STUDY ON PROPERTIES OF BINDERLESS PARTICLEBOARD FROM OIL PALM (*Elaeis guineensis*) BIOMASS

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UNIVERSITI SAINS MALAYSIA
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by

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LIST OF SYMBOLS AND ABBREVIATIONS

%	percentage
°C	degree celcius
ad	air dry
cm	centimeter
EFB	empty fruit bunch
FELDA	Federal Land Development Authority
FESEM	Field Emission Scanning Electron Microscopy
FRIM	Forest Research Institute of Malaysia
FT-IR	Fourier Transform Infra Red
g	gram
g/cm^3	gram per centimeter cube
HPLC	High Performance Liquid Chromatography
IB	internal bond
KBr	potassium bromide
kg/m^3	kilogram per meter cube
m	meter
MC	moisture content
MDF	medium density fiberboard
mid-part	middle part
mm	millimeter
MOR	Modulus of Rupture
MPa	mega pascal

MPOB	Malaysian Palm Oil Board
od	oven dry
OPF	oil palm frond
OPT	oil palm trunk
Pa	pascal
PF	phenol formaldehyde
PORIM	Palm Oil Research Institute of Malaysia
R&D	research and development
SEM	Scanning Electron Microscopy
TS	thickness swelling
UF	urea formaldehyde
WA	water absorption

KAJIAN KE ATAS SIFAT-SIFAT PAPAN SERPAI TANPA PENGIKAT DARIPADA BIOMAS KELAPA SAWIT (*Elaeis guineensis*)

ABSTRAK

Papan serpai tanpa pengikat telah dihasilkan daripada partikel-partikel kulit, daun, pelepah, bahagian tengah dan teras batang kelapa sawit pada dua perbezaan ketumpatan sasaran iaitu 0.8 g/cm^3 dan 1.0 g/cm^3 dan dua tekanan yang berbeza iaitu 5 MPa dan 12 MPa. Ujian fizikal dan mekanikal telah dijalankan ke atas papan serpai tersebut. Sebahagian analisis kimia juga telah dijalankan seperti penentuan ekstraktif, holoselulosa, alfa-selulosa, lignin, kandungan kanji, gula individu, dan jumlah gula yang hadir dalam bahan-bahan tersebut. Pencirian spektroskopi juga dilakukan dengan menggunakan Spektrofotometer Inframerah Transformasi Fourier (FT-IR) untuk mengkaji kewujudan kumpulan berfungsi yang terdapat di dalam gentian kelapa sawit sebelum dan selepas panel dihasilkan. Pemerhatian anatomi bahan mentah dan panel diperhatikan dengan menggunakan Mikroskop Elektron Pengimbas (FESEM). Keputusan menunjukkan panel yang diperbuat daripada teras batang kelapa sawit mempunyai nilai kekuatan modulus kepecahan (MOR) dan kekuatan ikatan dalaman (IB) yang paling tinggi, pengembangan ketebalan (TS) dan penyerapan air (WA) yang paling rendah berbanding dengan semua sampel yang lain. Sebahagian daripada panel yang dihasilkan telah memenuhi *Japanese Industrial Standards (JIS A- 5908)* untuk *Type 8, Type 13* dan *Type 18*. Walau bagaimanapun, panel yang diperbuat daripada kulit batang dan daun kelapa sawit tidak mempunyai kekuatan dan kestabilan dimensi yang memuaskan.

Berdasarkan keputusan yang diperolehi, biomas kelapa sawit dapat dipertimbangkan sebagai bahan mentah alternatif mesra alam untuk menghasilkan panel papan serpai tanpa pengikat.

STUDY ON PROPERTIES OF BINDERLESS PARTICLEBOARD FROM OIL PALM (*Elaeis guineensis*) BIOMASS

ABSTRACT

Binderless panels were manufactured from the particles of bark, leaves, fronds, middle-part and core-part of oil palm trunks at two different target densities (0.8 g/cm^3 and 1.0 g/cm^3) using two different pressures (5 MPa and 12 MPa). Binderless panels produced were tested for the physical and mechanical properties. Chemical analysis had also been conducted including determination of extractives, holocellulose, alpha-cellulose, lignin content, starch content, individual sugar, and total sugar content in oil palm fibers. Spectroscopic characterization was done using Fourier Transform Infrared (FT-IR) spectroscopy to detect the presence of the functional group that exists in oil palm fibres before and after the board was made. The anatomical features of the raw materials and the manufactured panels were viewed using Field Emission Scanning Electron Microscopy (FESEM). The results showed that panels produced from core portion of the trunks exhibited the highest Modulus of Rupture (MOR) and internal bond (IB) strength, but lowest thickness swelling (TS) and water absorption (WA) values among the samples. Some of the tested panels had met Japanese Industrial Standards (JIS A- 5908) for the Type 8, Type 13 and Type 18. However, panels made from bark and leaves did not have satisfactory strength and dimensional stability. Based on the results of this study, oil palm biomass could be considered as environmentally friendly alternative raw material for the manufacture of binderless particleboard.

CHAPTER ONE: INTRODUCTION

1.0 Background of the study

Malaysia is one of the world's largest producers and exporters of palm oil. The production of palm oil is reflecting on many sides as economic, environmental and social benefits. Solid wastes and oil palm by parts available in huge amount all over the year. Oil palm biomass of trunk, fronds, empty fruit bunches, fiber, shell and waste matter would be obtained during assiduous life of the palm covering about 25 years. The oil palm biomass such as oil palm trunks produced during felling of old trees were normally shredded and left in the field to decompose naturally (Khozirah et al., 1991; Mohamad et al., 1985). Previously, some estate burn these waste in the field for fast disposal. This will produce more carbon dioxide emission to the environment. The utilization of oil palm biomass to produce a value added product can reduce the effect of the activity in decomposing the waste due to environmental concern. Furthermore utilization of this waste will reduce the consumption of wood as raw material.

Particleboard is one of the extensively used wood based panels to manufacture building elements such as furniture components for interior purposes. The use of agricultural resources such as empty fruit bunch (EFB), kenaf, padi stalks, jute, flax, reed, cotton, grapevine, bagasse, straw, rice husks and bamboo have been used to make particleboards. As known, synthetic adhesive is required to manufacture a wood panel product. In particleboard manufacturing, adhesive is generally accepted to be the most costly raw material for making particleboard. Even though it is used only 8 % to 10 % of the weight of oven dries of the raw material, it still contributes 60 % to the overall cost of final product (Hashim et al., 2005; Laemsak & Okuma, 2000). Moreover, there are some harmful side effects such as health risks caused by the emission of volatile organic compounds from the adhesives. Many consumer products containing formaldehyde based resins release formaldehyde vapour, leading to consumer dissatisfaction and health related complaints. Therefore, manufacturing particleboard without any adhesive would provide an alternative to those with synthetic adhesive. The strategy of high income and zero waste are the goals towards sustainability because producing products such as binderless particleboard from oil palm biomass will benefit society, being environmentally friendly, recyclable, renewable and biodegradable.

1.1 Problem statement

Nowadays, there are global concerns for new energy resources from biomass. Huge amounts of oil palm biomass are being left unexploited in oil palm plantation. There were less old felled trunks and other oil palm biomasses been utilized and most of them have no convenient way of utilization and become troublesome wastes. In addition, the cost of particleboard manufacturing is high due to the use of adhesives because adhesive is one of the most costly raw materials for making particleboard (Laemsak & Okuma, 1999). Besides, emission of formaldehyde can cause health hazards contributed by formaldehyde based adhesives especially in particleboard manufacturing. Thus, in this research, a study on properties of binderless particleboards made from different types of oil palm biomass was being carried out.

1.2 Objectives

The main objective of this study is to produce binderless particleboard from different types of oil palm biomass.

The specific objectives are as follows:

a) to study and compare the physical and mechanical properties of binderless particleboard made from different types of oil palm biomass.

b) to compare the performance of binderless particleboard with the phenol formaldehyde particleboard, in accordance to JIS standard for particleboard Type 8, Type 13 and Type 18.

CHAPTER TWO: LITERATURE REVIEW

2.0 Oil palm industry in Malaysia

The oil palm in Malaysia is more than a century old. Oil palm (*Elaeis guineensis* Jacq) becomes better known crop, especially in Southeast Asia, than in its origin country, West Africa (Basiron & Chan, 2000). Currently, Malaysia and Indonesia are the main producers and supplying more than 85% of world oil consumption (Table 2.1). The table illustrates the world major producers of palm oil from 1999 to 2008. The producer countries have been facing a stern environmental problems concerning solid biowaste handling of oil palm industry. In the year of 1999, Malaysia produced about 10 554 000 tonnes of palm oil. The values had increased up to 17 734 000 tonnes in 2008, showing an increase of 68 % in the period of nine years.

In 2008, Malaysia was the world's major exporter of palm oil with 15.41 million tonnes or 45.84 % of the total world's exporters (Table 2.2). In Malaysia, palm oil has reached extraordinary growth in production and exports in the last few decades. Concurrence to Oil World Annual Statistics 2008, over the last decade between 1990-2008, the main palm oil producing countries have steadily increased their production. By the end of 2008, the major exporters of palm oil (in '000 tonnes), were Malaysia (15.41), Indonesia (14.47), Papua New Guinea (0.40), Columbia (0.33), and many other countries with smaller oil palm areas.

Table 2.1: World Major Producers of Palm Oil: 1999 – 2008 (‘000 tonnes)

Country	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Malaysia	10 554	10 842	11 804	11 909	13 355	13 976	14 962	15 881	15 824	17 734
Indonesia	6 250	7 050	8 080	9 370	10 600	12 380	14 100	16 050	17 270	19 330
Thailand	560	525	625	600	690	735	700	860	1 020	1 170
Nigeria	720	740	770	775	785	790	800	815	835	860
Columbia	500	524	548	528	527	632	661	713	732	800
Ecuador	263	218	228	238	262	279	319	352	396	415
Papua New Guinea	264	336	329	316	326	345	310	365	384	400
Cote d'Ivoire	264	278	205	265	240	270	320	330	320	330
Honduras	90	101	130	126	158	170	180	195	220	268
Brazil	92	108	110	118	129	142	160	170	190	220
Costa Rica	122	137	150	128	155	180	210	198	200	202
Guatemela	53	65	70	86	85	87	92	125	130	139
Vanezuela	60	70	52	55	41	61	63	65	70	56
Others	833	873	883	895	906	940	969	1 023	1 083	1 194
Total	20 625	21 367	23 984	25 409	28 259	30 987	33 846	37 142	38 674	43 676

Source: Oil World Annual (1999-2008) & Oil World Weekly (12 December 2008)

Table 2.2: World Major Exporters of Palm Oil: 1999-2008 (' 000 tonnes)

Country	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Malaysia	8 912	9 081	10 625	10 886	12 266	12 575	13 445	14 424	13 747	15 413
Indonesia	3 319	4 139	4 940	6 490	7 370	8 996	10 438	12 540	12 650	14 470
Papua New Guinea	254	336	327	324	327	339	295	362	368	395
Colombia	90	97	90	85	115	214	224	214	316	328
Singapore*	292	240	224	220	250	237	205	207	186	205
Cote d'lvoire	101	72	74	65	78	109	122	109	106	116
Hong Kong*	94	158	192	318	185	127	39	20	20	28
Others	788	896	1 099	1 027	1 320	1 647	1 736	2 121	2 474	2 665
Total	13 850	15 019	17 571	19 415	21 911	24 244	26 502	29 996	29 887	33 620

Note: * - Includes Re-Exporrting Countries

Source: Oil World Annual (1999-2008) & Oil World Weekly (12 December 2008)

2.0.1 Oil palm planted area in Malaysia

The oil palm was commercially exploited as an oil crop only from 1911 when the first oil palm estate was established in 1917 (Basiron et al., 2000). The expansion of the palm oil industry, in terms of planted area has been very speedy from 1975 until 2009 as seen in Table 2.3 and Table 2.4. In 2009, the total area planted with oil palm was 4.69 million, 53.1% or 2.49 million hectares being in Peninsular Malaysia, 29% or 1.36 million hectares in Sabah and 17.9% or 4.69 million hectares in Sarawak. The last decade had seen a quick extension in the cultivated area in Sabah and Sarawak while planting in Peninsular Malaysia had slowed down because of diminishing availability of new land for the crop.

Table 2.3: Oil palm planted area: 1975-1991 (Hectares)

Year	P.Malaysia	Sabah	Sarawak	Total
1975	568 561	59 139	14 091	641 791
1976	629 558	69 708	15 334	714 600
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	906 590	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	1698 498	276 171	54 795	2 029 464
1991	1 744 615	289 054	60 359	2 094 028

Source: Malaysian Oil Palm Statistic, 2009

Table 2.4: Oil palm planted area: 1992-2009 (Hectares)

Year	P.Malaysia	Sabah	Sarawak	Total
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
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	2 051 595	1 000 777	330 387	3 376 664
2001	2 045 500	1 027 328	374 828	3 499 012
2002	2 096 856	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	2 490 000	1 360 000	840 000	4 690 000

Source: Malaysian Oil Palm Statistic, 2009

2.0.2 Botanical classification of oil palm

Elaeis guineensis Jacq. which is universally known as the oil palm is the most vital species in the genus Elaeis. According to Taxonomic Information System, (2009) the oil palm taxonomy is shown below:

Kingdom : Plantae
Sub-Kingdom : Tracheobionta
Division : Angiospermae
Class : Monocotyledons
Sub-Class : Arecidae
Order : Arecales
Family : Arecaceae
Genus : Elaeis
Species : *Elaeis guineensis* Jacq
Common name : African oil palm

2.0.3 Oil palm biomass

Biomass can be defined as any organic plant product that has general uses. Lignocellulosics have been included in the term biomass. Therefore, oil palm biomass; the palm kernel, trunks, fronds, leaves, empty fruit bunches, pressed fruit fibers and shells consist of cellulosic fibers. Oil palm contains lignocellulosics material (Akmar & Kennedy 2001) which could be ideal for producing value-added composite panels and oil palm is one of the most versatile crops where nearly every part of the palm, from oil to the entire biomass can be utilized. Table 2.5 shows the wet weight of oil palm biomass available in Malaysia. The amount of oil palm biomass (wet weight) available annually is estimated to be from OPT: 13.93 million tonnes or 21.63 million cubic meters from replanting; and OPF, 75.90 million tonnes from the field.

Table 2.5: The wet weight of oil palm biomass available in Malaysia

Sources of oil palm biomass	Unit	
	Million tonnes per year (wet weight)	Million cubic meter (per year)
Peninsular Malaysia		
Oil Palm Trunk (OPT)	7.91	12.29
Oil Palm Frond (OPF)	43.12	
Empty Fruit Bunch (EFB)	9.69	
Sabah and Sarawak		
Oil Palm Trunk (OPT)	6.01	9.34
Oil Palm Frond (OPF)	32.78	
Empty Fruit Bunch (EFB)	6.36	
Total	105.87	21.63

(Source: Anis et al., 2008)

The oil palm biomass supply outlooks in Malaysia from 1996 to 2020 (t/yr, dry weight) is shown in Table 2.6. In future, total amount of the whole trunk in 2017-2020 will be estimated up to 2 971 934 t/yr, dry weight and total amount of leaf stalks and petiole (fronds) will be 13 643 185 and 7 141 490 t/yr, dry weight (Table 2.6). As the oil palm biomass consists of lignocellulosic material, it is a valuable raw material for value added products.

Table 2.6: Oil Palm Biomass Supply Outlooks in Malaysia from 1996 to 2020 (t/yr, dry weight)

	Year							
	1996	1997-2000	2001-2003	2004-2006	2007-2010	2011-2013	2014-2016	2017-2020
Oil Palm Trunk								
Total oil palm hectarage in 1994 (ha)	2 339 884							
Area due for replanting (% per year)	2.4	2.5	4.5	4.6	3.7	4.9	4.1	3.4
Total replanting hectarage (ha)	56 157	58 497	105 295	107 635	86 576	114 654	95 935	79 556
Number of felled palms	7 637 381	7 955 606	14 320 090	14 638 314	11 774 296	15 592 987	13 047 193	10 819 624
Amount of fibre bundles (t/yr, dry weight)	1 130 180	1 177 271	2 119 087	2 166 178	1 742 360	2 307 450	1 930 724	1 601 088
Amount of parenchyma (t/yr, dry weight)	664 605	692 297	1 246 134	1 273 826	1 024 599	1 356 902	1 135 367	941 524
Amount of bark (t/yr, dry weight)	303 051	315 678	568 221	580 848	467 204	618 730	517 713	429 323
Total amount of the whole trunk (t/yr, dry weight)	2 097 836	2 185 246	3 933 442	4 020 852	3 234 164	4 283 082	3 583 803	2 971 934
Pruned Fronds								
Area of palms aged 7 years and above (%)	79	82.9	76.7	72.7	71.3	70.4	72.9	73.9
Total hectarage (ha)	1 848 508	1 939 764	1 794 691	1 701 096	1 668 337	1 647 278	1 708 775	1 729 174
Amount of leaf stalks (t/yr, dry weight)	14 584 731	15 304 737	14 160 112	13 421 645	13 163 181	12 997 026	13 458 568	13 643 185
Amount of petiole (t/yr, dry weight)	7 634 340	8 011 225	7 412 074	7 025 525	6 890 233	6 803 260	7 044 853	7 141 490

Source: Malaysian Oil Palm Statistic, 2008

2.0.4 Oil palm trunk

2.0.4.1 Anatomical review of oil palm trunk

Oil palm is monocotyledonous species that does not have cambium, secondary growth, ray cells, annual or growth rings, sapwood and heartwood or branches and knots (Killman & Lim, 1985). The growth and increase in diameter of the trunk outcome from the overall cell division and cell enlargement in the parenchymatous ground tissue, together with the growth of the fibers of the vascular bundles (Khozirah et al., 1991). There are three main parts, namely cortex, peripheral region based and central region based on a cross sectional view of the oil palm trunk (Killman & Lim, 1985).

2.0.4.2 Cortex, periphery and central region

Cortex is approximately 1.5 to 3.5 cm wide, makes up the outer part of the trunk. It is largely composed of ground parenchyma with abundant longitudinal fibrous strands of small and irregular shaped fibrous strands and vascular bundles (Killman & Choon, 2001) as shown in Figure 2.1. Periphery area with slender layers of parenchyma is crowded with vascular bundles. It provides the main mechanical support for the palm trunk (Killman & Choon, 2001). The central region is composed of slightly larger and widely spotted vascular bundles embedded in the thin wall parenchymatous ground tissues. The bundles increase in size and are more widely spotted towards the core of the trunk (Killman & Choon, 2001).

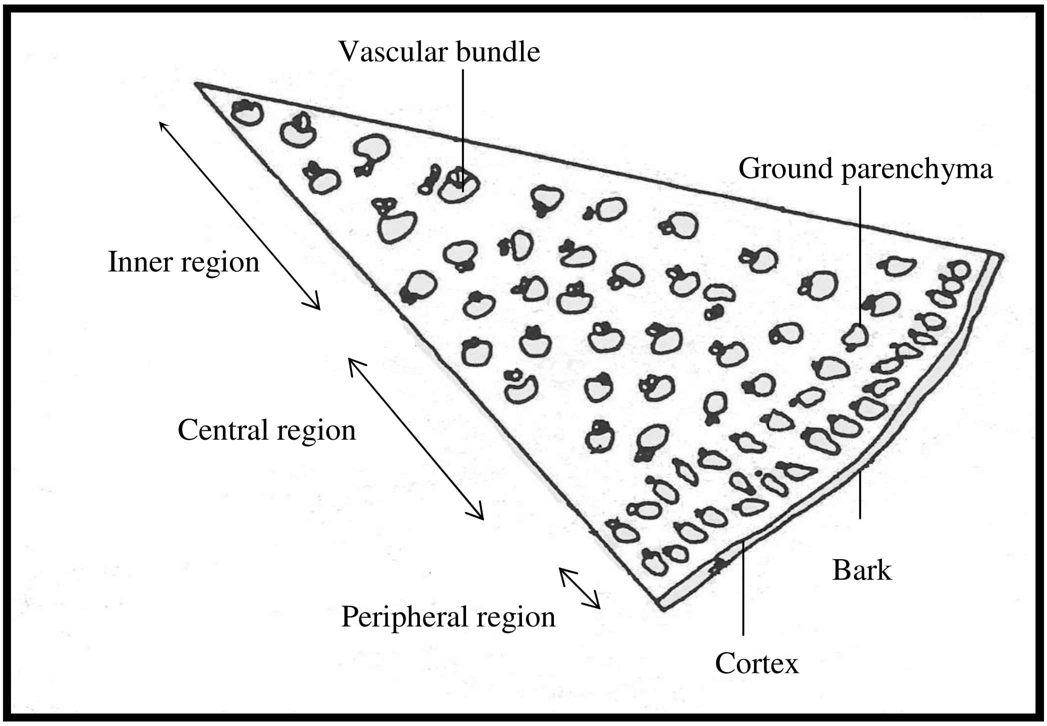

Figure 2.1: Cross section of an oil palm stem division into various anatomical parts. (Source: Killman & Lim, 1985)

2.0.4.3 Vascular bundles and parenchymatous tissue

The number of vascular bundles per unit area decrease towards the inner zones and increase from the butt end to the top of the palm (Killman & Lim, 1985). Each vascular bundle is mainly made up of a fibrous sheath, phloem cells, xylem and parenchyma cells (Figure 2.2). According to Lim & Khoo (1986) the xylem is sheathed by parenchyma and contains mainly one or two wide vessels in the peripheral region and two or three vessels of similar width in the central and inner region. Lim & Khoo (1986) also further stated that the distribution of fibrous strands depends on the number of bundles nearby. The ground parenchymatous cells consist mainly of thin-walled spherical cells, except in the area around the vascular bundles. The walls are progressively thicker and darker from the inner to the outer region (Killman & Lim, 1985; Basiron et al., 2001). The distribution of vascular bundles in the inner zone of the oil palm trunk varies depending on the palm. The fibers usually have a well developed secondary wall with a typically multilayered appearance. The trunk is primary tissue and is not compare in developmental terms to the wood of dicotyledons and gymnosperms. Vascular bundles in oil palm trunk range from about 1 to 3 mm in diameter depending on their location within the stem and the species (Parthasarathy & Klotz, 1976).

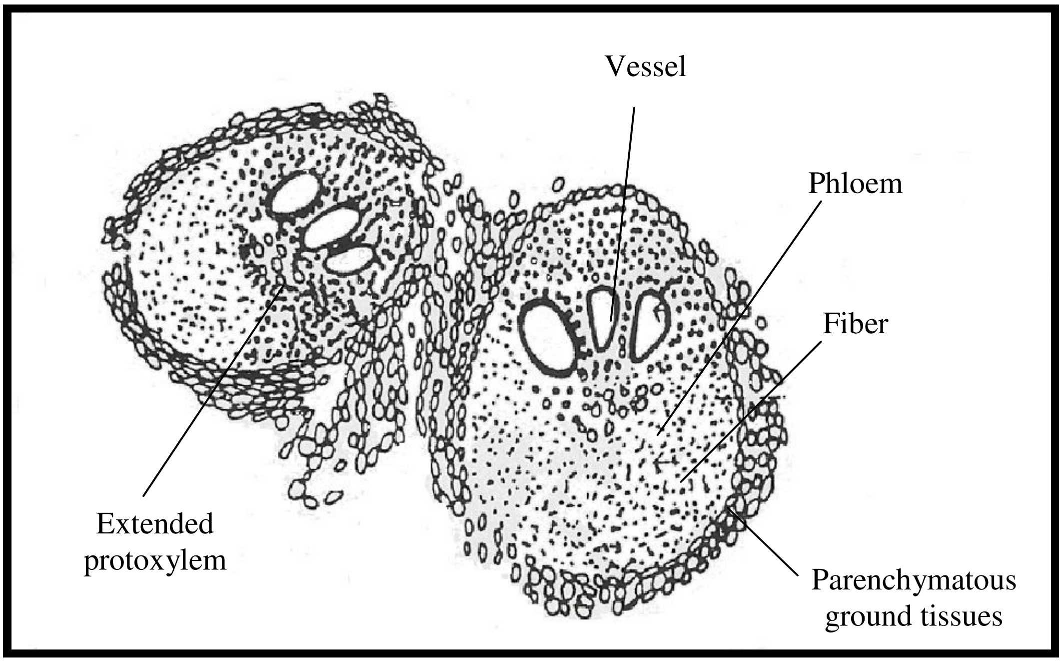

Figure 2.2: Fiber

(Source: Killman & Lim, 1985)

2.0.4.4 Physical properties of oil palm trunk

2.0.4.4.1 Moisture content

The initial moisture content of the oil palm trunk varies from 100 and 500% (Killmann & Lim, 1985). In the other study, oil palm trunks contain very high moisture content from 60-300% depending on the height and age of the trunk (Singh, 1994 and Mohammad 2000). A gradual increase in moisture content is indicated along the trunk height and towards the central region, with the outer and lower zone having far lower values than the other two zones. Based on depth of the trunk, the highest moisture content was reached at the central of trunk and a gradual decrease to the outer part of trunk while based on the trunk height factor, the moisture content was decreased from the bottom to the top of the oil palm tree (Lim & Khoo, 1986).

2.0.4.4.2 Density

Density values of the oil palm trunk range from 200 to 600 kg/m^3 with an average density of 370 kg/m^3. There is a variation of density values at different parts of the oil palm trunk consequently of its monocotyledonous nature. The density of oil palm trunk decreases linearly with the trunk height and towards the centre of the trunk and the outer region throughout the trunk shows density values over twice those of the inner areas (Lim & Khoo, 1986). Across the trunk the density is influenced largely by the number of vascular bundles per square unit which decreases towards the center. However, variations in density along trunk height are due to the vascular bundles being younger at the top and of the palm (Killmann et al., 1985; Husin et al., 1985).

2.0.4.4.3 Fiber dimensions

The palm development in trunk diameter caused by the widen of the fibrous bundle sheath, mostly those complementary the vascular bundles in the central region and the oil palm fiber length enlarges from periphery to the inner part. The fiber diameter decreases along trunk height because broader fibers are to be found in the larger vascular bundles nearer the base of the palm trunk (Lim & Khoo 1986). The fiber dimensions of oil palm trunk, fronds, rubberwood and douglas fir are shown in Table 2.7.

Table 2.7: Comparison of fiber dimension between oil palm trunk, fronds, EFB, rubberwood and douglas fir.

Dimension	Trunk	Fronds	EFB	Rubberwood	D/Fir
Fiber length (mm)	1.22	1.52	0.89	1.50	3.4
Fiber diameter (μ)	35.3	*19.4	25.0	40.0	40.0
Cell wall thickness	4.5	*4.6	2.8	5.3	**na

(Source: Mohamad et al., 1985)

* Liew, 1996

**na: not available

2.0.5 Oil palm fronds

The oil palm fronds are available during felling operations and during fruit harvesting. These are potential sources of fibers and are now used in the production of building materials, panel products, and for pulp and paper (Salleh et al., 2007). The fronds are also used as mulch in the field (Mohamad et al., 1985). In the process of replanting, pruned fronds are available in the field. The requirement of oil palm fronds for value-added is now had been competitive. While petiole is harvested, the rachis and leaflets are left behind (Mohamad et al., 1995 and Gurmit et al., 1999).

2.0.6 Oil palm leaves

The oil palm leaves are also available seasonally during felling operations. The oil palm leaf consists of leaflets, each with a lamina and midrib, a central rachis, to which the leaflets are attached, a petiole (the part of the leaf stalk between the lowest leaflets and the trunk), and a leaf sheath. The total number of leaves on a plantation palm depends largely on the harvesting and pruning methods in use. The oil palm single vegetative growing point is situated in a depression at the stem apex, as with other large palms. This meristem is continuously active, producing a new leaf primordium about every two weeks in a mature palm and the leaf takes about two years to develop from initiation to the time the leaflets unfold in the centre of the palm crown, and may then spend a further two years actively photosynthesizing, before senescence sets in (Corley, et al., 1982).

The leaf is pinnate, with the pinnae (leaflets) arranged in two or more planes on each side of the rachis. Leaf size increases progressively up to about eight or ten years after planting, when it reaches a maximum which is maintained for at least ten years and probably much longer (Corley, et al., 1982).

2.0.7 Chemical properties of oil palm biomass

The main constituent in oil palm fibers is cellulose. Oil palm trunk (OPT) fiber exhibited the highest content of extractives and lignin compared to empty fruit bunch (EFB), oil palm frond (OPF), hardwood and softwood (Abdul Khalil et al., 2008). The quantity of cellulose in fibers influences the property and economic production of fibers for different uses. Chemical composition varies from plant to plant and within plants from different parts of the same plant. It also varies between plants from different geographic locations, ages, climate and soil conditions (Rowell et al., 2000). The chemical compositions of oil palm biomass are presented in Table 2.8 together with the previously mentioned species as comparison.

Table 2.8: Chemical composition of oil palm biomass and wood fibers

	Extractives (%)	Holocellulose (%)	Alpha-cellulose (%)	Lignin (%)	Ash (%)
Oil palm trunk	-	45.70*	29.20*	18.80*	2.30*
	5.35**	73.06**	41.02**	24.51**	2.20**
Oil palm frond	-	80.50*	-	18.30*	2.50*
	4.40**	83.54**	56.03**	20.48**	2.40**
Empty fruit bunch	-	65.50*	-	21.20*	3.50*
	3.21**	80.09**	50.49**	17.84**	3.40**
Hardwood	0.1 - 7.7***	71 - 89***	31 - 64***	14 - 34***	<1***
Softwood	0.2 - 8.5***	60 - 80***	30 - 60***	21 - 37***	<1***
Rubberwood	-	67*	41.50*	26*	1.50*

Source:

*Mohamad et al., 1985

**Abdul Khalil et al., 2008

***Tsoumis, 1991

In general, oil palm has low lignin and holocellulose content as compared to hardwood, softwood and rubberwood (Table 2.8). The lignin content in oil palm range varies between 17 % and 25 %. Besides, Halimahton and Ahmad, (1990) observed that the lignin content was fairly evenly distributed throughout the tree except that the core in the upper region was slightly lacking in the component even as the bottom contained an extreme amount. The ash content also observed to be similar throughout the oil palm with the range varies between 2.2 % and 3.5 %.

2.0.7.1 Cellulose

Cellulose is a linear polymer of D-glucopyranose sugar units (the dimer, cellobiose) linked in a beta configuration and the average cellulose chain has a degree of polymerization of about 9,000 to 10,000 units (Rowell, 2005). Besides, approximately 65 percent of the cellulose is highly oriented, crystalline, and not accessible to water or other solvents. The strongest component of the lignocellulosic resource is the cellulose polymer. The remaining cellulose, composed of less oriented chains, is only partially accessible to water and other solvents as a result of its association with hemicellulose and lignin. None of the cellulose is in direct contact with the lignin in the cell wall (Tsoumis, 1991; Sjostrom 1993).

2.0.7.2 Hemicellulose

The hemicelluloses are a group of polysaccharide polymers containing the pentose sugars D-xylose and L-arabinose and the hexose sugars D-glucose, D-galactose, D-mannose, and 4-0-methylglucuronic acid (Tsoumis, 1991). Hemicellulose is amorphous and highly branched with a much lower degree of polymerization than cellulose. Hemicellulose varies in structure and sugar composition depending on the source (Reddy & Yang, 2005). Hemicellulose is soluble in alkali and is easily hydrolyzed by acids (Rowell, 2005).

2.0.7.3 Lignin, extractives and ash content

Lignin is amorphous, highly complex, and aromatic polymers of phenylpropane units (Sjostrom, 1993). Lignin does not have a single repeating unit of the hemicelluloses like cellulose, but consists of a complex arrangement of substituted phenolic units. Lignins are composed of nine carbon units derived from substituted cinnamyl alcohol; coumaryl, coniferyl, and syringyl alcohols that are highly branched, not crystalline, and their structure and chemical composition is a function of their source (Donaldson, 2001; Reddy & Yang, 2005). The molecular weight of lignin depends on the method of extraction. Klason lignin, because it is highly condensed, has molecular weights as low as 260 and as high as 50 million (Goring, 1962).

The extractives are a group of cell wall chemicals mainly consisting of fats, fatty acids, fatty alcohols, phenols, terpenes, steroids, resin acids, rosin, waxes, and many other minor organic compounds (Rowell, 2005). These chemicals exist as monomers, dimers and polymers. Extractives are responsible for the colour, smell and durability of the wood. The qualitative difference in extractive content from species to species is the basis of chemotaxonomy (taxonomy based on chemical constituents). The extractive materials are primarily composed of cyclic hydrocarbons. The remaining mass of lignocellulosics consists of water, organic soluble extractives, and inorganic materials. These vary in structure depending on the source and play a major role in natural decay and insect resistance and combustion properties of lignocellulosics (Mukherjee, 1972).

Ash content is the inorganic portion can vary from a few percent to over 15 percent, depending on the source. Ash content may be high for plant which has higher amount of silica (Rowell, 2005).

2.1 Particleboard

2.1.1 General

Particleboard is a composite material and product manufactured from wood particles, flakes, sawdust, or sawmill shavings using suitable binder or synthetic adhesive which is pressed together (Abdul Khalil & Hashim, 2004). It is produced by mechanically reducing the material into small particles, drying, screening, mixing with adhesives and additives, forming, consolidating a loose mat of the particles with heat and pressure into a panel product and finishing. The first industrial production of particleboard using synthetic resins is believed to have occurred in 1941 in Bremen, Germany using phenolic binders and spruce particles (Moslemi, 1973). Various size of wood particles were glued together to produce particleboard (Rowell, 2005). According to Moslemi, (1973) particleboard is cheaper, denser and more uniform than conventional wood and plywood. The properties of the board can be engineered to meet specific requirements such as sufficient bending strength and dimensional stability, flat and smooth surfaces and good machining characteristics. Dimensional stability of particleboard varies depending on the amount and type of adhesives and internal bond of particleboard (Rowell, 2005).

2.1.2 Raw materials of particleboard

The main components in particleboard are wood particle and adhesive. Soft wood and medium density hard wood are the common type of wood used to produce particleboard. Adhesive level usually is around 5 – 15% based on oven dry weight of the board. Urea formaldehyde and phenol formaldehyde is the common adhesive used in manufacturing particleboard (Rowell, 1992). At present, particleboards are manufactured from residues of non-commercial and low-grade timbers generated by the wood-based mills. The demand for rubberwood as sawn timber, furniture and other composites products has been increasing in the last ten years resulting in a price increase of rubberwood. Due to the increasing cost of rubberwood, the particleboard industry in Malaysia is looking into alternative supply of raw materials. The oil palm biomass seems to be potential raw materials in particleboard industry in Malaysia. The plentiful lignocellulosic residues are existing from the palm oil mills and plantations. This alternative raw material could be expected to ease the dependence on the forest.

2.1.3 Particle preparation and blending

Debarking process of log is the first step before being fed into disk chipper or flake machine (Chew, 1987). Then, the log is fed into disk chipper to be reduced to particle. Size particle varies and depends on manufacture. After chipping process, the particles are screened out and oversized particles are fed to the chipper again. Particles with required size will be dried up before it is used to produce particleboard. Particle is required to dry to uniform moisture content and the type of adhesive used depends on end use of the product (Moslemi, 1973).

2.1.4 Mat forming and pressing

The particles mixture is made into a mat after the adhesive has been mixed with the particles. The particles were spread by an air jet or extruder which throws finer particles further than coarse ones. The sheets formed were then cold compressed to reduce their thickness and sent to the hot press. Boards were compressed again, under pressures and temperatures between 140 to 220 °C (Moslemi, 1973). All aspects of this entire process were carefully controlled to ensure the accuracy of size, density and consistency of the board.

2.1.5 Properties and application of particleboard

The properties of particleboard depend on many factors including the type and size of particles, techniques of manufacture, 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). Particleboard bonded using melamine formaldehyde and phenol formaldehyde was reported to have better dimensional stability than urea formaldehyde (Moslemi, 1973). Higher board densities are related with higher strengths, more difficult machining characteristics, a greater degree of dimensional instability, and higher cost per unit volume**.** Low density board offers better insulating characteristics, higher dimensional stability, lower strength, and less unit cost. The direct influence of density over product weight is basic importance in many applications (Chew, 1987)**.** Particleboard with low density was less than 0.6g/cm^3, medium density between 0.6 g/cm^3 – 0.8 g/cm^3 and high density with more than 0.8 g/cm^3.

The applications of particleboard are commonly used as core material for furniture panels, flush doors, veneer wall panels, desk tops, drawer fronts, chest and table tops, dust dividers, shelves, chest sides, sewing machine cabinets, bed rails, headboards, bookcase sides, backs and shelves, interior ceilings and walls, components for interior millwork such as kitchen cabinets, wardrobe, flooring and other storage compartments (Carll, 1986).

2.1.6 Formaldehyde emissions

Formaldehyde is an important precursor for the preparation of urea, melamine and phenol formaldehyde resins which are used as binders in the wood based panel manufacturing. It is very reactive chemical and goes through a series of technically significant reactions. Formaldehyde release is highly unwanted because it causes assorted uneasiness including itchy and watery eyes. Formaldehyde release continuously sticks with at a high level for a long period of time after the product has begun service in the particular application (Roffael, 1993).

The past decade ago, publicity has come up about formaldehyde vapor contaminating air in dwelling. This infectivity can come from many sources, including tobacco smoke, urea formaldehyde foam insulation, carpeting, soft goods furnishings, particleboard and decorative plywood (Carll, 1986). Hydrolysis of the cured urea formaldehyde occurs in such an environment, and results in release of formaldehyde vapors and loss of the board strength. Carll (1986) further stated that hydrolysis can theoretically continue indefinitely if humidity and temperature remain at high levels.