PROPERTIES OF PARTICLEBOARDS MADE FROM OIL PALM TRUNK WITH ADDITION OF POLY-3-HYDROXYBUTYRATE

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PROPERTIES OF PARTICLEBOARDS MADE FROM OIL PALM TRUNK WITH ADDITION OF POLY-3-HYDROXYBUTYRATE

by

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%	percentage
°C	degree celcius
°C/min	degree celcius per minute
µl	microliter
µm	micrometer
AD	air dry
cm	centimeter
cm^3	centimeter cube
DSC	Differential scanning calorimetry
EFB	empty fruit bunch
SEM	Scanning Electron Microscopy
FTIR	Fourier Transform Infra Red
GC	Gas chromatography
h	hours
IB	Internal bond strength
KBr	potassium bromide
kg/m^3	kilogram per meter cube
m	meter
min	minute
ml/min	milliliter per minute
mm	millimeter
mm/min	millimeter per minute
MOR	Modulus of rupture
MPa	Mega Pascal

NPCM	non PHA cellular materials
OD	oven dry
OPF	oil palm frond
OPT	oil palm trunk
Pa	Pascal
PHA	Polyhydroxyalkanoates
P(3HB)	Poly-3-hydroxybutyrate
PORIM	Palm Oil Research Institute of Malaysia
R_a	average roughness
R_{max}	maximum roughness
R_z	mean peak-to-valley height
TGA	Thermogravimetric analyses
T_m	melting temperature
TS	Thickness swelling
WA	Water absorption
XRD	X-ray diffraction

SIFAT-SIFAT PAPAN SERPAI YANG DIPERBUAT DARIPADA BATANG KELAPA SAWIT DENGAN PENAMBAHAN POLI-3-HIDROKSIBUTIRAT

ABSTRAK

Kajian ini dilaksanakan bertujuan untuk mengkaji kesan penggunaan poli-3-hidroksibutirat [P(3HB)] ke atas sifat-sifat papan serpai yang dihasilkan daripada batang kelapa sawit (*Elaeis guinensis*). Dua jenis papan serpai iaitu papan serpai yang dihasilkan daripada partikel kelapa sawit yang dirawat dengan stim dan papan serpai tanpa rawatan stim dihasilkan dengan ke atas ketumpatan 0.80 g/cm^3, pada suhu tekanan 180 °C, kadar tekanan 5 MPa dan masa tekanan 20 min. Rawatan stim ke atas partikel kelapa sawit dilakukan pada suhu 130 °C selama 30 min sebelum ia digunakan untuk menghasilkan papan serpai. Poli-3-hidroksibutirat dalam bentuk kering sejuk beku dan tulen telah digunakan sebagai bahan tambahan dengan peratusan 1%, 3%, 5% dan 10% berdasarkan berat kering ketuhar partikel kelapa sawit yang digunakan. Kesan P(3HB) pada papan serpai yang dirawat dengan stim dan tanpa rawatan stim telah dianalisis secara fizikal dan mekanikal berdasarkan piawaian industri Japan, JIS. Analisis lanjutan seperti kekasaran permukaan, gas kromatografi, analisis termagravimetrik, spektroskopi inframerah tranformasi Fourier, belauan sinar-X, mikroskop pengimbasan electron dan juga pengimbasan kalorimetri pembezaan disiasat. Sifat-sifat mekanikal dan kestabilan dimensi spesimen meningkat apabila peratusan P(3HB) dalam panel bertambah untuk kedua-dua jenis panel. Semua panel menempati syarat minimum piawaian JIS untuk sifat-sifat mekanikal sahaja. Papan serpai tanpa rawatan stim dengan penambahan 10% P(3HB) tulen mempamerkan sifat fizikal dan mekanikal yang tertinggi. Berdasarkan keputusan yang diperolehi, P(3HB) boleh dipertimbangkan sebagai bahan tambahan berpotensi bagi meningkatkan ciri-ciri menyeluruh papan serpai tanpa pengikat tersebut.

PROPERTIES OF PARTICLEBOARDS MADE FROM OIL PALM TRUNK WITH ADDITION OF POLY-3-HYDROXYBUTYRATE

ABSTRACT

This study was designed to evaluate the influence of adding poly-3-hydroxybutyrate [P(3HB)] on the properties of particleboards made from oil palm (*Elaeis guinensis*) trunk. Two types of boards which are particleboards made up of steam treated particles and untreated particleboards, were manufactured from oil palm trunk particles with a target board density of 0.8 g/cm^3, pressing temperature of 180 °C, pressing pressure of 5 MPa and pressing time of 20 min. The steam treatment was carried out by subjecting the oil palm trunk particles at a temperature of 130 °C for 30 min before those particles was used for particleboard production. Poly-3-hydroxybutyrate in the form of freeze dried and pure were used as additives at various loadings namely 1%, 3%, 5% and 10% based on the oven dry weight of oil palm trunk particles used. The influence of P(3HB) towards untreated and steam treated particleboards were analyzed both physically and mechanically based on Japanese Industrial Standard, JIS. Further analysis such as surface roughness, gas chromatography, thermogravimetric analyses, Fourier transform infrared spectroscopy, X-ray diffraction, scanning electron microscopy and differential scanning calorimetry were also carried out. Mechanical properties and dimensional stability of panels were improved with increasing amount of P(3HB) added for both type of panels. All the panels meet the minimum requirement of JIS for mechanical properties only. The untreated particleboard with addition of 10% of pure P(3HB) seems to exhibit highest value for the mechanical and physical properties. Based on the findings, P(3HB) could be considered as a potential additive to improve the overall properties of such binderless particleboard.

CHAPTER ONE: INTRODUCTION

1.1 Background

Large scale plantation of oil palm (*Elaeis guineensis*) was rapidly developed in Malaysia since early 1960’s (Yusoff, 2006). The growth of the oil palm plantation has been phenomenal. It was cultivated mainly for its oil producing fruits for a certain period of time. After productive life span oil palms are harvested and replanting is carried out. However, harvested trunks are mostly left to rot or burned in the field which may cause an important environmental problem. Oil palm trunks which are considered as waste can be transformed as an alternative potential raw material to be used for manufacture of value added composite panels such as particleboard.

Development of composite from agricultural resources has attracted keen amount of interest due to the utilization of alternative raw materials. Alternative raw materials such as empty fruit bunch, kenaf, stalk, jute, flax, reed, cotton, sugarcane bagasse, rice straw, rice husks and even coconut husk (coir). In composite manufacturing, various types of binders had been implemented for satisfactory physical and mechanical properties of the panel. Formaldehyde based binder is the most commonly used as a binder in particleboard industry in almost all countries. However, formaldehyde emission from manufactured product is one important disadvantage of these binders. Thus, reducing consumption of formaldehyde based binder is desirable to minimize negative impact on the health and environment. Therefore, manufacturing of particleboard without any adhesives demonstrate an alternative way to eliminate harmful concepts of synthetic binders. Increased utilization of agricultural residues, in particular oil palm trunk, is strategically viable, as it can minimize the negative impacts on the environment and subsequently solve the agricultural disposal problem in an environmentally friendly manner.

1.2 Problem statement

The demand for wood based panels has increased substantially during the past few decades. However, continuous usage of wood as raw materials for furniture production leads to shortage of wood supply. Instead of depending on wood resources, agricultural residues can also be utilized. Huge amount of oil palm biomass is being produced every year from its plantation. They are mostly left to rot or burned in the field that lead to environmental problems. Moreover, cost of particleboard production is reaching sky due to the utilization of synthetic adhesives. It is one of expensive materials in the particleboard production (Laemsak and Okuma, 2000). It is a well known fact that formaldehyde emission not only affects health but also cause problem to the environment. Therefore, this study evaluates the influence of poly-3-hydroxybutyrate on the properties of particleboard made from oil palm trunk.

1.3 Hypothesis

The general hypothesis of this study is that it is possible that poly-3-hydroxybutyrate have some potential to enhance the basic properties of binderless particleboards made from oil palm trunk.

1.4 Objectives

The objectives of this study are:

a) To determine the bonding ability of oil palm trunk particles with poly-3-hydroxybutyrate [P(3HB)].

b) To study the mechanical and physical properties of binderless particleboard made from oil palm trunk.

c) To evaluate the influence of adding freeze dried P(3HB) and pure P(3HB) samples at various loading on the board properties.

d) To compare the properties of boards made from untreated and steam oil palm trunk particles.

CHAPTER TWO: LITERATURE REVIEW

2.1 Oil palm plantation industry

2.1.1 Development of oil palm in Malaysia

The oil palm was first introduced into Malaya as an ornamental plant way back in 1875 (Basiron, 2007). The first commercial planting was established in 1917 at Tennamaran Estate in Kuala Selangor (Hartley, 1967). Primarily, plantation sector starts with rubber and coconut; however prospects of high yields and profits of oil palm manipulated total of land (Corley and Tinker, 2003). After the World War II, rehabilitation was much faster in Malaysia and its oil palm industry was already in full operation by the year 1947 (Hartley, 1967).

The growth of its industry was initially very slow but steeply improved throughout the 1950s and then moves at a fast rate (Hartley, 1967). Much encouragement was given towards these industries not only for its future market for oil palm but also to diversify the country’s agricultural development from rubber to oil palm and to upgrade the socio-economic status of the growing population in the country.

2.1.2 Oil palm in Malaysia

Oil palm is one of the most economical perennial oil crops in Malaysia (Abdul Khalil et al., 2008). It belongs to the species *Elaeis guineensis* under the family *Aracaceae* and originated in the tropical forests of West Africa (Corley and Tinker, 2003). Malaysia is blessed with ideal tropical climate which is marked by all year round temperature ranging from 25 to 33 °C and evenly distributed rainfall of 2000 mm per year (Basiron, 2007). Such a favorable weather conditions which prevail throughout the year, appears to be an advantageous for palm oil cultivation. Thus, it is expected that highest yields have been attained from palms grown in this region that locates far from its natural habitat (Yusoff, 2006).

Palm oil is produced in 42 countries worldwide on about 27 million acres (Abdul Khalil et al., 2008). However, Malaysia emerged as the world's leading producer and exporter of palm oil comparable to Indonesia as can be seen in Table 2.1. The high demand for palm oil throughout the world had contributed to the increase in palm oil production and export to the countries. The country producers of 17.57 million tonnes of palm oil or 39% of the total world's palm oil producers and exports of 15.88 million tones of palm oil which equivalent to 45.2% of the total world's exporters (Tables 2.1 and 2.2).

2.1.3 Oil palm planted area in Malaysia

Over the last four decades, preference for oil palm has promoted to a rapid expansion of its planted areas in Malaysia (Basiron, 2007). Areas under oil palm increased from 54,000 hectares in 1960 and subsequently emerged as the world's leading producer and exporter of palm oil in 1971, with about 352,385 hectares of plantation. The total planted area had expanded to about 4.69 million hectares in 2009 (Table 2.3). This values continue to rise where current data indicated that the total oil palm planted area in Malaysia increased by 3.4% to 4.85 million hectares in 2010 compared to 2009 (Malaysian Oil Palm Statistic, 2011).

Table 2.1: World major producers of palm oil: 2000 – 2009 (‘000 tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Indonesia	7,050	8,080	9,370	10,600	12,380	14,100	16,050	17,270	19,200	20,900
Malaysia	10,842	11,804	11,909	13,355	13,976	14,962	15,881	15,824	17,734	17,565
Thailand	525	625	600	690	735	700	860	1,020	1,300	1,310
Nigeria	740	770	775	785	790	800	815	820	830	860
Colombia	524	548	528	527	632	661	714	733	778	765
Ecuador	218	228	238	262	279	319	352	396	418	448
Papua New Guinea	336	329	316	326	345	310	365	382	445	430
Cote d’Ivoire	278	205	265	240	270	320	305	315	290	325
Honduras	101	130	126	158	170	180	195	220	273	290
Brazil	108	110	118	129	142	160	170	190	220	260
Guatemala	65	70	86	85	87	92	125	130	185	238
Costa Rica	137	150	128	155	180	210	189	200	202	220
Venezuela	70	52	55	41	61	63	66	70	90	95
Others	873	883	895	906	1,131	1,099	1,202	1,262	1,340	1.359
TOTAL	21,867	23,984	25,409	28,259	31,178	33,976	37,289	38,832	43,305	45,064

Source: Malaysian Oil Palm Statistic, 2011

Table 2.2: World major exporters of palm oil: 2000 – 2009 (‘000 tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Malaysia	9,081	10,625	10,886	12,266	12,575	13,445	14,423	13,747	15,412	15,881
Indonesia	4,139	4,940	6,490	7,370	8,996	10,436	12,540	12,650	14,612	15,910
Papua New Guinea	336	327	324	327	339	295	362	368	446	425
Cote d’Ivoire	72	74	65	78	109	122	109	106	96	112
Colombia	97	90	85	115	214	224	214	316	310	205
Singapore*	240	224	220	250	237	205	207	186	205	197
Hong Kong*	158	192	318	185	127	39	20	20	13	19
Others	896	1,099	1,027	1,320	1,647	1,736	2,121	2,474	2,654	2,403
TOTAL	15,019	17,571	19,415	21,911	24,244	26,502	29,996	29,867	33,748	35,152

Note : * - Includes Re-Exporting Countries

Source : Malaysian Oil Palm Statistic, 2011

Table 2.3: Oil palm planted area: 1975 – 2009 (hectares)

Year	Peninsular Malaysia	Sabah	Sarawak	Total
1975	568,561	59,139	14,091	641,791
1976	629,558	69,708	15,334	741,600
1977	691,706	73,303	16,805	781,814
1978	755,525	78,212	19,242	852,979
1979	830,536	86,683	21,644	938,863
1980	906,509	93,967	22,749	1,023,306
1981	983,148	100,611	24,104	1,107,863
1982	1,048,015	110,717	24,065	1,182,797
1983	1,099,694	128,248	25,098	1,253,040
1984	1,143,522	160,507	26,237	1,330,266
1985	1,292,399	161,500	28,500	1,482,399
1986	1,410,923	162,645	25,743	1,599,311
1987	1,460,502	182,612	29,761	1,672,875
1988	1,556,540	213,124	36,259	1,805,923
1989	1,644,309	252,954	49,296	1,946,559
1990	1,698,498	276,171	54,795	2,029,464
1991	1,744,615	289,054	60,359	2,094,028
1992	1,775,633	344,885	77,142	2,197,660
1993	1,831,776	387,122	87,027	2,305,925
1994	1,857,626	452,485	101,888	2,411,999
1995	1,903,171	518,133	118,783	2,540,087

Year	Peninsular Malaysia	Sabah	Sarawak	Total
1996	1,926,378	626,008	139,900	2,692,286
1997	1,959,377	758,587	175,125	2,893,089
1998	1,987,190	842,496	248,430	3,078,116
1999	2,051,595	941,322	320,476	3,313,393
2000	2,045,500	1,000,777	330,387	3,376,664
2001	2,096,856	1,027,328	374,828	3,499,012
2002	2,187,010	1,068,973	414,260	3,670,243
2003	2,202,166	1,135,100	464,774	3,802,040
2004	2,201,606	1,165,412	508,309	3,875,327
2005	2,298,608	1,209,368	543,398	4,051,374
2006	2,334,247	1,239,497	591,471	4,165,215
2007	2,362,057	1,278,244	664,612	4,304,913
2008	2,410,019	1,333,566	744,372	4,487,957
2009	2,489,814	1,361,598	839,748	4,691,160

Source : Malaysian Oil Palm Statistic, 2011

2.1.4 Botanical classification

Oil palms are categorized as woody monocotyledons that derived from the family of Arecaceae (formerly known as the Palmae). The Arecaceae is placed in the order Arecales (Integrated Taxonomic Information System, 2009). The oil palm (*Elaeis guineensis* Jacq.) belongs to the subfamily of Arecoideae, tribe Cocoeae and sub tribe Elaeidinae. *Elaeis guineensis* Jacq. Species are also well known as the African oil palm (Integrated Taxonomic Information System, 2009).

2.1.5 Availability of oil palm biomass

As oil palm triggered the expansion of its plantation area around the world, apparently massive quantities of residues raise concerns. The oil palm industry produces more than one hundred million tonnes of residues worldwide yearly (Kelly-Yong et al., 2007). In Malaysia, large amount of residues being produced from oil palm plantation compared to other types of biomass (Kelly-Yong et al., 2007).

Oil palm appears to be a prolific producer of biomass which includes empty fruit bunches (EFB), oil palm fronds (OPF), oil palm trunks (OPT), fibers and shells. These types of biomass made available from replanting and through routine field and mill operation. From Table 2.4, it has been estimated that 77.24 million tonnes of biomass being generated from 4.69 million hectares of oil palm plantation area in Malaysia in 2009 (Malaysian Oil Palm Statistic, 2011). It comprises of 44.84 million tonnes of oil palm fronds (OPF), 13.97 million tonnes of oil palm trunks (OPT), 6.93 million tonnes of empty fruit bunches (EFB), 11.5 million tonnes of oil palm fibers and shells based on dry weight (Table 2.4).

Table 2.4: Potential availability of biomass from oil palm plantation

	Estimated amount
Oil palm plantation area	4.69 million hectares
Estimated biomass	77.24 million tonnes (dry)
Estimated oil palm fronds (OPF)	44.84 million tonnes (dry)
Estimated empty fruit bunches (EFB)	6.93 million tonnes (dry)
Estimated oil palm trunks (OPT)	13.97 million tonnes (dry)
Estimated oil palm fibers and shells	11.5 million tonnes (dry)

Source: Malaysian Oil Palm Statistic, 2011

2.1.6 Oil palm trunks

Oil palm trunks are one type of lignocellulosic material and major co-product accessible in mass quantities from oil palm plantation but with no commercial benefit. They are available only when the economic life span of the palm is reached at the time of replanting at the average age of replanting of about 25 years (Singh et al., 1999). As the height of palm tree reaches 13 m and above, and annual yield of bunches falling below 10-12 tonnes per hectare are considered important factors for felling (Singh et al., 1999). It is estimated that about 14 million tonnes of oil palm trunk will be available for 25 years of planting routine (Wahid et al., 2006).

At present, oil palm trunks are not efficiently utilized after cutting session and thus creating problems such as air pollution if they were burnt. A solution needs to be figured out to reduce waste of the oil palm plantation and to maximize the utilization of the oil palm trunks. Most of the research institution suggested that oil palm biomass can be considered as an optional material for manufacturing products for sawn timber, packaging, automotive, furniture and related wood industries (Ahmad et al., 2011).

The judicious utilization of oil palm trunk as raw material in the wood products could solve inadequacy supply of raw material. Most of the oil palm trunk is converted into various types of wood such as sawn timber and plywood or lumber. It has been reported that oil palm lumber has been utilized as core in the production of blockboard and sawn wood from oil palm for furniture due to its low specific density. They also stated that oil palm trunk can be used as plywood which was found to have comparable strength with the commercial plywood and particleboards with the addition of chemical binder (Sumathi et al., 2008).

2.1.6.1 Anatomical features

Oil palm trunk reaches a height of 7 to 13 m and diameter ranging from 45 to 65 cm at replanting period measuring at 1.5 m above the ground level (Singh et al., 1999). The trunk functions as a supporting, vascular and storage organ. It consists of long vascular bundles, encrusted in parenchymatous ground tissue.

The rate of expansion of a trunk in term of growth and diameter depend on the overall cell division and cell enlargement in the parenchymatous ground tissues and enlargement of fibers of the vascular bundles. In contrast to dicotyledons and gymnosperms, oil palms are categorized as a monocotyledonous species as it does not possess cambium and little or no true secondary thickening (Killmann and Lim, 1985).

2.1.6.1.1 Cortex, periphery and central

The trunks comprise of three distinguishable parts namely cortex, the peripheral region and the central zone based on the cross sectional view of the trunk (Figure 2.1). The outer part of the trunk is the ‘bark’ which has a narrow cortex with approximate of 1.5 – 3.5 cm wide. The cortex is largely composed of ground parenchyma with numerous strands of small and irregular shaped fibrous strands and vascular bundles.

The peripheral zone of the trunk composed of narrow layers of parenchyma and congested vascular bundles with fibrous phloem sheaths. This creates a sclerotic zone that provides the main mechanical support for the palm trunk. 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 the central zone, vascular bundles are much less densely packed because most of the storage tissue is located (Corley and Tinker, 2003). The size bundles increases and more widely scattered as approaching the core part of the trunk.

2.1.6.1.2 Vascular bundles and parenchymatous tissue

As shown in Figure 2.2, xylem of oil palm is always sheathed by parenchyma and contains 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 core. They are mostly secondary xylem, which consists of primary vascular bundles imbedded in parenchymatous ground tissues (Parthasarathy and Klotz, 1976). It was also found that along the core region, bundles with more than three vessels are arranged tangentially or in clusters. Throughout that region, extended protoxylems, reduced vascular tissue and small bundles with a small amount of fibrous tissue are more commonly observed.

Based on Killman and Lim (1985) study, phloem cells that are found between the xylem and the fiber strand are present in single strand. Bundles are generally smaller and irregular in shape throughout the peripheral region but, phloem reduced to small and tiny strand and almost disappears. The ground parenchymatous cells mainly consist of thin-walled spherical cells. The walls of these parenchyma cells progressively became thicker and darker as observed from the pith to the peripheral region. The texture was spongy, especially in the pith region.

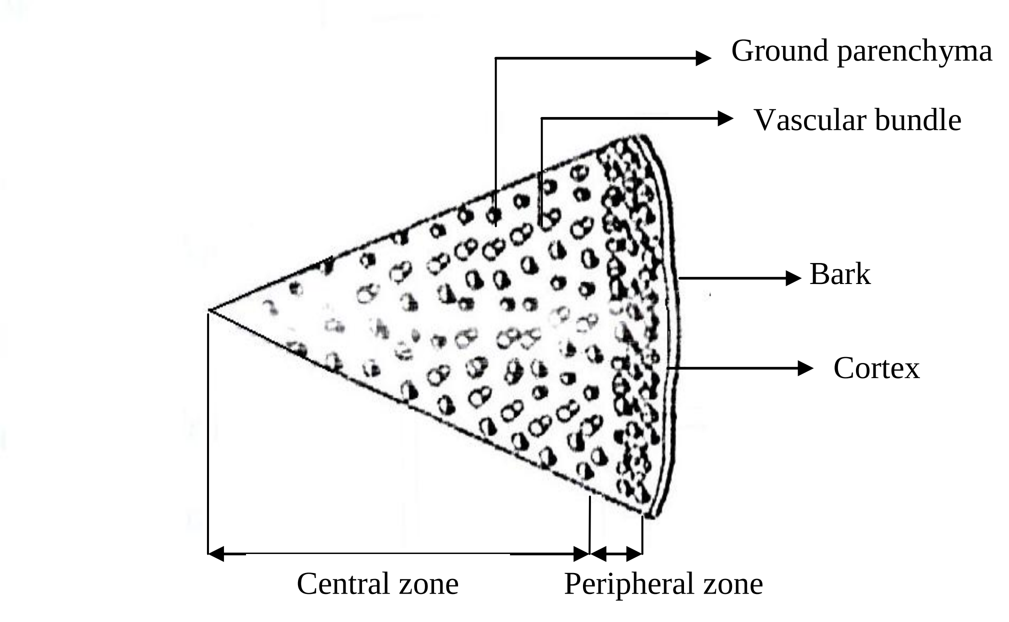

Figure 2.1: A schematic diagram on cross-section of an oil palm trunk division into various anatomical parts. (Source: Khozirah et al., 1991)

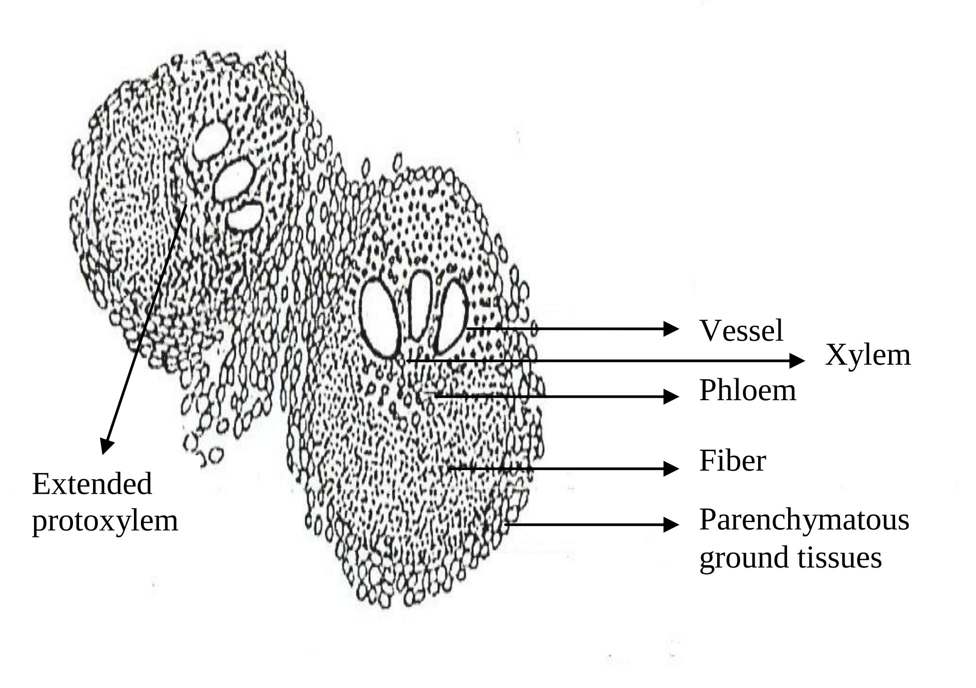

Figure 2.2: Vascular bundles of oil palm trunk which show the vessel, phloem, fiber and parenchymatous ground tissue. (Source: Killman and Lim, 1985)

2.1.6.2 Physical properties

A freshly felled trunk contains high moisture content, which is estimated to be about 1.5 to 2.5 times of the weight of the dry matter. Killman and Lim (1985) reported that moisture content of the trunk differs between 100 until 500%. Moisture content increases with increasing of trunk height (from bottom to top portion) and increases towards the central portion (from outer to inner portion) (Lim and Khoo, 1986). The accretion of moisture content is due to the distribution of the parenchymatous cells that retain more moisture than vascular bundles, which are more abundant towards the center pith region.

The monocotyledonous nature of oil palm trunk leads to a great variation of density values at different parts of the oil palm trunk. Lim and Khoo (1986) reported that the density value of the trunk range from 200 to 600 kg/m^3 with an average density of 370 kg/m^3. Unlike moisture content, density decreases linearly with trunk height and towards the center of the trunk. This is clearly reflected the hardness and weight between the outer and inner portions and the lower and higher portions of the trunk. Throughout the trunk, the outer portion showed density values over twice than those of the inner portion.

2.1.6.3 Mechanical properties

The mechanical properties of the oil palm trunk reflect the density variation in both radial and vertical direction. Unlike other timber species, the bending strength of oil palm trunk is generally poor but comparable to coconut wood (Lim and Gan, 2005). The lower portion of peripheral part of the trunk gives higher strength values than the central core of the top portion of the trunk. Variation of the compression strength parallel to grain also exhibits same trend as the bending strength.

The compression strength value of oil palm trunk is comparable to havea wood at similar density values even though it is inferior to other timber species (Singh et al., 1999). Despite, the hardness value of the trunk is generally lower than most timber species including rubberwood and coconut wood. However, the hardness of the trunk from the peripheral lower portion is comparable to those of Norway spruce and poplar wood (Killmann and Lim, 1985).

2.1.7 Chemical composition of oil palm tree

In general, oil palm consists of cellulose, hemicellulose and lignin, and its composition differs based on plant species. Cellulose is basically a polymer with linear chains of glucopyranose units with a molecular weight of about 100,000 linked to each other by its C1 and C4 in beta configuration. Hemicellulose is made up of a complex mixture of several polysaccharides such as mannose, glucose, xylose, arabinose, methylglucoronic and galacturonic acids. It is a component of the cell wall with average molecular weight of about 30,000. Lignin is a mononuclear aromatic polymer which is also found in the cell wall. Hemicellulose and lignin can form a complex component that is known as lignocellulose because both of these components are near and adjacent to each other in the cell wall (Goyal et al., 2008).

The different chemical composition in various types of oil palm fibers is shown in Table 2.5. Oil palm trunk fibers have the highest extractives content compared to other fibers. The high extractives content (especially oil and wax) contributes to the high dimensional stability in these fibers. They also have the highest percentage of lignin. This was expected since mature tissues at the base (trunk) accumulate higher amounts of metabolic products than the younger parts at the top portion (fronds and branches) (Ververis et al., 2004). Generally, oil palm fibers have higher ash content compared to wood fibers (Table 2.5).

Table 2.5: Chemical composition of oil palm tree and wood fibers

	Chemical composition (%)				
	Extractive	Holocellulose	Cellulose	Lignin	Ash
Empty fruit bunch (EFB)	3.21	80.09	50.49	17.84	3.4
Oil palm frond (OPF)	4.40	83.54	56.03	20.48	2.4
Oil palm trunk (OPT)	5.35	73.06	41.02	24.51	2.2
Hardwood	0.1 – 7.7	71 – 89	31 – 64	14 – 34	<1
Softwood	0.2 – 8.5	60 -80	30 – 60	21 – 37	<1

Source: Abdul Khalil et al., 2008 (EFB, OPF & OPT)

Tsoumis, 1991 (Hardwood & Softwood)

2.1.8 Major drawbacks of oil palm biomass

Oil palm biomass is suitable for manufacturing most of the wood based products such as composite products. However, there are a number of limitations as listed below in Table 2.6:

Table 2.6: Major drawbacks of oil palm biomass

Limitations	Explanations
Storage	• Oil palm biomass is highly susceptible to be attacked by fungi that cause discolouration, which may affect the final product. • This storage problem needs to be solved before setting up for the manufacture of wood-based products.
Parenchyma cell	• Parenchymatous ground tissue that cements the vascular bundles together is undesirable for the manufacture of wood-based products. • Especially in particleboard manufacturing, it may interfere with the bonding between particles and will reduce strength properties.
High silica content	• The high silica content presents difficulties in cutting and chipping the biomass into desired shapes and sizes. • It has been reported that the dulling of knife blades occurs after only five minutes of chipping of oil palm trunk. • The wood-based products obtained from oil palm biomass could also inherit this property unless the silica content is first reduced below the tolerable limit.
Low bulk density and high moisture content	• Apparently heavy weight of fresh oil palm trunk is attributed to high moisture content. • Thus, the high transportation cost of fresh oil palm biomass from the field to the factory will include cost for the transportation of water (about two to three times the weight of biomass), parenchyma cells (about 30% of biomass) which will have to be discarded.

Source: Basiron et al., 2000

2.2 Particleboard

2.2.1 General

In the forties, the development in the particleboard industry arises as research and industry integrate its contributions (Moslemi, 1973). It appears to be a new substitute to the exploitation and utilization of wood that has achieved high significant level. For years, the particleboard industry has rapid expansion in West Germany (Roffael, 1993). The large scales of such industry generate accessibility for cheap wood of low demand and wood has obtained competition against other materials.

Particleboard is a type of panel manufactured from lignocellulosic materials or wood in the form of discrete pieces or particles. It was combined with a synthetic resin and pressed in a hot press to bond together. The generic term of "particle" is applicable to all lignocellulosic constituents that are able to form particleboard. Currently, industry practices the term "particleboard" to illustrate products that made from various types of particles (Moslemi, 1973). Types of particles sizes (Figure 2.3) can be either coarse like pulp chips or as fine as sander dust for the manufacturing of particleboard.

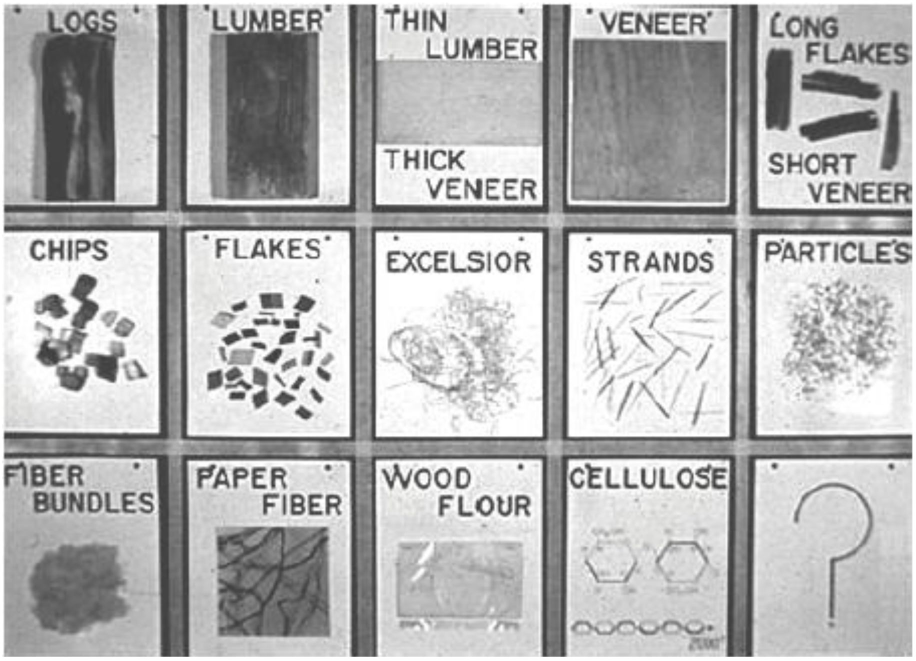

Figure 2.3: Types of particle sizes from largest to smallest. (Source: Marra, 1979)

2.2.2 Types of raw material

Abundant number of lignocellulosic materials is capable to be transformed for particleboard manufacturing. Basically, those materials must be available in adequate quantities, inexpensive, in a suitable form for board manufacturing and acquire relatively low cost of handling and storage. Wood has been extensively used as a source of raw material as it meets the entire requirement stated. In the particleboard industry, wood originates from various sources that can be classified as undried and dried sources (Table 2.7).

Table 2.7: Examples of various types of sources available

Sources	Examples
Undried	a) Planer shavings • from surfacing green lumber b) Plywood mill residue • normally in chipped form • from trimming veneer bolt and veneer clippings c) Sawmill residue • consists of chipped slabs, edgings, and trimmings d) Roundwood • reduced into particles e) Sawdust
Dried	a) Planer shaving • from surfacing kiln dried lumber b) Residue from plywood mills • obtained after the veneer has been dried c) Residue from dry rough lumber cuttings in furniture and millwork plants d) Dry sawdust

Source: Moslemi, 1973

The particleboard industry also has diversified its use of raw material by utilization of non-wood lignocellulosic materials especially agricultural residues. This includes bagasse, bamboo, flax shives, cotton stalks, cereal straw, papyrus, palms, African elephant grass, gum bark, coconut, peanut shells and others (Moslemi, 1973). Implementation of agricultural residues as raw material for particleboard manufacturing appears to be a potential to replace wood particularly as its availability is inadequate. Although, wood has well established as raw material in particleboard industry but increasing price of wood, certainly subscribe agricultural residues as an alternative source of raw materials for particleboard production (Roffael, 1993).

2.2.3 Manufacturing sequence

Commercially, particleboard manufacturing involves two major processes that are flat press and extrusion process (Moslemi, 1973). The board is pressed flat wise in the flat press process while the board is continuously extruded through a hot die in the extrusion process. Both of the process has basic procedures in their manufacturing sequence. Firstly, the raw material is reduced to desired particle size and shape by hogging, grinding, hammermilling, or flaking. The particles are dried to predetermined and uniform moisture content.

Screening or particle segregation is done to separate the oversized and fine particles. The fine particles are often deposited on the flat press boards to obtain smooth surface. The coarse particles are again directed into the reduction system for further refinement. Blending or in other term addition and mixing of adhesive binder and other additives with a predetermined amount is done by spraying or other method (Potter et al., 1976). Currently, urea formaldehyde and phenol formaldehyde are widely used as a adhesive binder. The blended particles are formed into a ‘mat’ in the flat press processes.

The mat for flat press process or blended furnish for extrusion process is consolidated under controlled heat and pressure to a given density in the hot press or extrusion die. Cooling, trimming and moisture equalization may carry out as the hot board emerges from the press. Further producers such as cutting to size, overlaying, routing or filling the surface take place depends on market demand.

2.2.4 Properties and application of particleboard

The properties of particleboard are influenced by variable of factors. The major factors include type and size of particles, techniques of manufacturing, type and amount of resin, particle distribution and orientation, board density, quality of manufacture (effectiveness of resin spread and forming), furnish moisture content and post manufacturing treatments (Moslemi, 1973). The flat press process is more favorable due to its strength; stiffness and dimensional stability of the boards are more uniform. Particleboards are used as furniture panel and for structural applications such as roof sheathing, wall panels, stair treads, and house floors.

2.2.5 Formaldehyde emissions

The adhesives play a role to bond the particles either obtained from synthetic or natural adhesives derived from the wood itself by chemical reactions. Currently, most of the commercially produced particleboard is bonded with formaldehyde-based adhesives. Eventually, substantial amount of formaldehyde emitted from a formaldehyde-based adhesives bonded particleboard. The quantity of formaldehyde released from particleboard depends on various numbers of exogenous factors such as atmospheric moisture, temperature or number of air exchanges; and endogenous factors such as wood species, type of resin or condition of manufacture (Roffael, 1993). Formaldehyde emission is highly unwanted because it causes assorted uneasiness including itchy and watery eyes.

2.3 Binderless Particleboard

2.3.1 General

There have been many researchers working out for the production of binderless particleboard as rising concern on the negative effects of synthetic adhesives from the commercial products. Especially, the self bonding ability of lignocellulosic materials in such types of panels has draw attention of many as its capability to manufacture wood and non wood based materials without any adhesives. The study of binderless panels starts as early as 1980 by Stofko, Shen and others (Stofko, 1980; Shen, 1986; Shen, 1991) and it continues to develop by using various types of raw materials.

Bonding plays a crucial role in such type of panel. Binderless boards have been developed from sugar containing lignocellulosic materials such as sugarcane bagasse, paddy stalks and especially, without the addition of adhesive, binders or bonding agents. The presence of sugar and water soluble materials within fibers, which will flux during the hot press procedure and will polymerize and bond in-situ the lignocellulosic materials (Shen, 1986).

Bonding can also be accomplished by chemical activation reactions and physical consolidation of particles under applied heat and pressure. The degradation of hemicelluloses and partial degradation of cellulose to produce simple sugars (Widyorini et al., 2005a) and by cross-linking carbohydrate polymers and lignin (Okuda et al., 2006) acts as bonding and bulking agents with the application of heat. Thus, they exhibit an excellent mechanical strength properties and dimensional stability (Shen, 1991).