STUDY ON HYGROSCOPICITY AND SORPTION OF OIL PALM TRUNK AND BAMBOO: COMPARISON STUDY WITH RUBBERWOOD

MOHD FAHMI BIN AWALLUDIN

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ABSTRAK

Satu kajian tentang sifat higroskopik dan kebolehserapan bahan bukan kayu, iaitu batang *Elaeis guineensis* (kelapa sawit) dan kulma buluh spesis *Gigantochloa schortechinii* telah berjaya dilakukan. Keputusan-keputusan yang diperolehi dibandingkan terhadap sifat higroskopik dan kebolehserapan bahan berkayu iaitu *Hevea brasiliensis* (kayu getah). Sampel batang kelapa sawit dan kayu getah (*Hevea brasiliensis*) berumur 25 tahun dan sedia ditebang untuk penanaman semula telah diperoleh daripada syarikat Central Kedah Plywood Factory Sdn. Bhd. di Kedah, Malaysia manakala sampel bagi kulma buluh berusia 6.5 tahun diperoleh daripada Hutan Simpan Nami di Kedah, Malaysia. Sampel batang kelapa sawit, kulma buluh dan kayu getah, telah didedahkan dalam tiga kitaran lembapan bandingan yang diubah-ubah dalam RH chamber sehingga kandungan lembapan sampel-sampel tersebut mencapai keseimbangan dengan lembapan setara yang telah ditetapkan. Pada kitaran pertama, sampel-sampel didedahkan kepada lembapan bandingan yang ditingkatkan dari 65% à 75% à 80% à 90%. Untuk kitaran kedua, sampel-sampel telah didedahkan kepada lembapan bandingan dalam urutan menurun iaitu dari 90% à 75% à 65% à 50% à 30%. Untuk kitaran terakhir, lembapan bandingan telah dinaikkan beransur-ansur dari 30% à 50% à 60%. Suhu dalam RH chamber ditetapkan kepada 25 °C. Kandungan lembapan setara (EMC) bagi semua sampel menunjukkan bentuk sigmoid. Keputusan ini menunjukkan batang kelapa sawit dan buluh mempunyai perilaku yang sama dengan

kayu getah dalam konteks hubungan dengan lembapan sekeliling. Dalam kajian sifat pengembangan, sampel batang kelapa sawit menunjukkan peratus pengembangan yang tidak signifikan antara arah tangen dan jejarian. Walaubagaimanapun, sampel-sampel kulma buluh menunjukkan perbezaan yang signifikan antara arah tangen dan jejarian di mana peratusan pengembangan arah tangen mengatasi arah jejarian. Perilaku sampel buluh ini menyamai perilaku kayu getah. Sampel-sampel tadi seterusnya menjalani ujian kekuatan mampatan. Untuk ujian kekuatan mampatan pula, semua sampel menjadi lemah apabila didedahkan kepada lembapan bandingan yang lebih tinggi. Kajian menentukan sifat kebolehserapan batang kelapa sawit dan buluh berbanding kayu getah dalam tiga kumpulan pelarut berbeza iaitu kumpulan *apolar aprotic*, *dipolar aprotic* dan *protic* telah dijalankan. Sampel-sampel yang direndam dalam pelarut jenis *apolar aprotic* telah menunjukkan peratus pengembangan yang paling rendah manakala kebanyakan sampel menunjukkan peratus pengembangan yang tinggi apabila direndam dalam pelarut jenis *protic* bagi pengembangan di kedua-dua arah jejarian dan tangen.

ABSTRACT

A study on the hygroscopicity and sorption properties of non wood biomass of *Elaeis guineensis* trunk (oil palm) and bamboo culm of *Gigantochloa schortechinii* (Semantan bamboo) has been successfully done. Results obtained later were compared to the hygroscopicity and sorption properties of wood which was *Hevea brasiliensis* (rubberwood). Samples of 25-year-old oil palm trunk and 25-year-old rubberwood (*Hevea brasiliensis*) were provided by Central Kedah Plywood Factory Sdn. Bhd. in Kedah, Malaysia while samples of 6.5-year-old bamboo culm were taken from Nami Forest Reserved, Kedah Malaysia. Samples of oil palm trunk, bamboo culm and rubberwood has been left in RH chamber to undergo three cycles of fluctuated relative humidity until their moisture contents equilibrium with the subjected relative humidity. In the first cycle, samples undergo incremental relative humidity of 65% à 75% à 80% à 90%. It was then followed by a reduction of relative humidity; 90% à 75% à 65% à 50% à 30%. The final cycle is adsorption cycle with increasing relative humidity; 30% à 50% à 60%. The temperature of the relative humidity chamber was kept constant at 25°C. All three species samples give a sigmoid curve. Oil palm trunk and bamboo have an equal behavior to rubberwood in the context of relationship with surrounding humidity. On swelling studies, oil palm trunk did not show any significant difference between swelling in tangential and radial direction. Meanwhile, bamboo culm shows a significant result where tangential direction swells higher than radial direction. This behavior of bamboo culm seems to be same as rubberwood. Samples then were subjected to undergo compression strength test. All samples which were exposed to higher relative humidity seem to have lower compression strength. In the second section of this study covers how the different types of organic solvents affect the shrinkage and swelling properties of oil palm trunk and bamboo. The sorption ability of oil palm trunk and bamboo culm compared to rubberwood in three different organic solvents groups which are group of *apolar aprotic*, *dipolar aprotic* and *protic* has been done. Samples soaked in *apolar aprotic* solvents showed less swelling percentage in both radial and tangential direction. Most of the samples showed high swelling percentage when soaked in *protic* solvents.

CHAPTER 1: INTRODUCTION

1.1 Introduction

The increases in timber prices and the shortage of timber supply have greatly affected the wood-based industries in Malaysia and elsewhere. The growing social demands on wood utilization have led to a continuous noble effort in finding cheap and new alternative of wood resources. Something that we can rely on to overcome this problem is oil palm and bamboo. Oil palm and bamboo has potential to be used as the alternative to future wood.

Oil palms are abundant in Malaysia since it becomes the most important crop to produce cooking oil which is the palm oil. The oil palm tree generally has a life span about 25 years and would be replanted after 25 to 30 years old and this process would contributed to a high amount of agricultural waste. The waste would be generated in the form of felled trunk and fronds. These wastes, especially the trunk would be great new sources of economy if we can maximally convert it into value added product and thus, the study on properties of the trunk seems to be relevant and more important.

Besides oil palm, Malaysia is also rich in bamboo resources. This includes the naturally bamboo stand in the Malaysia’s rainforest, near settlement or bamboo cultivated in bamboo plantations. In the government effort to abolish poverty, the study on bamboo properties hopefully can enliven the small and medium industries in Malaysia and thus improve the economy of rural and suburban people. This is due to the fact that people comes from these places are the closest persons to abundant sources of bamboo. Bamboo sources are cheap and even free. Through the understanding of the oil palm trunk and bamboo properties, better quality products can be produced.

Furthermore, many previous researchers worldwide seem to put their attention more on woody plant and less attention for non woody plant and for some good reasons, there is a need also to expand the knowledge on non wood properties.

At the same time, by maximizing the knowledge especially on oil palm crops, we can tell the world that Malaysia is a serious country in terms of minimizing the effect of agricultural wastes to the environment and also reducing the consuming of natural tropical hardwoods from our millions year old rainforest. This is a serious agenda because Malaysia had recently being attacked rigorously by foreign country because of it mass production of palm oil.

With the completion of the study, hopefully it will contribute to optimizing the use of biomass byproduct as well as giving better understanding and knowledge in non wood materials for a sustainable tomorrow.

1.2 Objectives

The overall objectives of this study were to evaluate the effect of hygroscopicity and sorption of oil palm trunk and bamboo and their influence on quality. The results later have been compared to the properties of rubberwood. The study covers only the mechanical and physical properties not the chemical properties and it comprise of two parts. In the first part covers only on effect of fluctuated relative humidity to the quality of subjected materials while in second part covers only effect of selected organic solvents on dimensional stability of subjected materials. The study consisted of the following specific objectives:

- To study the effect of cyclic moisture condition on dimensional stability and compressive strength of oil palm trunk and bamboo compared to rubberwood.
- To study maximum hysteresis and fiber saturation point of oil palm trunk and bamboo.
- To study swelling of oil palm trunk and bamboo in different polarity of organic solvents.
- To study the anatomical structure of oil palm trunk and bamboo.

CHAPTER 2: LITERATURE REVIEWS

2.1 Oil palm

Oil palm (*Elaieis*) is a species of the *Arecaceae* or palm family and divided into two species (Sumathi *et al.,* 2008). The first species is *Elaeis guineensis* which are also abundant in Malaysia is believe to be native to West Africa, while the second species is *Elasis oleifera* or commonly known as American Oil Palm is native to tropical Central America and South America (http://www.mpoc.org.my/The_Oil_Palm_Tree.aspx).

In early 1870's, oil palm tree was found to be suitable to be planted in Malaysia (Malaya at the time) as an ornamental plant. Until year 1911, there was some effort to commercialize the planting of oil palm tree to produce palm oil (Yusof Basiron *et al.,* 2000). This first commercial cultivation of oil palm took place in Tennamaran Estate in Selangor where its later brings a strong foundation for the vast oil palm plantations and palm oil industry in Malaysia. At the beginning in the sixties, the cultivation of oil palm rapidly increased under the government's agricultural diversification program. The government had introduced land settlement schemes for planting oil palm to eradicate poverty for the landless farmers and smallholders and at the same time reduce the country's economic dependence on rubber and tin (http://www.mpoc.org.my /The_Oil_Palm_Tree.aspx).

Figure 2.1 below shows an oil palm tree. In the morphological aspect, oil palm tree has pinnate leaves where it can reach between 3 and 5 meters long. Mature oil palm trees can grow up to 20 meters tall and single-stemmed (http://www.etawau.com

/HTML/OilPalm/OilPalm.htm). Normally the trunk grows 35 to 75 cm in height each year. This is depending upon the growing conditions, and also varying between different progenies. The trunk is functioning as supports to the leaves and to transport mineral nutrients and water from the roots upwards, and the products of photosynthesis from the leaves downwards. It also probably is functioning as a storage organ where abundant amount of starch granules can be found inside the trunk (Corley *et al.*, 1976).

Figure 2.1. An oil palm tree

Something mystery about the trunk is it will remains covered by old leaf bases until the palm is about 11 to 15 years old. After reaching this age, the leaf bases start to fall. Usually it fall first from the middle of the trunk and extending upwards and downwards until completely free of leaf bases except just below the crown. The old leaf bases can cause oil palm easily to be infected by “upper stem rot” because it can trap fungi from the surrounding and cause the tendency of oil palm to retain loose fruits. So any treatment that can accelerate the abscission of leaf base might be useful (Corley *et al.*, 1976).

The flowers of oil palm are small, with three sepals and three petals and produced in dense clusters. The propagation of oil palm is through seeds sowing either by human or animals. The fruit takes 5–6 months to mature where the fruit comprises of an oily pericarp, with a single seed or known as kernel, also rich in oil (Sumathi *et al.*, 2008). A cluster of oil palm fruit can reach the weigh up to 40-50 kg. The pericap oil mainly processed to make cooking oil as end product while kernel oil is widely used in processed foods (http://www.mpoc.org.my/The_Oil_Palm_Tree.aspx).

The objective of the oil palm cultivation is to produce palm oil. Malaysia is currently one of the world’s largest palm oil producers. In year 2006, it was estimated 4.17 million hectares land in Malaysia covered with oil palm plantation and it is still expanding year by year (Anis *et al.,* 2008). This is due to the greater demands on world’s palm oil consumption. According to Chan *et al.,* (2000), oil palm can produce averages of 10 tones of mature fruits for each hectare annually. This includes 3,000 kg of pericarp oil yields and 750 kg of seed kernels. The seed kernels yield 250 kg of high quality palm kernel oil as well as 500 kg of kernel meal. The kernel meal is normally used in livestock food production. Some varieties of oil palm have greater productivities. This fact made it the prime source of vegetable oil for many tropical countries. It is also likely to be used for producing the necessary vegetable oil for biodiesel.

Besides the palm oil, this industry also generates massive biomass quantities in the form of felled trunks (OPT), fronds (OPF) and empty fruit bunches (EFB) as shown in Figure 2.2. The biomass is available through the routine field, mill operations and replanting program (Khalil, 2008). The amount of biomass produced by an oil palm tree, inclusive of the oil and lignocellulosic materials is on the average of 231.5 kg dry weight/year (Husin, *et al.,* 2005).

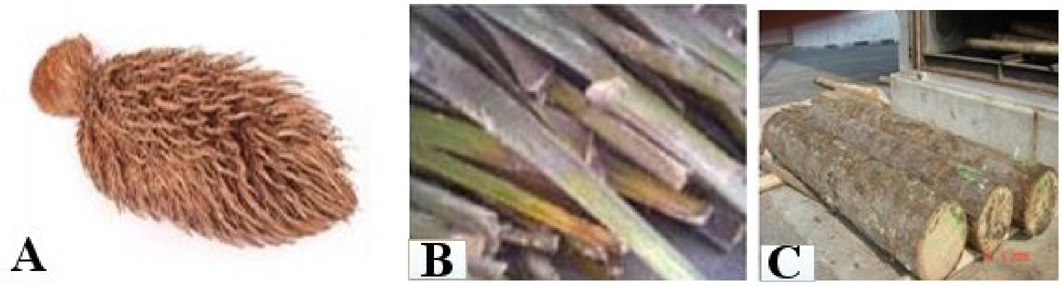

Figure 2.2. Oil palm biomass **A.** Empty fruit bunch (EFB) **B.** Oil palm fronds (OPF) **C.** Oil palm trunks (OPT) *Image source: http://www.bfdic.com/en/Features/Features/79.html*

Table 2.1 shows the total area planted with oil palm in Malaysia for year 2006. With total of 671 425 hectares, state of Johor has the largest land being covered with oil palm plantations in peninsular Malaysia. Combined with 623 290 hectares oil palm planted area in neighboring state, Pahang, these region commands 55.5 % of the total oil palm planted area in peninsular Malaysia. Meanwhile, Sabah has the largest oil palm planted area in whole Malaysia with total of 1 239 497 hectares.

Table 2.1. Oil palm planted area in Malaysia (2006)

State	Oil palm planted area (hectares)
Johor	671 425
Pahang	623 290
Perak	348 000
Terengganu	164 065
Negeri Sembilan	161 072
Selangor	128 915
Kelantan	94 542
Kedah	76 329
Melaka	52 232
Pulau Pinang	14 119
Perlis	258
PENINSULAR MALAYSIA	2 334 247
Sabah	1 239 497
Sarawak	591 471
SABAH & SARAWAK	1 830 968
TOTAL MALAYSIA	4 165 215

Source: MPOB, 2007

In the aspect of strength and hardness, oil palm trunk is generally classified to be lower than the most timber species including rubberwood, as well as coconut wood. The hardness value of the peripheral lower portion of the oil palm trunk is however, comparable to those of Norway spruce and poplar wood (Killman and Lim, 1985). The compression parallel to grain of the trunk was measured by Turner and Gillbanks (1974) where later they found oil palm trunk has average value of only 18Mpa. This is very low compression resistance value if compared to other timber species. They also found that the compression perpendicular to the grain of the trunk also very low with values between 2 and 3 MPa.

2.1.1 Oil palm trunk anatomy

Oil palm does not possess cambium, sapwood, heartwood and growth rings and hence their "wood" is the primary tissue itself (Parthasarathy, 1976). The "wood" of palms consists of discrete vascular bundles embedded in a parenchymatous ground tissue (Corley *et al.*, 1976). In palm stems vascular bundles range from about 1 to 3 mm in diameter depending on their location within the stem and the species. The course of vascular bundles within the stem has been studied in detail by Zimmermann and Tomlinson (1965; 1967; 1974).

The trunk grows upwards shortly below the apex. In this area lies the apical meristem in a slight depression. This apical meristem contributes to the produces of the leaf and inflorescence primordial. The thickening and extension of the stem are due to activity of the “primary thickening meristem” which lies below the apical meristem and leaf bases. The formation of the depression at the apex is also due to the activity of this meristem (Corley *et al.*, 1976). Internally, the trunk is very fibrous, with the vascular tissues providing both mechanical support and nutrient conduction. The stem functions as a nutrient reservoir to some extent and changes in stem diameter occur when there are wide fluctuations in the general nutrient status (Turner and Gillbanks, 1974). The cross section of oil palm trunk consists of three main categories which are the cortex, peripheral region and central region.

2.1.1.1 Cortex

The outer part of the trunk is constructed by the narrow cortex, which is approximately 1.5-3.5 cm wide. This cortex extremely composed of ground parenchyma with numerous strands of small and irregular shaped fibrous strands and vascular bundles (Killmann and Lim, 1985).

2.1.1.2 Periphery

The peripheral region is located between the cortex and the central region of the trunk. Periphery makes up almost 20 per cent of the total cross-section area of oil palm trunk (Chan *et al.*, 2000). In the peripheral zone, the vascular bundles of the central cylinder are more crowded than the inner zone (Parthasarathy, 1976). This is in agreement with research done by Killmann and Lim (1985) where they also found that this region covered with narrow layers of parenchyma and congested vascular bundles, thus gives rise to a sclerotic zone which provides the main mechanical support for the palm trunk.

2.1.1.3 Central

The central zone of the trunk makes up about 80 % of the trunk total area. It is composed of slightly larger and widely scattered vascular bundles embedded in the parenchymatous ground tissues. The parenchyma cells are formed by thin outer layer spherical cells except at the vascular bundles region. Generally the trunk consists about 30 to 50 % of parenchyma cells. The vascular bundles increase in size and are more widely scattered towards the core of the trunk (Killmann and Lim, 1985; Mohamad *et al.*, 1986).

2.2 Bamboo

Bamboo, an overlook biomass resource is another national property with a high potential to go for commercialize. Similar with oil palm tree, bamboo or so called giant grass is also a lignocellulosic material. Bamboo is grouped into giant grass family. Almost 72 genus and 1250 species of bamboo can be found worldwide. They can be found wild in all continents except Europe (Wong, 2004). Most of the species are widely distributed in Asian region (Liese, 1985). Around 200 species of bamboo occur in the Southeast Asian region, from Myanmar and Indo-China to Papua New Guinea, and including the Malay Archipelago (Dransfield and Widjaja, 1995).

In many parts of Southeast Asia, bamboos have long been recognized as village or cultivated bamboos and native to forest bamboos. In some cases, some species of *Gigantochloa* found only cultivated in Peninsular Malaysia and Java. Probably this is due to their present-day distribution reflects the historical migrations of people in the region (Wong, 2004).

In Malaysia, bamboo traditionally has been considered as wild in forest practice (Watson, 1961; Chin, 1977). According to Azmy (1991) Malaysia has about 70 species of bamboo from genera *Bambusa, Chusquea, Dendrocalamus, Dinochloa, Gigantochloa, Phyllostachys, Racemobambos, Schizostachyum, Thyrsostachys* and *Yushania* (Wong 1989; Azmy and Abd. Razak 1991). The Semantan bamboo

(*Gigantochloa scortechinii*) as shown in Figure 2.3, is one of most widely spread in Malaysia (Azmy and Abdul Razak 1991).

Figure 2.3. The Semantan bamboo

Bamboo is one of an alternative resource to wood that support the local wood industries need. Bamboo is very durable in extreme conditions. Some records show certain species can tolerate temperatures between 40 ^{o}C and 50 ^{o}C whereas others can withstand snow or even temperatures of severe frost. For many centuries bamboos have played an indispensable role in the daily life of the people especially those live in tropical countries (Sharma, 1980).

There are more than 1500 products made from bamboo either through modern or traditional manner has been recorded around the world. The important of bamboo in human daily life is undeniably. The many uses of bamboo range from handicrafts made *ad hoc* in village settings, such as personal ornaments, utensils and a most incredible variety of baskets and other containers, fences for rice field, poultry cages, bamboo blinds, umbrella handles, vegetable baskets, barbeque skewers, bird cages, poultry coops, musical instruments, to water pipes, bridges, house construction, fishing contraptions and source of edible shoots. Nevertheless, several attempts to manufacture bamboo pulp were made (Kurz, 1976; Wong, 1995; Peel, 1959; Schrubshall, 1984). Some of the bamboo application in human life is shown in Figure 2.4 below.

Figure 2.4. Bamboo application. Left: *Gigantochloa scortechinii* bamboo used as raw material to make vegetable baskets at Tapah, Perak, Peninsular Malaysia. Right: Rice grain stores and living quarters made from bamboo in a village at Changlun, Kedah, Peninsular Malaysia. *Image source: Bamboo the Amazing Grass (Wong, 2004)*

According to Roa (1997), high biomass content allows bamboo to be used in high quality bamboo pulp and paper manufacture, activated carbon and charcoal industry. Recently, human starts to look bamboo as high potential biological energy. The main use of bamboo has been limited to rural industrial products as mentioned above. The reason for this is because lack of information on its technical processing and potential.

Bamboo takes short time periods to become mature compared to wood (timber). Bamboo can be harvested at intervals of 3 to 5 years and it is sustainably a natural renewable resource (Sharma, 1980). This is an advantage for wood or bamboo based industry especially in management aspect where short harvesting cycle can be applied. It can reduce cost and ensure the continuous of raw materials supply. Mature bamboo culms can be converted into value added products easily because bamboo normally doesn’t involve heavy machinery or massive transportation like timber processing. Bamboo is environmental friendly and products made of bamboo are also categorized as environmental friendly (Fateh, 1931; Numata, 1979 and Liese, 1985).

In addition, bamboo also serves people indirectly by the existence of bamboo forest. Bamboo forest helps to balance the oxygen/carbon dioxide content in atmosphere and prevent landslide in river bank. The fast growth of bamboo roots also helps to recover the soil nutrient in deforestation area in a short while (Liese, 1985).

In the morphological aspects, bamboo is quite different from wood which coming from gymnosperms and dicotyledonous angiosperms. All the growth in bamboo occurs longitudinally and there is no lateral or radial growth as in trees (Ghosh and Negi, 1959). Basically, bamboo has a hollow stem or so called the culm and only in some species where the culm is in solid form. Parts where the culm is closed at frequent intervals are called nodes (Liese 1987). Bamboo culms are cylinder in shape where it’s diameter bigger in lowest part and becomes smaller across the height. The bark is green at young age and slowly become yellowish when mature, depends on species. Young twigs or branches could grow within the nodes (Tewari and Singh, 1979).

Bamboo culms in a clum are linkage to each other with its rhizome at the roots. According to Liese (1985), bamboo clum can be classify into *leptomorph* (individual culms), *pachymorph* (clums) and *metamorph* (both character) depend on their roots attribution.

Bamboo cells structure is build by various polylamella layers and multi orientation microfibrils. These characteristics give bamboo good strength properties (Murphy and Alvin, 1997). Liese (1985) found that the properties of bamboo are influenced by the properties and behavior of individual culm. The compatibility of bamboo for industry, construction and housing has a close relationship with its mechanical and physical properties.

Previous research done by Roa (1997) found that bamboo has 17% more tensile strength compare to alloy metal, 27% strengthen than red oak, and 13% harder than maple. Those properties make bamboo has high potential to be converted into high-tech products. This can be realize by mix-and-match all the fundamental properties of bamboo with the final product. Details anatomical, physical and mechanical properties are intensively studied by Abd. Latif & Mohd. Tamizi (1992), Abd. Latif & Mohd. Zin (1992) and Abd. Latif & Liese (1998).

Besides the fields of traditional application, modern processing techniques have considerably extended their usefulness. Despite increasing research efforts the bamboos have remained somewhat mysterious plants. They still hiding many secrets in their biology and much more information are required for their silviculture and utilization.

2.2.1 Bamboo anatomy

According to Liese (1985), the growing and maturing processes of bamboo culms are characterized by its anatomical structure. The anatomical structure of bamboo culms changed from one phase to another phase starting from its shoot until maturity age.

Roa (1985) stated that the formation of bamboo shoot starts with the development of primordial leaves arranged tangentially and covered the apex. Slowly, larger structure formed followed by the appearance of nodes below the apex and the arrangement of leaves. While for vascular bundles, it growth from the corpus zone. In the epidermis layers, two or three layers of sub-epidermis contains small cells are presented and then followed by the existence of tissue regions where multi sizes vascular bundles are located. Next is the formation of cells in the bamboo shoot to construct the culm wall followed by the construction of internodes which joined to one another by the nodes. Cells in the internodes are axially oriented while in the nodes are crosswise oriented.

The bamboo culm comprises about 50% parenchyma, 40% fibers and 10% vessels and sieve tubes (Liese 1987). Fiber percentage is higher in the outer one- third of the wall and in the upper part of the culm, contributing to its superior slenderness (Grosser and Liese, 1971). Most bamboo fibers have a thick polylamellate secondary wall (Parameswaran and Liese, 1976).

2.2.1.1 Parenchyma

Liese, (1985) found the parenchyma cells which are located in the ground tissues of the bamboo are in short cubical shape and distributed along the vertical direction. Parenchyma cells normally have thin cell wall and joined together by simple pits. The lignifications process of parenchyma cells started since the shoot grows up from the ground surface and between the moment, the starch content is relatively high (Parameswaran and Liese, 1975).

Alvin and Murphy (1988) concluded the starch content in 1 and 2-year-old bamboo culms are very high and reduce slowly as an effect of age. They mentioned that the amount of starch in bamboo shoots is affected by the growth cycle of bamboo clum. The next growth and the thickening of cell wall in earlier stage are dependent on amount of carbohydrate stored in rhizome. As replacement to the carbohydrates used previously, the bamboo leaves undergoing photosynthesis process to produce starch and then stored it in parenchyma cells. This starch is necessary for the rapid growth of bamboo culms until they become mature.

2.2.1.2 Vascular bundles

From the study on bamboo species in Asian by Grosser and Liese (1971), they found that Asian bamboos are characterized by it huge amount of vascular bundles. The vascular bundles seem to be bigger in inner portion and become smaller across the culm wall thickness.

Observation by Liese (1985) found that the vascular bundles of bamboo culms is constituted by xylem, one or two small protoxylem elements, two larger metaxylem with the size of around 40 – 120 µm and delignified phloem. Both of metaxylem and phloem are surrounded by sclerenchyma sheaths. He classified the vascular bundles according to its orientation. Type I contains centre vascular supported by the four sclerenchyma sheaths, type II contains centre vascular supported by the sclerenchyma sheaths, where the sclerenchyma sheaths in protoxylem regions are larger compared to other three, type III contains two parts which are the centre vascular with sclerenchyma sheaths and a vascular bundle. Type IV contains three parts which are the centre vascular with small sclerenchyma sheaths and two vascular bundles. Type V also known as 'half-open' type.

Meanwhile, there are some variations between genera and also species, partly related to the types of vascular bundles present (Taihui and Wenwei, 1987). Bamboo species such as *Arundinaria* and *Phyllostachys* (*Leptomorph* genera), represent the Type I (supporting tissue of the one vascular strand only as sclerenchyma sheaths) and have generally lower fiber content than other bamboo species from *pachymorph* genera, such as *Bambusa*. *Dendrocalamus* and *Gigantochloa*, especially with Type III and IV (vascular strand with smaller fiber sheaths and one or two isolated fiber bundles). These basic differences in the anatomical structure affect bamboo properties like density, strength, shrinkage, splitting and bending behavior (Liese, 1992).

Furthermore, the size of vascular bundles are distinctive depend on the height of the culms, age and species. In a study by Chung *et al.* (1991), bamboo species such as *Bambusa dissimulator, Bambusa textiles, Bambusa tulda* and *Gigantochloa apus* has large size of vascular bundles in bottom part and getting smaller across the height. They found the size of vascular bundles in 2nd internodes in a culm are around 455-680 µm and in 26th internodes are around 220-470 µm.

2.2.1.3 Fibers

Fibers in bamboos are grouped in bundles and sheaths around the vessels. Across the culm wall the fiber length often increases from the periphery towards the middle and decreases towards the inner part. Along the culm from base to top no remarkable pattern for the fiber length exists except a slight reduction, whereas a great variation is evident within one internode of up to 100% and more. The shortest fibers are always near the nodes, the longest are in the middle. Thus the nodal part has a reduced strength due to its shorter fibers and marks the breaking point for the standing culm. However, bamboo breaks hardly at the nodes because of a higher fiber portion due to reduced parenchyma and increased lignifications (Grosser and Liese, 1971; Liese, 1970 & 1987).

The ultrastructure of some of the fibers is characterized by thick polylamellate secondary walls. The lamellation consists of alternating broad and narrow layers with differing fibrillar orientation. This polylamellate wall structure is present especially in fibers at the periphery of the culm, and their significance for bending properties appears obvious. Thin walled fibers do not have such a lamellation (Parameswaran and Liese 1976). It remains enigmatic, why only some of the fibers become thick-walled and polylamellated.

The occurrence and distribution of such fibers will influence certain properties and processing qualities, so that detailed studies with technological superior and inferior bamboo species about the fiber type present appear useful. Considering in this respect the parenchyma it can be noted that all elongated cells have apparently a polylamellate wall structure with up to 15 alternating lamellae (Parameswaran and Liese, 1975).

2.3 Rubberwood Tree

The Standard Malaysian name for rubberwood tree (Figure 2.5) is *Hevea brasiliensis* (Euphorbiaceae). Vernacular names applied include *kayu getah* (Peninsular Malaysia and Sabah), *rubberwood* (Peninsular Malaysia, Sabah and Sarawak) and *para rubber* (Peninsular Malaysia, Sabah and Sarawak) (Anon, 1982).

The rubberwood tree (*Hevea brasiliensis*) is believed to be native to the Amazon forests of Brazil. The mature trees can about 25-30 metres tall with average girth of greater than 1 meter at breast height. The trees of Malaysian rubber plantations which are much smaller have been bred for the production of latex without taking into account the volume of wood produced. However, with the present scenario of increasing demand for rubberwood the criteria for breeding of rubber trees will include those for production of wood as well (Hong, 1995). The density of rubberwood ranges from 480 to 650 kg m^3 depending on their age and possibly due to their clonal variation (Lim *et al.*, 2003).

People have been tapping rubber trees for their latex for centuries, and although synthetic alternatives have been developed, there is still a lively market for natural latex. However, after around 30 years, a rubber tree will start to produce much less latex, making it no longer commercially sustainable. These older trees are cut down so that new rubber trees can be planted.

The wood of felled rubber trees has traditionally been used for fuel and to make furniture in the regions where these trees are cultivated, but latex farmers realized that the wood could have commercial value as well, and they started to export it. Since the trees are not felled specifically for timber use, many people consider rubberwood to be ecologically sound, simply using up a waste product of the latex production industry. It is also a great building material, since it is durable and very strong, and it takes a range of finishes.

Rubberwood is classified as a light hardwood. Its strength and mechanical properties are comparable to traditional timbers used for furniture making and woodworking. The natural color of rubberwood which is whitish yellow, is one of the principal reasons for its popularity. Besides, rubberwood also has even wood texture and has good overall woodworking and machining qualities for sawing, boring, turning, nailing and gluing. It also takes finishes and stains well (Balsiger, 2000). This combination of even texture and colour, with easy working properties, can, in the right circumstances, make rubberwood an attractive raw material for a wide range of wooden products.

Figure 2.5. Rubberwood trees
Image source: http://en.wikipedia.org/wiki/Para_rubber_tree

Rubberwood can serve as a substitute for certain tropical hardwoods that now risk depletion. Because rubber trees grow relatively rapidly and are comparatively inexpensive to cultivate, they represent an economical sustainable resource and can be a viable alternative to increasingly rare tropical timbers. Developing countries that are current or potential producers of rubber trees should look into the opportunities that this wood offers as a material for developing value-added export products.

2.4 Sorption

As stated by Brunauer (1943), the sorption of water vapor by all natural cellulosic materials including oil palm trunk and bamboo follows the type 2 sigmoid isotherm. Requirements for type 2 sorption are that monomolecular sorption is accompanied by a polymolecular sorption, and possibly some capillary condensation in deformable molecular pores, with a considerable evolution of heat. It holds for non-polar non-swelling vapors such as nitrogen at liquid nitrogen temperatures and hydrocarbon vapors at room temperature on the naturally occurring internal surfaces of cellulose and wood (Haselton, 1954 and Merchant, 1957). It further holds for the sorption of polar swelling vapors such as water vapor within the cell walls of cellulose and wood (Stamm, 1964).

The correlation between wood swelling and liquid properties are not always clear, it is generally accepted that the swelling of the woody materials involves competitive process of the adsorption by hydrogen bonding and the scission of internal hydrogen bonds between the amorphous molecules of wood constituents, and therefore depends on the hydrogen bonding properties of the liquids.

2.5 The shrinkage and swelling as effect of humidity

Present knowledge about variation of moisture content in wood exposed to changes in climatic conditions or surrounding humidity is extensively studied by wood researchers. Nevertheless, the same knowledge on non wood such as oil palm trunk and bamboo is scarce. For example, Chomcharn and Skaar (1983) have reported results from an investigation on the relationship between moisture sorption in wood, dimensional changes, time and relative humidity. Test specimens from three different hardwood species were exposed to sinusoidally varying relative humidity between 77% and 47% at 25 ° C for several cycles. Four different cycling periods were used (5.33, 10.67, 16.0 and 25.33 hours). As a main conclusion they found that both moisture and dimensional changes were generally sinusoidal, but lagged behind the imposed relative humidity. The phase lag decreased and the amplitude increased with increasing cycling period.

Droin-Josserand et al. (1988) have done sorption experiments on wood exposed to changes in relative humidity in order to verify a numerical mathematical model. Specimens of two different thicknesses, 5 mm and 20 mm, with a transverse transport direction were tested. The relative humidity of the atmosphere has been varied with a constant rate of 5% RH per hour, increasing from 55% RH to 80%, thereafter decreasing from 80 to 55% RH. The temperature was kept constant at 30°C. One of the conclusions drawn from the work is that there is a phase lag between the changes in moisture content relative to the change in relative humidity. And the maximum moisture content does not correspond with the maximum of relative humidity.

One curve that expresses equilibrium moisture content as a function of percent relative humidity at constant temperature is called the moisture sorption isotherm (Skaar, 1988). The relationship is generally sigmoidal but the original desorption isotherm cannot be repeated when a specimen subsequently adsorbs or desorbs moisture. Specifically, any subsequent adsorption or desorption isotherm usually falls below the original desorption curve, thereby forming a hysteresis loop (Spalt 1957). Generally