INVESTIGATION ON PERFORMANCE OF OIL PALM TRUNK AS A LAMINATED VENEER LUMBER USING VARIOUS THERMOSET ADHESIVES

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UNIVERSITI SAINS MALAYSIA

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%	percentage
^{0}C	degree celcius
ad	Air dry
ANOVA	Analysis of variance
ASTM	American Society for testing and material
BSI	British standard institute
cm	centimeter
EFB	Empty fruit bunch
FESEM	Field emission scanning electron microscopy
FRIM	Forest research institute Malaysia
g	gram
g/m^{2}	gram per metre square
kN/min	kilonewton per minute
LVL	Laminated veneer lumber
m	metre
MC	Moisture content
mm	milimetre
MPa	megapascal
MUF	Melamine urea formaldehyde
od	Oven dry
OPF	Oil palm frond
OPT	Oil palm trunk
PF	Phenol formaldehyde
POME	Palm oil mill effluent
PRF	Phenol resorcinal formaldehyde
RH	Relative Humidity
RW	Rubberwood
SEM	Scanning electron microscope
UF	Urea formaldehyde
TS	Thickness swelling
WA	Water absorption

KAJIAN TENTANG PRESTASI BATANG POKOK KELAPA SAWIT SEBAGAI VENIR TERLAMINASI MENGGUNAKAN PELBAGAI PEREKAT TERMOSET

ABSTRAK

Eksperimental bod terlaminasi atau “laminated veneer lumber” (LVL) dihasilkan menggunakan perekat urea formaldehid, fenol formaldehid, urea formaldehid dan fenol-resorcinal formaldehid. Ujian fizikal, kekuatan ricihan, sudut sentuhan, ujian ‘soil burial’, dan kelembapan relatif telah dijalankan. Berdasarkan keputusan ujian, didapati ketumpatan bod terlaminasi kelapa sawit lebih tinggi daripada ketumpatan batang kelapa sawit. Walaubagaimanapun, nilai ini masih rendah jika dibandingkan dengan nilai ketumpatan bod terlaminasi yang diperbuat daripada batang pokok getah. Keputusan juga menunjukkan pengembangan ketebalan dan penyerapan air bod terlaminasi daripada batang kelapa sawit lebih tinggi daripada bod terlaminasi daripada pokok getah. Bod terlaminasi menggunakan resin fenol resorcinol formaldehid menunjukkan keputusan kekuatan ricihan yang tinggi jika dibandingkan dengan bod terlaminasi menggunakan resin yang lain. Sudut sentuhan permukaan longgar venir kelapa sawit adalah lebih rendah daripada permukaan tegang kelapa sawit dan permukaan venir pokok getah. Resin fenol formaldehid menunjukkan keputusan sudut sentuhan yang tinggi daripada resin-resin yang lain. Bod terlaminasi daripada urea formaldehid juga menunjukkan ketahanan apabila ia menunjukkan peratus kehilangan berat yang rendah dalam ujian ‘soil burial’. Keputusan juga menunjukkan takat tepu gentian bod terlaminasi kelapa sawit lebih rendah daripada bod terlaminasi pokok getah. Daripada kajian yang telah dijalankan terhadap penggunaan sebaran perekat yang berbeza, didapati panel yang dihasilkan menggunakan sebaran perekat 500g/m^2 telah menghasilkan sifat fizikal dan mekanikal yang lebih baik terhadap kedua-dua LVL, OPT dan kayu getah. Secara keseluruhannya, OPT LVL yang dihasilkan melalui kajian ini boleh diperbandingkan dan diterima pakai berdasarkan BS 6566: Part 8 (1985).

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ABSTRACT

Experimental laminated veneer lumber (LVL) was manufactured from oil palm veneer using urea formaldehyde, phenol formaldehyde, melamine-urea formaldehyde, and phenol-resorcinal formaldehyde adhesives. The laminated veneer was tested for physical properties, shear strength, contact angle, soil burial and relative humidity. Based on the findings, the density of the oil palm laminated veneer lumber was slightly higher than the solid oil palm trunk. However, these values were lower in comparison to the rubberwood laminated veneer lumber. The thickness swelling and water absorption of laminated veneer lumber of oil palm was higher than those made from rubberwood. Laminated veneer lumber of oil palm bonded with phenol-resorcinal formaldehyde adhesive showed higher shear strength compared to panels bonded with other adhesives. The contact angle on the loose surface of oil palm veneer was lower than on the tight surface of oil palm veneer and rubberwood. Phenol formaldehyde adhesive has a higher contact angle compared to the other adhesive used in this study. Laminated veneer lumber of oil palm bonded with urea formaldehyde showed good durability and it has less percentage of loss weight in soil burial testing. The results also show that the fiber saturation point of oil palm laminated veneer lumber was lower than rubberwood laminated veneer lumber. The observation on using spread level, panels bonded with 500g/m^2 of spread level was showed better performance on physical and mechanical properties compared to 250g/m^2 both for OPT LVL and rubberwood LVL respectively. As compared to BS 6566: Part 8 (1985) standard, the OPT LVL bonded with these four adhesives was comparable and acceptable.

INTRODUCTION

1.1 General

Oil palm belongs to the species *Elaeis guineensis* and originated in the tropical forest in West Africa. The seed was transferred from West Africa to the Bogor Botanical Gardens, Indonesia in 1848. The seeds arrived on Malaysian shores in 1871 as ornamental plant (Basiron, *et al*., 2000). The oil palm tree becomes one of the most important commercial crops in Malaysia. The summary report on the performance of the Malaysian oil palm industry showed that oil palm planting area increased from 3.82 x 10^6 ha (2004) to 3.96 x 10^6 ha (2005). In year 2006, the total oil palm planted area was 4.17 million hectares (Anis *et al*., 2006). With such large area of plantation, the amounts of oil palm biomass are definitely in a large amount and it can be converted into value-added product.

Wood industry especially those using veneer for plywood had a major problem in getting raw materials at competitive price. Oil palm trunk (OPT) is abundant easily available, and it is cheaper than wood. Using oil palm biomass as a raw material will reduce the cost of production and also increased the economics return. It is environmentally friendly when considering it as agricultural waste. In fact it had been major focuses in veneer associated industry to use OPT as a raw material in certain application. Oil palm trunk (OPT) could be used for laminated products such as laminated veneer lumber and plywood (Nordin *et al*., 2004; Sulaiman *et al*., 2008).

Laminated veneer lumber (LVL) is an engineered wood product manufactured from veneers that are rotary peeled, dried and laminated together with parallel oriented grains under heat and pressure with a waterproof adhesive (Llaufenberg, 1982). The demand for engineered wood products such as laminated veneer lumber has increased as a result of a constant increase in the global population (Baldwin, 1995). Laminated products from wood however are hygroscopic materials, which lose and gain moisture when there is a change in relative humidity. When these products are in use, the dimensional stability and strength could be affected especially when there is occurrence of moisture changes due to stresses in swelling and shrinkage. Shrinkage and swelling are very important properties that determined the quality of the products (Noack, *et al.*, 1973).

One of the advantages of using LVL is that specific performance characteristics can be incorporated into its design. By the nature of their manufacturing process, large defects such as knots and other strength-reducing characteristics are eliminated or dispersed throughout the cross-section to produce a homogenous product (Wang, *et al.*, 2003; Hing, *et al.*, 2001). The LVL manufacturing process creates a strong and stable product that can reliably support large areas. A second important benefit of LVL is that the veneering and gluing process enables large beams to be made from relatively small diameter logs of many species, thereby provide for efficient use of forest resources. Due to their advantages mentioned above, LVL has been suggested as a good alternative for structural purposes (Kamala, *et al.*, 1999). The physical and mechanical properties of laminated materials manufactured depend on the types of species from which the lumber manufactured, general properties of different materials used in the layers, the composition of wood species, glue types and ply thickness (Kamala, *et al.*, 1999; Baldwin, *et al.*, 1995).

Urea formaldehyde (UF), phenol formaldehyde (PF), melamine-urea formaldehyde (MUF) and phenol-resorcinal formaldehyde (PRF) are classified as thermosetting polymers. Urea formaldehyde (UF) is produced by condensation polymerization reaction between urea and formaldehyde. Urea formaldehyde (UF) is the most important adhesives resin use in production of wood-based panels. It has excellent adhesion to lignocelluloses and also excellent in intrinsic cohesion, ease of handling and application, without giving any colour in the finished product, and the low cost of UF have led the resin to be the most widely used adhesives for bonding wood products. However, lack of resistance to weather and water and their susceptibility to emission of formaldehyde vapours are the main disadvantages of UF resin (Pizzi, 1994).

Phenol formaldehyde (PF) resin is slower curing than UF and is more heat stable. Bond strength is considered high and deterioration at elevated temperatures in the presence of moisture is low compared with UF. The percentage loss in strength following long time soaking is only slightly lower than that UF boards (Dinwoodie, 1978). Melamine urea formaldehyde (MUF) resin is produced by a condensation reaction between melamine, urea and formaldehyde. These MUF polymers can be formulated to provide various degrees of water and weather resistance for use in exteriors, humid and indoor climate. Melamine urea formaldehyde is more attractive adhesives on the grounds of its resistance to moisture in the cured state and the use of shorter press time than those necessary for PF resin. However, this resin is more expensive than UF and PF (Dinwoodie, 1978). Phenol-resorcinal formaldehyde (PRF) is produced by a condensation polymerization between formaldehyde, phenol and resorcinol. Phenol-resorcinal formaldehyde (PRF) has high weather and water resistance as well as heat resistance and can be used in products for exterior, humid and interior climates. Phenol-resorcinal formaldehyde (PRF) adhesives can also be used in hot bonding and radio frequency curing equipment to speed up the curing process.

Shortages of wood as raw material for wood based product have been a major problem in the wood industry. The world demand for wood product nowadays have forced wood based industry to produce more products to achieve the demand of wood product in the market but as stated above the raw materials are limited and therefore a lot of study and research need to be done to find alternative to substitute wood as a raw material and oil palm biomass appears to be viable alternatives. Research on the use of oil palm biomass for various products is on-going and the findings have shown good prospects for these materials to replace some forest species for wood and fibre (Anis, 2006). Oil palm trunk had a potential to replace wood and furthermore oil palm trunk is abundant and after the tree fell down for replanting it normally just left rot, so using oil palm trunk not only could overcome some of the problem of limited raw material but it is also environmentally friendly and increased the economic returns. Therefore, the aim of this research is to produce laminated veneer lumber from waste of oil palm trunk and subsequently to investigate the suitability of some adhesives to bond with oil palm veneer in order to produce laminated veneer. Four types adhesives were are urea formaldehyde (UF), phenol formaldehyde (PF), melamine-urea formaldehyde (MUF) and phenol-resorcinal formaldehyde (PRF). The physical and mechanical properties of the experimental laminated veneer lumber were evaluated.

1.2 Objectives

The objectives of this study are:

1. To investigate the suitability of variety types of adhesives on the performance of oil palm veneer as laminated veneer lumber.
2. To evaluate the physical and mechanical properties of laminated veneer lumber from oil palm veneer.
3. To determine the properties of laminated veneer lumber manufactured using different glue spread level.

LITERATURE REVIEW

2.1 Oil Palm Tree

2.1.1 History of Oil Palm Tree

Oil palm tree (*Elaies guineensis*) is originated from West Africa (Figure 2.1). Oil palm plantations have become one of the fastest growing monocropping plantations in the tropics not only of Africa, but also in Asia-Pacific, Latin America and the Caribbean (Corpuz. and Tamang. 2007). The earliest evidence of the preliminary introduction of oil palms into South-east Asia was of four seedlings planted in the Buitenzorg which is now recognized as Bogor at Botanic Gardens in 1848 in Java. Two of these seeds were from Amsterdam Botanic gardens, but its origin is not known. The other two were from 'Bourbon or Mauritius' in the Indian Ocean. The palms that appear from these four seedlings were all quite similar, and it has assumed that they were all originally produced in Amsterdam, from seeds brought from Africa. The uniformity of the progeny suggests that all four seedlings may well have originated from a single parent palm. After the transfer of the progeny of these parents palms to Sumatra in 1875, they became the foundation stock for the South-east Asian industry (Corley and Tinker 2003).

Figure 2.1: Oil Palm Tree (*Elaeis guineensis*)

The history of development of oil palm plantation begun from a Belgian agronomist named M. Adrian Hallet who is the first person responsible for commercialize oil palm plantation in Sumatra, Indonesia. Then, the development of this industry in Malaysia is attributed to Frenchman, Henri Fauconnier and his association with Hallet. In 1911, Fauconnier visited Hallet's oil palm development in Sumatra and he was interested to plant oil palm tree in Malaysia. He purchased some oil palm seeds and these were planted at his Rantau Panjang Estate in Selangor. The following year, he returned to Sumatra to obtain seeds that he had been selected together with Hallet from Tanjong Morawa Kiri Estate for further planting. Fauconnier established the first commercial oil palm planting at Tennamaram Estate with seedlings obtained from 1911 and 1912 importation to replace an unsuccessful planting of coffee bushes (Tate, 1996).

Described by Gray 1969 and Harcharan Singh 1876 in their analyses of the palm oil industry in Malaysia, the development of the industry in

Peninsular Malaysia is classified into three distinct phases, starting with the experimental phase from the late 1800s, early 1900 to 1916 while the plantation development phase commenced in 1917 with Tennamaram Estate until about 1960. The expansion phase from the 1960s was the response to the Government's diversification policy to reduce the dependence of the national economy on natural rubber, which had faced declining prices and competition from synthetic rubber. Following the recommendation of the World Bank Mission in 1955, the Government decided to promote the planting of oil palm. A key driver for this effort was the Federal Land Development Authority (Felda) which was established in 1956 with the socio-economic responsibility of developing plantation land for the rural poor and landless. The palm oil industry has undergone two further phases, from 1970 with the expansion of large scale planting in Sabah and Sarawak and from around 1995 when Malaysian extended their upstream operations off-shore, particularly to Indonesia where there is adequate supply of workers and availability of land for plantation development and cost of production is lower than in Malaysia.

2.1.2 Oil Palm Industry

Development of oil palm plantation in Malaysia had grown increasingly until the end of the twentieth century. Malaysia and Indonesia have become dominant in the trade, and have built up a very large basis of experience, both in the actual production of palm oil and palm kernel oil. Malaysia and Indonesia now also have very efficient supply chains and reputation of reliable partners in trade. The developments of oil palm industry begin from the smallholder plots and farms and used for the farmer's domestic purposes or sold locally. Estimates suggest that world-wide production rose from 2.2 million tonnes of palm oil and 1.2 million tonnes of kernels in 1972 to 21 million tonnes of oil, 6 million tonnes of kernels and 2.6 million tonnes of kernel oil in 2000. Most of this increase can be attributed to Malaysia and Indonesia, and to some smaller Asian producers (Corley and Tinker 2003).

The production of palm oil has now overtaken that of other vegetable oils, apart from soybean oil (Figure 2.2). At present, production costs for palm oil are below those of other vegetable oils even though the crop is manually harvested. This is mainly due to the availability of cheap labour.

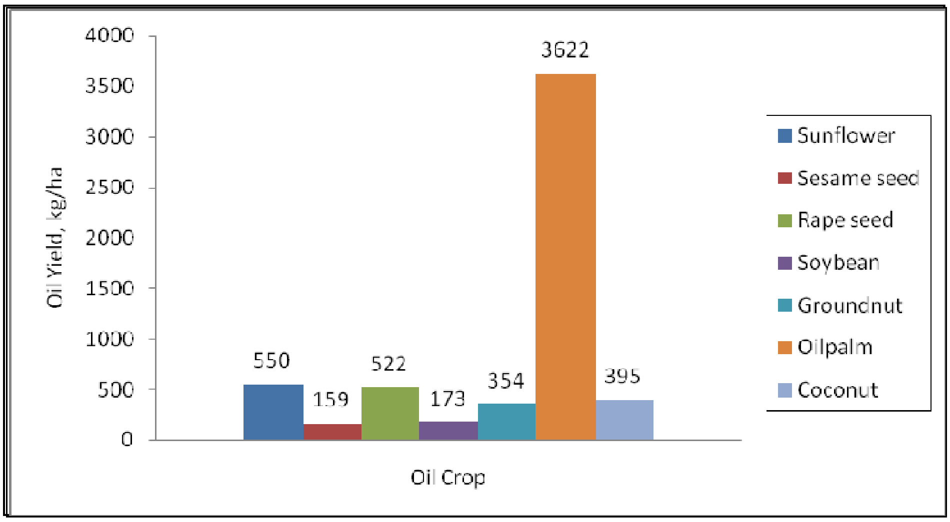

Figure 2.2: Oil yield (in oil equivalents) for major vegetable oil crops. (Mielke 1991).

Almost 80% of world palm oil production is located in South-east Asia and most of it in Malaysia and Indonesia. Besides, there are 260,000 hectares are planted in Thailand and smaller areas exist in the Philippines or were recently planted in Cambodia and Myanmar. There are estimated that world production and demand of crude palm oil increase to 30 and 36 million tons crude palm oil towards 2010 and Malaysia and Indonesia are expected to maintain their leading role in this respect (Table 2.1) (Ernst and Thomas 1999).

Table 2.1: World Production and Consumption of Palm Oil, 1990 – 2010

	Production Million tons				Demand
Year	Malaysia	Indonesia	Others	World	World
1990	6.1	2.4	2.5	12.0	12.5
1995	7.8	4.7	3.1	15.6	16.6
2000*	9.4	7.0	4.0	20.4	22.1
2005*	11.0	10.4	4.5	25.9	28.4
2010*	12.0	12.6	5.2	29.8	35.5

Source: (PPI-PPIC-ESEAP, 1998)
*Forecast

In Table 2.2 it was indicated the South-east Asia's harvested area of oil palm and fresh fruit bunch (FFB) production has increased by four times between 1980 and 1998.

Table 2.2: Oil palm development of harvested area, fresh fruit bunch (FFB) yield and FFB production in a Southeast Asia, 1980 – 1998.

		1980	1985	1990	1995	1998
Area harvested	(000 ha)	1013	1718	2622	3693	4388
Fruit yield	(t FFB ha)	16.9	17.5	17.1	18.5	17
Production	(Mt FFB)	17.1	30.1	44.8	68.4	74.7

Source: (FAO Agriculture Statistic Database, 1999)

The area harvested in Southeast Asia as in Table 2.3 is similar to the total area harvested in Africa and America but greater productivity has been maintained with yields of over 3 tons crude palm oil ha^{-1} in South-east Asia compared to 1 tons ha^{-1} in Africa and America. There are several reasons for this rapid expansion. Crude palm oil and kernel oil prices have been strong, due to the rapid increase in consumption of dietary oils and fats in the developing economies of China and India. This has encouraged investors to develop plantations on the large areas of suitable land found in Peninsular Malaysia and the islands of Sumatra in Indonesia and Borneo, where some part belongs to Malaysia (Sabah and Sarawak) and some part to Indonesia (Kalimantan) (Ernst and Thomas, 1999).

Table 2.3: Oil palm, area, yield and production in South-East Asia, 1998

Country or Region	Planted (ha x 10^3)	Mature (%)	Expansion (ha x 10^3)	Yield (t ha^{-1})		Production (t x 10^3)	
				FFB	CPO**	CPO***	PK**
Indonesia	2245	80	4500	14.9	2.8	5022	1050
Malaysia	2967	78	1000	18.9	3.6	8370	1650
Thailand	188	76	100	16.1	2.7	380	90
Philippines	29	66	30	14.4	2.1	40	8
SW Pacific*	84	86	50	15.6	3.2	230	45
SE Asia	5513	79	5680	17.1	3.2	14042	2843
Africa	4915	82	2000	5.5	1.0	3955	879
America	434	88	500	6.0	1.1	412	92
World	10904	81	8180	11.3	2.1	18409	3814

Source: (PPI-PPIC Singapore, 1999)
* Papua New Guinea and Solomon Islands, **CPP = Crude palm oil
***PK = Palm kernel oil.

Oil palm cultivation and processing, like other agricultural and industries activities, are regulated by a number of environmental legislation aimed at conserving and protecting the natural environment. These rules and regulations play a significant role in minimising the degradation of the soil, water and atmospheric environment. With such large area of oil palm plantation year by year will lead to the abundant of oil palm biomass due to replanting of oil palm tree when the tree mature and of course it also can be a reason of pollution to environment if this biomass were not managed in correct way. Research on oil palm biomass have been started to help to reduce waste of the oil palm biomass and in the same time can increased the economic return of the country.

2.1.3 The Oil Palm Tree

The Oil Palm (*Elaeis guineesis*) is an unbranched monoecious plant. It can grow to a length of 20m – 30m. The Oil Palm has a typical adventitious root system. All mature plants have a solitary columnar stem with persistent frond bases. The stem supports a crown of fronds. The frond consists of leaflets, each with a lamina and midrib, a central rachis to which the leaflets are attached, a petiole and a frond sheath (Corley and Gray, 1976).

The oil palm produces either a male or female or at certain stages hermaphrodite inflorescence in each of the frond axils during the mature stage. The proportion of male or female inflorescences to total inflorescences (sex ratio) determines the yield. High yield tend to be obtained with a high female sex ratio. The female inflorescence, on its flowers being pollinated and fertilized, becomes the fresh fruit bunch (FFB). The fertilized flower produces a fruit, which grow and ripens over about 6 months. The oil palm fruit is a sessile drupe and consist essentially of an exocarp (skin), a fleshly mesocarp which contains palm oil, a hard stony endocarp (shell) and kernel (seed) the source of the kernel oil and meal. There are three main varieties of oil palm distinguished by their fruit characteristics (Chin, 1992). These are:

1. Dura, which has a thick shell separating the pulp from the Kernel. The Kernel tends to be large comprising 7% - 20% fruit weight.
2. Tenera, which has a thin shell between pulp and kernel, together with a fibrous layer round the nut. The kernel is usually smaller comprising of 3% - 15% of fruit. The oil content is higher at 24% - 32%.
3. Pisifera, which has no shell and is very frequently female sterile.

As a result of their very marked tendency to female sterility, Pisifera palm are not used for commercial planting. The pericarp is composed of large numbers of oil cells, which are full of oil when the fruit is freshly ripe (Corley and Tinker, 2003).

2.1.4 Oil Palm Biomass

The meaning of biomass is any organic plant product that has general uses. Each year, the oil palm industry in Malaysia generates more than 30 million tons of biomass in the forms of empty fruit bunches, oil palm trunks and oil palm fronds. Oil palm biomass of trunks, fronds, empty fruit bunches, fibre, shell and effluent is obtained under two situations. First, trunks and fronds from oil palm growing in the plantation and second are the remaining four from oil palm processing (Hassan *et al.*, 1997).

Oil palm trunks are available only when the economic life-span of the palm is reached at the time of replanting. The average age of replanting is about 25 years. The main economic criteria for felling are the height of palm reaching 13m and above, and annual yield of bunches falling below 10-12 t/ha. Oil palm fronds are obtained during replanting and either harvesting or pruning time. Normally at the time of replanting, the crown gives approximately 115kg/palm of dry fronds. On an annual basis, 24 fronds are pruned and the weight of fronds varies considerably with ages of the palms with an average annual pruning of 82.5 kg of fronds/palm/year (Chan *et al.*, 1980).

Over the years, the oil palm industry has been very responsible and all the co-products have gradually been utilized. The utilization of the various co-products through nutrient recycling in the fields had reduced the environment impact paving the way towards a zero-waste policy. In 1990 there is a further move to improve the use of these co-products through the development of the value-added products. Figure 2.3 indicated the uses of oil palm biomass in manufacturing and food industries (Gurmit *et al.*,1999).

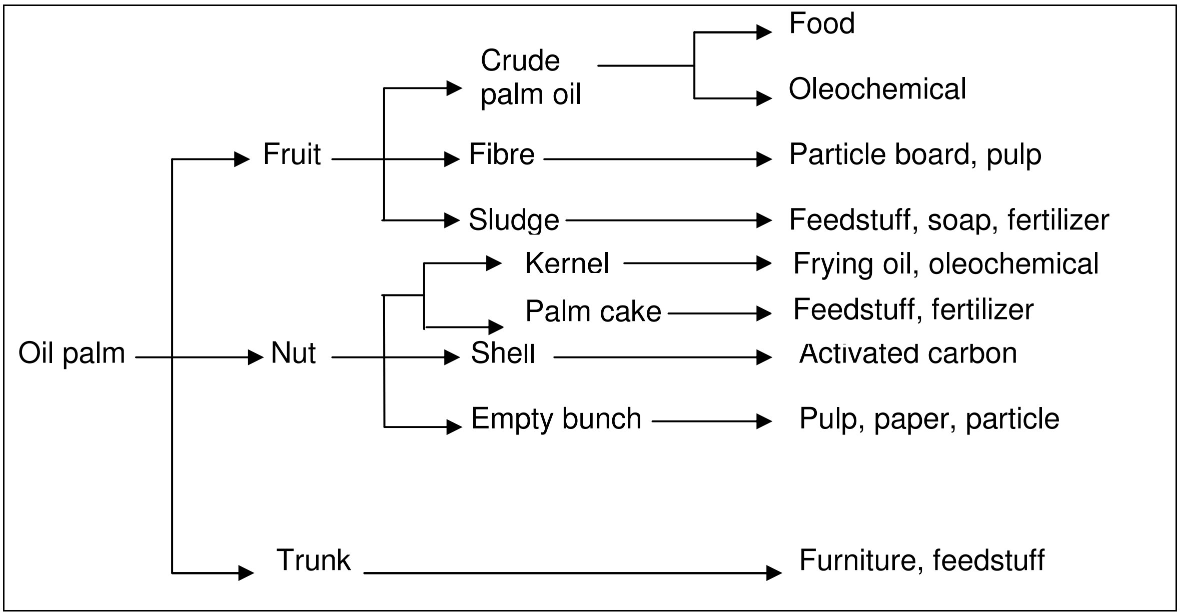

Figure 2.3: Uses of palm oils and biomass in food and manufacturing industries (Gurmit *et al*., 1999)

2.1.4(a) Oil Palm Trunk

There are a lot of uses of oil palm trunk in term of wood product such as particleboard, laminated board, plywood, fibreboard, finger joints,and furniture. Oil palm trunk also can be use as pulp in paper making. It also can be use as nutrient in plantation and can use as erosion control measure by placing at the lip of planting terrace. Besides, it also can use as animal feed (Gurmit *et al*.,1999; Sulaiman *et al*., 2008)

2.1.4(b) Oil Palm Fronds

Oil palm fronds when piled in between palm rows are important sites for development of feeder roots of oil palm. Pruned fronds are good source of organic matter that can help reduce soil erosion when placed across harvesting paths and along contours (Maene *et al*.,1979). Fronds can be used to extract vitamin E, pulp and fibre for paper, silage for animal feed, also as furniture and can be recycled as mulch and nutrients in plantation. The competitive use of palm fronds for other value-added requirements would mean that more nutrients are taken out of the plantation ecosystem and correspondingly more mineral fertilizers would have to be added to compensate whole frond removal. To overcome this problem only petiole is harvested, leaving behind the rachis and leaflets (Mohamad *et al.*,1986; Husin *et al.*, 1995; Gurmit *et al.*, 1999).

2.1.4(c) Empty Fruit Bunches (EFB)

In the past most of the EFB was incinerated to obtain ash which was used as a substitute for muriatic of potash and detergent. However, there are more advantages from EFB when used as mulch. The other uses of EFB are for pulp, wood composite products such as fibreboard and medium density board. It also can be use as adjunct to improve efficiency in fertiliser uptake (Chan *et al.*, 1999; Sulaiman *et al.*, 2008)

2.1.4(d) Shell and Fibre

Generally both shell and fibre are used as fuel to generate heat for boilers. The residual boiler slag after sieving and the ash is used for surfacing of roads. The new uses and value-added products developed from shell are lightweight concrete and activated carbon and from fibre as roof tiles and fibre-boards. Fibre also can be used as pulp for paper making (Husin *et al.*, 1995; Basiron *et al.*, 1997).

2.1.4(e) Palm Oil Mill Effluent (POME)

Palm oil mill effluent (POME) is the waste comes from the oil palm processing mill. Palm oil mill normally generates a huge amount of wastewater effluent. The amount of effluent production from the average mill is about 65% to 70% of the fresh fruit bunch processed or 2.5 times for every tone of crude palm oil produced. Palm oil mill effluent (POME) can be converted as cellulose and single cell protein from sterilizer condensate, biogas, fertilizer, and animal feed (Husin *et al.*, 1995; Corley and Tinker 2003).

2.1.5 The Anatomy of Oil Palm Trunk

Oil Palm tree is a non-wood tree. Oil palm is a monocotyledonous species and does not have cambium, secondary growth, growth rings, ray cells, sapwood and heartwood or branches and knots. The growth increased in diameter of the stem results from the overall cell division and cell enlargement in the parenchymatous ground tissues, together with the enlargement of the fibres of the vascular bundles. There are three main parts first is cortex, second the peripheral region, and last the central zone in the cross section of the oil palm trunk (Killmann and Lim 1985; Corley and Tinker 2003).

After 25 years normally oil palm will replant. At replanting age, the oil palm trunk has a height that ranges between 7 to 13 m and diameter between 45 and 65cm, measured 1.5 m above ground level. The trunk tapers towards the crowns which generally produce about 41 fronds when mature.

The anatomical features of cross-section of oil palm trunk described based on the work by Killmann and Lim, (1985) in Figure 2.4.

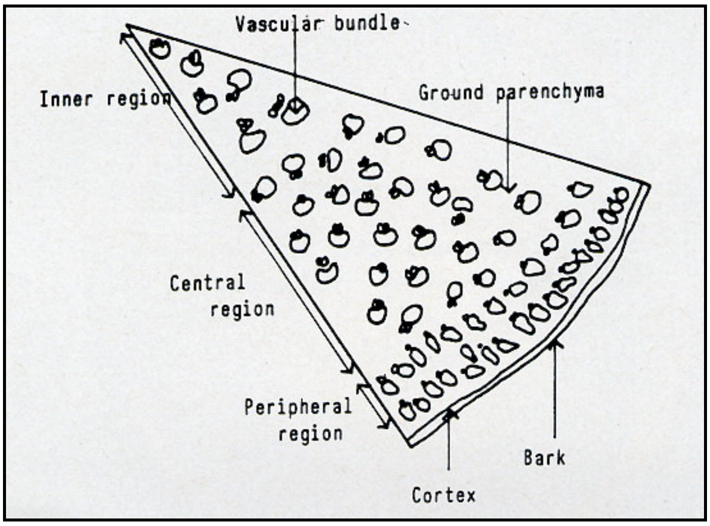

Figure 2.4: Cross-section of oil palm trunk (Killmann and Lim, 1985)

2.1.5(a) Cortex

A narrow cortex, which is approximately 1.5 – 3.5cm wide, makes up the outer part of the trunk (Figure 2.4). It is largely composed of ground tissue parenchyma with numerous longitudinal fibrous strands of small and irregular shaped fibrous strands and vascular bundles (Lim and Khoo, 1986).

2.1.5(b) Periphery

This region with narrow layers of parenchyma and crowded vascular bundles (Figure 2.4), gives rise to a sclerotic zone which provides the main mechanical support for the palm trunk. The peripheral region normally contains a large number of radially extended fibrous sheaths, thus providing the mechanical strength to the palm. This region makes up about 20% of the total area of the cross-section. The fibres have multi-layered secondary walls and increase in length from the periphery to the pith. The basal parts of the stem, being older normally has better developed secondary walls than do the top parts. The phloem cells, in single strand, are present between the xylem and fibre strands. According to Lim and Khoo 1986, they estimated that the number of vascular bundles is about 87/cm^2 at periphery region (Killman and Lim, 1985).

2.1.5(c) Central

This zone makes up about 80% of the total area, is composed of slightly larger and widely scattered vascular bundles embedded in the thin-walled parenchymatous ground tissues (Figure 2.4). Towards the core of the trunk the bundles increase in size and are more widely scattered. According to Lim and Khoo 1986, they estimated that the number of vascular bundles is about 37/cm^2 at central region (Killmann and Lim, 1985).

2.1.5(d) Vascular Bundles

Each vascular bundle is basically made up of a fibrous sheath, phloem cells, xylem and parenchyma cells (Figure 2.4 and 2.5). According to Lim and Khoo (1986), the number of vascular bundles per unit area decreases towards the inner zones and increases from the butt end to the top of the palm. The xylem is sheathed by parenchyma and contains mainly one or two wide vessels in the peripheral region or two or three vessels of similar width in the central and core region (Killman and Lim, 1985).

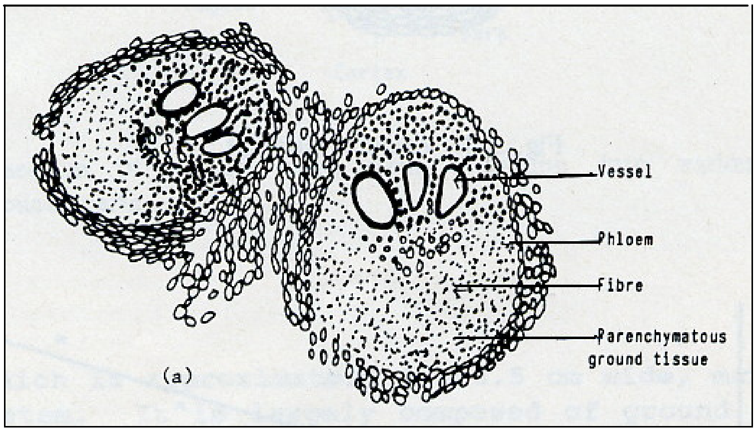

Figure 2.5: Vascular bundles with vessels (Killmann and Lim, 1985)

2.1.5(e) Parenchymatous Tissue

The ground parenchymatous cells consist mainly of thin-walled spherical cell, except in the area around the vascular bundles (Figure 2.4 and 2.5). The walls are progressively thicker and darker from the inner to the outer region (Killman and Lim, 1985).

2.1.6 Physical Properties of Oil Palm Trunk

2.1.6(a) Moisture Content

The moisture content of oil palm trunk is usually higher than other wood. Moisture content of the oil palm stem varies between 100 and 500% (Killmann and Lim 1985). The trend of the moisture content from the outer zone (bark) to central zone (pit) is gradually increases. The outer zone has the lowest moisture content because outer zone is the most outer part of the oil palm trunk which contain most abundant of the vascular bundle. The vascular bundle is the less hygroscopic compared to the non-vascular bundle region. The non-vascular bundle region is more hygroscopic because it is almost full filled by the parenchyma. This trend in moisture content increment can be explained by the distribution of the parenchymatous cells that retains more moisture than vascular bundles. These tissues are more abundant towards the apex of the palm stem as well as radially from the periphery towards the centre pithy region (Kilmann and Lim, 1985; Lim *et al.*, 1986).

2.1.6(b) Density

Density is defined as the amount of the material per unit volume. It is considered as the important characteristic in the utilization of oil palm trunk because it has great influence on the mechanical properties of the final product. Density values of oil palm stem range from 200 to 600 kg/m^3 with an average density of 370 kg/m^3. The density of oil palm stem decreases linearly with stem height and towards the centre of the stem. Generally, the density is highest at the peripheral region of the bottom end and the lowest at the central core region of the top end of the oil palm trunk. The variations in density along stem height are due to the vascular bundles being younger at the top of the palm (Killmann and Lim, 1985; Husin *et al.*, 1985).

2.1.6(c) Fiber Dimension

Oil palm stem fibres show a slight increase in length from the butt end to a height of 3 to 5 metres before decreasing continuously towards the top. Longer fibres at the butt are probably due to more matured fibrous tissue in this region (Killmann and Lim, 1985). Fiber diameter decreases along the stem height because broader fibres are found in the larger vascular bundles nearer the base of the palm stem (Lim *et al.*,1986). Oil palm fiber length increases from the periphery to the pith. This is due to the nature of the palm growth where the overall increase in stem diameter is due to enlargement on the fibrous bundle-sheaths, particularly those accompanying the vascular bundles in the central region. The width decreases from the outer region to the pith (Lim *et al.*, 1986). Table 2.4 shows the comparison between oil palm fiber dimension with Douglas Fir and Rubberwood.

Table2.4: Oil palm fiber dimension compared to Douglas Fir and Rubberwood

Dimension	Oil palm	Rubberwood	Douglas Fir
Length(mm)	1.22	1.40	3.40
Width(micron)	35.20	31.30	40.00
Thickness of the cell wall(micron)	4.5	5.0	-

(Sreekala, 1997; Bolton, 1994).

2.1.7 Mechanical Properties of Oil Palm Trunk

Mechanical properties are directly proportional to density. Table 2.5 compares some mechanical properties of the trunk with those of conventional timber species and two typical monocots.

Table 2.5: Comparison of properties of *Elaeis guineensis* with those of other species

Species	Density kg/m^3 (od)	MOE (MPa)	MOR (MPa)	Compression Parallel to Grain (MPa)	Hardness (N)
Oil Palm (30 years old)	220-550	800-8,000	8-45	5-25	350-2,450
Coconut (60 years old)	250-850	3,100-11,400	26-105	19-49	520-4,400
Date Palm	410	1,719-2,745	11-23	6-10	2,000
Norway Spruce	300-640	11,000	66	43	2,140
Beech	490-880	16,000	105	53	5,650
Poplar	360-560	8,300	76	36	2,500
Cengal	820	19,600	149	75	9,480
Kapur	690	13,200	73	39	5,560
Dark Red Meranti	540	12,700	71	38	3,960
Rubberwood	530	8,800	58	26	4,320

(Killmann and Lim, 1985)