THE CHARACTERIZATION OF SOME PHYSICAL AND MECHANICAL PROPERTIES OF MEDIUM DENSITY PARTICLEBOARD MADE FROM OIL PALM TRUNK WITHOUT FORMALDEHYDE BASED ADHESIVES

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by

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LIST OF ABBREVIATIONS

DSC	Differential scanning calorimetry
FTIR	Fourier Transform Infrared
MOR	Modulus of rupture
PF	Phenol formaldehyde
SEM	Scanning electron microscopy
TGA	Thermogravimetric Analysis
UF	Urea formaldehyde

PENCIRIAN SEBAHAGIAN SIFAT SIFAT FIZIKAL DAN MEKANIKAL PAPAN SERPAI BERKETUMPATAN SEDERHANA YANG DIPERBUAT DARIPADA BATANG KELAPA SAWIT TANPA PENGIKAT BERASASKAN FORMALDEHID

ABSTRAK

Penyelidikan ini mencirikan sebahagian sifat sifat papan serpai batang kelapa sawit diperbuat tanpa pengikat berasaskan formaldehid. Parameter pemprosesan termasuk suhu mampatan panas, jangkamasa mampatan panas dan tekanan mampatan panas untuk menghasil papan serpai batang kelapa sawit yang partikel saiz kasar (disaring dengan penapis No. 10) telah dikaji. Penambahan lignin, penambahan kanji, pra-rawatan stim dan pra-rawatan asid pada takat berlainan diperkenalkan dalam pembuatan papan serpai tanpa pengikat sintetik. Papan serpai diperbuat dengan 5% fenol formadehid dan 10% urea formadehid digunakan sebagai perbandingan. Sifat sifat papan serpai termasuk pembengkakan ketebalan, perubahan dimensi dengan perubahan kelembapan relatif, kekuatan ikatan dalaman, modulus kepecahan, penguraian selepas tanam dalam tanah telah dinilaikan. Tambahan, penguraian kulat dan penguraian anai anai ke atas papan serpai diperbuat dengan penambahan lignin, penambahan kanji, pra-rawatan stim, pra-rawatan asid dan pengikat sintetik termasuk fenol formadehid and urea formadehid telah dinilaikan. Papan serpai diperbuat pada 200 °C selama 20 minit pada tekanan mampatan 10 MPa menunjukkan keputusan paling memuaskan dalam pembengkakan ketebalan, perubahan dimensi dengan perubahan kelembapan relatif, kekuatan ikatan dalaman, modulus kepecahan dan penguraian tanam dalam tanah semasa penilaian keadaan parameter pemprosesan. Papan serpai diperbuat dengan penambahan lignin menunjukkan peningkatan dalam penilaian pembengkakan ketebalan, perubahan dimensi dengan perubahan kelembapan relatif, kekuatan ikatan dalaman dan modulus kepecahan, penguraian

tanam dalam tanah dan penguraian kulat dengan menentang kulat jenis reput perang. Papan serpai diperbuat dengan penambahan kanji menunjukkan peningkatan dalam penilaian kekuatan ikatan dalaman dan modulus pemecahan. Akan tetapi, ia menunjukkan kesan buruk dalam penilaian pembengkakan ketebalan, perubahan dimensi dengan perubahan kelembapan relatif dan penguraian tanam dalam tanah. Papan serpai diperbuat dengan serpai yang dirawat dengan stim menunjukkan peningkatan dalam penilaian pembengkakan ketebalan, perubahan dimensi dengan perubahan kelembapan rerlatif, kekuatan ikatan dalaman dan modulus kepecahan, penguraian tanam dalam tanah dan penguraian kulat. Papan serpai diperbuat dengan serpai yang dirawat dengan asid menunjukkan peningkatan dalam penilaian pembengkakan ketebalan, perubahan dimensi dalam perubahan kelembapan relatif, penguraian kulat. Akan tetapi, masa rawatan terlampau panjang menunjukkan kemerosotan ke atas penilaian. Papan serpai diperbuat dengan penambahan 5% lignin menunjukkan keputusan setanding dengan pembengkakan ketebalan dan perubahan dimensi dengan perubahan kelembapan relatif papan serpai diperbuat dengan 5% fenol formadehid. Papan serpai diperbuat dengan penambahan 5% lignin dan 5% kanji menunjukkan kekuatan ikatan dalaman setanding dengan papan serpai diperbuat dengan 5% fenol formadehid. Disamping itu, papan serpai diperbuat dengan tambahan 5% lignin dan serpai yang telah di pra-rawat stim selama 60 minit menunjukkan modulus kepecahan setanding dengan panel diperbuat dengan 5% fenol formadehid.

THE CHARACTERIZATION OF SOME PHYSICAL AND MECHANICAL PROPERTIES OF MEDIUM DENSITY PARTICLEBOARD MADE FROM OIL PALM TRUNK WITHOUT FORMALDEHYDE BASED ADHESIVES

ABSTRACT

This research characterized some properties of oil palm trunk particleboard made without formaldehyde based adhesives. The processing parameters including hot pressing temperature, hot pressing time and hot pressing pressure to produce oil palm trunk particleboard using coarse size particles (sieved with No. 10 filter) were studied. Lignin add-on, starch add-on, steam pretreatment and acid pretreatment at different degree were introduced into the making of particleboard without synthetic adhesive. Particleboard making with 5% phenol formaldehyde and 10% urea formaldehyde were used as a comparison. The properties of particleboard including thickness swelling, dimensional changes with changes of relative humidity, internal bond strength, modulus of rupture, soil burial decay were evaluated. In addition, fungal decay and termite decay on particleboard made with lignin add-on, starch add-on, steam pretreatment, acid pretreatment and synthetic adhesive including phenol formaldehyde and urea formaldehyde were evaluated. Particleboard made at 200°C for 20 minutes at 10 MPa pressing pressure showed the best result in thickness swelling, dimensional changes with changes of relative humidity, internal bond strength, modulus of rupture and soil burial decay during the evaluation of processing parameter condition. Particleboard made with lignin add-on showed improvement in evaluation of thickness swelling, dimensional changes with change of relative humidity, internal bond strength and modulus of rupture, soil burial decay and fungal decay with against brown rot fungi. Particleboard made with starch add-on showed improvement in evaluation of internal bond strength and modulus rupture. However, it showed adverse effect in the evaluation of thickness swelling,

dimensional changes with changes of relative humidity and soil burial decay. Particleboard made with steam pretreated particles showed improvement in evaluation of thickness swelling, dimensional changes with changes of relative humidity, internal bond strength and modulus of rupture, soil burial decay and fungal decay. Particleboard made with acid pretreated particles showed improvement in evaluation of thickness swelling, dimensional changes with change of relative humidity, fungal decay. However, the prolonged acid treatment showed the adverse effect in evaluation. Particleboard made with 5% lignin add-on showed compatible results with the thickness swelling and dimensional changes with changes of relative humidity of specimens made with 5% phenol formaldehyde. Particleboard made with 5% lignin add-on and 5% starch add-on showed compatible internal bond strength with particleboard made with 5% phenol formaldehyde. Meanwhile, particleboard made with 5% lignin add-on and 60 minutes steam pretreated particles showed compatible modulus of rupture with particleboard made with 5% phenol formaldehyde.

CHAPTER 1 – INTRODUCTION

1.1 General background

Wood is a remarkable material in human history. It has been wisely used from ancient time till nowadays. The application of wood for human use is very wide and important, for example, for construction, furniture, arts and etc. Others than natural solid wood lumber, human has developed engineered wood and widely use in packaging, furniture and etc. Wood waste or sawmill scrap was used for engineered wood production. However, due to the high demands, expensive wood price, and environmental issue from rapid wood logging activities, these problems have made the world need to look for other alternatives. Therefore, agriculture crop byproduct or waste from plant, either wood or non wood has become one of the popular and important materials for engineered panel.

Oil palm plantation is the largest agriculture sector in Malaysia. The plantation area of oil palm in Malaysia has reached 5 million hectares in year 2011 and still increasing (Anonymous, 2011a). Other than producing large amount of cruel palm oil, perhaps, it also forms the largest portion of total agricultural waste in Malaysia (Sumathi et al., 2008). Oil palm trunk is the one of major wastes during oil palm replanting. Some of the felled trunks were chipped into mulch as fertilizer, but most of felled trunks just left unused and landfill on plantation in whole trunk (Ahmad et al., 2007). This huge size waste could turn into more valuable item, for example, as reinforcement material for engineered panel.

Particleboard is one of the common engineered panels. It is a panel made from the mixture of particles and synthetic resins, and some additives for property enhancement. It was invented in 19th century, but commercialise in 1940s, due to the shortage of lumber to manufacture plywood, and particleboard as replacement (Chapman, 2006). Nowadays, particleboard shows the rapid growth in world market, including in Malaysia. According to Malaysian Timber Industry Board (Anonymous, 2011b), the export of particleboard of Malaysia in year 2011 has already reached nearly RM337.8 million, not including conversion product from particleboard, such as furniture.

However, people start aware and concern about environmental and health hazard issue recently. The conventional particleboard is usually bonded with formaldehyde based adhesives, such as phenol formaldehyde and urea formaldehyde, and these resins will release the formaldehyde emission which is carcinogenic (Que et al., 2007; Buyusari et al., 2010). Furthermore, the slow degradation rate of thermoset adhesives has become another environmental issue as well (Nayak, 1999; Mohanty et al., 2000). These issues have forced to seek for alternatives to more green solutions.

Synthetic adhesive has been developed as environmental friendly alternative to conventional particleboard (Hashim et al., 2011a). Recently, the numbers of research on lignocellulosic based panel made without synthetic adhesives has significantly increased (Anglès et al., 2001; van Dam et al., 2004; Halvarsson et al., 2009; Hashim et al., 2010, 2011a, 2011b). Oil palm trunk showed potential as suitable biomass material in producing particleboard without synthetic adhesives, with some promising properties. However, such particleboard panel still has space of improvement. Furthermore, the previous researches were focusing on high density panel. It could be a challenge to convince market with high density panel in some applications.

1.2 Problem statement

Water uptake resistant is a crucial issue of panel made without synthetic adhesives. It is still facing many challenges to compete with conventional particleboard (Anglès et al., 2001), especially if made from agricultural crop waste (Halvarsson et al., 2009) which is poor against moisture. Panel made from oil palm trunk without synthetic adhesives having poor water resistant have been previously reported Hashim et al. (2011a, 2011b). Similar poor water uptake resistant properties also found in the oil palm trunk panel made with synthetic adhesives (by Sulaiman et al., 2009). Therefore, treatments are necessary in order to improve the water uptake resistant of such panel made from oil palm trunk.

Previous research of lignocellulosic panel without synthetic adhesives including particleboard mainly focus on high density, which is 800 kg m^{-3} and above (Anglès et al., 2001; van Dam et al., 2004; Hashim et al., 2010; Hashim et al., 2011a, Hashim et al., 2011b). Density is an important factor affecting most physical and mechanical properties, Cai et al. (2004) reported that density profile showed linear correlations with various properties of particleboard. Hence, higher density may provide panel with better physical and mechanical properties. However, such high density panel is not suitable in some applications such as furniture fitments and as packaging materials. The development of medium density particleboard is keen.

Oil palm industrial is the largest agricultural business in Malaysia. Despite oil palm sector generating profits to the country, its produce massive byproducts and create pollution (Sumathi et al., 2008). Some crops wastes are turned into some secondary products such as kernel cake for feedstock and the trunk chip into fertilizing mulch, but many are left unused. The unused wastes could be the reason for open air burning and create occupation hazardous (Anonymous, 2012). Utilization of such crop waste into new products will not only help in solving the environmental issue, but also generating additional income to the oil palm industries.

1.3 Objective

This research aims to provide important information to the problem stated in Section 1.2. Regards the problem statements, the main objective of this study is to characterize some properties of medium density oil palm trunk particleboard made without synthetic adhesive that using several methods

The specific objectives are:

1. To study the optimization of processing parameter in producing medium density particleboard without synthetic adhesives using coarse size oil palm trunk particle

2. To evaluate some physical, mechanical and biodegradation resistance properties of medium density particleboard without synthetic adhesives that produce using several methods such as lignin add-on, starch add-on, steam pretreatment and acid pretreatment

3. To study the comparison of some physical, mechanical and biodegradation resistance properties of such medium density particleboard with medium density particleboard bonded with formaldehyde based adhesives according to internationally recognized standard.

CHAPTER 2 - LITERATURE REVIEW

2.1 Oil palm tree

Oil palm tree, belongs to the species name of *Elaeis guineensis*, it is one of common species of palm tree (as shown in Figure 2.1). The mature oil palm tree averagely can grow up to 20 meters, with pinnate shape leaves, and bunches of reddish palm fruit (Sumathi et al., 2008). Currently, the core purpose of oil palm planting is for the extraction of palm oil from the fruits (Yusoff, 2006). Palm oil is the largest production in the oils and fats sources compared with the other major sources such as soy oil, rapeseed oil, sunflower seed oil and etc (Anonymous, 2013). Other than palm oil extraction from oil palm fruits, the other biomass components of oil palm tree are still underutilized.

Figure 2.1: oil palm trees located at oil palm plantation

In Malaysia, oil palm plantation currently is a major crop in the plantation sector. In year 2011, oil palm plantations in Malaysia have reached approximately 5 million hectares, equally 16% of total land mass of Malaysia (Anonymous, 2011a). At the same year, Malaysia has 426 palm oil mills and processing 99.85 million tons fresh fruit bunch, following with 56 palm oil refineries mills and producing 18.91 million tons of crude palm oil (Anonymous, 2011c). The export trading of palm oil including crude and process palm oil to worldwide in 2011 was averagely 1.5 million tons per month (Anonymous, 2011d). This huge oil palm commerce sector is not only benefits to the country incomes, but also creating plenty of job opportunity to the citizen.

Other than palm oil, the other major oil palm products include palm kernel oil, palm kernel cake, oleochemicals, biodiesel and others. Palm kernel oil should not be confused with palm oil. Palm kernel oil is the oil derived from the kernel of oil palm. It is more saturated than palm oil, and commonly used in commercial cooking as it is more stable at high temperature comparing to palm oil (Edem, 2002). Palm kernel cake is the byproduct after palm was kernel oil pressed out from oil palm kernel. It is one of important ingredient for animal feeds (Sabu et al., 2005). Oil palm oleochemical is the chemical derived from oil palm fats. It has been widely used in production of laundry detergent and personal care items, such as soap bars, shampoo and etc (Murphy, 2007).

2.1.1 Oil palm crop waste and potential

The crop waste produces from oil palm plantation is one of the critical issues in oil palm sector. According to Malaysian Palm Oil Board, oil palm plantation is one of the main reasons for forest fires and haze in many countries. In Malaysia, Environmental Quality Act has been introduced and it is significantly contributing in reduced the open burning oil palm crop waste problem (Anonymous, 2012). Some solutions have been introduced and practicing in plantation and processing mill.

However, not all the oil palm wastes issues were successfully solved due to its massive amount. Oil palm empty fruit bunches and fruit kernels are the crops waste produced massively daily. Some of the empty fruit bunches are usually used as fuel to generate electricity for the mill, the major of unused empty fruit bunch will usually with or without converted into mulch and landfill the plantation site (Sumathi et al., 2008; Chiew et al., 2011). The oil palm kernel after palm oil pressing, usually will be grounded and pressed into palm kernel cake and used for animal feeds.

During replanting, massive old oil palm trunk and fronds are felled. Most of oil palm plantations in Malaysia are practicing the method of chipping the old oil palm trunk and fronds and placing the residues as fertilizer mulch at the inter row of new planting oil palm. However, the quantity of oil palm crop waste from plantations site is massive, including the huge trunk. Furthermore, the application of mulching is limited by the concern of encouraging agricultural pest in the plantation site (Sulaiman et al., 2011). Other than fertilizing, some of these biomass wastes used as fuel, some used as raw material for certain production, most of it was left unused. Thus we are still facing issues from these under utilize crop waste. Furthermore, as the demand of biomass material in worldwide is increasing, these unused waste components could have a better value.

Many researches have been carried out lately, in the effort to utilize oil palm crop wastes. Rosalina Tan et al. (2011) studied the potential of oil palm leaves as a dietary supplement. The result from the study is quite promising. The findings suggest that the oil palm leaves are potential as alleviation of diabetic. The flavonoids contents in the oil palm leaves could be the potential active components of exhibit antihyperglycaemic effect. Noor et al. (1999) and H'ng et al. (2011) proposed oil palm trunk as a resource of starch. In their research, they found out the yield extracting from oil palm trunk is satisfactory. Noor et al. (1999) works success to obtain 7.15% of starch yield extracted from oil palm trunk using 0.5% (w/v) of sodium metabisulphite aqueous solution. H'ng et al. (2011) works success to obtain 1.7% of starch yield using lactic acid extraction. Yamada et al. (2010) and Kosugi et al. (2010) studied the sugar produced oil palm trunk for bioethanol production. Their findings indicated the old oil palm trunks are significant resource for fuel ethanol production. The sugar containing in the sap are rich and suitable to be fermented into ethanol using yeast strain. Shinoj et al. (2011) mentioned that fiber extracted from empty fruit bunches is a good raw material for biocomposites after being treated with alkaline to improve its fiber-matrix adhesion.

There are few challenges of oil palm biomass utilization facing in nowadays. First, the different properties of these oil palm biomass comparing to wood. Second, transportation and storage, most of this biomass are bulky and high moisture content, some of oil palm biomass collection point is scattered. This will increase the transportation cost. The oil palm biomass have low durability against fungus infection, especially if the biomass with high moisture content. Third, the poor impression of oil palm biomass product especially for furniture or wood based product application. This is one of the big challenges in convincing the industries and consumers to attempt to use oil palm biomass product.

2.1.2 Oil palm trunk

Generally, oil palm trees have 25 years of life span averagely to harvest the oil palm fruit before replanting (Noor et al., 1999). Replanting will be conducted after the yield is reduced and the tree reached the height that is hard to harvest which is more than 10 meters height. Oil palm trees are felled massively during replanting. Some of these trunks were used as fuel, some being chipped into mulch and most of them left unused. In Malaysia at year 2010, approximately 15.5 million tons (in dry weight) of oil palm trunks were felled from replanting site that the total area is approximately 200 000 hectares. The amount of oil palm trunk felled in year 2010, is just approximately 3 million tons less than estimated dry weight of empty fruit bunches generated on that year (Anonymous, 2011e).

Currently, there are some researches indicated the potential of oil palm trunk in many kinds of applications as mentioned in Section 2.1.1, such as sugar extraction and starch extraction. Hashim et al. (2010, 2011a, 2011b) have published few researches regarding potential of oil palm biomass including oil palm trunk as raw material for binderless panel. However, these applications are still not practically turn into industries application yet. Oil palm trunk has been used to produce palm plywood and palm lumber for furniture, and these have been commercialized

(Anonymous, 2012). However, the production is not in mass and still many trunks left unused.

2.2 Lignocellulosic based composite panel

In the past seventy years, the World War II and the explosive growth of America have urged the seeking for alternative to replace the shortage of construction solid wood. Nowadays, the demand of lignocellulosic based composite panel is still high and not only in America but worldwide. Currently, the lignocellulosic based composite panels are not limited in construction but also being involved in other sectors including packaging, furniture manufacturing and others (Chapman, 2006).

Lignocellulosic based composite panel is the man made panel derives from lignocellulosic material, binding together with the adhesives. It is also called as engineered panel. The lignocellulosic material can be in the form of strands, particles, fibers, chips and others. Nowadays, many studies showed that lignocellulosic materials use in engineered wood are not limited to wood only but also possible of many others non wood materials, such as crops straw, oil palm, kenaf, sugar cane and etc. This could be a great effort to solve the crops waste issue and promote the commercial value to these crops.

The common type of lignocellulosic based composite panels available nowadays includes plywood, particleboard, fiberboard, plastic wood and others (Abdul Khalil and Hashim, 2004). The common commercial adhesives used in lignocellulosic based composite panels are phenol formaldehyde, urea formaldehyde, melamine formaldehyde and MDI (Chapman, 2006). The different kind of lignocellulosic based composite panels is designed for different purposes, according to its properties.

Lignocellulosic based composite panel has few advantages compared to solid lumber. The main advantage of such composite panels comparing to solid lumber is that composite panels have uniform properties and controllable properties. Solid wood properties from the same species but different tree, as well as different part from the same tree, could even have significant difference of properties. Other than this, modification or improvement on composite panel properties is easier than on solid wood. The penetration of chemical into particles is easier than into solid wood.

2.2.1 Particleboard

Particleboard is a panel manufactured from lignocellulosic based particles, by bonding the particles together with synthetic adhesives. The compatibility of particleboard into many applications and its uniform properties together with the price of particleboard are relatively cheaper compared to solid wood, have made particleboard with great demands in worldwide.

Generally, particleboard can be classified according to density. The low density particleboard in the range of 250 –400 kg m^{-3}, while medium density particleboard in the range of 400 – 800 kg m^{-3} and high density particleboard is in the range of 800 – 1200 kg m^{-3} (Abdul Khalil and Hashim, 2004). Application of the particleboard that not involves heavy duty loading may have lower requirements on density and strength performance. The high density particleboard usually has better performance. However, the high density will increase the costs of making process as well as transportation of final product due to its heavy weight (Chapman, 2006). Other than density, the performance of particleboard is also influenced by many factors. The performance of particleboard can be controlled in the process of making particleboard. The raw materials of particleboard, such as type of adhesives, the species of lignocellulosic used as particles, as well as processing parameters, such as pressing condition, resin content, significantly influence the performance of particleboard (Nemli et al., 2007).

In this paragraph, the literature of the basic of making particleboard was written according to the review of Abdul Khalil and Hashim (2004) and Chapman (2006) books. The basic of making particleboard generally involves chipping, screening, drying, blending, mat forming, pre pressing, hot pressing and finishing as shown in Figure 2.2. Chipping is the process of reducing size of wood to smaller size and shape according to requirement. Material source to be used in chipping can be uniform or mix of different species of wood. The process of screening is to reject the particles that are larger or smaller than required. Particles that are larger than required size will be sent to chipping again. During drying process, the particles will be dried in the dryer to desired moisture content. The excessive moisture adversely affects the adhesion performance of particles with adhesives. Blending is the process of mixing the particles with adhesives and additives. However, addition of additives is optional. The addition and choice of type of additives are in accordance with final service of the product. The details of adhesives and additives will be discussed in Section 2.4 and 2.5. Pre pressing is the process of pressing the mixture of particles with adhesives and additives that is optional before hot pressing, to form particles

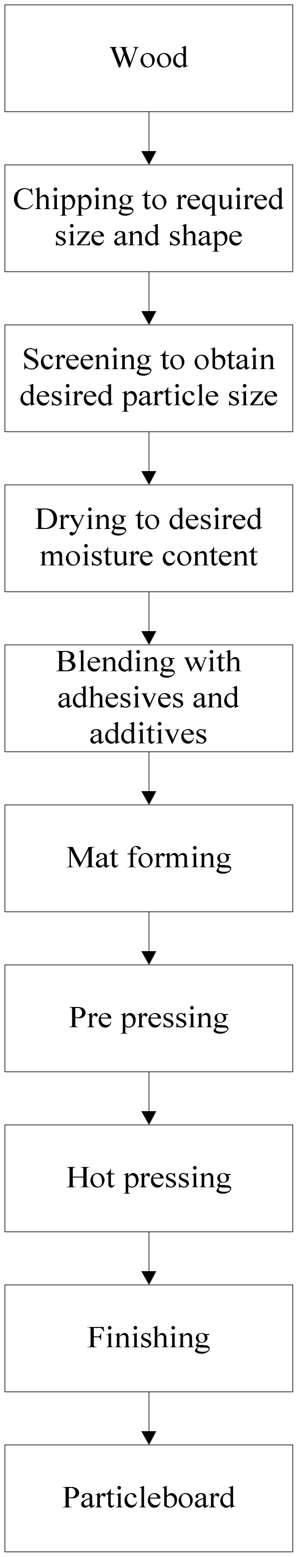

Figure 2.2 General flow of process of making particleboard (Abdul Khalil and Hashim, 2004)

mat with good contact between particles and adhesives. During hot pressing, the pressing process conducted at pressing temperature above curing rate of adhesives, together with sufficient hot pressing time and pressing pressure, these allowing the adhesives in the mat to cure and binds the particle together at targeted thickness. Finishing such as trimming and sanding is the final process in making particleboard, in order to give particleboard desired appearance.

Comparing with solid lumber, the particleboard provides decent strength properties and able to being produced in larger size at uniform properties (Chapman, 2006). Also, with cheaper price than most of wood lumber, these reasons made particleboard become popular and widely used in furniture industries nowadays. However, particleboard is potential source of indoor air pollution, especially if it is made with formaldehyde based adhesives. Formadehyde is one of volatile organic compounds with strong smell. Formaldehyde is an aldehyde organic compound that widely used in many applications. The formaldehyde emission found in the household is significant from wood product using formaldehyde based adhesives (Garrett et al., 1999).

Formaldehyde emission is the one of a critical issue that brings health and environmental impact. The exposure to formaldehyde significantly brings the negative effect to human health. With level as low as above 0.1 ppm of air, the formaldehyde is potentially to cause burning sensation in the eyes, nausea, coughing, skin rashes and allergic reactions (Anonymous, 2011f). At high level, it has been scientifically proved that formaldehyde can cause tumors at laboratory animals (Woutersen et al., 1989), thus believing formaldehyde may cause the cancer in humans as well, potentially as human carcinogen. Therefore, the rules and regulation on formaldehyde emission from formaldehyde based products become stringent in many countries (Kim and Kim, 2005).

2.3 Lignocellulosic based engineering panel without synthetic adhesives

Lignocellulosic based engineering panel without synthetic adhesives is more environmental friendly products compared to composite panel that is using synthetic adhesive as binder. The binding mechanism depends on temperature (heat) and compression effect during pressing that allows the lignocellulosic material to achieve self bonding. One of the lignocellulosic based engineering panels without synthetic adhesives are fiberboard (Chapman, 2006).

Comparing to conventional adhesives bonded lignocellulosic based panel, the temperature required in hot pressing to form wood panel without adhesives is usually higher. The high temperature is needed to ensure the potential chemical compounds in promoting self bonding to react (Hashim et al., 2011b; Chapman, 2006). The temperature used in hot pressing for making synthetic adhesives bonded panel are subjected to curing of the adhesives. The temperatures for curing the common adhesives use in manufacturing are usually in the range of 140 °C-160 °C. After reviewed the findings from Anglès et al. (2001), Xu et al. (2004), van Dam et al. (2004), Hashim et al. (2010, 2011a, 2011b), it can be concluded that the hot pressing temperature for making wood panel without adhesives usually is higher than 160 °C.

Many researches of binderless panel have been done. Anglès et al. (2001) studied the effect of steam pretreatment with adding of acid on the manufacturing of binderless panel using softwood material including spruce and pine in fine powder. Their research claims that the hemicellulose is responsible for the water uptake and biodegradation in wood.

Currently, most of the researches on wood panel made without synthetic adhesives are not limited on wood only, there are lignocellulosic material such as kenaf, coconut husk, oil palm biomass that also showed good potential (Xu et al., 2004; van Dam et al., 2004; Hashim et al., 2010; Hashim et al., 2011a, Hashim et al., 2011b).

Xu et al. (2004) success developed a low density binderless particleboard using kenaf core as material with steam treatment. From the findings, Xu et al. (2004) indicated that steam treatment could improve the dimensional stability of the panel with increasing treatment duration. However, the strength properties were unable to measure due to its low density, in the range of 100 kg m^{-3} to 300 kg m^{-3}. Xu et al. (2004) proposed that such low density binderless particleboard is designing as building materials for sound absorption and thermal insulation application.

van Dam et al. (2004) reviewed the potential of coconut husk as materials to produce binderless fiberboards. van Dam et al. (2004) suggested that high lignin content in the coconut husk could act as the binder for coir fibers at high temperature and under pressure. The panels produced from short fiber after refine from husk showed excellent strength performance compared to commercial MDF and particleboard. Meanwhile, the 24 hour soaking thickness swelling of the coconut husk fiberboard is only 8% while the commercial MDF is 17%. However, the density of such coconut husk fiberboard produced at high density, at the range of 1300 kg m^{-3} – 1400 kg m^{-3}, which is relatively high compared to commercial MDF.

Hashim et al. (2010, 2011a, 2011b) investigated the potential of oil palm biomass at potential material to produce binderless board. The research (Hashim et al., 2011a) studied the potential of various biomass components from oil palm and found out the oil palm trunk showed great potential amount other biomass components. The mechanical properties and water uptake resistant of panel produced from oil palm trunk showed better performance than the panel made from oil palm frond, bark and leaves in the study.

Later, the research from Hashim et al. (2010, 2011b) focused on the binderless particleboard produced from oil palm trunk. Hashim et al. (2010) focused on the effect of particle geometry on the properties of oil palm trunk binderless particleboard. From the findings, the research indicated that the panel made from particles in strands shape showed better strength properties than panel made from fine particles. The strength properties from such panel success met the JIS standard.

Hashim et al. (2011b) studied the effect of press temperature on the properties of the binderless particleboard made from fine oil palm trunk particles. This research indicated that increasing pressing temperature can improve the properties of binderless particleboard. However, the water uptake resistant of such oil palm trunk binderless particleboard from Hashim et al. (2010, 2011a, 2011b) still not meet the international standard requirement. This is the main challenge of using crop waste as material is that the material usually is weak to the water and has low moisture resistant (Anglès et al., 2001).

2.4 Adhesives

Adhesive is the substance applied on surfaces of two or more substrates, to join the substrates together and resist from separations. The common adhesives found in the market include cement, glue, paste (Pizzi and Mittal, 2003). Adhesives can be found in nature, but for most of the industrial use adhesives nowadays belongs to synthetic resins. Comparing to natural adhesive, synthetic adhesive are more stable in performance.

The earliest use of adhesives was approximately 2000 years ago (Pizzi and Mittal, 2011). The first discovered adhesive in mankind history is birch bark tar. However, the technology of adhesives was begun rapidly from 1940s. The reason for this is the employment on adhesives in the high demands on the composite and others synthetics polymers at World War II (Utracki, 2002).

The advantages and demands on adhesives have driven the continual growth and development on science of adhesives. Comparing to other joint methods such as screw and welding, the techniques of applying adhesives are frequently found more convenient. Furthermore, adhesives offer better distribution of stress on the joint surface, as well on dissimilar substrates. However, it is facing challenges such as stability in high temperature compare to joints method such as screw and welding (Kinloch et al., 2000; Blackman et al., 2005).

Wood adhesives are important in lignocellulosic products. Two thirds of lignocellulosic products in nowadays are bonded with adhesives, either in partial or total (Pizzi and Mittal, 2011). The reason for this is that, for wood and other lignocellulosic based component, adhesive bonding provides many advantages comparing other joining methods as discussed in Section 2.2.

Wood adhesives are basically solid. To achieve intimate contact with substrates, wood adhesives will usually apply in liquid form. Adhesives in liquid form are more able to penetrate into wood and other lignocellulosic based material and to provide better adhesion between surface of material substrates. Other than wettability of adhesives, the quality of adhesion also depend on parameters such as surface of material substrates, chemical of wood material, area of contact, quality of contact. (Abdul Khalil and Hashim, 2004)

There are many types of wood adhesives. Generally, these wood adhesives can be divided into thermoset resins and thermoplastic resins. Thermosets resins are usually popular and widely used in wood composite industries. Thermoset resins are polymers that crosslink together during curing process and form an irreversible bonding. It is resistant to high temperatures with excellent dimensional stability (Saheb and Jog, 1999). It is suitable for the heavy duty woody panel. One of the common thermoset resins is formaldehyde resin.

Formaldehyde resins are the resins using formaldehyde as base ingredient. These formaldehyde resins are commonly found in wood composite panel such as plywood and particleboard (Chapman, 2006). The formaldehyde based resins commonly found in the market are phenol formaldehyde, urea formaldehyde and melamine formaldehyde. The different type of formaldehyde resins has different properties, including different curing temperature, colors, strength (Chapman, 2006).

2.4.1 Phenol formaldehyde

Phenol formaldehyde resin is one of the oldest commercial synthetic polymers. It was invented in 1909 and established in 1940s. It belongs to thermosetting resins in which the resin is cured irreversibly. It is an important type of adhesive in wood based panel production due to its superior water resistant. It can be usually found in powder and liquid form.

The phenol formaldehyde resin is synthetic polymers of reaction between phenol and formaldehyde. Generally, there are two types of phenol formaldehyde resin in term of preparation, which are the novolacs and resoles. Novolacs phenol formaldehyde resin is made with formaldehyde to phenol ratio less than one, with the polymerization using acid catalyst. Resoles phenol formaldehyde, are made with formaldehyde to phenol ratio greater than one, and catalyzed with base. In particleboard formation, resol type is more common and popular. One of the reasons is because the resol type phenol formaldehyde can be hardened without curing agent. (Pizzi, 1983)

In wood based panel, phenol formaldehyde resins are usually applied on panel that is designed for exterior application. Phenol formaldehyde resin is not only providing strong adhesion for wood panel, it is also having good resistant properties. Phenol formaldehyde resin is excellent in water resistant, in both cold and hot water

Other than water resistant, phenol formaldehyde resin is also good in resisting to common organic solvent, weak acid and base. Furthermore, it also has high resistance to thermal, fungi, and insect (Chapman, 2006).

However, phenol formaldehyde resin does have some weaknesses. Phenol formaldehyde resins require high curing temperature, which is approximately 140 – 160 °C. The application needs high energy to produce a high temperature for hot pressing process, thus, high cost for end production. Besides this, phenol formaldehyde resin products are currently facing the restriction on the regulation regarding formaldehyde release. The formaldehyde is believed as the carcinogenic and able to cause respiratory problem to human (Amaral-Labat et al., 2008).

2.4.2 Urea formaldehyde

Urea formaldehyde resin is one of the thermosetting resins. It belongs to aminoresin. It is based on manifold reaction of two main monomers, urea and formaldehyde (Dunky, 1998). Higher formaldehyde ratio to urea can provide better water resistant, strength properties and high reactivity. However, the cost will be higher as formaldehyde is more expensive than urea. Furthermore, the end product that is using urea formaldehyde resins produced with high ratio of formaldehyde to urea will emit more formaldehyde (Dunky, 1998).

Generally, urea formaldehyde resin needs to be cured in acidic condition. Ammonium chloride is the common accelerator used in urea formaldehyde resin curing system (Conner, 1996). The consumption of ammonium chloride in curing urea formaldehyde is usually small, less than 1.5% over weight of urea formaldehyde resin. The excessive of accelerator might cause slightly changes in color of the urea formaldehyde resin (Dunky, 1998).

Comparing to other formaldehyde based resins such as phenol formaldehyde resin, urea formaldehyde resin has some advantages. Urea formaldehyde resin has high reactivity, thus, shorter curing time. This reactivity can increase the production yield and lower the production cost. Furthermore, comparing to phenol formaldehyde resin, urea formaldehyde resin is giving better aesthetic value to the end products. Urea formaldehyde resin is usually giving clear glue line (Conner, 1996). In addition, urea formaldehyde resin is non flammable due to their high content of nitrogen.

However, urea formaldehyde resin has poor water and weather resistance. The aminomethylene linkage tends to hydrolyze, thus, is not stable at high humidity, especially with high temperature (Conner, 1996). The formaldehyde emission from wood panel using urea formaldehyde resins is continual. The formaldehyde gas release from the urea formaldehyde bonded panel can be present from the residual formaldehyde trap in the board. Besides, the hydrolysis on weak bonding formaldehyde also will release the formaldehyde emission (Pizzi, 1983).

2.5 Lignocellulosic material additives

Additive is the substances added into products during the making process, in order to enhance and improves the properties of the products. In the lignocellulosic industries, additive has been used to improve or repair the wood and lignocellulosic panel properties. Many types of additives are found in wood industries, and usually each substance is specializing to enhance specific properties, such as bonding properties, moisture resistant, microbial decay resistant, fire retardant and etc (Chapman, 2006). Some enhancement on wood properties can have several choices of substances as additives, for example, both titanate and silanes are common coupling agent use in wood composites industries (Xie et al., 2010). Most of the additives found in wood industries are synthetic chemicals. Some of the chemicals found in these additives have drawback effects on environment and health (Klein et al., 2001).

2.6 Lignocellulosic biomass chemical constituents

Lignocellulosic biomass in both wood and non wood, is a remarkable material in the mankind history. It is one of natural composite found on Earth. Lignocellulosic and its products can often be found in construction, packaging, furniture, arts and decoration, and etc. The application of lignocellulosic depends on such material properties such as mechanical strength, resistance to moisture, resistance to biological attack, fire retardant. These lignocellulosic properties are direct or indirectly related with lignocellulosic chemical constituents.

Lignocellulosic organic chemical constituent essentially consists of cellulose, hemicellulose, lignin, and extractives. Other than these constituents, starch, pectin, sugar and etc are the minor compounds found in lignocellulosic. Other than organic compounds, lignocellulosic also consists of a small proportion of inorganic compounds, such as calcium, magnesium and potassium which these metal salts compound also known as ash compounds in lignocellulosic material (Walker, 2006). The distribution of the chemical constituent containing in lignocellulosic, varies from species to species, as well as from tree to tree at same species, and parts to parts of