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DRYING OF OIL PALM LUMBER BY COMBINING AIR-FORCE AND MODIFIED SUPER FAST DRYING METHOD

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By

MUHAMMAD NADZIM BIN MOHD NAZIP

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman : Associate Professor Edi Suhaimi Bakar, PhD
Faculty : Forestry and Environment

Having a unique wood structure and very high moisture content (MC), the drying has been one of big challenges in the utilization of oil-palm lumber (OPL). Drying of OPL took very long time and creates many defects. For any utilization, the wood needs to be dried. Since the drying of OPL took very long time and creates many defects, and also not all parts of OPL can be processed, the utilization of OPL becomes not economically attractive to the wood industry. An efficient method for drying of OPL needed to introduce. Basically, a new efficient drying method suitable for OPL has been introduced, i.e. “Super-Fast Frying” (SFD). The SFD was patented by Bakar *et al.* (2016) to solve the drying problems of OPL. This method is very efficient which can dry both outer and inner parts of OPL in not more than 3 hours. However, this SFD method involves the holing of the lumber before proceeding to the two-stage drying, the hot pressing and high temperature drying. These holes limit the application of super-fast dried OPL. On top of that, the method is quite complex since the processes is different for inner and outer OPL. Therefore, there is a need to improve the SFD method that capable to dry OPLs without involving the holing and the same processing procedure for inner and outer OPL. In our preliminary study it was found that the “Super-fast drying” can be made without holing when the MC of OPL is reduced. So in this study we are developing a “Modified Super-fast drying” method, (MSFD) in which the MC before the “Super-fast drying” is reduced to a certain intermediate MC. So, the “Modified Super-fast drying” method process consists of pre-drying (Air force drying) (AFD), hot-pressing and high-temperature drying. A series of intermediate MC of 100, 80 and 60% with AFD is tested and optimized based on drying performance (drying time, drying defects) and physical and mechanical properties of super-fast dried OPLs. The AFD was to determine the acceptable OPL thickness based on the drying performance in achieving the intermediate MCs. The MSFD was the comparison between “Super-fast drying” and “Modified super-fast drying” method in term of total drying time and super-fast dried OPL properties. The drying rates, physical and mechanical properties of dried OPLs were analyzed. The result showed that the AFD method dries OPLs at a faster rate than AD with very minor defect. The AD took very long time with a drying rate of (1.64-3.65 % per day) and create many defect (100 %) as compare to AFD (2.98-6.57% per day). This suggests that AFD can be used as pre-drying in the “Modified super-fast drying” method. The Modified super-fast drying can be made without holing by using intermediate MC between 100-60%. The process less complicated since the outer and inner OPLs can undergo the same procedure. All tested intermediate MCs treatment (100, 80, 60%) gave no significant effect on the physical and mechanical properties of super-fast-dried OPL, that suggest the 100% is the best intermediate MCs in term of total drying time. Comparing among the drying methods, MSFD, AFD and SFD, it can summarized that the “Modified super-fast drying” takes longer time (1 to 2 weeks, 3 hours) than the “Super-fast drying” (3 hours), but provide better TS, WA and SMOE than the “Super-fast drying”. These are much better than the “Air drying” as it reduce the drying time and drying defects, as well as improve the mechanical properties (SMOE and SMOR). It can be concluded that the MSFD as the best drying method since it does not require the holing process and has better properties.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGERINGAN KAYU KELAPA SAWIT DENGAN MENGGAMBUNGKAN KAEDAH DAYA ANGIN DAN PENGERIGAN KELAJUAN TINGGI YANG DIUBAHSUAI

Oleh

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Pengerusi : Profosor Madya Edi Suhaimi Bakar, PhD
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Mempunyai struktur kayu yang unik dan kandungan lembapan yang sangat tinggi, pengeringan kayu menjadi salah satu cabaran besar dalam penggunaan kayu kelapa sawit. Pengeringan mengambil masa yang lama dan menghasilkan banyak kerosakan. Untuk sebarang penggunaan, kayu perlu dikeringkan. Memandangkan pengeringan kayu sawit mengambil masa yang lama dan menghasilkan banyak kerosakan, tambahan pula tidak semua bahagian kayu sawit boleh diproses, penggunaan kayu sawit menjadi tidak menarik secara ekonomi untuk industri kayu. Cara yang berkesan untuk pengeringan kayu sawit perlu diperkenalkan. Pada asasnya, kaedah pengeringan cekap yang sesuai untuk kayu sawit telah diperkenalkan, iaitu "Super-Fast Frying" (SFD). SFD dipatenkan oleh Bakar *et al*. (2016) untuk menyelesaikan masalah pengeringan OPL. Kaedah ini sangat berkesan yang boleh mengeringkan bahagian luar dan dalam OPL dalam masa tidak lebih dari 3 jam. Walau bagaimanapun, kaedah SFD ini melibatkan lubang pada kayu sebelum meneruskan pengeringan dua peringkat, pengeringan panas dan suhu tinggi. Lubang-lubang ini mengehadkan penggunaan OPL tetapi dapat kering dengan sangat cepat. Selain itu, kaedah ini agak kompleks kerana prosesnya berbeza untuk OPL bahagian dalam dan luar. Oleh itu, terdapat keperluan untuk memperbaiki kaedah SFD yang mampu mengeringkan OPL tanpa melibatkan proses lubang dan prosedur yang sama untuk OPL dalam dan luar. Dalam kajian awal kami mendapati bahawa "pengeringan Super cepat" boleh dibuat tanpa lubang apabila MC OPL dikurangkan. Oleh itu dalam kajian ini kita sedang membangunkan kaedah "Modified Super-fast drying" (MSFD) di mana MC sebelum "pengeringan Super cepat" dikurangkan kepada MC pertengahan tertentu. Jadi, proses kaedah "Modified Super-fast drying" terdiri daripada pra-pengeringan (Air force drying) (AFD), pengeringan panas dan suhu tinggi. Satu siri MC pertengahan 100, 80 dan 60% dengan AFD diuji dan dioptimumkan berdasarkan prestasi pengeringan (masa pengeringan, kecacatan pengeringan) dan sifat fizikal dan mekanikal OPL kering yang sangat cepat. AFD adalah untuk menentukan tebal OPL yang boleh diterima berdasarkan prestasi pengeringan dalam mencapai MC pertengahan. MSFD adalah perbandingan antara kaedah pengeringan "Super cepat" dan "Modifikasi cepat pengeringan" dalam jangka masa pengeringan dan harta OPL yang sangat cepat. Kadar pengeringan, sifat fizikal dan mekanik OPL kering telah dianalisis. Hasilnya menunjukkan bahawa kaedah AFD kering OPL pada kadar yang lebih cepat daripada AD dengan kecacatan yang sangat kecil. AD mengambil masa yang sangat lama dengan kadar pengeringan (1.64-3.65% per hari) dan mencipta banyak kecacatan (100%) berbanding dengan AFD (2.98-6.57% sehari). Ini menunjukkan bahawa AFD boleh digunakan sebagai pra-pengeringan dalam kaedah "Modified super fast drying". Pengeringan super cepat yang diubah suai boleh dibuat tanpa holing dengan menggunakan MC pertengahan antara 100-60%. Proses yang kurang rumit kerana OPL luar dan dalaman boleh menjalani prosedur yang sama. Semua rawatan MC perantara yang diuji (100, 80, 60%) tidak memberikan kesan yang signifikan terhadap sifat fizikal dan mekanik OPL yang sangat cepat kering, yang menunjukkan bahawa 100% adalah MC pertengahan terbaik dalam tempoh masa pengeringan. Membandingkan antara kaedah pengeringan, MSFD, AFD dan SFD, dapat dirumuskan bahawa "Pengeringan yang super cepat" memakan waktu lebih lama (1 hingga 2 minggu, 3 jam) daripada "Super cepat pengeringan" (3 jam), tetapi memberikan lebih baik TS, WA dan SMOE daripada "pengeringan Super cepat". Ini lebih baik daripada "pengeringan udara" kerana ia mengurangkan masa pengeringan dan kerosakan pengeringan, serta memperbaiki sifat-sifat mekanik (SMOE dan SMOR). Ia dapat disimpulkan bahawa MSFD sebagai kaedah pengeringan terbaik kerana ia tidak memerlukan proses holing dan mempunyai sifat yang lebih baik.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Kg/m^3	Kilogram per meter cube
N/mm^2	Newton per millimeter cube
ANOVA	Analysis of variance
Cm	Centimeter
EFB	Empty Fruit Bunches
EMC	Equilibrium Moisture content
kN	Kilo newton
MC	Moisture content
Mm	millimeter
MOE	Modulus of elasticity
MOR	Modulus of rupture
N	newton
OPF	Oil-Palm Fronds
OPL	Oil-Palm Lumber
OPT	Oil-Palm Tree
OPT	Oil-Palm Trunks
OPW	Oil-Palm Wood
PPF	Palm Pressed Fibers
SAS	Statistical Analysis System
SFD	Super-fast drying
TAPPI	Technical Association of the Pulp and Paper Industry

CHAPTER 1

INTRODUCTION

1.1 General introduction

Oil palm (*Elaeis guineensis*) tree is originated from tropical rain forest of West Africa. The oil palm tree has long been domesticated by many West African coastal dwellers before the advent of the white man to West Africa. Currently, the oil palm tree can be grown in many countries around the world which has similar tropical climate such as the Pacific Island, South America and popular in South East Asia especially in Malaysia and Indonesia. Corley and Teo (1976), reported on the origin of the oil palm and claimed that this tree crop from West Africa was first introduced to Brazil and other tropical countries in the 15th century by the Portuguese but the propagation did not start immediately until the 19th century. Although, the oil palm originated from West Africa, South-East Asia, particularly Malaysia and Indonesia, are now the leading producers of palm oil and palm kernel (Ndon, 2006).The reason why oil palm developers were interested in South East Asia such as Malaysia is due to the favorable climate, low labor cost, low land rents and government assistance in developing the industry (Colchester, 2006).

There are two main oil products from palm oil tree which is the crude palm oil and palm oil kernel. These oils can be made into a wide range of products which are both consumable and non-consumable. Eirwinsyah (2004) stated that product made from palm oil are cooking oil, shortening ice creams and margarine. Non-consumable products such as lubricants, esters, plastics, textile, emulsifiers, explosives and pharmaceutical products. These oil products are only 10% products from the oil palm tree while the other 90% were biomass (Abdullah, 2012).These biomass mainly consist of the Oil Palm Trunk (OPT) which has been underutilized due to the unique characteristics which differ from other woody species. These unique characteristic of the OPT are the reason why it is currently underutilized and result to major disposal problem. Therefore, utilizing the full potential of the OPT waste is desirable for both the environmental and economic reasons.

Abudllah *et al.* (2012) states that there is abundance raw materials available from the OPT that consisting of around 90% of biomass wastes and only around 10% of oil. Killman and Choon (1985) found that the high percentage of biomass underutilized reflects due to density variation in both radial and longitudinal direction. The average economic life-span of the oil palm is 25 years to 30 years and are then replanted (Lim, 1999). Because growth and yield starts to decline as it reaches to that life span. Therefore, the trees are felled and replanted (Hartley, 1988). The felled trunks are left to decompose to act as a fertilizer. Currently, there is very limited economic use for the OPT and its disposal imposes a heavy financial burden to plantation owners. The increasing number of replanting programs anticipated in the near future will inevitably bring even greater problems associated with the disposal of the large amount of trunks generated (Table 1.1).

Due to this, the newly cut tree cannot be burn. It will be left to decompose at the filed which can takes about five to six years (Husin, 1986). The felled trunks are known to be a favorable focus for diseases and pests, such as basal stem rot, Ganoderma and Rhinoceros beetles (*Oryetes rhinocerous*) (Geoffrey *et al.*, 2010).

Table 1.1 : Economic and industry development division, MPOB (2016-2018)

LOCATION	CONDITION	Year		
		2016	2017	2018
Peninsular Malaysia	Mature	2.349	2.388	2.407
	Immature	0.33	0.319	0.32
Sabah and Sarawak	Mature	2.652	2.722	2.782
	Immature	0.406	0.38	0.339
Total		5.737	5.809	5.848

Drying of Oil Palm Lumber (OPL) needs to be carried out as fast as possible in order to protect the lumber from primary decay, fungal stain and insects attack. Several studies has been done to expand the usage of the OPT but required complex drying procedure. The complex drying procedure is the reason why there is very limited economic use for the OPT and its disposal imposes a heavy financial burden to plantation owners and the industries (Bakar *et al*., 2006). Having found that key problem in utilization in OPW is due to wide range of green Moisture content (MC) (100-400%) very poor drying properties, low mechanical properties and lack of strategic sawing pattern (Khalil *et al.*, 2009), it is necessary to develop a drying method which can be flexible to fully dry OPL and produce OPL with minimum drying defect.

Air drying (AD) of OPL can be define as the drying of the lumber that expose to the environment. The process can be done by making stacks of lumber in which each layer are separated by stickers. The drying rate of this process is dependent on the climate condition of the surrounding, thus makes the user hard to control (Desch *et al.*, 1996). AD of OPL is to expose the lumber to the outside environments and would take a long time to reach air dried. But before reaching air dried, as stated before, the lumber would attract rhinoceros beetle (*O. rhinocerous),* rats and *Ganoderma bominense* disease. Thus a controlled drying environment is to be preferred (Liau and Ahmad, 1991).

Kiln drying is the process where the lumber is dried artificially by introducing a heat sources in order to dry faster in a controlled environment. These controlled environments can regulate the atmospheric pressure, temperature of the surroundings, relative humidity and air circulation (Walker *et al*., 1993; Desch and Dinwoodie, 1996). The kiln drying is to ensure that this process can overcome the challenges made from drying direct to the environment. The main advantages for this method is that user can utilize this method in large scale and has a better control for the desired final MC. Anis *et al.* (2016) and Balfas (2006), had found that kiln drying of OPL though various drying schedule (MTIB, 2015) has resulted to a low recovery of 28%. The other 72% of the OPL was full of drying defect. These drying defect consists of warping, honey combing and cracking. Simpsons (1997), concluded that due to high temperature and low relative humidity during the drying process was the main factor. Anis *et al.* (2016) also include that due to the OPL which has high green moisture content and wide variation in density is also the reason where recovery is low and advised that a mild drying schedule is needed. Therefore, another complex method needs to be introduce in order to combat the different drying properties in OPL.

Mircrowave drying was introduce as an trial for a fast drying process which took 10 minutes from green MC to oven dried MC (Amouzgar *et al.*, 2010). During the process, there were reported 3 periods of drying which was a warm up, evaporation and a heating up period. During the warming up period, the MC reach a plateau which is roughly the boiling point of water. The evaporation occur at this decrease as the surface was not affected. This drying process was not the same as conventional drying as the microwave drying generate heat by colliding molecules in the material not relying the surrounding temperature (Guanben Du *et al.*, 2005). Due to the drying takes part in the inner part, the rate of evaporation was able to maintain a steady rate thought the sample from the inner to the outer. In the heating up period, energy form the microwave energy was used to heat up the strands. Charring can occur during this process as the temperature of the strands can be high. Uneven drying can occur as the OPL consists of wide variation of drying properties. Thus a pre drying solution which utilize air drying was determine to be an effective method in reducing the duration of microwave drying (Luntz, 2004; Shulamn, 2003).

Since conventional method proves to be difficult to control the drying process of the OPL, non-conventional method can be utilized in order in solves the drying problem. Non-conventional method can be define as drying method that is not common or practical. The examples of these method are drying by, radio frequency, microwave, press, vacuum, boiling in oil, inferred and so on. One of the recent discovery to dry OPL is by the Super-Fast Drying method (SFD). The SFD method of OPL is unique process that involves three steps of drying which are holing, direct contact drying or hot pressing, and high temperature drying (Bakar *et al.*, 2016). The holing is intended to accelerate water evaporation by increasing the surface area. The Direct Contact Drying (DCD) is made by hot pressing the lumber at 180°C for certain period of time, compression level and cycle depend on the portion/mc/density of OPL and high temperature drying is made by kiln or oven set to a high temperature of 120°C or more. Referring Figure 1.1, it was reported that OPL can be prepared into two categories in this drying. The outer portion or MC less than 200% or density the same or more than 0.3 g/cm^3 and the inner portion of mc more than 200% or density less than 0.3 g/cm^3. For the outer of OPL (a), the hot pressing is done for one cycle of 10-20% compression and for the inner part (b) the hot pressing is done for two cycle, the first cycle with 10-20% compression and the second cycle with 20-60% compression (Bakar *et al.,* 2016). Furthermore, the inner portion of first cycle only reduce the green MC to half of the intermediate Moisture content at 200**%** and the second cycle will dry the OPL to 20-40**%** and continue to the oven dry process.

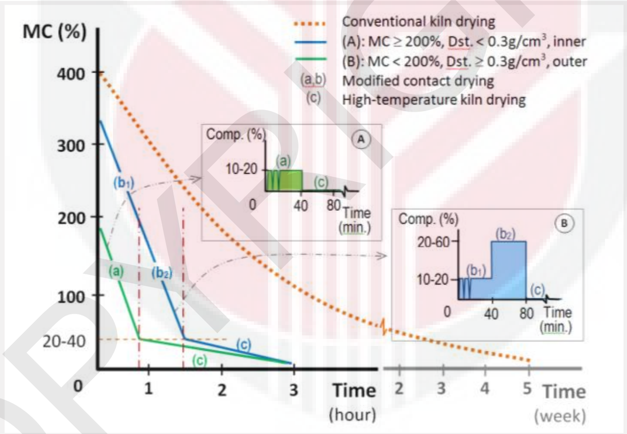

Figure 1.1 : Drying rate for SFD OPL (Bakar *et al.,* 2016)

The SFD method is capable to dry both the outer and inner portion OPW with relatively free of defect in just 3 hours. This makes the method very efficient and fast that should be attractive to the industry. The SFD method however involves the holing of the OPL and the process is different for both inner and outer portion of the lumber. The holing of the OPL will make application of the SFD OPW limited. Since this method can be considered to be non-conventional method, there is a need to improve the method. Aspect of the method can be modified is to remove the holing process and to simplify the process by the two step pressing process for the inner portion of the lumber. In order to remove the holing process, the preliminary study show that it is needed to reduce the green MC of the lumber to at least half of the initial MC.

Wood drying can be define as removing excess moisture in the wood before the final usage. In air force drying, the wood is dried using air forced in a one direction that flows through the lumber in order to remove the excess moisture in wood. This method dry the wood without any external heat source. Desch *et al.* (1996) found that a uniform flow of air through a pile of lumber can increase the chances for a successful drying but tests toward OPL has not been conducted by previous studies. In a study to determine the effectiveness of the Air force Drying (AFD) for OPL, it is found that AFD method was chosen as the preliminary drying process as it is faster drying method than AD and slower than kiln drying.

1.2 Problem statement

Wood resources in Malaysia are limited and the industries is in a dire need of alternative solution. There are abundant of OPL that is being underutilized. Therefore, OPL has the potential to reduce the stress on tropical lumber sought from the wood industry (Bakar *et al*., 2006; Abdul Khalil *et al.*, 2010; Anis *et al.,* 2011). Not only OPL is abundant in Malaysia, but it is also cheap, due to be readily available as after the economic life span of 25-30 years, the tree is felled and replanted. Furthermore, the OPL is considered as an environmental friendly resources and has the potential to be converted into highly value added products. Despite that the anatomy of OPL is different from wood, but with some modification, it is possible to use this non-woody material as an option for woody material. This opportunity give birth to optimizing OPL to combat solid wood depletion. But several aspect needs to be taken when utilizing OPL.

OPL has wide range of green MC and density. There can be two different method in segregation of the OPL which is by density and moisture content. Segregation by density can be categorized into 3 different parts, the inner zone (IZ), central zone (CZ) and peripheral zone (PZ). Where else by the MC, It can be differentiate between Inner and outer portion. Characteristics of the inner part has the MC above 200% while the outer part has the MC below 200%. When sawing OPT, it is advisable to take this matter into consideration. Therefore processing needs to be strategically a different method of cutting pattern than tropical lumber. From inner part to the outer part, density, number of vascular bundle and moisture content varies significantly. Furthermore Mohamad (1989) and Killmann (1983) proposed that the core of OPL cannot be used because of its poor drying properties, and because of that he suggested the necessity of OPL segregation according to the potential uses. Similarly, Fauzi *et al*. (2012) also recommended segregating lumber made from OPT by densities prior to lumber manufacturing. In addressing to this problem in terms of segregation of the lumber, a strategic sawing pattern must be selected. Sawing technique of OPL is not like other timber products. It is need to segregate the OPL into inner and outer part as the highest quality is the outer layer which only cover 30% (Bakar *et al.*, 2006). Conventional sawing techniques such as life or plain sawing were design based on the hardwood and softwood species. Due to the priority of producing the heartwood resides in the core and the while the sapwood at the periphery of the lumber (Bowyer *et al.*, 2005; Desch and Dinwoodie, 1996). Contrarily for OPT the sawing pattern intended for the outer portion as it is the best properties. Therefore, it is needed to use different sawing pattern in order to fully utilize the OPL for Inner and Outer portion of the trunk. Addressing the sawing pattern issue, Bakar *et al.* (2006) have found that the polygon sawing as the best method to adjust the inner and outer portion of the OPL.

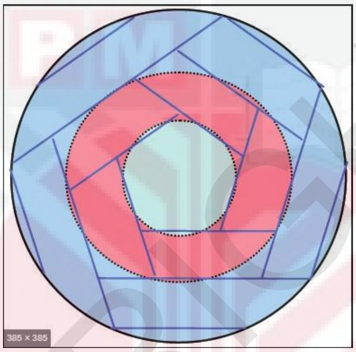

Figure 1.2 : Polygon sawing of OPL (Bakar *et al*., 2006)

As can be seen from the Figure 1.2, good quality lumber from polygon sawing need to OPT on the carriage for many times. Since the angle of rotation is not 90° (common rotation angle in sawing) the polygon sawing is difficult to operate and requires skilled operator. Therefore, a simpler sawing pattern needs to be constructed which can be used by moderate skilled worker and without any modification to the existing sawing machine.

Drying of OPL has been a challenge for effectively utilizing the OPL. Air drying and kiln drying of OPW result to unsatisfactory result. The different drying properties between inner and outer proves a difficult aspect to tackle. This can be further true for the inner part as stated in study by Lim and Gan (2005). Through the process, the OPL suffers from various drying defect, fungal and insects attack due to the high sugar content. One of the method to combat the drying challenges is by the Super-Fast Drying (SFD) method of the OPL. Which is by design an effective and fast drying method has been developed. Generally, the SFD method involves drilling holes in OPL and apply a light compression to produce the defect free board. This process requires high precision as the method for the inner portion and outer portion are different. In SFD, OPL is segregated by the MC. Segregation of the inner and outer is needed as both portion have different drying process. The inner portion require two higher compressions cycle while the outer portion undergoes 1 cycle with lower compression. Therefore, a modified version needs to be introduced. But to make the method to be more affective and attractive to the wood industry, the drawback mentioned above needs to be solved. It is found in our preliminary studies, that SFD can be made without holing if the initial MC of the OPW or green MC is lowered to less than 200% (Bakar, 2016). Therefore, in the current study, SFD is to be modified by reducing the initial MC of OPL to certain level before proceeding to the actual SFD. The initial MC of the OPL were reduced by AFD method. The AFD was selected since it is faster and produce less defect than that of AD method and cheaper than kiln drying method. So, the Modified Super-Fast Drying (MSFD) Method consist of two segments. The first is to dry OPL to a certain intermediate MC (IMC) (60, 80 and 100%) and the second is to dry OPL from intermediate MC to final target MC (<10%) by the SFD method. This study aims to eliminate the holing process of the SFD by reducing the initial MC. In this case, using AFD to achieve suitable MC that can ignore the holing. The end result should have the OPL to reach final MC of less than 10% without holing and enable OPL to undergo the same process despite the portion.

1.3 Objectives

The general objectives of this study was to dry the OPL efficiently without involving the holing of Super-Fast Drying (SFD) method. The specific objectives of the studies were:

1. To analyze the drying rate of OPL using AFD method at different drying parameters
2. To evaluate the drying defect of OPL using Air Force drying method at different drying parameters
3. To analyze the intermediate moisture content suitable for MSFD method in terms of drying rate
4. To evaluate the physical and mechanical properties of MSFD OPL at different drying parameters

1.4 Hypothesis

The hypotheses was that with optimum intermediate MC, both outer and inner portion of the OPL can be dried by MSFD method without involving holing process and the same process and giving the OPL quality improve or equivalent of that the final product of SFD method OPL. To examine the obtained result, the following hypothesis were proven.

Concerning the **thickness and portion** affecting the drying parameters of the AFD method of OPL:

H0: The thickness and portion of the OPL have insignificant effect on the drying rate and drying defects in Air Force Drying.

H1: The thickness and portion of the OPL have significant effect in the drying rate and drying defect of the OPL.

Regarding the **intermediate MC** affecting the physical and mechanical of MSFD method of OPL.

H0: The intermediate MC have insignificant effect in the drying rate, physical and mechanical properties of MSFD OPL.

H1: The intermediate MC have significant effect in the drying rate, physical and mechanical properties of the MSFD OPL.

In relation to the **drying treatments** affecting the physical and mechanical of OPL.

H0: Drying treatments have insignificant effect in the drying rate, physical and mechanical properties of OPL.

H1: Drying treatments have significant effect in the drying rate, physical and mechanical properties of OPL

The experimental factor examined were based on the portion of the MSFD OPL as the properties were vastly different.

1.5 Structure of the thesis

The thesis is organized into 5 Chapters as follows:

Chapter 1 gives the general overview of this study and basically include the background, problem statement, objectives and hypothesis of this study

Chapter 2 provide a compressive review of exiting and relevant literature review on OPW, OPL and its drying process.

Chapter 3 explain the methodology of AFD, MSFD and AD as well as the testing method and statistical analysis that would be used in this study.

The results for the test made in chapter three are compiled and discuss in chapter four. It includes the drying performance and drying quality of AFD, drying performance and drying properties of MSFD.

Chapter 5 concludes the finding of this project and recommendation for future research and development.

1.6 Limitation of study

This Study was limited only to the outer and inner part of OPW as the main material for the experimental analysis of MSFD method in order to improve the SFD method. The investigation was to investigate the AFD method on OPL as the preliminary drying process. The air-flow from the AFD method was fixed and almost equally constant to the lumber stack. Furthermore, the chamber of the AFD method was conducted in a kiln drying which air intake and outtake were limited. The reading of the MC of OPL were using the weight reduction method as there were no MC measurement suitable for a high green MC of OPL. The characteristics of OPL from the MSFD method on the physical, mechanical and drying properties from different IMC in comparison with the SFD method. Specific modulus was used in order to remove the density affecting the result.

1.7 Significant of the study

The findings of this study will rebound to the benefit of the Oil-palm Plantation in the underutilization of the OPW. The demand of solid lumber will be reduce towards tropical lumber and have other options that are more sustainable. Drying of the OPL will be much more practical without any special or modifying the current drying techniques that are available. Thus potential usage of the dried OPL can be strategically used to fulfill the industries demand of biomass. For the researchers, the study will help them to utilized dried OPL from inner and outer as the raw material was difficult to dry from green MC to AD mc. Thus a new method can be constructed from utilizing dried OPL.

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