A.J., Ghasebinasab, H., Roohnia, M., & Karagarfard, A. (2012). The effect of fiber moisture and drying temperature fiber physical chemistry and strength of medium density fiberboard, *Lignocellulose*,*1*(1), 3-12.

Lee, D., Owens, V.N., Boe, A., & Jeranyama, P. (2007). *Composition of herbaceous biomass feedstocks*. North Central Center.

Lee, H.V., Hamid, S.B.A., & Zain, S.K. (2014). Conversion of lignocellulosic biomass to nanocellulose: structure and chemical process. *The Scientific World Journal*, *2014*, 20.

Lehmann, W.F. & Hefty, F.V. (1973). *Resin efficiency and dimensional stability of particleboard.* FPL 208, Forest Products Laboratory, US Department of Agriculture, Pullmann, USA.

Liauw, M.Y., Natan, F.A, Widiyanti, P., Ikasari, D., Indraswati, N. & Soetaredjo FE. (2008). Extraction of neem oil (Azadirachta indica A. Juss) using n-hexane and ethanol: studies of oil quality, kinetic and thermodynamic. *Journal of Engineering and Applied Sciences*, *3*(3), 49-54.

Li, B., Zheng, Y., Pan, Z., & Hartsough, B. (2009). Improved properties of medium-density particleboard manufactured from saline creeping wild rye and HDPE plastic. *Industrial Crops and Products*, *30*(1), 65–71.

Lynam, F.C. (1959). Factors influencing the properties of wood chipboards. *Industrial Wood Science, 2* (4), 18 – 20.

Mahdavi, M., Clouston, P.L., and Arwade, S.R. (2012). A low-technology approach toward fabrication of laminated bamboo lumber. *Construction Building Material, 29*, 257-262.

Malik, A.Q. (2012). *Potential and use of bioenergy in the association of southeast asian nations (ASEAN) countries – a review*. in *sustainable energy - recent studies rent*. Fiji National University.

Mat Rasat, M.S., Wahab, R., Sulaiman, O., Moktar, J., Mohamed, A.,A. Tabet, T., & Khalid, I. (2011). Properties of composite boards from oil palm frond agricuktural waste. *BioResources*, *6*(4), 4389–4403.

MNBS 2020. (2011). National Biomass Strategy 2020 : New wealth creation for Malaysia ' s Palm Oil Indusry.

Mo, X., Cheng, E., Wang, D., & Sun, X.S. (2003). Physical properties of medium-density wheat straw particleboard using different adhesives. *Industrial Crops and Products*, *18*(1), 47–53.

Mohebby, B., & Ilbeighi, F. (2007). Physical and mechanical properties of hydrothermally modified medium density fiberboard (MDF). *International Panel Product Symposium*, pp. 341–349.

Morrell, J.J. (2010). *Decay and termite resistance of western juniper sapwood and heartwood under tropical conditions*. Corvallis, Oregon.

Morrell, J.J., (2002). Wood-based composites: what have we learned? *International Biodeterioration and Biodegradation, 49,* 253–258.

Mourabet, M., El Rhilassi, A., El Boujaady, H., Bennani-Ziatni, M., & Taitai, A. (2014). Use of response surface methodology for optimization of fluoride adsorption in an aqueous solution by Brushite. *Arabian Journal of Chemistry*, *1*, 11.

MPOC. (2015). Annual Report 2014. Kuala Lumpur.

MTIB. (2015a). Average domestic prices of logs, sawn timber, plywood and MDF in Peninsular Malaysia. Kuala Lumpur: Malaysian Timber Industry Board.

MTIB. (2015b). MTIB E-statistic export January-April 2015. Kuala Lumpur: Malaysian Timber Industry Board.

Muilerman, H., & Blonk, H. (2001). Towards a sustainable use of natural resources. Stichting Natuur en Milieu

Myers, R.H., Montgomery, D.C., & Anderson-Cook, C.M. (2009). *Response surface methodology - process and product optimization using designed experiment.* 3rd ed. Hoboken, New Jersey: John Wiley & Sons.

Nandika, D. (1998). Effect of boric acid treatment on termite resistance of particleboard composed of different ratio of oil palm and acacia fiber. *Proceedings of the Fourth Pacific Rim Bio-Based Composite Symposium*, pp. 181-188.

National Research Council. (1992). Neem a tree for solving global problems. Natinal Academic Press, Washington, DC.

Ncube, E., Chungu, D., Kamdem, D.P., & Musawa, K. (2012). Use of a short span field test to evaluate termite resistance of eucalyptus grandis and bobgunnia madagascariensis in a tropical environment. *BioResources*, *7*(3), 4098–4108.

Nemli, G., & Kalaycioglu, H. (2001). Suitability of date palm (Phoenix dactyliferia) branches for particleboard production. *Holz Als Roh- Uns Werkstoff*, *59*, 411–412.

Nemli, G. (2002). Factors affecting the production of E1 type particleboard. *Turkey Journal of Agricultural and Forestry*, *26*, 31–36.

Ng, F.Y., Yew, F.K., Basiron, Y., & Sundram, K. (2011). A renewable future driven with malaysian palm oil-based green technology. *Oil Palm and The Environment*, (2), 1–7.

Ngee, P., Yoshimura, T., & Chow-yang, L. (2004). Foraging populations and control strategies of subterranean termites in the urban environment , with special reference to baiting. *Japanese Journal of Entomology and Zoology*, *15*(3), 197–215.

Nicholas, D.D., & Freeman, M.H. (2000). Comparative performance of pentachlorophenol and copper naphthenate in a long term field stake test . Kona, Hawaii.

Nigro, N., & Storti, M. (2001). Hot-pressing process modeling for medium density fiberboard (MDF). *International Journal of Mathematics and Mathematical Sciences*, *26*(12), 713–729.

NIST/SEMATECH. (2012). Engineering statistic handbook. *http://www.itl.nist.gov/div898/handbook/pri/section3/pri336.htm*.

Nurhazwani, O., Jawaid, M., Paridah, M.T., Juliana, A.H., & Hamid, S.A. (2016). Hybrid particleboard made from bamboo (dendrocalamus asper) veneer waste and rubberwood (hevea brasilienses). *BioResources*, *11*(1), 306–323.

Ormondroyd, G.A., & Stefanowski, B. (2015). *Wood Composites*. Cambridge: Woodhead Publishing Ltd.

Osman, F. (2015). Wood-Based Industry. *Ministry of International Trade and Industry (MITI)*.

Pan, C., & Wang, C. (2015). Sodium fluoride for protection of wood against field populations of subterranean termites. *Journal of Economic Entomology Advance*, *1*(4), 1–4.

Pan, M., Zhou, D., Ding, T., & Zhou, X. (2010). Water resistance and some mechanical properties of rice straw fiberboards affected by thermal modification. *BioResources*, *5*(2), 758–769.

Panel Guide (2014). Panel guide *Annex 2F: Wet Process fibreboards*. United Kingdom.

Papadopoulos, A.N. (2006). Property comparisons and bonding efficiency of uf and pmdi bonded particleboards as affected by key process variables. *BioResources*, *1*(2), 201–208.

Paridah, M.T., Hafizah, A.W.N., Zaidon, A., Azmi, I., Nor, M.Y.M., & Yuziah, M.Y. N. (2009). Bonding properties and performance of multi- layered kenaf board. *Tropical Forest Science*, *21*(2), 113–122.

Parnphumeesup, P., & Kerr, S.A. (2011). Stakeholder preferences towards the sustainable development of CDM projects: Lessons from biomass (rice husk) CDM project in Thailand. *Energy Policy*, *39*(6), 3591–3601.

Peralta, R.C.G., Menezes, E.B., Carvalho, A.G., & Aguiar-Menezes, E. de L. (2004). Wood consumption rates of forest species by subterranean termites (isoptera) under field conditions. *Journals - Società Italiana Di Fisica*, 283–289.

Peters, B.C., Bailleres, H., & Fitzgerald, C.J. (2014). Susceptibility of coconut wood to damage by subterranean termites (Isoptera: Mastotermitidae, Rhinotermitidae). *BioResources*, *9*(2), 3132–3142.

Porter, B. (2012). Manufactured boards and panel products. In *Carpetry and Joinery 1*. 3rd ed. Routledge.

Ragasa, C.Y., Nacpil, Z.D., Natividad, G.M., Tada, M., Coll, J.C. & Rideout, J.A. (1997). Tetranortriterpenoids from Azadirachta Indica. *Journal of Phytochemistry*. 46, 555–558.

Ramli, R., Shaler, S., & Jamaludin, M.A. (2002). Properties of medium density proper operties fibreboard from oil palm empty fruit bunch. *Journal of Oil Palm Research*, *14*(2), 34–40.

Rathke, J., Sinn, G., Harm, M., Teischinger, A., Weigl, M., & Muller, U. (2012). Effects of alternative raw materials and varying resin content on mechanical and fracture mechanical properties of particle board. *Design of Particleboard*, *7*(3), 2970–2985.

Ratnasingam, J., Ioraş, F., & Wenming, L. (2011). Sustainability of the rubberwood sector in Malaysia. *Not Bot Horti Agrobo*, *39*(2), 305–311.

Ratnasingam, J., & Jalil, M.H. (2011). Rubberwood - Its future in Malaysia. IFRG Report No. 23, Singapore.

Razak, W., Mahmud, S., Hashim, W.S., Mohd.Tarmizi, M., & Azmy, H.M. (2003). In-ground perfomance of ammoniacal copper quaternary and copper chrome arsenate treated bamboo. *Borneo Science*, *14*, 1–8.

Razzaghi-Asl, N., Ebadi, A., Edraki, N., Mehdipour, A., Shahabipour, S., & Miri, R. (2012). Response surface methodology in docking study of small molecule BACE-1 inhibitor. *Molecular Modelling*, *18*, 4567–4576.

Ressel, J. (2008). Adhesive application. *3rd International Wood Academy*.

RISI. (2015). *Helping the forest products industry make better decisions*. *RISI European Conferenc*, p. 25.

Ross, A.S., Ward, H.A., & Smith, W.R. (2003). An overview on new generation of preservation treatments for wood-based panels and other engineered wood products. In *Seventh European Panel Products Symposium*, pp. 219–225.

Rowell, R.M. (2012). *Handbook of Wood Chemistry and Wood Composites.* 2nd ed. CRC Press LLC.

Rowell, R.M., Han, J.S., & Rowell, J.S. (2000). *Natural polymers and agrofibers composites*. São Carlos - SP, Brazil: Embrapa Instrumentação Agropecuária / Botucatu: UNESP.

Saadaoui, N., Rouilly, A., Fares, K., & Rigal, L. (2013). Characterization of date palm lignocellulosic by-products and self-bonded composite materials obtained thereof. *Materials & Design*, *50*, 302–308.

Salim, N., Hashim, R., Sulaiman, O., Ibrahim, M., Sato, M., & Hiziroglu, S. (2012). Optimum manufacturing parameters for compressed lumber from oil palm (Elaeis guineensis) trunks: Respond surface approach. *Composites Part B: Engineering*, *43*(3), 988–996.

Satyanarayana, K.G., Arizaga, G.G.C., & Wypych, F. (2009). Biodegradable composites based on lignocellulosic fibers-An overview. *Progress in Polymer Science*, *34*(9), 982–1021.

Schmutterer, H. (2002). The neem tree and other meliaceous plants. Neem Foundation: Mumbai, India.

Schneider, M.H., Chui, Y.H., & Ganev, S. (1996). Properties of particleboard made with a polyfurfuryl-alcohol/urea–formaldehyde adhesive. *Forest Products*, *46*(9), 79–83.

Scouse, A.A. (2013). *Essential oil treatment of VTC wood.* Master Thesis. Oregon State University.

Shinoj, S., Visvanathan, R., Panigrahi, S., & Kochubabu, M. (2011). Oil palm fiber (OPF) and its composites: A review. *Industrial Crops and Products*, *33*(1), 7–22.

Shmulsky, R., & Jones, P.D. (2011). *Forest products and wood science*. 6th ed., West Sussex, UK: John Wiley & Sons.

Shupe, T., Lebow, S., & Ring, D. (2008). Causes and control of wood decay, degradation & stain. (Technical report). LSU Centre.

Sihabut, T., & Laemsak, N. (2010a). Feasibility of producing insulation boards from oil palm fronds and empty Fruit bunches. *Songklanakarin Journal of Science Technology*, *32*(1), 63–69.

Sihabut, T., & Laemsak, N. (2010b). Sound absorption capacity of oil palm frond fiberboard with different finishing. *Environmental and Natural Resources*, *8*(1), 38–43.

Smil, V. (1999). Crop Residue: Agriculture's Largest Harvest. *bioScience*, *49*(4), 299–308.

Sotannde, O.A., Yager, G.O., Zira, B.D., & Usman, A. (2011). Termicidal effect of neem oil. *Forestry*, *5*(3), 128–138.

Sreekala, M.S., Kumaran, M.G., Joseph, S., & Jacob, M. (2000). Oil palm fibre reinforced phenol formaldehyde composites : influence of fibre surface modifications on the mechanical performance. *Applied Composite Materials*, *7,* 295–329.

Stark, N.M., Cai, Z., & Carll, C. (2010). *Wood handbook; wood as an engineering material*. Madison, WI: U.S.: Department of Agriculture, Forest Service and Forest Products.

Steffen, A., Rapp, A., Humphrey, P., & Tho, H. (1999). Temperature and gas pressure in MDF-mats during industrial continuous hot pressing. *Holz Als Roh- Und Werkstoff*, *57*, 154–155.

Su, N.Y., Scheffrahn, R.H., & Ban, P.M. (1993). Barrier efficacy of pyrethroid and organophosphate against subterranean termites (Isoptera: Rhonotermidae). *Household and Structural Insect, 86*(3), 772–776.

Suchsland, O., & Woodson, G.E. (1986). *Fiberboard manufacturing practices in the United States agricultural handbook*. Washington, D.C: Department of Agriculture, Forest Service.

Suhasman, S., Hadi, Y.S., & Santoso, A. (2013). Binderless particleboard resistance to termite attack. *The International Conference on Wood Adhesives*, p. 43.

Sulaiman, F., Abdullah, N., Gerhauser, H., & Shariff, A. (2011). An outlook of Malaysian energy, oil palm industry and its utilization of wastes as useful resources. *Biomass and Bioenergy*, *35*(9), 3775–3786.

Sumardi, I., Ono, K., & Suzuki, S. (2007). Effect of board density and layer structure on the mechanical properties of bamboo oriented strandboard. *Journal of Wood Science*, *53*(6), 510–515.

Tanaka, R., Wan Rosli, W.D., Magara, K., Ikeda, T., & Hosoya, S. (2004). chlorine-free bleaching of kraft pulp from oil palm empty fruit bunches. *Japan Agricultural Research Quarterly*, *38*(4), 275–279.

Tascioglu, C., Yoshimura, T., & Tsunoda, K. (2013). Biological decay and termite resistance of post- treated wood-based composites under protected above-ground conditions : a preliminary study after 36 months of exposure. *BioResources*, *8*(1), 833–843.

Tekle, H. (2014). *Life cycle assessment of kitchen cabinet : the case of Finfine*. Addis Ababa University Addis.

Teoh, C.H. (2002). The palm oil industry in malaysia - From Seed to Frying Pan.

Thoeman, H., Irle, M., & Sernek, M. (2010). *Wood-Based Panels An Introduction for Specialists.* 1st ed. London: Brunel University Press.

Tran, N.H. (2011). *Transformation de la biomasse aérienne de Miscanthus giganteus: aptitude à la dégradation enzymatique et valorisation des coproduits en agromatériaux*. Université de Picardie Jules Verne d'Amiens.

Tsai, C., Tong, L., & Wang, C. (2010). Optimization of multiple responses using data envelopment analysis and response surface methodology. *Tamkang Journal of Science and Engineering*, *13*(2), 197–203.

UNEP. (2012). Converting waste oil palm tree into a resources. Osaka, Japan.

Usta, M., Ustaomer, D., Kartal, S.N., & Ondaral, S. (2009). Termite resistance of MDF panels treated with various boron compounds. *International Journal of Molecular Sciences*, *10*(6), 2789–97.

Venmalar, D., & Nagaveni, H.C. (2005). *Evaluation of copperised cashew nut shell liquid and neem oil as wood preservatives.* International Research Group on Wood Preservation. 36th Annual Meeting, IRG/WP 05-30368, Bangalore, India.

Verma, M., Sharma, S., & Prasad, R. (2009). Biological alternatives for termite control: A review. *International Biodeterioration & Biodegradation*, *63*(8), 959–972.

Vuorinen, T., & Alen, R. (2013). *Analytical Methods in Wood Chemistry, Pulping and Papermaking*. Springer Science & Business Media.

Wahid, Z., & Nadir, N. (2013). Improvement of one factor at a time through design of experiments. *World Applied Sciences Journal 21 (Mathematical Applications in Engineering), 21*, 56–61.

Wan Nadhari, W.N.A., Hashim, R., Sulaiman, O., Sato, M., Sugimoto, T., & Selamat, M.E. (2013). Utilization of oil palm trunk waste for manufacturing of binderless particleboard: optimization study. *BioResources*, *8*(2), 1675–1696.

Wan Rosli, W.D., Zainuddin, Z., Law, K.N., & Asro, R. (2007). Pulp from oil palm fronds by chemical processes. *Industrial Crops and Products*, *25*, 89–94.

Wan Rosli, W.D., & Law, K. (2011). Oil palm fibers as papermaking material: potentials and challenges. *BioResources*, *6*(1), 901–917.

Wang, X., Hu, J., Liang, Y., & Zeng, J. (2012). TCF bleaching character of soda-anthraquinone pulp from oil palm frond. *Bioresource Technology*, *7*(1), 275–282.

Widyorini, R., Xu, J., Umemura, K., & Kawai, S. (2005). Manufacture and properties of binderless particleboard from bagasse I: effects of raw material type, storage methods, and manufacturing process. *Journal of Wood Science*, *51*(6), 648–654.

Winandy, J. E., & Krzysik, A. M. (2007). Thermal degradation of wood fibers during hot-pressing of MDF composites : part i . Relative effects and benefits of thermal exposure. *Wood and Fiber Science*, *39*(3), 450–461.

Wong, A.H.H., Grace, J. K., & Kirton, L.G. (1998). *Termite resistance of Malaysian and exotic woods with plantation potential field evaluation*. International Research Group on Wood Preservation. 29th Annual Meeting, IRG/WP 98-10298, Maastricht, Netherlands.

Wong, H.K., & Wan Zahari, M. (2011). Utilisation of oil palm by-products as ruminant feed in malaysia. *Journal of Oil Palm Research*, *23*(8), 1029–1035.

Wong, K.K. (2012). *Optimising resin consumption , pressing time and density of particleboard made of mixes of hardwood sawmill residue and custom flaked softwood*. RMIT University, Australia.

Yalinkilic, M.K., Imamuraa, Y., Takahashi, M., Kalaycioglub, H., Nemli, G., Demirci, Z., & Ozdemir, T. (1998). Biological, physical and mechanical properties of particleboard manufactured from waste tea leaves. *International Biodeterioration & Biodegradation*, *41*, 75–84.

Yang, F., Fei, B., Wu, Z., Peng, L., & Yu, Y. (2014). Selected properties of corrugated particleboards made from bamboo waste (Phyllostachys edulis) laminated with medium-density fiberboard panels. *BioResources*, *9*(1), 1085–1096.

Yokoyama, S., & Matsumura, Y. (2002). Biomass resources. In *Asian Biomass Handbook*. Ministry of Agriculture, Forestry, and Fisheries, Japan.

Yokoyama, S., & Matsumura, Y. (2008). *A Guide for Biomass Production and Utilization Support*. Ministry of Agriculture, Forestry, and Fisheries, Japan.

Youngquist, J.A. (1999). *Wood handbook—Wood as an engineering material.* Madison, WI: U.S. Department of Agriculture, Forest Service.

Zaidon, A., Nizam, A.M.N., Faizah, A., Paridah, M.T., Jalaluddin, H., Nor, M.Y.M., & Yuziah, M.Y.N. (2008). Efficacy of pyrethroid and boron preservatives in protecting particleboards against fungus and termite. *Journal of Tropical Forest Science*, *20*(1), 57–65.

Zainal, S., Kong, A., Kasinathan, V., & Zakaria, K. (2015). Timber Malaysia. *Malaysian Timber Council*, *21*, 40.

Zakaria, N.A., Merous, N.H., & Ahmad, I. (2014). Assessment of rubberwood value-added in Malaysia's wooden furniture industry. *Int. Journal of Economics and Management*, *8*(1), 1–9.

Zhang, L., & Hu, Y. (2014). Novel lignocellulosic hybrid particleboard composites made from rice straws and coir fibers. *Materials & Design*, *55*, 19–26.

Zhu, B.C.R., Henderson, G., Chen, F., Fei, H., & Laine, R.A., (2001). Evaluation of vetiver oil and seven insect-active essential oils against the formosan subterranean termite. *Journal of Chemical Ecology*, *27*, 1617–1625.

Zitrom, V.C. (1999). One factor at a time versus designed experiments. *The American Statistician*, *53*(2), 136–131.

Zulkifli, R., Mohd Nor, M.J., Ismail, A.R., Nuawi, M.Z., Abdullah, S., Mat Tahir, M. F., & Ab. Rahman, M.N. (2009). Comparison of acoustic properties between coir fibre and oil palm fibre. *European Journal of Scientific Research*, *33*(1), 144–152.

Zulkifli, R., Zulkarnain, M.N., & Mohd Jailani, M.N. (2010). Noise control using coconut coir fiber sound absorber with porous layer backing and perforated panel. *Applied Scince*, *7*(2), 260–264.

APPENDIX A

Table A.1 Box-Behnken Design and measured response for the particleboards production

Std. order	Factor A Temp. (°C)	Factor B Time (min)	Factor C EFB/OPF ratio (%)	Actual MOR, y_1 (MPa)	Predicted MOR, y_1 (MPa)	Actual MOE, y_2 (MPa)	Predicted MOE, y_2 (MPa)	Actual IB, y_3 (MPa)	Predicted IB, y_3 (MPa)	Actual WA, y_4 (%)	Predicted WA, y_4 (%)	Actual TS, y_5 (%)	Predicted TS, y_5 (%)
1	150	3	20	9.4	9.1	1130	1150	0.24	0.25	98.6	98.5	33.1	33.2
2	190	3	20	13.2	13.0	1751	1748	0.50	0.49	60.9	61.4	19.2	19.0
3	150	7	20	11.9	12.1	1541	1544	0.42	0.43	76.1	75.7	19.6	20.8
4	190	7	20	12.3	12.5	1693	1732	0.49	0.49	58.7	58.8	19.2	19.9
5	150	5	0	11.0	11.0	1319	1291	0.35	0.34	90.3	89.7	27.5	27.9
6	190	5	0	14.0	14.0	1877	1883	0.45	0.45	64.3	63.1	18.5	19.3
7	150	5	40	12.9	13.0	1677	1671	0.38	0.37	85.4	86.7	26.5	26.1
8	190	5	40	14.2	14.2	1836	1864	0.55	0.56	58.7	59.3	19.6	19.6
9	170	3	0	12.4	12.7	1608	1606	0.45	0.45	78.8	79.6	26.3	26.1
10	170	7	0	14.9	14.7	1701	1726	0.51	0.51	66.7	67.9	22.2	21.1
11	170	3	40	14.2	14.5	1843	1718	0.49	0.49	78.3	77.2	25.4	26.0
12	170	7	40	15.2	15.0	1973	1975	0.62	0.61	64.4	63.6	19.9	19.6
13	170	5	20	14.4	14.4	1861	1852	0.57	0.58	70.4	68.3	23.7	23.2
14	170	5	20	14.6	14.4	1891	1852	0.58	0.58	67.1	68.3	21.3	23.2
15	170	5	20	14.4	14.4	1862	1852	0.60	0.58	65.9	68.3	27.3	23.2
16	170	5	20	14.1	14.4	1791	1852	0.60	0.58	68.4	68.3	22.6	23.2
17	170	5	20	14.3	14.4	1857	1852	0.57	0.58	69.9	68.3	22.8	23.2

APPENDIX B

Publication

Wahida, A.F., & Najmuldeen, G.F. (2015). One layer experimental particleboard from oil palm frond particles and empty fruit bunch fibers. *International Journal of Engineeing Research & Technology*, *4*(1), 199–202.

Under review

Authors: Wahida Amat Fadzil, Ghazi Faisal Najmuldeen, Zulkafli Hassan
Title: Optimization of the fabrication process for particleboards made from oil palm fronds blended with empty fruit bunch using response surface methodology
Indian Journal of Scince and Technology.
Submission Date: 16 August 2016

Authors: Wahida Amat Fadzil, Ghazi Faisal Najmuldeen, Zulkafli Hassan
Title: Evaluation of cypermethrin and neem oil in protecting particleboard manufactured from oil palm fronds blended with empty fruit bunch against subterranean termite.
Journal of Oil Palm, Environment and Health.
Submission Date: 12 October 2016

Conference

Wahida, A.F., & Najmuldeen, G.F. (2014). Properties of particleboards fabricated from oil palm fronds and its blend with empty fruit bunch fibre. *International Conference on Multidisciplinary Innovation for Sustainability and Growth (MISG)*. Kuala Lumpur, Malaysia.

Patent

Title: A particleboard comprising oil palm residue
UI Application: UI 2016701948

Award

Creation, Innovation, Technology and Research Exposition 2014 (CITREX), Bronze medal.