EFFECT OF PARTICLE GEOMETRY ON PROPERTIES OF BINDERLESS PARTICLEBOARD FROM OIL PALM (*Elaeis guineensis*) TRUNK

by

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%	percentage
°C	degree celcius
ad	air dry
cm	centimetre
EFB	empty fruit bunch
FESEM	Field Emission Scanning Electron Microscopy
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
FRIM	Forest Research Institute of Malaysia
FTIR	Fourier Transform Infra Red
g	gram
g/cm^3	gram per centimetre cube
IB	internal bond
KBr	potassium bromide
Kg/m^3	kilogram per meter cube
m	meter
MC	moisture content
MDF	medium density fiberboard

mm	millimetre
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
RISDA	Rubber Industry Smallholders' Development Authority
R&D	Research and development
SEM	Scanning Electron Microscopy
TS	thickness swelling
UF	urea formaldehyde
WA	water absorption
WCB	wood cement board

KESAN-KESAN BENTUK DAN SAIZ PARTIKEL KE ATAS CIRI-CIRI BOD PARTIKEL TANPA PEREKAT DARIPADA BATANG KELAPA SAWIT (*Elaeis guineensis*)

ABSTRAK

Bod partikel tanpa perekat dihasilkan daripada batang kelapa sawit (*Elaeis guineensis*) yang terdiri daripada 2 jenis partikel yang mempunyai bentuk dan saiz yang berlainan. Jenis partikel yang digunakan ialah strand dan partikel halus. Strand ialah partikel yang terdiri daripada vascular bundles dan sedikit sel parenkima yang melekat di atasnya, manakala partikel halus pula terdiri daripada partikel yang bersaiz kurang daripada 1000 µm. Bod partikel tanpa perekat bagi kedua-dua jenis partikel ini dihasilkan pada ketumpatan 0.8 g/cm^3. Sifat-sifat mekanikal dan fizikal bod partikel tanpa perekat ini diuji dengan menjalankan ujian kekuatan modulus kepecahan (MOR), kekuatan ikatan dalaman (IB), pengembangan ketebalan (TS), penyerapan air (WA) dan kekasaran permukaan ke atas semua bod partikel tanpa perekat. Penentuan kandungan kimia dilakukan melalui analisis kimia seperti penentuan kandungan kanji dan jumlah gula dalam bahan tersebut. Pencirian spektroskopi juga dijalankan untuk mengkaji dan mengenalpasti kewujudan kumpulan berfungsi yang terdapat pada gentian kelapa sawit sebelum dan selepas bod partikel tanpa perekat ini dihasilkan. Ujikaji ini dilakukan menggunakan alat Spektrofotometer Inframerah Transformasi Fourier (FTIR). Selain kumpulan berfungsi, pemerhatian ke atas anatomi dalam bod partikel tanpa perekat juga dijalankan menggunakan Mikroskopik Elektron Pengimbas (SEM). Ujikaji thermogravimetrik (TGA) turut dijalankan untuk melihat hubungan di antara perubahan berat yang berlaku akibat peningkatan suhu. Ujikaji ini juga dapat menentukan degradasi bod partikel. Berdasarkan keputusan yang diperolehi, bod partikel tanpa perekat yang diperbuat daripada strand mempunyai nilai kekuatan modulus kepecahan (MOR) dan kekuatan ikatan dalaman (IB) yang tinggi berbanding partikel tanpa perekat yang diperbuat daripada partikel halus iaitu 0.93 dan 24.95 MPa. Pengembangan ketebalan (TS) dan penyerapan air (WA) bagi bod partikel diperbuat daripada strand lebih rendah berbanding bod partikel diperbuat daripada partikel halus iaitu 41.59 dan 79.96 %. Sifat mekanikal bod partikel tanpa perekat yang dihasilkan bagaimanapun memenuhi piawaian yang termaktub dalam Japanese Industrial Standards (JIS A-5908) untuk bod partikel jenis 8, 13 dan 18. Data juga menunjukkan sifat mekanikal dan fizikal untuk bod tanpa perekat bagi kedua-dua jenis partikel meningkat dengan pengaplikasian rawatan wap ke atas bahan mentah. Keputusan dari hasil ujikaji menunjukkan bahawa kepelbagaian saiz, bentuk batang kelapa sawit dan proses pengewapan (130°C, 30 minit) memberikan kesan terhadap sifat-sifat bod tanpa perekat. Walau bagaimanapun, bod partikel tanpa perekat bagi kedua-dua jenis partikel perlu menjalani pengubahsuaian lagi supaya memiliki kestabilan dimensi yang lebih memuaskan.

EFFECT OF PARTICLE GEOMETRY ON PROPERTIES OF BINDERLESS PARTICLEBOARD FROM OIL PALM (*Elaeis guineensis*) TRUNK

ABSTRACT

Binderless particleboard panels were manufactured from two different particle geometry of oil palm (*Elaeis guineensis*) trunk. The types of particle used were fine particles and strands. Strands that were composed of vascular bundles with some parenchyma cells attached together while fine particles were grounded particles with size less than 1000 μm. The binderless particleboard panel was manufactured with target density of 0.80 g/cm^3. Binderless particleboard panels were tested for their mechanical and physical properties such as modulus of rupture (MOR) or bending strength, internal bond strength (IB), thickness swelling (TS), water absorption (WA) and surface roughness. Chemical analysis such as starch analysis and total sugar analysis were carried out to determine the starch and sugar content in the sample. Besides that, spectroscopic characterization was carried out using Fourier Transform Infrared (FTIR) spectroscopy to detect the functional group presence in the sample for untreated and steam pre-treated samples. Scanning electron microscopy was done to observe the anatomical features of binderless particleboard panels of different type particles using Scanning Electron Microscopy (SEM) from the micrograph taken. Characteristic such as weight changes in relation to temperature was tested by Thermogravimetric (TGA) equipment. TGA can also determine the degradation of binderless particleboard panels. The results showed that binderless particleboard panels made using strands had higher modulus of rupture (MOR) and internal bond (IB) than fine particles binderless particleboard panels which were 0.93 MPa and 24.95 MPa respectively. Moreover, the dimensional stability in term of thickness swelling (TS) and water absorption (WA), binderless particleboard panels made from strands is better compared to fine particles binderless particleboard panels which were 41.59 % and 79.96 % respectively. Both panels had met Japanese Industrial Standards (JIS A- 5908) for particleboard type 8, 13 and 18. The results showed some improvement for both panels in term of mechanical and physical properties after steam pre-treatment being applied to the raw material. Based on this study, particle geometry and steam pre-treatment (130°C, 30 minutes) did give effect on properties of binderless particleboard from oil palm trunk. However both type of binderless particleboard need some modification in order to obtain better dimensional stability characteristic.

CHAPTER 1.0: INTRODUCTION

1.1 Background of the study

Oil palm has become the most preferable plant agricultural sector in Malaysia since years ago due to the commercial value and high demand of palm oil product. Nowadays, Malaysia is one of the largest palm oil producers and exporters in the world. It is estimated that that, 51 % of world palm oil is produced by Malaysia. Palm oil normally being exported to countries like China, India, Netherlands and Pakistan (Wan Asma et al., 2010). This have resulted the plantation area of oil palm keeps increasing day by day. Consequently, a large amount of oil palm biomass being generated every year in form of trunks, fronds, empty fruit bunches, and leaves in harvesting site (Salleh et al., 2007). The oil palm biomass generated unfortunately was not utilized effectively. The oil palm trees that were felled to the ground are normally being shredded and left for biodegradation process which known as nutrient recycling process (Wan Asma et al., 2010). However, this process takes a long time for the biomass to decay.

In order to eliminate them faster, open burning and land filling are done. These practices give negative impact towards environment. The open burning will cause air pollution and lead to health problem especially breathing system. Moreover, open burning activity has been restricted by a strict regulation due to the environmental concern (Hashim et al., 2012). The awareness of environment had encouraged researchers to use oil palm biomass as one of the lignocellulosic materials (Akmar and Kennedy, 2001) to produce value added product (Abraham et al., 1998; Laemsak and Okuma, 2000; Kamarulzaman et al., 2004; Hashim et al., 2011).

Wood-based panel such as particleboard normally require synthetic adhesive in the manufacturing process in order to produce a final product with a proper physical and mechanical properties. The end use of the composite panel will determine the type of adhesive that is going to be used. The most common adhesive used in particleboard industries is formaldehyde-based adhesive which is urea formaldehyde (Hashim et al., 2009). Urea formaldehyde adhesive is the cheapest adhesive among other types of adhesive available in the market. Even though it is the least expensive adhesive and only being used around 8 to 10 %, it still makes up about 60 % of overall cost production (Laemsak and Okuma, 2000; Hashim et al., 2005). Moreover, the consumption of formaldehyde based adhesive is harmful towards environment.

The emission of volatile organic which is formaldehyde vapour can lead to health problem and pollution to the environment. Therefore, the idea of binderless board is an option that is available to cut the cost production of composite panel and at the same time to preserve the environment. Besides that, the idea of binderless board is one step towards zero waste and sustainability. Thus, the product can be classified as environmentally friendly which is recyclable, renewable and biodegradable. This can give a lot of benefits to society.

Research on the effect of particle geometry towards properties of oil palm trunk was carried out because the limitation of data on binderless board using oil palm trunk. Besides that, the potential, availability and suitability of oil palm trunk as raw material were among the factors. Furthermore, the data on particle geometry in this field not been reported yet. This parameter is believed to have influence on the physical and mechanical properties of binderless particleboard panel.

1.2 Problem statement

All people around the world nowadays are very concern towards the awareness on environment through their creations which emphasize more on environment, zero waste and sustainability. Oil palm biomasses which can be abundantly found in Malaysia are one of lignocellulosic resources that have potential to produce value added composite panel. This kind of agricultural residues being left at harvesting site for decomposition or be burned to eliminate them. Moreover, this kind of resources could replace the usage of timber or solid wood in particleboard industries. In addition the high cost of particleboard manufacturing process is due to the synthetic adhesive which makes up about 60 % of total cost production. Besides the usage of adhesive give negative impact to our environment. The emission of formaldehyde which is volatile organic in the adhesive will cause air pollution and health problem. Therefore the idea of binderless particleboard panel is developed.

1.2 Hypothesis

It is the hypothesis of this thesis that the variety of particle geometry including shape and size of oil palm trunk particles would give influence towards the physical and mechanical properties of binderless particleboard panel.

1.3 Objectives

The main goal of this study is to produce panel using different particle geometry. The specific objectives of this study are as follows:

1. To study the effect of particle geometry such as strands and fine particles on the mechanical and physical properties of binderless particleboard made from oil palm trunk particles.
2. To determine the optimum size between fine particles and strand of oil palm trunk particle for binderless board manufacturing.
3. To characterize the influence of steam pre-treatment towards the properties of binderless particleboard panels made from variety of particle geometry

CHAPTER 2.0: LITERATURE REVIEW

2.1 Introduction on oil palm in Malaysia

2.1.1 General

The oil palm (*Elaeis guineensis*) which is native's species to Africa, have commercial values mainly in the oil production. The commercial values of palm oil have made oil palm industry being operated more than a century in Malaysia. In Southeast Asia, oil palm (*Elaeis guineensis*) being more recognized crop than in West Africa even though its origin country (Basiron and Chan, 2000).

The oil of oil palm normally is obtained from two different sources which are mesocarp of the fruit and also kernel of the nut. In year 2008, total oil palm products being exported was 21 763 929 tonnes with value of RM 65 215.20 as shown in Table 2.1. The volume increased to 22 427 049 tonnes by the year 2009. Palm oil is normally being used in food industries as cooking oil, margarine and shortening. Besides that, it also widely utilise in non- food application such as soap, detergent, cosmetic and many more.

The growth of oil palm industry has been phenomenal. The increment is very encouraging and proved that oil palm products have high demand in market thus, boost the growth of oil palm plantation in Malaysia. However, this increment somehow had caused the producer countries to face serious environment pollution due to substantial amount of biomass generated (Wan Nadhari, 2010). Every year, at least, more than 15 million tonnes of oil palm biomass being produced (Asma et al., 2010).

Table 2.1: Export volume (tonnes) and value (RM million) of oil palm products: 2008 and 2009

Products	2008		2009	
	Volume (Tonnes)	Value (RM million)	Volume (tonnes)	Value (RM million)
Crude Palm Oil	2,336,577	6,379.40	2,537,433	5,739.50
Processed Palm Oil	13,075,935	41,546.60	13,343,311	31,208.10
Total Palm Oil	15,412,512	47,925.90	15,880,744	36,947.60
Crude Palm Kernel Oil	149,182	521.00	184,296	408.20
Processed Palm Kernel Oil	898,236	3,638.80	933,182	2,613.00
Total Palm Kernel Oil	1,047,418	4,159.80	1,117,478	3,021.20
Palm Kernel Cake	2,261,268	990.90	2,381,571	496.10
Oleochemicals	2,075,897	8,706.40	2,174,667	6,582.90
Biodiesel	182,108	610.70	227,457	605.80
Finished Products	670,612	2,656.60	580,233	1,913.20
Others	114,114	164.80	64,898	92.20
Total Oil Palm Products	21,763,929	65,215.20	22,427,049	49,659.00

Source: Malaysian Palm Oil Council Annual Report 2010 private estates possessed the largest oil palm plantation which is about 3,025,556 hectares. The least plantation area is RISDA with 78,858 hectares.

Table 2.3: Oil palm planted area (hectare) by category as at September 2011

Category	Hectare	Percentage(%)
Private Estates	3,025,556	60.8
FELDA	702,941	14.1
FELCRA	162,321	3.3
RISDA	78,858	1.6
GOVT./ STATE AGENCIES	320,812	6.4
Independent Smallholders	685,286	13.8
MALAYSIA	4,975,774	100

Source: Malaysian Palm Oil Council Annual Report 2010

The expansion was increased dramatically from 1975 until 2009 as illustrated in Table 2.4. Based on the table, Peninsular Malaysia had at least 2.49 million hectares of oil palm plantation area while Sabah had 1.36 million hectares and Sarawak covered area around 840 000 hectares on year 2009. Sabah and Sarawak had shown a quick extension in the cultivated area of oil palm plantation while Peninsular Malaysia had slowed down the last decade due to the diminishing availability of new land for the crop.

Table 2.4: Oil palm planted area (hectares): 1975-2009

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	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
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: Department of statistics Malaysia: 1975-1984; MPOB: 1985-2009

2.1.3 Botanical classification of oil palm

Botanical classification is used to identify the plant's name and it's featured. The oil palm is a species of monocotyledonous plant. It does not have cambium, secondary growth, growth rings, ray cells, sapwood and heartwood like other wood species. Moreover, it also does not have branches and knots. Cell division and cell enlargement activities in the parenchymatous ground tissues and fibres of the vascular bundles resulted in the increment of oil palm diameter and the growth of the plant (Killman and Lim, 1985).

The act of the classification is used to define the group of individual which have certain features or properties in common. Oil palm (*Elaeis guineensis*) for example is an important species in the genus *Elaeis*. The taxonomic is which is based on the Taxonomic Information System (2009) is illustrated in Table 2.5:

Table 2.5: Taxonomic of oil palm (*Elaeis guineensis*)

Taxonomic of Oil Palm (*Elaeis guineensis*)	
Kingdom	Plantae
Sub-kingdom	Tracheobionta
Division	Angiospermae
Class	Monocotyledons
sub-class	Arecales
Family	Arecaceae
Genus	Elaeis
Species	*Elaeis guineensis*

Source: Taxonomic Information System (2009)

2.1.4 Oil palm biomass

The increment of oil palm plantation area had caused the increasing in oil palm biomass production such as trunks, fronds, empty fruit branches, fibre, shell and effluent. The production of this biomass is from two situations; the first two co-products trunks and fronds from plantation site and the remaining four from palm oil processing (Corley et al., 1976).

The oil palm trunks are available when the economic life span of the palm is reached at the time of replanting. This is where the average age of replanting is about 25 years cycle during replanting and the height of palm reaching 13 m above (Wan Asma et al., 2010). The annual yield of bunches at this rate falling below 10-12 t/ha (Corley et al., 1976). The oil palm trunk is having high amount of moisture content. Besides that, it is very susceptible to degradation agent such as fungi. Previous study proved that oil palm trunk has bio fuel potential because it contained sap that can be converted into bio ethanol (Murai et al., 2009).

Oil palm fronds can be obtained during replanting session. Besides, oil palm fronds are also available during pruning and harvesting time. It is estimated that approximately 115 kg/palm of dry fronds are being obtained from a crown during replanting time (Chan et al., 1980). Only 24 fronds are pruned with an average annual pruning of 82.5 kg of fronds/palm/year on an annual basis (Chan et al., 1980). Table 2.6 shows the wet weight of oil palm biomass found in Malaysia. The availability of oil palm biomass in wet weight is estimated oil palm trunk: 13.93 million tonnes or 21.63 million cubic meters from replanting; and oil palm frond, 75.90 million tonnes from the field.

Table 2.6: The wet weight (tonnes) 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	7.91	
Oil Palm Frond	43.12	12.29
Empty Fruit Bunch	9.69	
Sabah & Sarawak		
Oil Palm Trunk	6.01	
Oil Palm Frond	32.78	9.34
Empty Fruit Bunch	6.36	
Total	105.87	21.63

Source: Anis et al., 2008

Increasing pattern of oil palm biomass supply outlooks in Malaysia can be seen in Table 2.7. Malaysia is targeted to produce total amount of the whole trunk started year 2017 until 2020 which will be 2,971,934 t/yr whereas dry weight and total amount of leaf stalks and petiole known as fronds up to 13,643,185 and 7,141,490 t/yr.

Table 2.7: Oil palm biomass supply outlook 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 year & 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: Malaysia oil palm statistic, (MPOB) 2008

2.1.5 Oil palm trunk

2.1.5.1 The anatomical features of oil palm trunk

Oil palm trunk is a rich source of lignocelluloses and available during replanting together with the crown which is suitable to be used in particleboard industries. Research on the utilisation of oil palm trunk has been on-going for several years and the results were extremely encouraging (Laemsak and Okuma, 2000; Kamarulzaman et al., 2004).

The oil palm trunk is vital to supports the leaves, transport mineral nutrients and water from the roots upwards and products of photosynthesis from leaves downwards, and also function as a storage organ. Oil palm trunk consists of a mass of vascular bundles, which are embedded in parenchymatous tissue. The growing of the trunk happens shortly below the apex. It also grows to its full width and no secondary thickening occurs. The apical meristem crucial in producing the leaf and inflorescence primordial and also contribute to the stem tissue lies in a slight depression at the apex of the stem (Rees, 1964). The depression at the apex formed because of the meristem activity.

In the beginning of one or two years of the growth, thickening result in a broad base to the trunk. At this time the trunk diameter maybe up to 60 cm. Thereafter, the growth in height becomes rapid and the diameter becomes narrower. Normally the trunk growth is around 35 to 75 cm per year. This trend of growth is depending on growing condition and also different progenies (Corley et al., 1976). The height of oil palm trunk at replanting age is between 7 to 13 m and the diameter between 45 and 65 cm. The height and diameter were measured at 1.3 m above ground level. Based on previous study, the trunks tapers towards the crown generally have 41 fronds when mature (Mohamad et al., 1985).

Data on total dry weights of oil palm trunk for various ages is presented in Table 2.8 (Gary, 1969). Mean density of the trunk (dry weight) show increment with palm age (Corley et al., 1971). Based on the data, dry matter content also show variation considerably from top to bottom and from inside to outside of the trunk.

Table 2.8: Dry weight (percentage of fresh weight) of trunk sections of equal length

Trunk section	Apical (Top)	2	3	4	5	6	Basal (Bottom)
6½ yr. old palm							
Inner	8.6	10.4	11.7	12.9	11.2	11.1	12.7
Outer	10.3	14.9	17.5	15.1	14.8	14.2	15.1
17½ yr. old palms							
Inner	10.2	17.1	19.6	19.4	21.7	21.2	21.1
Outer	11.6	23.2	23.8	23.8	25.3	26.9	24.4

Source: Gray, 1969

Cortex is mostly composed of ground parenchyma with large numbers of strands. The strands shaped are small and irregular which are fibrous strands and vascular bundles (Killman and Lim, 1985). A cortex which is narrow in shaped has diameter approximately 1.5–3.5 cm wide makes up the outer parts of oil palm trunks. Periphery is made up of narrow layers of parenchyma and tightly packed with vascular bundles. This region gives rise to a sclerotic zone which is pivotal in providing the main mechanical support for the oil palm trunk (Killman and Lim, 1985). Central region is made up of slightly larger and widely scattered vascular bundles. These vascular bundles are embedded in the thin-walled parenchymatous ground tissues. Towards the core of the trunk, the size of bundles increased and are scattered more widely. The central region makes up about 80 per cent of the total area (Killman and Lim, 1985).

Vascular bundle is made up of several cells such as fibrous sheath (A), vessel (B) and parenchyma cells (C) as portrayed in Figure 2.1. The figure displayed common features of vascular bundles. The vascular bundles normally consisted of fibres, vessels and phloem which is found embedded in parenchymatous tissue (Hashim et al., 2011). Killman and Lim (1985) mentioned that the amount of vascular bundles per unit area decreased towards the inner zones but increased from the butt end to the top of oil palm tree. The ground parenchymatous cells mainly consist of spherical cells with a thin wall except the area around the vascular bundles. The walls are getting thicker and darker in colour from the inner to the outer region (Killman and Lim, 1985; Basiron et al., 2001).

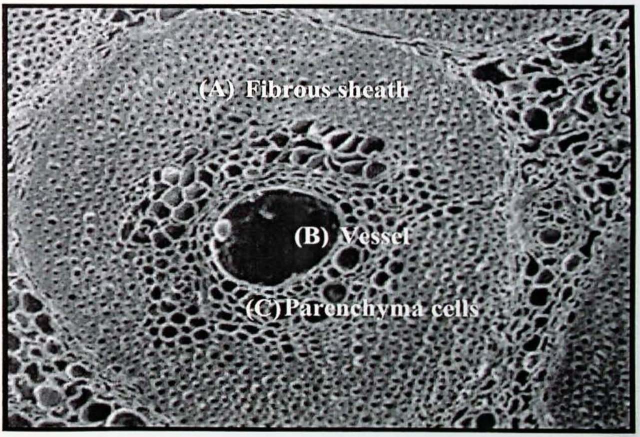

Figure 2.1: SEM of vascular bundles of oil palm trunk (Source: Hashim et al., 2012)

Meanwhile, the xylem cell is sheathed by parenchyma cells. In the peripheral region of the xylem cell contains one or two wide vessels. The central and core region had two or even three vessels that have similar width (Lim and Khoo, 1986). The distribution of fibrous strands depends on the amount of bundles nearby (Lim and Khoo, 1986).

2.1.5.1.1 Fibre dimension

Fibre dimension between oil palm trunk, fronds, empty fruit bunch, rubberwood and doughlas fir are shown in Table 2.9. The growth of trunk in diameter is caused by the enlargement of fibrous bundle sheath in the central region. Thus has completed most of the vascular bundles in the central region and also the enlargement of fibre length from the periphery to the inner part.

The diameter of the fibre decreases along the height of the trunk because most of the broader fibres are located in the larger vascular bundles which are nearer the oil palm trunk base (Lim and Khoo 1986).

Table 2.9: Comparison of the fibre dimension between oil palm trunk, fronds, EFB, rubberwood and douglas fir

Dimension	Trunk	Fronds	EFB	Rubberwood	D/Fir
Length (mm)	1.22	1.52	0.89	1.5	3.4
Width (μm)	35.3	[a]19.4	25	40	40
Cell wall thickness(μm)	4.5	[a]4.6	2.8	5.3	[b]na

Source: [a]Liew, 1996, [b]na: not available, Mohamad et al., 1985

2.1.5.2 Physical properties

2.1.5.2.1 Moisture content

Moisture content is the amount of water in a material or substance. Moisture content is pivotal to ascertain the characteristic of a material in term of physical properties. Oil palm trunk has high moisture content which in range from 120 to more than 500 % (Killmann and Lim, 1985). Previous study mentioned that oil palm trunk had extremely high moisture content which was around 60 to 300 % depending on its height and age (Singh, 1994; Mohamad, 2000). This reading is based on oven dried weight.

The moisture content value keeps increasing gradually along the trunk height and towards the central region, where the outer and lower parts having much more lower moisture content compare to other two parts (Lim and Khoo, 1986). The highest moisture content can be found at the centre of the trunk where parenchyma cells are found abundantly and decreased gradually to the outer part of the trunk (Lim and Khoo, 1986). Lim and Gan (2005) mentioned that relative amount of parenchyma cells and vascular bundles had relation with the variation of moisture content within the oil palm. The later preserved more moisture compare to the former.

2.1.5.2.2 Density

Density can be defined as physical property of a material or matter. Each element and compound has its own density. Density is a qualitative manner as the measure of heaviness of objects divided with a constant volume (kg/m^3). The density value of oil palm trunk varies for different parts of it due to its monocotyledonous nature. The values are in between 200 to 600 kg/m^3 with an average value of about 370 kg/m^3 (Lim and Khoo, 1986).The variation of density is due to the distribution of vascular bundles at radial direction along oil palm trunk (Loh et al., 2011). The density values decrease linearly with height of oil palm trunk and towards the centre of the trunk itself (Killman and Lim, 1985). This situation can be observed through the hardness and weight between outer and inner portions and also the butt and higher regions of the oil palm trunks.

Several factors have influenced the variation density values of oil palm trunk. The density value decrease when the number of vascular bundles per square unit increases across the trunk towards the centre. Besides that, the variation of density value along the oil palm trunk height is due to the vascular bundles that are younger at the top end of the trunk (Lim and Khoo, 1985).

2.1.6 Chemical properties of oil palm biomass

Cellulose is an organic compound which can be found in all species of wood and non-wood for example in oil palm fibres. The usage of the fibres is depending on the amount of cellulose content in the fibre itself. The variation of chemical composition can be found among different species of plant and also from a different part of the same species of plant. Besides, the chemical composition also varies among the plants from different ages, soil conditions, geographic location and climate (Rowell et al., 2000).

Chemical components of oil palm trunk such as cellulose, hemicelluloses, lignin and extractives are illustrated in Table 2.10. Based on the table, the distribution of extractives found in leaves of oil palm is the highest which is 20.60 if compared to other parts of oil palm tree (Hashim et al., 2011). Moreover, the value of extractives and lignin in oil palm especially bark, leaves, mid-part and core part of the trunk are higher than softwood and hardwood (Abdul Khalil et al., 2008; Hashim et al., 2011).

Generally, lignin and holocellulose content of oil palm are lower than hardwood, softwood rubberwood based on Table 2.10. In oil palm itself, the amounts of lignin can be found in range of 20 up to 27 % depends on parts of the oil palm (Hashim et al., 2011).The distribution of lignin is slightly less at the core in the upper region even though the bottom has a large amount and distributed evenly throughout the tree (Halimahton and Ahmad, 1990). Lignin is believed has pivotal role in binderless board.

Table 2.10: Chemical composition of parts of oil palm and wood

Parts of oil palm	Extractives	Chemical composition (%)		
		Holocellulose	Alpha cellulose	Lignin
Bark [a]	10	77.82	18.87	21.85
Leaves[a]	20.6	47.7	44.53	27.35
Frond[a]	3.5	83.13	47.76	20.15
Mid-part of trunk[a]	14.5	72.6	50.21	20.15
Core-part of trunk[a]	9.1	50.73	43.06	22.75
Frond[b]	1.4	82.2	47.6	15.2
Trunk[c]	5.35	73.06	41.02	24.51
Kenaf[d]	-	82	-	-
Hardwood[e]	0.1-7.7	71-89	31-64	14-34
Softwood[e]	0.2-8.5	60-80	30.6	21-37

Source: [a] Hashim et al., 2011; [b]WanRosli et al., 2007; [c]Abdul Khalil et al., 2008; [d]Okuda et al., 2006; [e]Tsoumis, 1991

2.1.6.1 Cellulose

Cellulose is an organic compound found in lignocellulosic material. Cellulose is a linear polymer comprising of D-glucopyranose sugar units. These units are known as dimer, cellobiose. Beta configuration had linked the D-glucopyranose sugar units where each of the cellulose chain has high degree of polymerization which in range about 9000 to 10 000 units (Rowell, 2005). Cellulose polymer normally is one of the strongest components in lignocellulosic material. Moreover, it is crystalline and not accessible to water or other solvents. Furthermore, 65 % of the cellulose is highly oriented. The remaining cellulose contained fewer oriented chain, thus only part of it be able to access to water and other solvents. This is because cellulose associates with hemicelluloses and lignin. In addition, there is none of cellulose that is directly contact with lignin in the cell wall (Tsoumis, 1991; Sjostrom, 1993).

2.1.6.2 Hemicellulose

Hemicelluloses which are non crystalline in structure are mainly built up by several heteropolymers or polysaccharides polymer. Heteropolymers and polysaccharides polymer exist in almost all plant cell wall. Hemicelluloses are contained with five carbon sugars D-xylose and L-arabinose and hexose sugars D-glucose, D-galactose, D-mannose as shown in Figure 2.2 (Walker, 2006). Besides that it also contained 4-0-methylglucuronic acid (Tsoumis, 1991). Unlike cellulose, hemicellulose consists of shorter chain of sugars units, amorphous and highly branched. It also can be categorized as polymer with low molecular weight if compared to cellulose. Due to low molecular weight and non crystalline properties, hemicelluloses are easy to access and susceptible to hydrolysis (Walker, 2006). Besides that, the structure of hemicelluloses also varies where the composition of sugar is depending on its source (Reddy and Yang, 2005). Moreover, it is soluble in alkali and can be hydrolyzed with acid (Rowell, 2005).

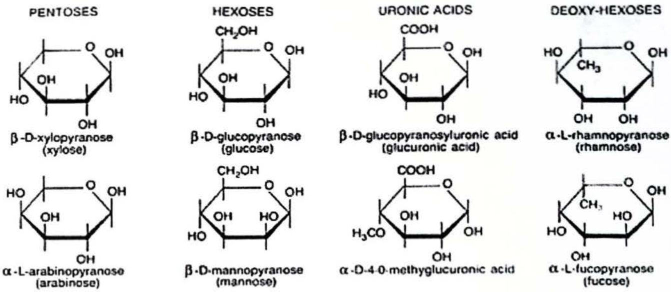

Figure 2.2: Common sugars in hemicellulose (Source: Walker, 2006)

2.1.6.3 Lignin, extractive and ash content

Lignin is an aromatic substance that composed of nine carbon units. The composition and bonding of lignin are varying which depends on species and tissue (Walker, 2006). Lignin is derived from cinnamyl alcohol; coumaryl, coniferyl, and syringyl alcohols. Lignin can be found in amorphous structure. The chemical compound of lignin is hydrophobic and insoluble in most of the solvents. Lignin is a polymer that is comprised of phenylpropane units in which the arrangement of substituted phenolic units is complex (Sjostrom, 1993). Thus, no single repeating unit of hemicelluloses can be found in lignin structure. Those units of lignin are utmost branched and not crystalline. Besides, the structure and chemical composition of a lignin is a function of its source (Donaldson, 2001; Reddy and Yang, 2005). Lignin has molecular weight about 260 up to 50 million because the amount of molecular weight is depends on the method of extraction being used. An example of the method used to extract lignin which is intensely condensed is Klason lignin (Goring, 1962).

Extractives are an assortment of chemical compounds of wood species that could be extracted out using either polar or non polar solvents (Walker, 2006). Extractives are responsible to give odour, durability and colour of the wood species. Besides that, extractives also function as antioxidants, antiviral, fungicides, bacteriacides, cytotoxins and many more. The compound that mainly found in extractives are fats, fatty alcohol, fatty acids, terpenes, phenols, steroids, resin acids, rosin, waxes and other minor organic compounds which also be referred as resin content (Rowell, 2005; Walker, 2006). The chemicals present in the wood in a form of monomers, dimmers or even polymers which are particularly comprised of cyclic hydrocarbons.

Ash content refers to the inorganic mineral content which is solid and particulate that resulted from combustion process. It can be determined by burning a certain quantity of material such as lignocellulosic material under prescribed conditions. Then, the residue left is measured and referred as ash content. The percentage depends on the source of the material. High ash content indicates that the plant has a higher amount of silica (Rowell, 2005).

2.2 Particleboard

2.2.1 General

Particleboard is a composite material that can be defined as an engineered wood product. Normally, particleboard is manufactured in three layers (Youngquist, 1999) The raw materials used in particleboard get from variety sources such as wood chips, sawmill shavings, saw dust or trimmings that were sprayed or dusted (speckled) with suitable synthetic resin or binder resin and are bonded together with pressure and heat (Moslemi, 1973; Abdul Khalil and Hashim, 2004). Besides wood, particleboards can be manufactured as panels from other sources of raw material such as lignocellulosic materials such as kenaf, oil palm trunk, baggase and many more (Okuda et al., 2006; Hashim et al., 2012).

The term particleboard is a general term which includes a number of different panel types such as "chipboard", "flakeboard", "strandboard" and "waferboard". Those panels depend on size and shapes of particles used in the manufacturing process. The variety size of particles were bonded together in order to make a particleboard (Rowell, 2005).

Most of the particleboard is manufactured by pressing technique in producing a mat of resin-speckled with particles flat wise. Meanwhile, extruded board was produced by forcing the resin-speckled particles between parallel heated dies represent a miniscule proportion of the particleboard produced (Moslemi, 1973). The properties of a particleboard depend on the raw material used, type and amount of adhesive.

2.2.2 Types and properties of raw material

There are many sources of raw material that can be used to manufacture particleboard. The selection of raw material depends on some criteria and requirements such as availability of the material, inexpensive, suitable to be manufactured as board and low cost to handle and storage. The main raw materials in particleboard manufacturing are adhesive and wood. Urea formaldehyde is the most common adhesive and widely used (Rowell, 1992)

Wood sources can be categorized into undried and dried sources. The wood sources from undried category can be found from planer shavings generated in surfacing green lumber, plywood mill residue, sawmill residue, particles produced from round wood and sawdust. Meanwhile, wood sources from dry category comprised of planner shavings from surfacing kiln dried lumber, plywood mills residues generated after veneer has been dried, dry rough lumber cutting residue and dry sawdust (Stillinger, 1967). Planner shavings become one of predominance sources of raw materials for particleboard manufacture due to its low cost and availability. However this source does not have the best particle geometry characteristic because it is bulky, curled and weak (Moslemi, 1973).

The utilization of lignocellulosic materials such as baggase, kenaf and oil palm biomass in particleboard industry has become favourable due to its abundance (Widyorini et al., 2005; Okuda et al, 2006; Sulaiman et al., 2009; Halvarsson et al., 2009). Thus, lignocellulosic material had become an option as raw material to produce composite instead of wood sources. The non-wood lignocellulosic material, particularly agricultural residues have the capability to produce acceptable particleboard. Fiberbase board for example, can be made from wheat straw, oil palm trunk, baggase, bamboo,