EFFECT OF COLD SETTING ADHESIVES AND GLUE SPREAD ON PROPERTIES OF OIL PALM TRUNK LAMINATED VENEERS

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By

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LIST OF ABBREVIATIONS

%	percentage
(-N=C=O)	Isocyanate group
ANOVA	Analysis of variance
ASTM	American society for testing material
BSI	British standard institute
cm	centimetre
DIN	Deutsche industrie normen
EFB	Empty fruit bunch
EPI	Emulsion polymer isocyanate
FESEM	Field emission scanning electron microscopy
FRIM	Forest research institute Malaysia
g	gram
g/m^2	gram per metre square
kg/cm^2	kilogram per centimetre square
kg/m^3	kilogram per metre cubic
kN/min	kilonewton per minute
LVL	Laminated veneer lumber
m	metre
MC	moisture content
MDF	Medium density fibreboard
MDI	4,4'-diphenylmethane-diisocyanate
mm	millimetre
MnT	million tonne
MPa	mega pascal
MPOB	Malaysian palm oil board
MRB	Malaysian rubber board
MTC	Malaysian timber council
NaOH	Natrium hydroxide
OBM	Original brand manufacturing
^oC	degree celcius
ODM	Original design manufacturing
odmt	total dry matter

OPF	Oil palm frond
OPT	Oil palm trunk
pMDI	polymeric diphenylmethane diisocyanate
POME	Palm oil mill effluent
PORIM	Palm oil research institute Malaysia
PVAc	Polyvinyl acetate
R&D	Research and development
SBR	Styrene butadiene rubber (1,3-butadiene-styrene)
SEM	Scanning electron microscope
T_g	glass transition
UF	Urea formaldehyde
VAc	Vinyl acetate
VOC	Volatile organic compound

KESAN PENGGUNAAN PEREKAT BERTEKANAN SEJUK DAN SEBARAN PEREKAT TERHADAP SIFAT VENIR TERLAMINASI DARIPADA BATANG KELAPA SAWIT

ABSTRAK

Kajian terhadap penghasilan venir terlaminasi (LV) daripada batang kelapa sawit (OPT) semakin meningkat selaras dengan tujuan untuk mengurangkan bahan buangan daripada kelapa sawit. Walau bagaimanapun, kajian terhadap penggunaan perekat bertekanan sejuk ke atas kekuatan ricih, kekuatan ikatan, pengecutan dan pengembangan terhadap venir terlaminasi daripada OPT masih kurang diberi perhatian. Objektif utama kajian ini adalah untuk mengkaji sifat-sifat fizikal dan mekanikal LV yang dihasilkan daripada venir OPT dengan menggunakan beberapa jenis perekat bertekanan sejuk iaitu *Emulsion polymer isocyanate* - *copolymer Vinyl acetate* (EPI-Vac), *Emulsion polymer isocyanate - copolymer Styrene butadiene rubber* (EPI-SBR) dan *Polyvinyl acetate* (PVAc). Tiga lapis LV bersaiz, 23 cm lebar; 23 cm panjang; 4.5 mm ketebalan venir, dihasilkan daripada OPT dengan menggunakan dua nilai rebakan perekat; 250 g/m^2 dan 500 g/m^2 (dengan sapuan perekat pada sebelah permukaan). Perekat disapu dan diratakan secara manual dengan menggunakan rod kaca. Panel LV dikenakan mampatan pada 1MPa untuk jangka masa yang berbeza bagi setiap jenis perekat. OPT LV daripada EPI-VAc dan EPI-SBR dikenakan mampatan selama 30 minit pada suhu 30^{o}C. OPT LV daripada PVAc dikenakan mampatan selama 60 minit pada suhu 30^{o}C. Sebanyak 10 replikasi dihasilkan untuk setiap jenis perekat. LV yang dihasilkan daripada

kayu getah digunakan sebagai sampel bandingan. Anatomi dan sifat-sifat batang kelapa sawit turut dikaji. Sifat kebolehbasahan venir oleh perekat ditentukan melalui penentuan sudut sentuhan. Daripada kajian yang telah dijalankan, didapati bahawa kelikatan perekat dan tekstur permukaan venir dapat mempengaruhi penentuan sudut sentuhan. Hasil kajian, didapati bahawa terdapat interaksi antara jenis perekat dan sifat-sifat mekanikal / fizikal LV yang dihasilkan daripada OPT. Melalui ujian ricihan yang dijalankan, didapati LV yang dihasilkan daripada venir OPT menggunakan perekat PVAc adalah standing dengan LV yang dihasilkan daripada venir kayu getah. Di antara ketiga-tiga jenis perekat yang digunakan, OPT LV yang dihasilkan menggunakan EPI-SBR didapati mempunyai kadar serapan air dan pengembangan ketebalan yang paling rendah berbanding OPT LV yang dihasilkan menggunakan EPI-VAc dan PVAc. Sifat fizikal dan mekanikal menurun apabila panel LV dikenakan rawatan air sejuk, air panas dan *cyclic*. Melalui kajian sifat penjerapan dan penyaherapan dalam kelembapan bandingan yang berbeza, LV daripada venir OPT yang dihasilkan menggunakan EPI-VAc menghasilkan takat tepu gentian yang paling memberansangkan manakala OPT LV yang dihasilkan menggunakan PVAc menghasilkan takat tepu gentian yang paling rendah. Panel LV yang dihasilkan daripada OPT dan kayu getah didapati mengalami pengecutan dan pengembangan apabila kadar kelembapan bandingan berubah. Kajian terhadap ketahanan panel dalam tanah didapati bahawa LV panel yang dihasilkan daripada OPT mudah didegradasikan. LV yang dihasilkan daripada OPT dan kayu getah menggunakan EPI-SBR mengalami peratus kehilangan berat yang paling tinggi berbanding LV yang dihasilkan daripada

OPT dan kayu getah menggunakan EPI-VAc dan PVAc. Daripada kajian yang telah dijalankan terhadap penggunaan sebaran perekat yang berbeza, didapati panel yang dihasilkan menggunakan 500 g/m^2 telah menghasilkan sifat fizikal dan mekanikal yang lebih baik berbanding 250 g/m^2 terhadap kedua-dua LV; OPT dan kayu getah. Secara keseluruhannya, OPT LV yang dihasilkan melalui kajian ini boleh diperbandingkan dan diterima pakai berdasarkan BS 6566: Part 8 (1985).

EFFECT OF COLD SETTING ADHESIVES AND GLUE SPREAD ON PROPERTIES OF OIL PALM TRUNK LAMINATED VENEERS

ABSTRACT

Researches on Laminated Veneer (LV) manufactured from oil palm trunk (OPT) veneers are being developed in line to reduce waste from oil palm biomass. However, there was little information available concerning the effects of adhesives types on tensile shear strength, bonding, shrinkage and swelling of these laminated products from oil palm. The objective of this study was to investigate some of the properties of LV made from OPT using cold setting adhesives namely Emulsion polymer isocyanate - copolymer Vinyl acetate (EPI-VAc), Emulsion polymer isocyanate - copolymer Styrene butadiene rubber (EPI-SBR) and Polyvinyl acetate (PVAc). Three layers of LV were produced based on the lab scale size (23 cm width by 23 cm length by 4.5 mm of each veneer) using two different adhesives spread level; 250 g/m^2 and 500 g/m^2 on single bonding surface of the veneers (single glue line). Adhesives were spread uniformly on the veneers manually. The panels were pressed at 1MPa for different duration. Oil palm trunk LV bonded with EPI-VAc and EPI-SBR was pressed for 30 minutes at a temperature of 30^oC. Oil palm trunk LV bonded PVAc were pressed for 60 minutes at 30^oC. Ten replicates were used for each adhesives type. Laminated veneer made from rubberwood was used as a control samples. The anatomy and properties of OPT were also evaluated. The wettability of veneer by an adhesive was measured by the contact angle. From the study, the liquid viscosity and the roughness of the surfaces affected the final measurements of contact angle droplets. The results showed that there was significant interaction between adhesives and properties of the LV panels. Values of shear strength for OPT LV panels were comparable with rubberwood LV especially those produced using PVAc adhesive. The OPT LV bonded with EPI-SBR was showed the lowest percentage of thickness swelling and water absorption as compared to OPT LV bonded with EPI-VAc and PVAc adhesive respectively. The physical and mechanical properties were decreased after exposed to cold, hot and cyclic treatment. From the observation on absorption and desorption properties in different relative humidity condition, OPT LV manufacture with EPI-VAc perform the highest fibre saturation point and the least was experienced by OPT LV bonded using PVAc. The OPT and rubberwood LV panels were detected to have a dimensional change as the relative humidity was shifted. The soil burial study showed OPT LV was easily proned to biodeterioration attack. The OPT LV and rubberwood LV produced with EPI-SBR were exhibited the highest percentage of weight loss as compared to OPT LV and rubberwood LV bonded with EPI-VAc and PVAc. From the observation on using different spread level, panels bonded using 500 g/m^2 of spread level was showed better performances through the physical and mechanical properties for both as compared to 250 g/m^2 spread level; OPT and rubberwood LV respectively. As compared to BS 6566: Part 8 (1985) standard, the OPT LV bonded with those adhesives was comparable and acceptable.

CHAPTER ONE

INTRODUCTION

1.1 Wood-Based Composites

The acceptance of wooden building materials in form of wood-based composites has increased substantially during the past few decades. The main advantages of these materials are availability, renewability, lower processing costs and simplicity of dismounting and disposal at the end of their service life. Wood is still considered indispensable compared with many substitute materials like iron, steel, concrete and plastic. These substitutes have not always been successful as it is difficult to match the versatility and intrinsic properties of wood as a natural engineering material.

Wood-based composite seem to provide alternatives for use of low-grade and small-diameter hardwood. Composites products have the advantage of using the entire log in a highly efficient manner. Thus, lower product prices may be more than offset by lower processing costs and higher yields. However, when there are certain standard need to be achieve base on their application, the production of wood composite is much harder, for example, the selection of the materials itself and the manipulation of their production. However, many wood composite products are limited in their performances. This is because, their achievement did not fulfill the market demand and the quality of the natural products that had been stated by the producer is still vague (Abdul Khalil and Hashim, 2004).

Research in the benefits of composite technology for wood-based materials for structural and non-structural usage increased in order to overcome the technical problems and improved the quality (Shukla and Kamdem, 2007). One of the objectives of composite technology is to produce a product with acceptable performance characteristics using low quality raw materials combining beneficial aspects of each constituent. New composites are produced with the aim to reduce the costs and to improve performances (Schular and Adair, 2003).

Laminated Veneer Lumber (LVL) is a panel product manufactured by laminating selected veneers in a parallel alignment. By the nature of their manufacturing process, large defects such as knots and other strength reducing characteristics are either eliminated or dispersed throughout the cross-section to produce a more homogeneous product. Laminated veneer lumber may be used as a substitute for solid woods as they retain the structural properties of wood. Kamala et al., (1999) state that, veneers from medium or small diameter logs could be converted into LVL, which can be used as alternative for structural purposes, as its properties are superior to those of wooden planks.

Laminated veneer lumber has the potential to be used in structural and non-structural applications such as construction and furniture industry, material for flooring and numerous other areas (Eckelman, 1993; Hayashi and Oshiumi, 1993; Wong et al., 1996; Ozarska, 1999; Lam, 2001). In advanced countries, LVL is practically produced of any length by the continuous laminating technique (Jagadish, 1991). It can safely be treated as solid wood, even with certain advantages over the same higher design strength and availability in larger dimensions. Some examples of non-residential uses of LVL include commercial and industrial buildings, marines, transmission structures, highway and railroad bridges, bridge stringers and cantilever or continuous beam.

However, in Malaysia none of the above applications uses LVL. It is mainly used for non-structural components such as window framing, doors and doors jambs (Anon, 1998). Efficient usage of laminated veneer lumber in construction industry requires an understanding of the structural behaviour of numerous species and species groups due to the large inherent material variations.

1.2 Oil Palm Residues By-Products

Currently, there is limited use of timber in wood industry especially for permanent structural use due to poor and inconsistent quality, high and fluctuating cost, associated with shortage of supply (Kamala et al., 1999). Due to depletion of forest resources, there is a shortage of wood required by the industry too. It is not surprising that more and more are switching over to alternative materials to overcome the over dependence on local timber industry.

The growth of the oil palm industry has been phenomenal and it was cultivated in Malaysia for its oil producing fruits. The oil palm cultivation has led to a rapid expansion of its planted areas in Malaysia. Besides palm oil, the industry also generates massive amounts of lignocellulosics residues. Based on MPOB, in 2006, it was estimated about 30 million tonnes of lignocellulosics residue such as trunks, fronds and empty fruit bunches from oil palm industry.

Intensive research work is ongoing using variable technologies to convert oil palm fronds (OPF) and oil palm trunk (OPT) for the manufacture of commercially viable composite panel products (Sulaiman et al., 2008; Laemsak and Okuma, 2000; Chew, 1987; Ho et al., 1985). Most of the OPT is converted into various types of wood such as saw-wood and plywood or lumber. Oil palm lumber has been successfully utilized as core in the production of blackboard. The saw-wood produced from OPT can be used to make furniture but not for building structure due to its low specific density. However, the strength of the plywood produced from OPT was found to be comparable with commercial plywood. OPT also has been used to produce particleboards with chemical binders. Moreover, OPF are a source of food for ruminants (cattle and goats). OPF was also left to rot in between the rows of oil palm trees in the plantation for following reasons: (a) soil conservation; (b) increase the fertility of the soil; (c) increase the amount of water retain in the soil; (d) erosion control; and (e) provide a source of nutrient to the growing oil palm trees (nutrient is recycled, as a long term benefits) (Husin et al., 2005).

Research had found that the OPT can be used in the making of laminated veneer lumber (LVL), to produce various products including furniture and partition walls. LVL from OPT and the completed products produced by several manufactures in the country had already produce and used in the Japanese markets in June 2004 (Abdul Hamid, 2006). It has the strength, durability and dimensional stability compared to normal solid oil palm. It provides the flexibility of shape and form, enabling designers and manufacturers to create furniture in varied shapes and forms using the mould design (Mohd Ariff et al., 2007).

Oil palm by-products are available in large quantity sufficient for industrial raw materials in agro-based industries. The endless and consistent supply of lignocellulosic materials from oil palm industry should be considered as new resources. New products from oil palm are now at their stage of research to be developed later on.

1.3 Defining the Problems

The utilisation of oil palm by-products in wood composites is still limited in case of its properties. Some of the problems were low average density and density gradient exist in the radial direction of OPT. This could have influence the stability and strength properties of the products (Husin et al., 1986).

Tomimura (1992) reported from his study, OPT tissue consists mainly of vascular bundles and parenchyma cells. Starch content was remarkably high in parenchyma cells. Xylose and glucose were the main sugar components in both tissue, indicating that the polysaccharide consists of xylan, starch, and cellulose. This could be influence the deterioration by fungal which shortened the span life of the products.

Oil palm in general has low lignin and holocellulose content but high in the extractives and ash content compared with rubberwood and bagasse. The chemical composition of oil palm is tabulated in Table 1.1.

Table 1.1 Chemical compositions of oil palm lignocellulosic by products in comparison with rubberwood and bagasse. (Source: Husin et al., 1986).

Chemical Composition	Trunk	Frond	Bunch	Rubberwood	Bagasse
Lignin	18.8	18.3	21.2	26.0	22.0
Holocellulose	45.7	80.5	65.5	67.0	66.1
Pentosan	18.8	na	na	19.4	30.2
Hot Water solubility	14.2	12.4	17.2	4.8	2.3
Alcohol-Benzene Solubility	9.8	5.0	4.1	1.5	na*
1% NaOH Solubility	40.2	na	na	19.2	29.1
Alpha-Cellulose	29.2	na	na	41.5	na*
Ash	2.3	2.5	3.5	1.5	1.3

*(na – not available)

Products from oil palm are hygroscopic, which could lose and gain moisture when there is a change in relative humidity. This resulted effect the dimensional stability of the oil palm products especially the strength when there is occurrence of moisture changes.

Characteristics of adhesive and their application methods for lamination processes play an important role on physical and mechanical properties of laminated product which will influent its final quality. It is very important to select right adhesive type and control overall process to have laminated product from oil palm with acceptable strength properties.

Limited studies had been carried out in evaluation of lamination techniques. Study on properties of the LVL made from OPT bonded with urea formaldehyde were studied by Wahab et al., (2008) and it was shown that LVL from OPT behave differently when tested for their physical, mechanical and glue delaminating properties. Evaluation on some finishing properties of oil palm plywood has been investigated by Sulaiman et al., (2008). Nordin et al., (2004) determined the bending and compression strength of the OPT LVL were found almost comparable to solid rubberwood. Combination of OPT veneers with several layers of Malaysian oak veneers during the process of LVL has resulted in improvement in bending and compression strength of the LVL compared to those produced entirely from OPT. In other study, the manufacture of particleboards from oil palm trunk resulted that oil palm particles (vascular bundles) are suitable cellulosic materials for the manufacture of single-layer, homogeneous particleboards either individually or mixed with particles from other timber species (Chew, 1987). Uysal, (2005) found that the uses of adhesives types are important according to the wood materials used on dry and damp conditions.

1.4 Objectives

Most of the laminated products from OPT studied carried out based on formaldehyde adhesives like UF and PF. UF and PF emit formaldehyde after the products being manufactured.

Emission of formaldehyde associated to health hazards that are produce from formaldehyde based adhesives. There is growing interest in the usage of free-formaldehyde based in furniture, residential construction, paper, textile and other adhesive industry (Shukla, 2007). Consumer’s products, especially construction materials, are a major source of formaldehyde in the indoor environment. Many consumer products containing formaldehyde-based resins release formaldehyde vapour, leading to consumer dissatisfaction and health related complaints. Therefore, substitution material, especially formaldehyde-based adhesives to free formaldehyde, in wood products is vital to reduce pollutants from building materials and to control indoor air quality.

In this research, we are emphasising on the importance of adhesive type and processing conditions. Adhesive that do not emit formaldehyde were chosen. Adhesive that does not emit formaldehyde normally classified under cold setting adhesive. Furthermore, the study on this type of adhesive is very limited. Development of cold-setting adhesives by which adhesion is carried out without using hot plates, have been of great interest in view of reduces in energy costs. Beside, by using cold-setting based on free-formaldehyde adhesives will influent the environmental friendly and avoid any hazardous. Therefore, the main objectives of this study are;

a) To study the physical and mechanical properties of laminated veneer manufactured from oil palm trunk bonded with cold setting adhesives namely; emulsion polymer isocyanate and polyvinyl acetate.
b) To determine the properties of laminated veneer manufactured using different glue spread level.
c) To determine the natural durability of laminated veneer manufactured from oil palm trunk.
d) To compare the physical and mechanical properties of laminated veneer manufactured from oil palm trunk and rubberwood.

CHAPTER TWO

LITERATURE REVIEW

2.1 Oil Palm

Globally, peoples were talking about utilization of oil palm residues or known as oil palm biomass. Every single part, from bottom to top part of the oil palm tree was examined to found potential so that it could be converted into value added products. In Malaysia, large amounts of oil palm residues are generated by the oil palm industry, for example 5000 million tonnes (green) of felled trunk in 2000 (as projected by Husin et al., 1986) 36 million tonnes (odmt) per year of fronds from pruning and replanting (Wan Zahari et al., 2004) and 5.2 million tonnes per annum of empty-fruit bunches (EFB) in 2002 (Tanaka and Yamamoto, 2004).

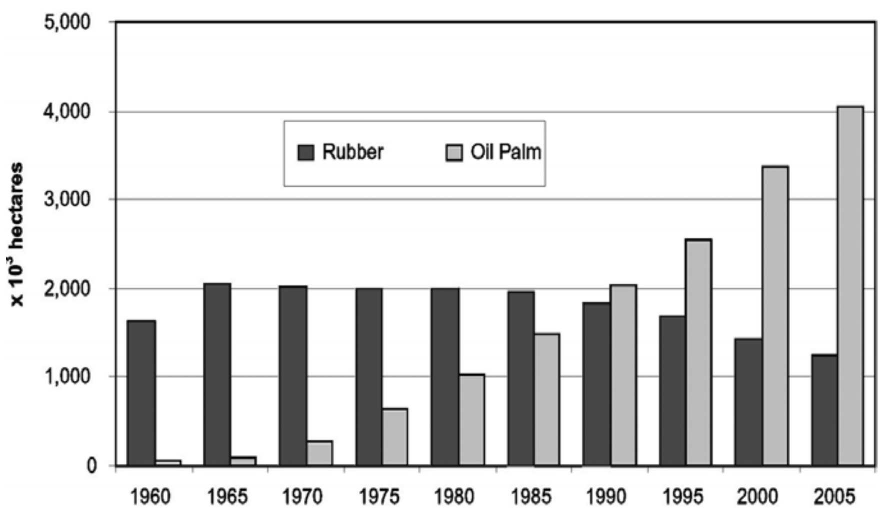

Figure 2.1 Planted area for oil palm and rubber in Malaysia from 1960 to 2005. (Source: Basiron, 2007).

Areas under oil palm in Malaysia increased from 54,000 hectares in 1960 to 4.05 million hectares in 2005 (Basiron, 2007). In comparison with rubberwood, these can be seen in Figure 2.1. The oil palm is tropical palm tree therefore; it can be cultivated easily in Malaysia.

The rapid expansions of oil palm cultivation are due to several reasons. Crude palm oil and kernel oil prices have been strong, due to the rapid increase in consumption of dietary oils and fats in developing country such as China and India (Fairhust and Mutert, 1999). Crude oil palm and palm kernel oil are adaptable vegetable oils and now have a wide range of markets in the food and oleochemicals industries (Figure 2.2). This has encouraged investors to develop plantations on the large areas of suitable land in Peninsular Malaysia and the Islands of Sumatra in Indonesia and Borneo, where partly belongs to Malaysia (Sabah and Sarawak) and partly to Indonesia (Kalimantan).

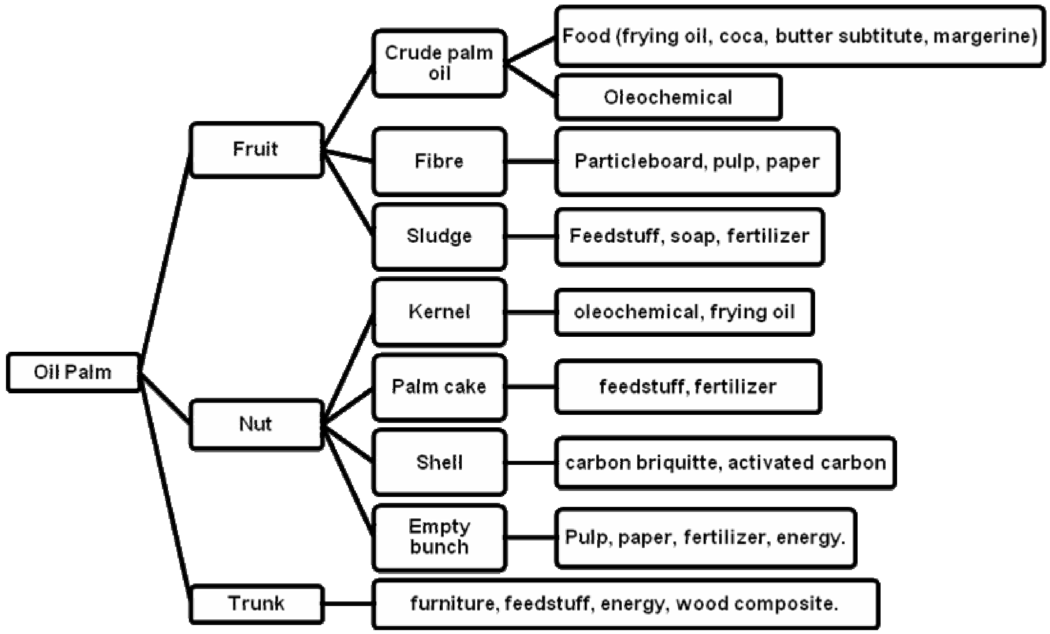

Figure 2.2 Uses of oil palms and biomass in food and manufacturing industries. (Source: Fairhust and Mutert, 1999).

Oil palm plays a vital role in the economy of many developing countries in Southeast Asia, particularly Malaysia and Indonesia. It is a very important crop often used for replacement of primary and secondary tropical forests in many developing countries. 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 (Corley and Tinker, 2003). As labour costs are likely to rise, mechanization will become more important. Increasing environmental concerns about loss of tropical rain forest will also create pressure for increasing oil yields per hectare on existing plantations (Zuzana et al., 2007).

2.1.1 Botanical Classification

Palms are woody monocotyledons in the family Arecaceae (an alternative name to *Palmae*) which is placed in the order Arecales (Jones 1994).

The oil palm (*Elaeis guineensis* Jacq.) belongs to the subfamily Arecoideae, tribe Cocoeae and sub tribe Elaeidinae. The analysis of biogeography patterns present in tribe Cocoeae suggests that the tribe is of Gondwana origin and primary diversification in this group might have coincided with continental breakup (Hahn, 2002). The sub tribe Elaeidinae includes only the genus *Elaeis* (from the Greek *elaia*, for the olive tree) and *Barcella* and is always recovered as monophyletic (Hahn, 2002). The genus *Barcella* has no commercial use at present. The genus *Elaies* consists of only two species; the African oil palm, *E. guineensis* Jacq. and the Latin American oil palm, *E. oleifera* Cortez (Corley and Tinker, 2003). Although the two *Elaeis* species occur on separate continents and have different growth habits, they are very similar.

Figure 2.3 Oil Palm tree (*Elaeis guineensis*)

Zuzana *et al*., (2007) reported that there are no subspecies in *E.guineensis* Jacq. However, there are range of breeding populations of restricted origin (BPRO) such as Pobe, Yangambi, Deli *dura*, Algemene Verneiging Rubber Planters Oostkust, Sumatra (AVROS) and others which play an important role in many breeding programs. One that is important is Deli *dura*, which is believed to be descended from four palms which were planted in 1848 in the Bogor Botanical Gardens, Indonesia.

The commercial variety of oil palm planted in Malaysia is originated from the African oil palm, *E. guineensis* Jacq (Figure 2.3). According to Basiron and Kook Weng, (2004) from a mere four original palms introduced from West Africa to the Bogor Botanical Gardens, Indonesia in 1848, their seeds soon arrived on Malaysian shores in 1871. The R&D undertaken soon showed the potential of the new crop. Following this, the first commercial planting was done in 1911 at Tenammaran Estate, Kuala Selangor. The area expanded quickly occurring during the 1930s, 1970s and 1980s.

Due to a very narrow genetic base of only four mother palms in Malaysia, the industry has since added to the genetic collection of African palms to improve the population base for breeding purposes. These include improved oil quality, reduced height of the mature palms and higher contents of carotenoids and vitamin E. Besides, experiments have been carried out to produce hybrid strains of oil palm that give higher yields of oil. The progress in breeding to enhance the yield has meant that the viability of oil palm cultivation continues to improve, and such progress has stimulated expansions of cultivation (Basiron, 2007).

2.1.2 Utilization of Oil Palm

The palm oil industry in Malaysia will continue to be dependent on its traditional edible and non-edible uses. Sambanthamurthi et al., (2000) reported that, about 90% of world's palm oil is used for edible purposes. Oil is the main commercial product of the oil palm. The oil is extracted from the fruit mesocarp (palm oil – by far the most important product) and nut kernels (kernel oil). Palm oil, extracted from the fibrous flesh of fruits (mesocarp) after they have been hot squeezed, has oil content from 40 - 70%. Prime oil, commercially known as palm kernel oil, is extracted from the seeds, which are firstly shelled and ground which it can be occasionally extracted by means of chemical solvents. The traditional products from palm oil and palm kernel oil are medium for frying, shortening (for example; margarines, vanaspati, bakery products and confectionary fats) and as novel food products (for example; whipping cream, filled cream, *Trans* fatty acid-free formula and palm-based cheese).

The oil palm is a great producer of biomass. According to Basiron and Kook Weng, (2004) oil constitutes only about 10% of the palm production while the rest is biomass. Biomass of oil palm consist of the vegetative mass of the oil palms which ranges from the palm trunks and fronds in the field, to shells, empty fruit bunches, pressed fruit fibres (mesocarp fibres) and palm oil mill effluent (POME) at the oil palm mills. Products that can be utilized and evaluated from oil palm biomass include veneer and saw-wood from oil palm trunks, particleboards or fibreboards, composites products from a mixture of palm biomass and other materials, moulded products (for example, food containers) and energy generation from oil palm biomass. It implies that, if fully exploited, the oil palm industry can generate a new industry and employments. Table 1.1 shows types of residues from oil palm tree and the quantities produced per annum in MnT.

Table 2.1 Estimated availability of oil palm residues quantity produced. (Source: MPOB, 2006).

No	Type of Residues	Quantity/annum (MnT)
1.	Empty fruit bunch	15.8
2.	Fronds	12.9
3.	Mesocarp fiber	9.6
4.	Trunk	8.2
5.	Shell	4.7

The main residues in the field are the pruned fronds removed during harvesting and the trunk and fronds removed at replanting activity. Many other biomass products generated by the oil palm plantations are often underutilized commercially. The mill residues include mesocarp, fibre, shell, palm kernel cake, boiler ash, palm oil mill effluent and bunch ash. The fibre-type products in the form of empty fruit bunches and fruit mesocarp fibres, were mostly sent back to the plantations for mulching, for soil conservation purposes. Some amount of the fruit fibres and the kernel shells are burnt in boilers to generate steam and electricity for the mills (Basiron, 2007).

The oil palm residues can be utilized to produce various types value added products which mean the resources of the substitute's material on wood based industry. Empty fruit bunch (EFB) and mesocarp fibre (MF) have been modified and processed to produce moulded oil palm (MOP) products which is a unique bio-based material made from oil palm particles and thermoset resin in matched metal disc under heat and pressure (Anon, 2006). MOP products are extremely versatile and can be used in furniture, building, electronics, packaging and automobile industries. Development efforts undertaken on production of pulp and paper making, the suitability of this abundant, inexpensive and renewable raw material for papermaking resource has been explored using a variety of pulping methods (Akamatsu et al., 1987; Khoo and Lee, 1991; Wan Rosli et al., 1998; Mohd Yusof, 1997), with most studies using oil palm trunks, and to a lesser amount on fronds and EFB. It is reported in an earlier work (Wan Rosli et al., 1998), that soda pulping of EFB appears to be the most interesting process when its efficacy and environmental friendliness is taken into consideration.

Presently, most of the EFB and MF are used as soil conditioners in estates and plantations and incinerated to obtain oil palm ash (OPA) that can be used as a source of fertilizer due to its high potassium content (Husin et al., 2005). EFB and MF also have been used to manufacture medium density fibre-board (MDF) and blackboard (Ridzuan et al., 2002). The latest research and output of the local scientists proved that the palm kernels, EFB, palm shells, and stones can be converted into value added products such as oil palm activated carbon (Jia and Aik Chong, 2002). Oil palm activated carbon has been used to treat air toxics such as carbon monoxide (CO) and sulphur monoxide (SOx).

Palm oil now would be used as an ingredient in bio – diesel and as fuel to be burnt in power stations to produce electricity (Choo and Cheah, 2000). It can be burned directly as boiler fuel or as diesel for power generation or vehicle propulsion. This is new market for palm oil which has the potential to increase global demand for this commodity. Bio-diesel (palm ethyl ester) which can be used as a subtitute for, or, additive to, petroleum diesel in most transport and non-transport applications are much more cheaper. Bio-diesel from oil palm provide 30% more mileage per liter compared with gasoline. The biomass from the mill, such as EFB, fibre and shell, can be used for electricity generation. More than 10 out of the country's 360 mills are applying to supply electricity to Tenaga Nasional Berhad (Basiron and Kook Weng, 2004). New technologies are now available to harness the biogass from effluent ponds for power generation. It is also estimated that if all the biogas is used for the mill operation, than all the fibre and shell can be freed for generating electricity for sale.

In addition to this, alcohol can also be produced by fermention of carbohydrates (Corley and Tinker, 2003) and burned. Biodegradable plastics such as polyhydroxybutyrate (PHB) can be produced from palm oil. PHB can be synthesized from acetylcoenzym A, the precursor for fatty acid synthesis by transforming palm oil (Masani et al., 2001).

2.1.3 Oil Palm Trunk (OPT)

The oil palm is a tree without branches but with many wide leaves (or fronds) at its top (or crown). Oil palms are felled after an economic life-span of 25 – 30 years. Normally, the fronds and trunks were left behind after harvested during replanting. The trunks tappers gradually towards the crown and normally there are 41 fronds on each mature palm. Corley and Gray (1976) found that the trunk remains covered by old leaf bases until the palm is about 11 to 15 years old. At this time the leaf start to fall, usually first from the middle of the trunk and extending upwards and downwards. The trunk of an old palm will usually be completely free of leaf bases except just below the crown.

Research on OPT was developed and it had been recognized as a valuable residual from oil palm. OPT would be exploited commercially for various purposes such as the manufacture of composite panel products like medium density fibreboard (MDF), block board, laminated veneer lumber (LVL), mineral–bonded particleboard and plywood.

2.1.3.1 Anatomy of Oil Palm Trunk

As a monocotyledon, oil palm has many differences from hardwood and softwood timbers. Based on the work by Killman and Lim, (1985) the oil palm does not have cambium, secondary growth, annual growth rings, ray cells, sapwood, heartwood and branches.

Based on a cross-sectional view of the OPT, there are three main parts that are easily distinguishable namely; cortex, the peripheral region and the central zone (Figure 2.4). The trunk consisted of long vascular bundles, encrusted in parenchyma ground tissue. The growth and increase in diameter of the stem result from overall cell division and cell enlargement in the parenchymatous ground tissues which located at the inner zone, together with enlargement of the fibres of the vascular bundles.

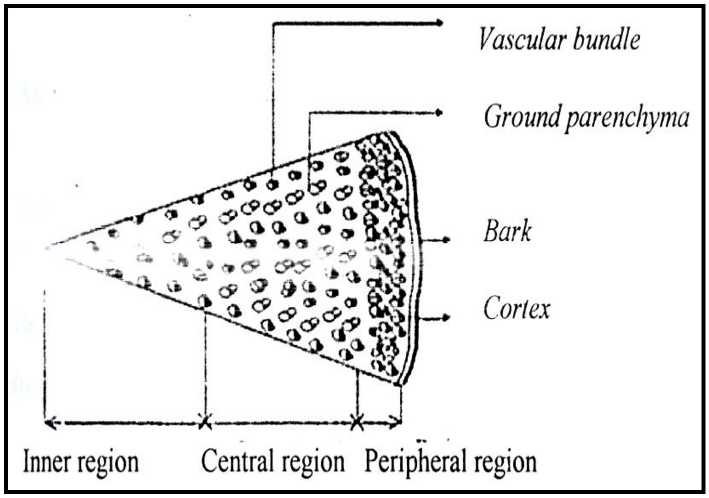

Figure 2.4 A schematic diagram on cross-section of an oil palm trunk-division into various anatomical parts. (Source: Khozirah et al., 1991).

The outermost layer of the trunk is the 'bark' or known as cortex which is approximately 3 to 3.5 cm thick. The cortex is largely made up of ground parenchyma with numerous strands of small and irregular shaped fibrous strands and vascular bundles. The peripheral zone consists of narrow layers of parenchyma and congested vascular bundles. It provides the main mechanical support for the palm stem. The central zone, which makes up of about 80% of the total area, consist of slightly larger and widely scattered vascular bundles imbedded in the thin-walled parenchymatous ground tissue. Each bundle is basically made up of fibrous sheath, phloem cells, vessels (or xylem cells) and parenchymatous cells (Killman and Lim, 1985).

Xylem of oil palm is always sheathed by parenchyma and contains one or two vessels of 0.17 mm average width in the peripheral region and two or three vessels with 0.18 – 0.19 mm diameter in the core as shown in Figure 2.5. It was also found that bundles with more than three vessels arranged tangentially or in clusters, particularly throughout the core region.

Along the core region, extended protoxylems, reduced vascular tissue and small bundles with small amount of fibrous tissue are more commonly found.

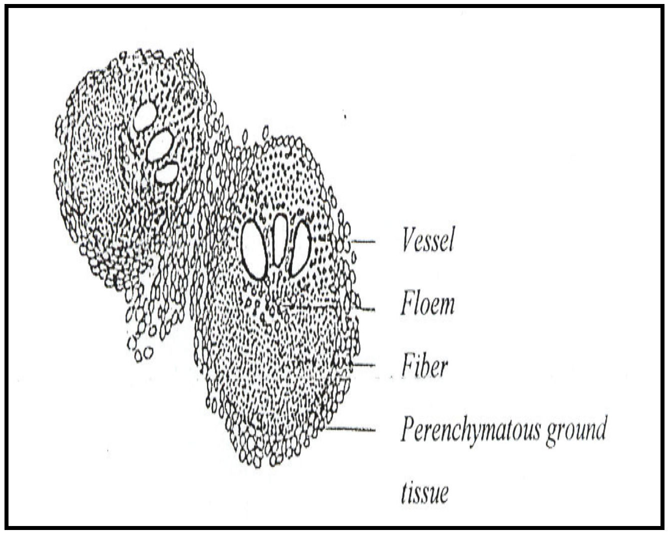

Figure 2.5 Vascular Bundles of oil palm trunk which show the vessel phloem, fibre and parenchyma ground tissue. (Source: Killman and Lim, 1985).

According to Killman and Lim (1985), phloem's cells, which are present in single strand, are found between the xylem and the fibre strand. Throughout the peripheral region, where the bundles are generally smaller and in irregular shape, the phloem tends to be reduced to a small and tiny strand and almost disappear. The ground parenchymatous cells were observed to consist of mainly thin-walled spherical cells. The walls of these parenchyma cells are progressively thicker and darker from the pith to the peripheral region. The texture was spongy, particularly at the pith region.

2.1.3.2 Properties of Oil Palm Trunk

At replanting age, the trunk ranges between 7 m to 13 m in height and 45 to 65 cm in diameter, measured 1.5 m above the ground level (Husin et al., 1986). Freshly felled trunk contains of high moisture content, which is estimated to be about 1.5 to 2.5 times the weight of the dry matter. Killman and Lim, (1985) reported that moisture content of the OPT ranged between 100 until 500 %. A study by Lim and Khoo, (1986) indicated a gradual increase in moisture content along the stem height and towards the central region, with the outer and lower zones having far lower values than the other two zones. This trend in moisture content increment can be explained by the distribution of the parenchymatous cells which retain more moisture than vascular bundles.

Husin et al., (1986) reported that the density of OPT ranges from 230 to 520 kg/m^3 with an average density of 370 kg/m^3. The trunk indicates high density gradient between the central core and the peripheral zone. This is reflected in the clear distinction observed in hardness and weight between the outer and inner portions and the butt and higher regions of the trunk. The contradictory density distribution could be due to the morphological structure different from other palms, change of pattern with age and size, the movements of starch deposits in parenchyma cells up to the top of palm and larger amount of fibrous bundles in top core than bottom core (Corley and Gray, 1976).

Generally, OPT consists of three main components, cellulose (45%), hemicelluloses (25%) and lignin (18%) beside extractives (10%). All the components can be fractionated, isolated and purify to obtain value added products (Anis, 1999). A few number of studies was carried out through the evaluation on chemical characteristics of OPT. Law et al., (2007) studied on chemical and physical characteristics of fibres from OPT and found that when bleached to the desired brightness, OPT fibre can be used to replace, totally or partially, the hardwood Kraft component in printing and writing grades. Anis et al., (2000) run a study on hemicelluloses from OPT. In the study, analysis on the sugar components were done and xylose was found to be the major sugar in each fraction, with glucose and arabinose as minor constituent (Table 2.2). From the evaluation, it was found that it is good potential for the use of hemicelluloses as a food ingredient such as dietary in food formulation.

Table 2.2 Monosaccharide compositions in extracted hemicelluloses. (Source: Anis et al., 2000).

	Percentage (%)	
Monosaccharides Compositions	Hemicelluloses A, 50%	Hemicelluloses B, 30%
Xylose	39.5	45.90
Arabinose	0.40	3.79
Glucose	2.66	5.94

The mechanical properties of wood are measures of its resistance to exterior forces, which tend to deform its mass. In contrast to metals and other materials of homogenous structure, wood exhibits different mechanical properties in different growth directions (axial, radial, and tangential) and therefore, it is mechanically anisotropic (Tsoumis, 1991). Mechanical properties of wood are closely related to the density itself. According to the study by Killman and Lim, (1985) common features in OPT are; pronounced decrease from periphery to pith on all levels of trunk height for MOE, MOR, compression and hardness. Over the trunk height on chosen axis, MOE, MOR and compression were decreased while compression and hardness increased in the pith. The mechanical properties of the OPT are rather poor. It would be, therefore, a poor choice for construction as well as for flooring and framing.

2.2 Rubberwood

Rubberwood has emerged as an integral part of Malaysia's rubber industry. The rubber cultivation became a major raw material supplier to value-added resources-based industries. The rubber products manufacturing from Natural Rubber (NR) has achieved remarkable progress. According to MTC (2008), in the last seventeen years (1990 – 2007) total rubber consumed by the industry increased by 209% from 157 592 tonnes to 579 248 tonnes, of which NR was the main material used.

The commercial utilisation of rubberwood has been successfully accepted as an alternative timber to the natural forest species for products such as mouldings, furniture and carpentry. In furniture industry itself, rubberwood has been transformed from what was once considered as fuel wood to a much sought after timber material for furniture making. The growth of the furniture industry, especially for export, has been largely owed to the availability of rubberwood. As reported by Malaysian Timber Council (Anon, 2004), export value of rubberwood-based products in 2003 was worth