THE EFFECT OF ADDITION OF POLYLACTIC ACID ON THE PROPERTIES OF OIL PALM TRUNK PARTICLEBOARD AND ITS POTENTIAL AS A PHANTOM MATERIAL

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by

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°C.min^{-1}	degree Celcius per minutes
µ	linear attenuation coefficient
µl	microliter
µm	micrometer
AD	air dry
ANOVA	Analysis of Variance
CCRD	Central composite rotatable design
CT	Computed tomography
DSC	Differential scanning calorimetry
EFB	empty fruit bunch
FTIR	Fourier Transform Infra-Red
IB	internal bond strength
KBr	potassium bromide
keV	kilo electron volt
kVp	peak kilovoltage
ml/min	milliliter per minutes
mm/min	millimeter per minutes
MeV	mega electron volt

MOR	modulus of rupture
Mo	Molybdenum
MPa	mega pascal
MPOB	Malaysian Palm Oil Board
NaOH	sodium hydroxide
Nb	Niobium
OD	oven dry
OPF	oil palm frond
OPT	oil palm trunk
Pa	Pascal
Pd	Palladium
PLA	polylactic acid
SEM	Scanning Electron Microscopy
Sn	Tin
TGA	thermogravimetric analyses
T_g	glass transition temperature
T_m	melting temperature
TS	thickness swelling

σ	Error
WA	water absorption
χ^2	Chi-square
XRD	X-ray diffraction
XRF	X-ray fluorescence

KESAN PENAMBAHAN ASID POLILAKTIK KE ATAS SIFAT BOD PARTIKEL BATANG KELAPA SAWIT DAN POTENSINYA SEBAGAI BAHAN FANTOM

ABSTRAK

Kajian ini dilaksanakan untuk mencirikan beberapa sifat bod partikel daripada batang kelapa sawit untuk menentukan parameter optimum dalam menghasilkan bod partikel, kesan penambahan asid polilaktik (PLA) dan penggunaannya sebagai bahan fantom. Sampel bod partikel dihasilkan pada lingkungan parameter penghasilan dengan suhu tekanan dari 160 ºC kepada 200 ºC dan tempoh penekanan dari 20 min hingga 30 min pada ketebalan sasaran 5 mm, 10 mm dan 15 mm untuk menentukan parameter optimum untuk menghasilkan bod partikel daripada batang kelapa sawit dengan ketumpatan 0.8 g/cm^3. Reka bentuk komposit putaran berpusat (CCRD) daripada perisian Kaedah Permukaan Sambutan (RSM) digunakan untuk menilai sifat mekanikal dan fizikal bagi mengenalpasti korelasi antara setiap parameter. Dengan purata parameter optimum untuk menghasilkan bod partikel yang diperolehi daripada peringkat pertama, bod partikel tanpa perekat dan bod partikel dengan penambahan PLA daripada batang kelapa sawit pada ketumpatan sasaran 0.8 g/cm^3 dihasilkan untuk menilai kesan penambahan PLA terhadap bod partikel daripada batang kelapa sawit. Selain itu, analisis termagravimetrik, pencirian spektroskopi, ciri-ciri kehabluran dan sifat mofologikal juga ditentukan. Potensi penggunaan bod partikel sebagai bahan fantom di julat tenaga diagnostik dinilai dengan menentukan ciri-ciri penentuan pekali pengecilan jisim bagi bod partikel tanpa perekat dan bod partikel dengan penambahan PLA. Bod partikel daripada batang kelapa sawit dihasilkan dengan ketumpatan 1.0 g/cm^3 supaya bersamaan dengan bahan fantom yang diperbuat daripada air dan pekali pengecilan jisim dinilai pada julat tenaga foton 16.59 – 25.26 keV dengan menggunakan teknik sinar-X pendarlour. Ciri-ciri pekali pengecilan jisim bod partikel daripada batang kelapa sawit dibandingkan dengan pekali pengecilan jisim air yang dihitung daripada data asas tenaga foton. Pengimbas tomografi komputer sinar-X (CT) digunakan untuk menyiasat taburan ketumpatan di dalam bod partikel. Keputusan menunjukkan suhu tekanan 191 ºC dan tempoh tekanan 23 min untuk ketebalan 5 mm, suhu tekanan 196 ºC dan tempoh tekanan 24 min untuk ketebalan 10 mm dan suhu tekanan 195 ºC dan tempoh tekanan 30 min untuk ketebalan 15 mm akan menghasilkan bod partikel dengan ciri-ciri yang ideal yang menepati piawaian industri Jepun untuk bod jenis 8. Bod partikel dengan penambahan PLA menunjukkan ciri-ciri mekanikal yang memuaskan berdasarkan piawaian industri Jepun untuk bod jenis 8. Pekali pengecilan jisim bagi kedua-dua bod partikel daripada batang kelapa sawit mempunyai nilai yang hampir dekat dengan nilai air yang dihitung. Ia dinyatakan bahawa bod partikel tanpa perekat daripada batang kelapa sawit mempunyai nombor CT yang terdekat dengan air jika dibandingkan dengan bod partikel dengan penambahan PLA daripada batang kelapa sawit. Bod partikel daripada batang kelapa sawit menunjukkan sifat potensinya sebagai bahan fantom.

THE EFFECT OF ADDITION OF POLYLACTIC ACID ON THE PROPERTIES OF OIL PALM TRUNK PARTICLEBOARD AND ITS POTENTIAL AS A PHANTOM MATERIAL

ABSTRACT

This study was designed to characterize some properties of oil palm trunk particleboard to determine optimum manufacturing conditions, effect of adding polylactic acid (PLA) and its application as phantom material. Particleboard samples were manufactured at a range of manufacturing parameters with pressing temperature of 160 ºC to 200 ºC and pressing time of 20 min to 30 min at target thickness levels of 5 mm, 10 mm and 15 mm to evaluate optimum manufacturing conditions to manufacture oil palm trunk particleboard with density of 0.8 g/cm^3. A central composite rotatable design (CCRD) of Response Surface Methodology (RSM) software was used to evaluate mechanical and physical properties to identify the correlation between each parameter. With the average optimum manufacturing condition obtained from first stage, binderless particleboard and particleboard with addition of PLA at target density of 0.8 g/cm^3 were manufactured to evaluate the effect of PLA on oil palm trunk particleboard. Besides that, thermal degradation, spectroscopic characterization, crystallinity properties and morphological properties were also determined. Potential use of particleboard as phantom material in the diagnostic energy range was evaluated by determining the mass attenuation coefficients of binderless particleboard and particleboard with addition of PLA. Oil palm trunk particleboards were manufactured at density of 1.0 g/cm^3 as to be equivalent to the water phantom and its mass attenuation coefficient was measured at photon energy range of 16.59 – 25.26 keV by employing X-ray fluorescent technique. The mass attenuation properties of oil palm trunk particleboard were compared with calculated mass attenuation coefficient of water by photon energy data base. An X-ray computed tomography (CT) scanner was used to analyze the density distribution inside the particleboard. The finding showed that pressing temperature of 191 °C and pressing time of 23 min for 5 mm thickness, pressing temperature of 196 °C and pressing time of 24 min for 10 mm thickness and pressing temperature of 195 °C and pressing time of 30 min for 15 mm thickness would result in particleboards with ideal properties that met the requirement of Japanese Industrial Standard for board Type 8. Particleboard with addition of PLA exhibited satisfactory mechanical properties based on Japanese Industrial Standard for board Type 8. The mass attenuation coefficients of both types of oil palm trunk particleboards were very near to the calculated values for water. It is noted that binderless oil palm trunk particleboard having the nearest CT number to water as compared to particleboard with addition of PLA. Oil palm trunk particleboard exhibited potential properties for phantom material.

CHAPTER ONE: INTRODUCTION

1.1 Introduction

The world’s forest areas are decreasing in an alarming manner whilst the wood consumption of the world is increasing enormously as increasing demand for high quality construction material and furniture, thus shortages of wood resources are looming up in the worldwide (Hakeem et al., 2015). Apart from wood resources, non wood natural fibers or lignocellulosic materials with commercial values present in enormous quantity appears as a potential source of feedstock as a replacement to wood products.

Oil palm (*Elaeis guineensis*) is one of the most economically important non wood crops in Malaysia (Ateeqah et al., 2014). The growth of oil palm plantation was phenomenal due to its oil production, which is extracted from the fruits. In contrast, a large portion of waste was generated from the field during replanting period (Sumathi et al., 2008). The replanting which takes place after a certain period from 25 to 30 years where the harvested palm tree chipped into mulch as fertilizer, but mostly left to rot by itself or burned in the field. This subsequently contributes to severe environmental issues although it has been prohibited in most countries.

Oil palm wastes are present in many forms such as oil palm fronds, oil palm trunks, empty fruit bunches, palm kernel shells, mesocarp fiber and palm oil mill effluent. Especially oil palm trunks can be transformed into potential raw material to manufacture valuable by products based on its suitability. Apart from their availability and also renewal properties, utilization of oil palm trunk is preferably environmentally friendly practice rather than usual disposal techniques that have been practised such as land filling or burning (Kloeser et al., 2007). Moreover, it is an advantage to utilize those trunks as it is cheaply and readily available throughout the year.

One of the most promising valuable by products is the composites from agricultural wastes. Prasad et al. (2013) reported that the development of composite products such as particleboard and fiberboard from many agricultural resources or lignocellulosic materials are successfully developed in many industries and so developing countries. In the commercial production of particleboard, various kinds of synthetic resins had been implemented to obtain boards with satisfactory performance. However, those synthetic resins emit formaldehyde emissions which are a problem of environmental concern due to the negative impact on health (Buyuksari et al., 2010). Thus, it is crucial to reduce the consumption of formaldehyde based resins to minimize negative impact on the health and also environment.

The design and development of particleboard without synthetic resin or also called as binderless particleboard is an excellent substitute to eliminate harmful concepts of formaldehyde emission. Instead of that, it is an effective way to produce self bonding board in other means it involves activation of chemical components (Sasaki, 1980) especially those of agricultural residues. Binderless particleboards at thickness level of 5 mm were successfully obtained from oil palm trunk particles based on its chemical composition of oil palm trunk (Hashim et al., 2011a). Nevertheless, the properties of such particleboards still need improvement in term of dimensional stability.

Particleboards were manufactured at different thickness levels depends on its final product desired; usually they are used for furniture panel and also for structural applications. Binderless board of higher thickness were developed from coconut husk and bagasse (Panyakaew & Fotios, 2011) and also cotton stalk fibers (Zhou et al., 2010) for thermal insulation material. However, there are no findings on higher thickness binderless particleboards from oil palm trunk. Apart from that, natural binders from renewable resources regained wide range of interest in particleboard production instead of conventional resin which is hazardous to human health and environment (Pizzi, 2006). Polylactic acid (PLA) is a biodegradable thermoplastic which have been used for biocomposites purposes (Wahit et al., 2012). Thus, its potential use as natural binder was investigated in this study.

In this study, the application of oil palm trunk particleboard as phantom material has been investigated. Phantom is a terminology used for tissue stimulating materials to mimic the properties of human or animal tissue in medical physics application. The properties of a phantom material are measured in term of mass attenuation coefficients, derived from Beer-Lambert law (Beutel et al., 2000), where the values obtained when the beams that passes through material is attenuated exponentially. Particleboard from wood resources specifically *Rhizophora* spp. particleboard exhibited excellent compatible with the mass attenuation coefficients of water because water is major constituents of human body hence proven to be a suitable tissue equivalent phantom material (Tousi et al., 2014b). Therefore, mass attenuation properties of oil palm trunk particleboard were determined to identify its suitability as phantom materials.

1.2 Problem statement

Over the years, oil palm industries generates substantial amount of waste from its plantation with its rapid development. It contributes adverse effect to the environment if those waste not managed properly. Utilization of those wastes for particleboard production may help to curb severe issue from the field. Thus, manufacturing particleboard of higher thickness may replace the demand for wood based products subsequently save natural resources for sustainability.

The major problem of particleboard from agricultural residues is its dimensional stability. The hygroscopic nature of oil palm particle tend to absorb water and moisture when expose to high humidity environments. Therefore, the study on manufacturing of oil palm trunk particleboard was designed to obtain improved dimensional stability with addition of polylactic acid which will be utilised as natural binder and also identify its potential use as phantom material.

1.3 Hypothesis

The general hypothesis of this study is that it is possible to manufacture binderless oil palm trunk particleboard of various thickness levels. It is possible that polylactic acid (PLA) have some potential to enhance basic properties of binderless particleboards. It is possible to use those particleboards as phantom material in the diagnostic energy range.

1.4 Objectives

The objectives of this study are:

a) To obtain optimum manufacturing conditions for binderless oil palm trunk particleboard at different thickness levels

b) To evaluate the properties of binderless particleboard and particleboard with addition of polylactic acid (PLA)

c) To investigate the mass attenuation properties of those boards as phantom material to be used at diagnostic energy range application

CHAPTER TWO: LITERATURE REVIEW

2.1 Oil palm

2.1.1 Description of oil palm

The oil palm (*Elaeis guineensis*) (Figure 2.1) is a tropical palm plant which originates from tropical forests in Africa. It is classified under family of *Aracaceae* with monocotyledons characteristics (Corley & Tinker, 2016). The African oil palm belongs to *Cocos* (the coconut) and other genera in the subfamily of *Arecoideae* and *Cocoseos* tribe (Adam et al., 2005). It is derived from hybrid of the *dura* and *pesifera* which belongs to the *tenera* variety (Keshvadi et al., 2011).

The *Elaeis guineensis* oil palm is a monoecious crop which both male and female flowers are found on the same tree. Oil palm trees are normally present as single-stemmed that can reach a height of up to 20 to 30 m at maturity (Edem, 2002). The oil palm tree is a large feather palm because it is covered with pinnate or "feather-like" shape leaves. Oil palm tree begins to yield fruits after 30 months of field planting and its productive period will continue for the next 25 to 30 years. Replanting process which is also called as economic life span of oil palm takes place as the height of tree reaches 7 to 13 m with diameter of 45 to 65 cm along with its age of 25 to 30 years (Corley & Tinker, 2016).

Figure 2.1: Oil palm trees (*Elaeis guineensis*)

2.1.2 Development of oil palm in Malaysia

Malaysia is blessed with ideal tropical climate throughout the year with temperature around 25 to 33 ºC and uniform distribution of rainfall of 2000 mm per year (Basiron, 2007). The strategic and comprehensive weather marked by all year, appears to be an essential factor for cultivation of oil palm in Malaysia. Hence, highest yields are expected to be attained from palm trees grown in this area (Yusoff, 2006).

The plantation was first introduced in Malaysia in the year 1870 as an ornamental plant and grows well as ambient climate for oil palm plantation. It was then established as commercial scale planting in the year 1917 at Tenamaran Estate, Selangor. Primarily, plantation sector began with rubber and coconut however oil palm manipulated total of land due to its high yields and also profits. The rehabilitation after the World War II was much faster in Malaysia and its oil palm industry was already in full operation by the year 1947 (Corley & Tinker, 2016).

Unsurprisingly, oil palm industry evolved as the most important agricultural crop and lead to the national economic expansion (Chiew & Shimada, 2013; Hashim et al., 2010; Sulaiman et al., 2009). Much encouragement from Malaysian government was given towards these industries not only for its future market but also to diversify the country's agricultural development from rubber to oil palm (Yusoff, 2006).

Malaysia emerged as one of leading producer and exporter of palm oil in the world as can be seen in Table 2.1 and Table 2.2. Oil palm industry in Malaysia producers of 19.22 million tonnes of palm oil or 34.4% of the total world's palm oil producers and exports of 17.20 million tonnes of palm oil which is equivalent to 41.4% of the total world's exporters.

Table 2.1: World major producers of palm oil: 2009 - 2013 ('000 tonnes)

Country	2009	2010	2011	2012	2013
Indonesia	19,324	21,958	23,097	26,016	26,896
Malaysia	17,565	16,994	18,912	18,785	19,217
Thailand	1,388	1,288	1,650	1,780	1,970
Nigeria	1,233	971	930	940	960
Colombia	805	753	805	973	1041
Papau New Guinea	478	500	580	520	500
Honduras	280	353	373	398	425
Cote d'Ivoire	345	360	371	418	415
Guatemala	180	182	248	310	402
Brazil	240	250	270	310	340
Ecuador	328	400	300	325	325
Costa Rica	206	227	242	256	300
Others	1,488	1,533	1,569	1,565	1,602
TOTAL	43,860	45,769	49,347	52,596	54,393

Source: Food and Agricultural Organization of the United Nations (FAOSTAT, 2015)

Table 2.2: World major exporters of palm oil: 2009/2010 - 2012/2013 ('000 tonnes)

Country	2009/2010	2010/2011	2011/2012	2012/2013	2012/2013 as % of world total
Indonesia	16,573	16,423	18,452	20,100	48.3
Malaysia	15,530	16,596	16,600	17,200	41.4
Papua New Guinea	520	577	587	620	1.5
Thailand	121	382	290	480	1.2
United Arab Emirates	344	400	385	350	0.8
Others	2,424	2,484	2,720	2,840	6.8
Total	35,315	36,862	39,034	41,590	

Source: Food and Agricultural Organization of the United Nations (FAOSTAT, 2015)

After the independence of Malaysia in the year 1957, the commercial cultivation of palm oil increased dramatically begin with 54,000 hectares in the year 1960 and subsequently emerged as leading palm oil producer and exporter by the year 1971, with plantation area of 352,385 hectares. Oil palm plantation in Malaysia had expanded in both Peninsular and East Malaysia, where Sabah and Sarawak cover largest portion of area of plantation. By 2013, total plantation area in Malaysia had expanded collectively about 5.23 million hectares (Figure 2.2). These values continue to increase by 3% to 5.39 million hectares in 2014 in comparison to the year 2013.

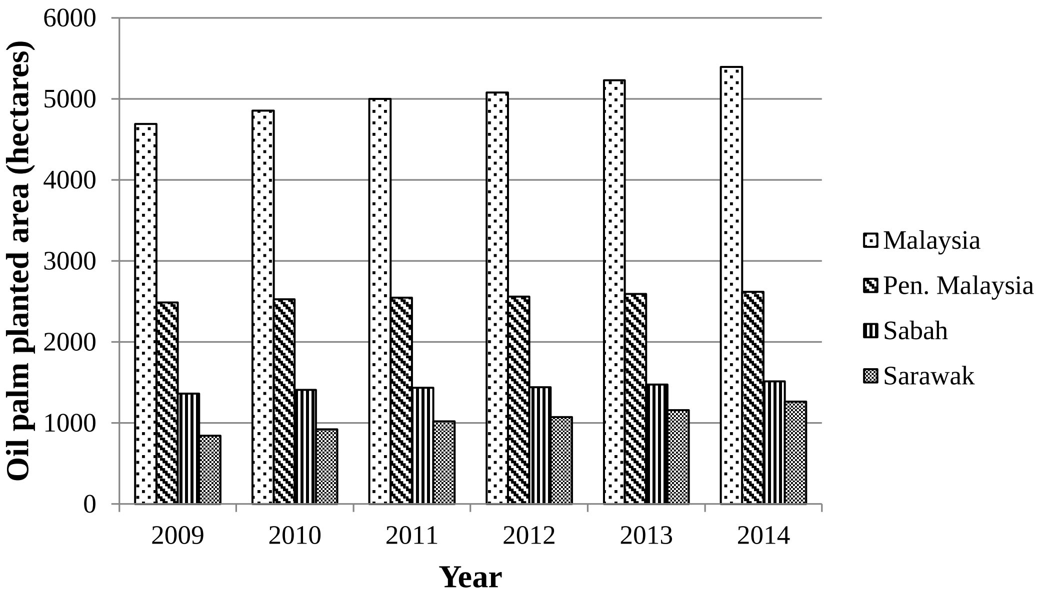

Figure 2.2: Oil palm planted area: 2009 - 2014 (hectares)

Source: Malaysian Oil Palm Statistic (MPOB, 2014)

2.1.3 Oil palm biomass

Subsequently, the palm oil industry also generates significant amounts of biomass every year. Most of the biomasses are converted as fertilisers in the plantation. Oil palm biomass produced as by-products from plantation can be divided into six categories namely oil palm fronds (OPF), oil palm trunks (OPT), mesocarp fibre (MF), empty fruit bunches (EFB), palm kernel shells (PKS) and oil palm mill effluent (AIM, 2013).

Malaysia has 5.39 million hectares of oil palm planted area and producing 19.67 million tonnes of crude palm oil in 2014 (MPOB, 2014). Thus, it is expected that they are more than 70,000 hectares of potential oil palm area which is due for replanting every year (Lai et al., 2012). During the replanting process, approximately 9 million palms will be felled. Apart from the felled oil palm trunks, large amount of other solid biomass such as empty fruit bunches and oil palm fronds also available from replanting process and also from routine field and mill operations.

As illustrated in Figure 2.3, it is estimated that about 85 million tonnes of biomass based on dry weight will be generated by the year 2020 (AIM, 2013). There are about 75% of the solid biomass namely fronds and trunks found in the oil palm plantation whereas the remaining 25% is produced during the extraction of oil in the mills.

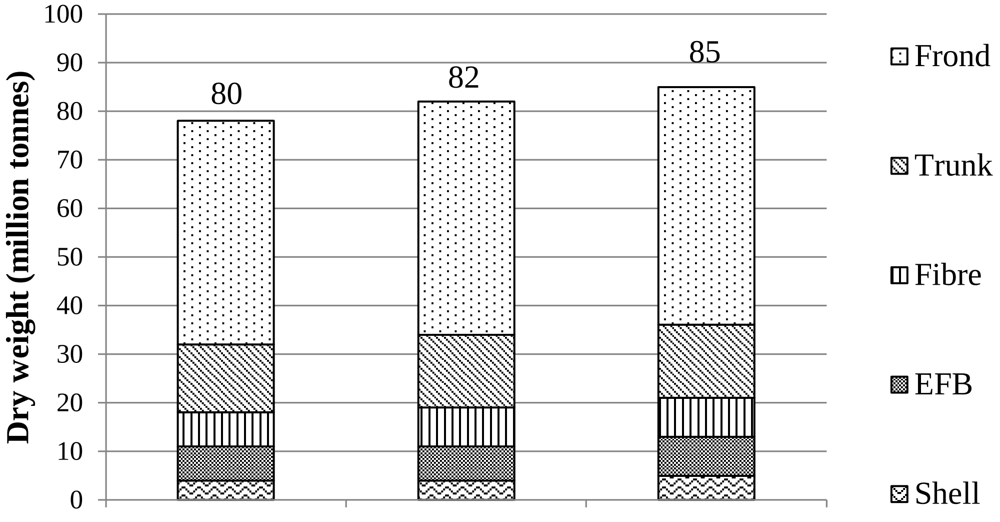

Figure 2.3: Potential availability of solid waste biomass from oil palm plantation Source: Agensi Inovasi Malaysia (AIM, 2013)

2.1.4 Oil palm trunks

Malaysia generates about 15.2 million tonnes of oil palm trunks annually (Shafawati & Siddiquee, 2013) and approximately 240 million tonnes of trunks will be generated for the next 10 years (AIM, 2013). Those trunks will be only available when the economic life span of palm tree achieved replanting period at an average age of about 25 years. At replanting stage, the length of felled palm trunk ranges from 7 to 13 m and 45 to 65 cm in diameter as measured from the breast height (Shafawati & Siddiquee, 2013). Currently, most of the trunks are retained in the field as fertiliser. They are either chipped or felled to decompose naturally in the plantation.

The judicious utilization of oil palm trunk as starting material in the wood industry could overcome dependent on wood material supply as depleting wood resources. Currently, some of those trunks were considered for niche uses such as flooring, plywood, fibre board and furniture in the wood industry (AIM, 2013). Some of the research institution also initiated the utilization of oil palm biomass for value added products for automotive, furniture, packaging, sawn timber and also wood industries (Ahmad et al., 2011). Oil palm trunk has been successfully used to produce particleboards with chemical binder (Chew & Ong, 1985) and also particleboard without binder or binderless (Hashim et al., 2012).

2.1.4(a) Anatomical features

Oil palms is categorized as monocotyledonous species, as such the trunk does not have cambium, secondary growth, ray cells, sapwood, heartwood, branches or knots (Lim & Gan, 2005). The rate of expansion of a trunk in term of growth and diameter is influence by the overall cell division and enlargement of cell of parenchymatous ground tissues and fibers enlargement in the vascular bundles (Sulaiman et al., 2012). It functions as supporting vascular and storage organ with long vascular bundles which encrusted in parenchymatous ground tissue.

The trunk comprise of three distinguishable parts namely cortex, the peripheral region and the central region based on the cross sectional view of the trunk (Figure 2.4). The outer region of oil palm trunk, bark, has a narrow cortex with approximate of 1.5 – 3.5 cm wide. The cortex is mostly composed of ground parenchyma with numerous strands of small and irregular shaped fibrous strands and vascular bundles (Lim & Khoo, 1986).

The peripheral zone of trunk is made up of narrow layers of parenchyma and congested vascular bundles with fibrous phloem sheaths. It contributes main mechanical support for the tree which is known as sclerotic zone. The central zone covers about 80% of the total area of the trunk. It comprises of slightly larger and widely scattered vascular bundles imbedded in the thin-walled parenchymatous ground tissue. In this zone, vascular bundles are much less densely packed as the presents of most storage tissue (Corley & Tinker, 2016). The size of bundles increase and also more widely scattered as nearing the inner part of the trunk.

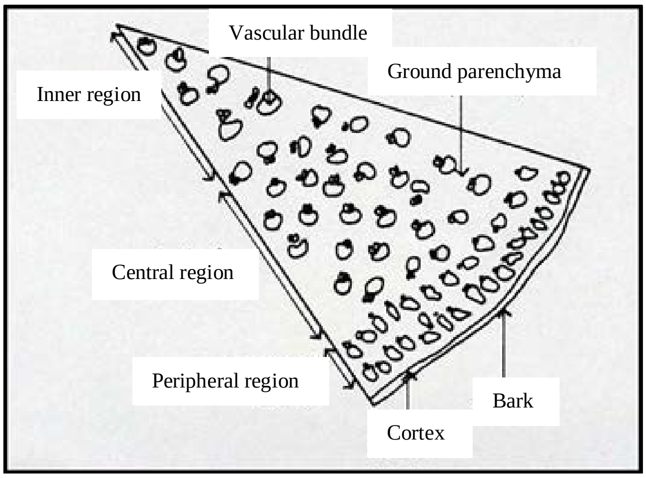

Figure 2.4: A schematic diagram on cross section of oil palm trunk (Sulaiman et al., 2012)

Xylem of oil palm is always covered by parenchyma which consists of one or two vessels with an average width of 0.17 mm in the peripheral region and two or three vessels with a diameter of 0.18 – 0.19 mm in the center region (Lim & Khoo, 1986). They are mostly secondary xylem, which comprise of primary vascular bundles imbedded in parenchymatous ground tissues as shown in Figure 2.5. Along the core region, bundles found to have more than three vessels which are arranged tangentially or in cluster. Apart from that, extended protoxylems, reduced vascular tissue and small bundles with little amount of fibrous tissue were also observed commonly in that region.

Phloem cells that present between xylem and fiber strand are in the form of single strand. Bundles generally are smaller and also irregular in shape, but phloem decrease in size to small and tiny strand and almost visible along the peripheral region. The ground parenchymatous cells mainly comprise of thin walled spherical cells which gets thicker and darker as observed from pith to peripheral region (Killmann & Lim, 1985).

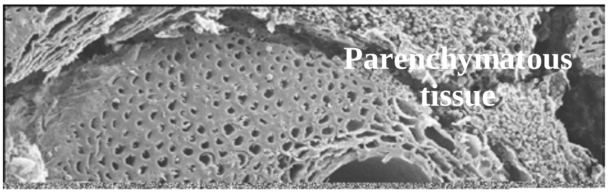

Figure 2.5: Vascular bundles with vessels of the core oil palm trunk

2.1.4(b) Physical properties

Some important physical properties of oil palm trunk are moisture content and density. The initial moisture content of a fresh felled trunk is estimated to be 1.5 to 2.5 times of the weight of the dry matter which varies between 120 to 500% (Lim & Gan, 2005). Moisture content increases as the height of trunk (from bottom to top portion) and towards the central region (from outer to inner portion) (Bakar et al., 1998). The accretion of moisture content influenced by the distribution of parenchymatous cells which retain more moisture than vascular bundles, abundantly present towards the center pith region.

Unlike moisture content, density reduces linearly with height of the trunk and towards the center of trunk that contributes to the hardness and weight of outer, inner, lower and higher portions of the trunk. The monocotyledonous nature of oil palm trunk contributes to wide differences of density values at each part of the oil palm trunk. Lim & Khoo (1986) reported that density value of the trunk range from 200 to 600 kg/m^3 with an average density of 370 kg/m^3.

2.1.4(c) Mechanical properties

The mechanical properties such as bending, compression and hardness of oil palm wood are influenced by density variation in both radial and vertical direction. The middle core part of the top portion of trunk exhibits lower strength value than the lower portion of peripheral region of trunk. Unlike other timber species, the bending strength of oil palm wood is generally poor in comparison to coconut wood, but lower compared to rubberwood (Lim & Gan, 2005).

The compression strength value of oil palm wood is in comparison to hevea wood with similar density values although it is inferior to other timber species (Singh et al., 1999). The hardness value of trunk is also lower than most timber species such as rubberwood and coconut wood. However, its hardness value towards peripheral lower portion, in the range of 350 – 2450N, in comparable to Norway spruce and poplar (Killmann & Lim, 1985).

2.1.4(d) Chemical composition of oil palm trunk

Oil palm biomass is a lignocellulosic residue consists of cellulose, hemicellulose and lignin, and its chemical composition varies based on different part of the tree and also its species. Cellulose is an organic compound found in lignocellulosic material which determines its chemical characteristics including degree of swelling by water, presence of specific functional groups, crystallinity and accessibility to cellulolytic enzyme. Hemicelluloses are responsible for moisture sorption and biological degradation in wood. Whereas lignin is a rigidifying and bulking agent and also works as adhesion in wood structure (Anglès et al., 1999).

Comparison of chemical composition of oil palm trunk by various authors is shown in Table 2.3. Oil palm trunk has remarkable high holocelluloses content followed by lignin content then little amount of extractives. Mature tissue at the base of tree accumulates higher amounts of metabolic products than the top portion of a tree which is the younger parts (Ververis et al., 2004).

Table 2.3: Chemical composition of oil palm trunk by various authors

Chemical composition (%)	Oil palm trunk			
	Kelly-Yong et al. (2007)	Abdul Khalil et al. (2008)	Hashim et al. (2011a)	
			Mid-part of trunk	Core-part of trunk
Cellulose	34.5	41.02	50.21	43.06
Hemicellulose	31.8	32.04	22.39	7.67
Lignin	25.7	24.51	20.15	22.75
Extractive	3.7	5.35	14.50	9.10
Ash	4.3	2.2	-	-

2.2 Composite panel

The terminology composite panel refers to any products that are manufactured from mechanically chipped, milled and grounded or refined wood, which are then bonded by adhesives at high temperature and pressure (Kharazipour, 2004; Maloney, 1993; Youngquist et al., 1997). They encompass a wide range of products such as plywood, strandboard, particleboard, fibreboard and etc as shown in Figure 2.6. The primary differences between them are specific density, density, raw material, particle size and also processing methods as illustrated in Figure 2.7. Composite panels are preferable for non-structural and also structural applications such as panels for interior covering and exterior purposes in furniture and as supporting structures in buildings (Stark et al., 2010).

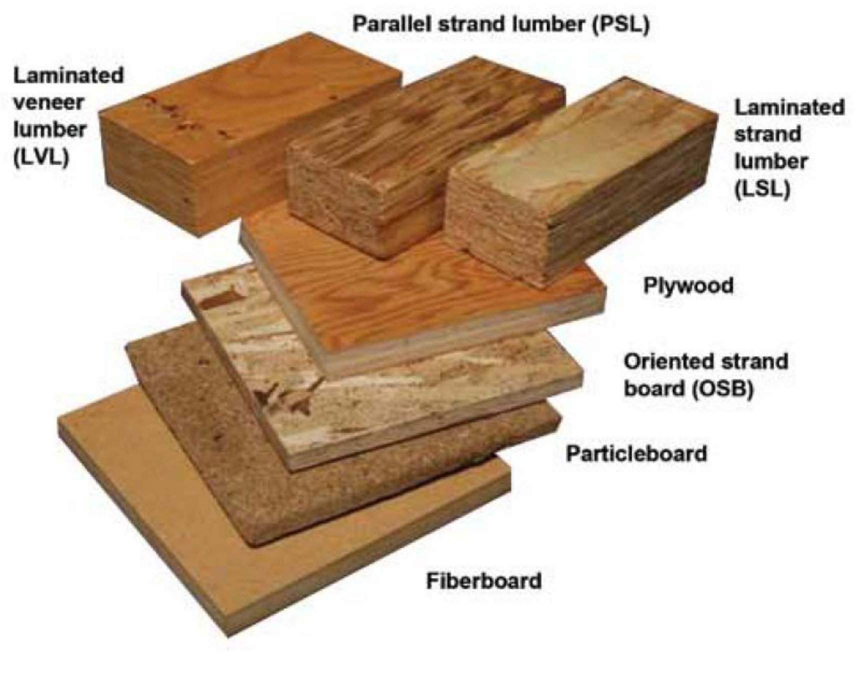

Figure 2.6: Examples of various types of composite panels (Stark et al., 2010)

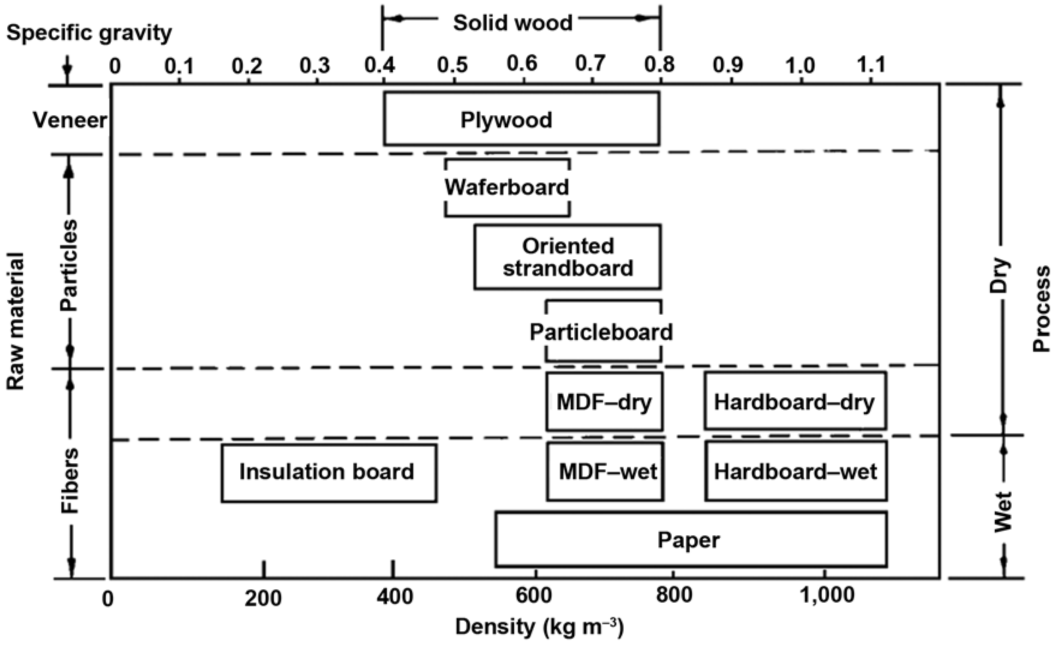

Figure 2.7: Classification of composite panels by particle size, density and processing method (Suchsland & Woodson, 1990)

2.2.1 Particleboard

2.2.1(a) General

Particleboard is a generic term used for any composite panels manufactured from mechanically reduced wood or other lignocellulosic materials into discrete particles (Maloney, 1993). Those particles are bonded together by applying synthetic adhesives, resins or binders and consolidating them under heat and pressure (Thoemen et al., 2010). The major types of particles used for particleboard manufacturing as shown in Figure 2.8. It is essential to classify the shape, size and type of particle used to define the type of product. However, the term particleboard pertains only for boards produced from a mixture of wood particles rather than wafers or flakes.

Figure 2.8: Common types of particles used as furnish for particleboard from top left, clockwise: shavings, sawdust, small particles, large particles, wafers and strands (Stark et al., 2010)

Particleboard was first manufactured in Bremen, Germany in the year 1941 (Walker, 1993) and currently it comprises large part of composite panels industry. Primarily, the economic concern on wood resources prompted development of particleboard from sawdust, planer shavings and also wood of smaller dimension includes mill residues and other waste materials (Stark et al., 2010). Particleboard exhibited satisfactory performance for interior applications in furniture for decorative purposes and do-it-yourself furniture, flooring as underlayment, panelling substrate and others.

In term of basic properties, particleboard is comparable to wood. It is homogenous or no grain direction and has same degree of strength in different directions. The density of particleboard varies between 0.60 to 0.80 g/cm^3, lowest and highest density randomly obtained, and also thickness range from 2 mm and 4 cm depends on its final product application (Abdul Khalil & Hashim, 2004). The most important strength properties of particleboard are modulus of elasticity (MOE), modulus of rupture (MOR) and internal bond strength (IB). Other properties include screw holding strength, thermal conductivity and sound insulation (Abdul Khalil & Hashim, 2004) primarily depends on density and thickness of board.

2.2.1(b) Types of raw material

Rubberwood is the most prominent and conventional source of raw material for particleboard manufacturing in Malaysia (Azry et al., 2015) as it meets the entire requirement of the industrial standard for particleboard. The rubberwood supply is being strained with its limited source, especially for furniture industry, as growing demand for rubberwood. Abundant number of lignocellulosic materials is available and capable to replace demand for rubberwood and transformed into particleboard. Those materials generally available in adequate quantities, inexpensive, in a suitable form for board manufacturing and acquire relatively low cost of handling and also storage.

The particleboard industry also has diversified its use of raw material by utilization of non wood lignocellulosic materials especially agricultural residues. In Malaysia, particleboards were manufactured from empty fruit bunch (EFB) for school and office desks and chairs, table tops and also cabinets. Production of particleboards were successfully produced from materials such as wheat straw, paddy straw, reed, *Miscanthus* fibers, bamboo, hemp fibers, flax, jute fibers, kenaf core, cotton stalks, banana fibers, sunflower stalks and peels, corn stover and maize cobs, rice husks, peanut shells, almond husks, durian peels, coconut stem chips, pith and coir, oil palm fronds and trunks, sugarcane bagasse, sisal, rattan and many others (Prasad et al., 2013).

2.2.1(c) Manufacturing process

Commercially, particleboard manufacturing involves dry process. The basic process of particleboard manufacturing process as illustrated in Figure 2.9.

Particle preparation involves reduction of raw material by combinations of chippers, hogs, hammermills, ring flakes, ring mills and attrition mills (Stark et al., 2010). Particles are sorted and separated according to size and shape, such as fine, coarser and oversize, to reduce negative impact on final product. The fine particles increase particle surface area and also give a smooth surface on finished product. The coarse or oversized particles have negative influence on the quality of final product due to internal flaws in the particles (Stark et al., 2010).

Moisture content of particle is constrained by drying process; usually it is reduced up to 4 to 8% depends on the type and amount of resin. Such a low moisture content required as it is unfavourable during hot pressing procedure. The type and amount of resin used in the particleboard production depends on type of product desired. Urea formaldehyde and phenol formaldehyde are commercially used resins for particleboard manufacturing at average resin content of 4% to 10% (Thoemen et al., 2010).

The blended particles are formed into a mat to be pressed into a board. The formed mat generally pre pressed in order to decrease height of mat and consolidate the mat before pressing stage (Stark et al., 2010). The mats are hot pressed into boards after pre pressing procedure. Cooling, trimming and moisture equalization were carried out after pressing. Particleboards are then cut into size, overlaying, routing or filling the surface depend on the market demand (Stark et al., 2010).

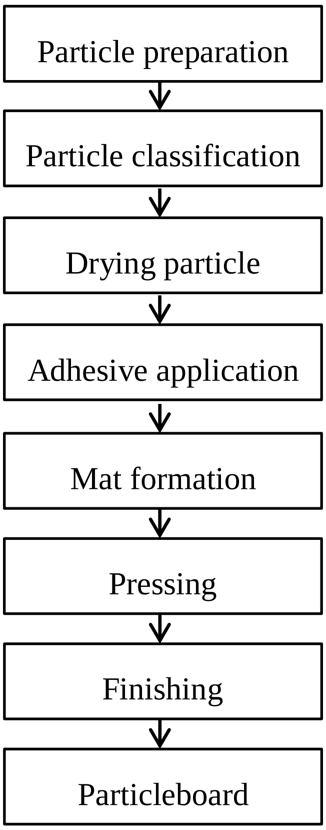

Figure 2.9: General flow of process of particleboard production (Abdul Khalil & Hashim, 2004)