A Review: Characteristics of Oil Palm Trunk (OPT) and Quality Improvement of Palm Trunk Plywood by Resin Impregnation

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Due to the shortage of solid wood as a raw material of plywood and the abundance of oil palm trunk (OPT) waste in Malaysia, OPT has become one of the potential replacements for timber. However, OPT plywood has low performance compared with commercial plywood, due to the poor properties of OPT. There are many recent studies related to quality improvement using thermosetting impregnation, especially with formaldehyde-based resins such as urea formaldehyde (UF) and phenol formaldehyde (PF). Nevertheless, there are very limited studies related to palm trunk plywood using thermoplastic impregnation and formaldehyde-free adhesive. Formaldehyde effects can be avoided by replacing it with a thermoplastic adhesive, such as acrylonitrile butadiene styrene (ABS), to enhance and improve the quality of the plywood manufactured from OPT. In Malaysia, palm trunk plywood is used currently for non-structural materials such as formworks, cabinets, and packaging material. Hence, the enhanced quality of palm trunk plywood with a formaldehyde-free thermoplastic adhesive could produce a higher quality palm trunk plywood.

Keywords: *Oil Palm Trunk; Palm Trunk Plywood; Quality Improvement; Thermoplastic Impregnation*

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INTRODUCTION

In 1870, oil palm (*Elaeis guineensis*) was introduced to Malaysia as an ornamental plant, and since 1960, the planted area for oil palm has increased at a rapid rate. There were about 1.5 million hectares of oil palm planted area in 1985, and in the latest count in 2014, that number had increased to 5.4 million hectares (Malaysian Palm Oil Board [MPOB] 2011; 2015). Oil palm is the most important commodity crop in Malaysia. The harvesting of oil palm begins two to three years after planting in the field, and it has an economic life of 25 to 30 years, upon which the tree is chopped for replanting. As the first plantations started in the mid-1980s, the felling of trees has already begun, with several million trees scheduled for cutting every year for the foreseeable future. Consequently, a large quantity of biomass waste will be generated in Malaysia in the coming years (United Nations Environment Programme [UNEP] 2012).

Oil palm industries generate large quantities of oil palm biomass, for instance, oil palm trunk (OPT), oil palm frond (OPF), and oil palm empty fruit bunch (EFB) (Khalil *et al.* 2012). Oil palm trunks are normally left to burn or decay in the plantation area.

However, freshly felled trunks, with their high moisture content, cannot easily be burned in the field. Leaving the trunks in the field without further processing physically hinders the process of planting new crops, as the stem can take about five years to decompose completely (Abdullah *et al*. 2012). Furthermore, a study by Najmie *et al.* (2011) reported the proliferation of a soil fungus pathogen, *Ganoderma boninense*, which causes basal stem rot in oil palm trunk that can reduce the stem stiffness and weaken the building structure of the oil palm tree. It will also cause the oil palm tree to fall down, besides encouraging insect attacks by such as ants, termites, and tree worms. The utilization of OPT can solve environmental problems by implementing "zero-burning" method and waste can be converted to a valuable product.

Oil palm biomass utilization can be achieved by as early as 2020, with a progressive switch of palm biomass product value from low-value palm biomass products to higher-value palm biomass products (Ng *et al*. 2012). Table 1 shows the various products that have been produced from OPT, such as fiber reinforced concrete, medium density fiberboard (MDF), particleboard, laminated veneer lumber (LVL), blackboard, and compressed wood. In addition, there are many studies on manufacturing plywood from OPT. While the strength of palm trunk plywood may be comparable with commercial plywood, it exhibits poor performance of mechanical properties due to density variation and instability of the OPT (Feng *et al*. 2011). Thus, there is a major challenge in transforming OPT into products of suitable quality and market acceptability, as has been achieved with rubber wood or other tropical wood (Mokhtar *et al.* 2011).

Table 1. Products Manufactured from Oil Palm Trunk (OPT)

Products	References
Fiber reinforced concrete	Ahmad *et al*. 2001; Mahat *et al.* 2010; Abdullah *et al*. 2013
Medium density fiberboard (MDF)	Ibrahim *et al.* 2014
Particleboard	Hashim *et al*. 2011; Jumhuri *et al*. 2014; Lamaming *et al.* 2014; Saari *et al.* 2014
Laminated veneer lumber (LVL)	Sulaiman *et al*. 2009
Blackboard	Husin *et al.* 2001
Compressed wood	Sulaiman *et al*. 2012
Plywood	Husin *et al.* 2003; Abdul Khalil *et al.* 2010; Feng *et al*. 2011; Mokhtar *et al.* 2011; Hoong *et al*. 2012; Hoong and Paridah 2013

In Malaysia, oil palm plywood is currently used for non-structural materials including formworks, cabinets, and packaging material (Ahmad Shamim *et al*. 2014). Its use is limited, especially in structural material and other applications. To realize the potential of palm trunk plywood, further research on quality enhancement through its impregnation by thermoplastic resin is needed. This work should also include promoting the utilization of the oil palm waste abundance in Malaysia as well as the application of a formaldehyde-free resin for plywood.

OIL PALM BIOMASS IN MALAYSIA

Malaysia is one of the most important palm oil producers in the world; oil palm trunk has become one of the potential replacements for future timber. There has been a rapid increase in the plantation area since 1970 from 261,199 hectares to the current planted area of about 5.39 million hectares (Fig. 1) (MPOB 2014). Figure 2 shows the growth of the total oil palm planted area in Malaysia; within 5 years (2010 to 2014), it increased by 11% from 4.85 million hectares to 5.39 million hectares (MPOB 2015; 2015a, b, c). With such a large plantation area available, there is a large amount of oil palm biomass. Oil palm trees were felled annually for replanting, and they are normally left to rot or are burned in the plantation area (Abdullah *et al*. 2012). Thus, environmental threats such as air pollution affect the environment. With the realization of its potential as a "green" product, oil palm waste contributes to Malaysia's economic and sustainable development. In other words, the waste has been converted into potential wealth (Ng *et al*. 2012).

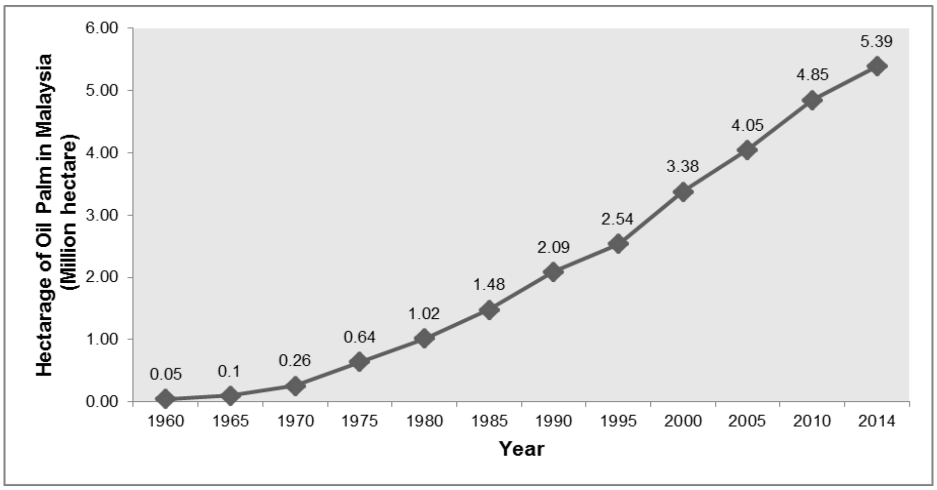


Fig. 1. Oil palm planted area from 1960 to 2014 (Malaysian Palm Oil Board 2014)

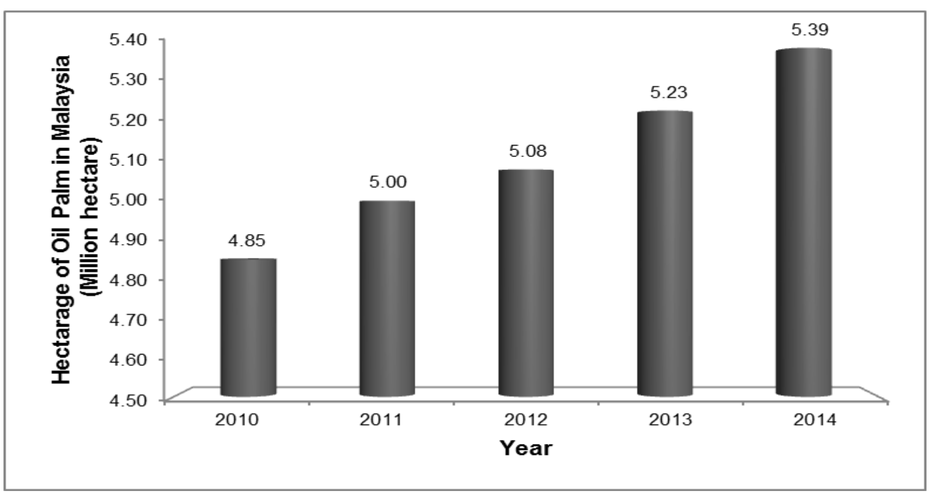


Fig. 2. Oil palm planted area from 2010 to 2014 (Malaysian Palm Oil Board 2015; 2015a, b, c)

Biomass is defined as organic matter derived from living or recently living organisms. In agriculture, it is simply the organic waste left behind. Some prefer the name "by-product" because the so-called waste is not necessarily wasted at all but has potential use, and even potential profits to be gained (Koay 2014). In the oil palm industry, the huge amount of solid biomass waste is generated in two ways: 1) harvested trunks during replanting and pruned fronds from fruit harvesting on oil palm plantations, or 2) empty fruit bunches (EFB), mesocarp fiber, and palm kernel shells (PKS) from palm oil extraction mills (Awalludin *et al*. 2015).

The oil palm industry generates the largest amount of biomass: 83 million tons in 2012, which is expected to grow to more than 100 million tons by 2020. Most solid biomass (75%) is found on plantations as OPF and OPT, and the rest is generated in mills during the extraction of oil palm (Agensi Inovasi Malaysia [AIM] 2013). Currently, most oil palm biomass is disposed of at the oil palm plantation or burned at the mills to produce oil palm ash (Khalil *et al*. 2012). However, the abundance of OPT waste can be used as an alternative raw material for plywood that would help decrease deforestation and reduce the environmental problems related to the disposal of oil palm waste.

ANATOMICAL AND MORPHOLOGY PROPERTIES OF OPT

The palm family Arecaceae (formerly known as the Palmae) forms a distinct group of monocotyledon plants (Corley and Tinker 2003). Anatomically, palms do not possess cambium; hence their "wood" is primary tissue and is not comparable in developmental terms to the wood of dicotyledons and gymnosperms. Thus, unlike the wood of dicotyledons and gymnosperms, which is mostly secondary xylem, palm "wood" consists of primary vascular bundles imbedded in a parenchymatous ground tissue (Parthasarathy and Klotz 1976). Figure 3 shows that the OPT shape is normally circular in the transverse direction, and the two parts of OPT are: 1) the main part of the trunk that consists of three zones: outer, middle, and inner, and 2) the cortex with the bark (Dungani *et al*. 2013). Because OPT is not truly a woody material, it poses a big challenge for developing products of suitable quality and market acceptability, as has been achieved with rubber wood or other tropical wood.

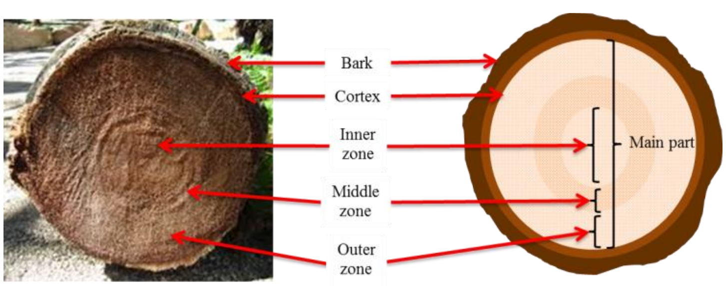


Fig. 3. Schematic drawing with an actual end and a crosscut of OPT

The three main components of oil palm trunk structures are parenchymatous cells, fibers, and vascular bundles. Scanning electron microscopy shows the morphological details of dried OPT structures, particularly the parenchyma tissues (Fig. 4). Parenchyma tissues are bowl-shaped and provide spaces for resin, which improves the characteristics of an OPT polymer composite. The parenchyma content decreases in each part of the inner, middle, and outer part of the OPT, while the vascular bundle content increases. Thus, the inner part of the OPT contains the highest moisture content, due to the variation of parenchyma and vascular bundles in each zone. Parenchyma has a high capacity for absorbing water compared with vascular bundles, which are less hygroscopic; this effect could be due to its anatomical structure (Ramle *et al*. 2012). An individual vascular bundle of OPT consists of fibers, phloem, vessels, parenchymatous tissues, and three wide metaxylem vessels (Fig. 5(a)). In Fig. 5(b), the three metaxylem vessels are very large and isolated from each other, and each vessel is surrounded by parenchyma cells (Abdul Khalil *et al.* 2008).

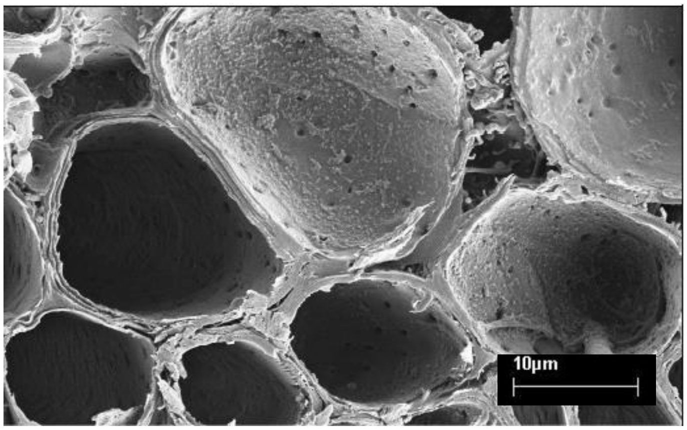
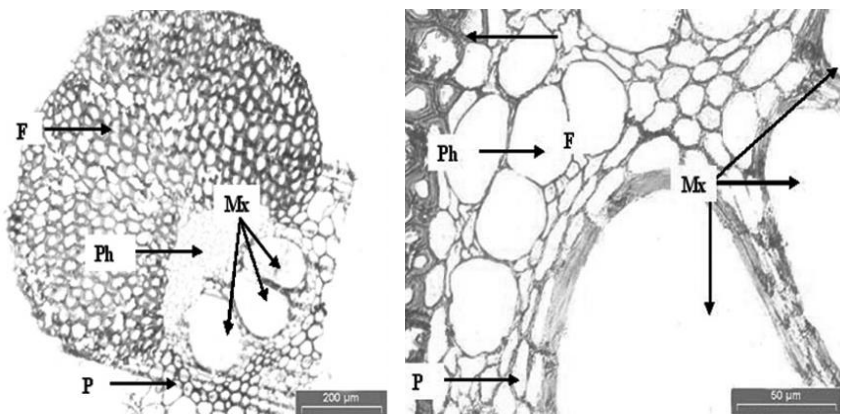


Fig. 4. Scanning electron micrograph (SEM) of parenchyma in dried oil palm trunk (Abdullah *et al*. 2012)



(a) (b)

Fig. 5. Transverse section of oil palm trunk at low magnification (4x), after being stained with toluidine blue; F: fiber, P: parenchyma, Mx: metaxylem, and Ph: phloem (Abdul Khalil *et al*. 2008)

PLYWOOD

In 2014, plywood was the second major export item amongst Malaysia's timber and timber products, contributing to 25% of the overall timber exports, as shown in Fig. 6 (Department of Statistics [DOS] Malaysia and Malaysian Timber Industry Board [MTIB] 2014). However, the shortage of raw material, namely logs, may hamper future growth within the industry. Estimates indicate that the annual production of logs from the permanent reserved forests (PRFs) would be reduced to 14 million m^3 for the period of 2016 to 2020 from about 19.4 million m^3 during the period of 2006 to 2010 (Ministry of

Plantation Industries and Commodities Malaysia, 2009). Currently, the Malaysian Timber Industry Board (MTIB) encourages an expansion of palm trunk plywood production and export because of the abundant availability of oil palm trunks and a cheaper selling price compared with timber plywood. The MTIB is also working on market acceptance and promoting oil palm plywood as an environmentally friendly and green product for the export market (Lumper, 2015).

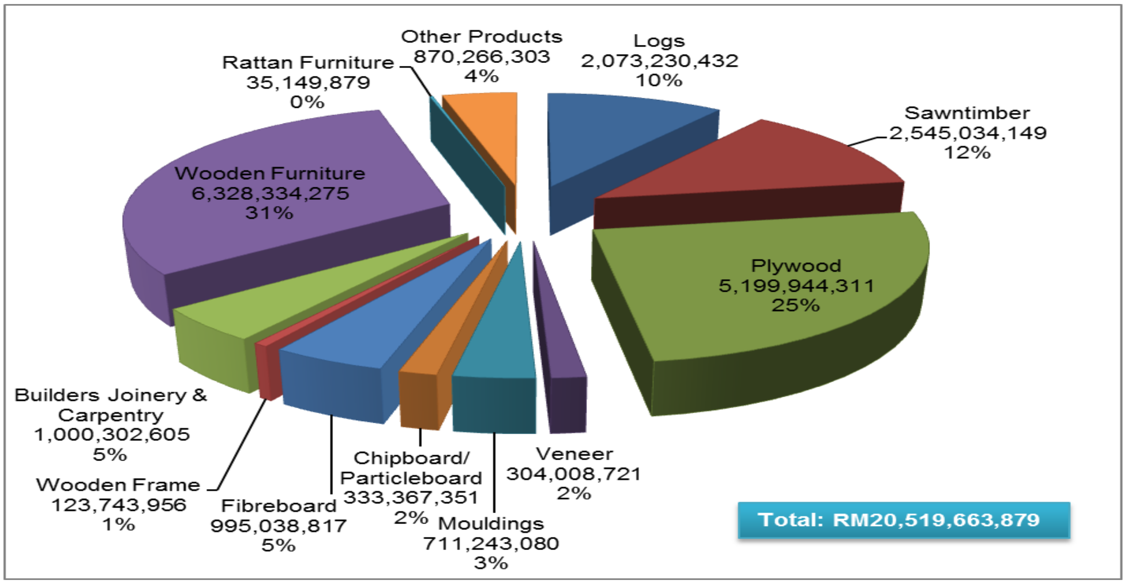


Fig. 6. Malaysia export timber products from January 2014 to Dec 2014 (Department of Statistics Malaysia and Malaysian Timber Industry Board 2014)

Plywood is a flat panel from either a soft or hard wood built up of sheets of veneer, called plies, which are united by a bonding agent under pressure that creates a panel with an adhesive bond between plies. Plywood is always arranged with an odd number of layers, with the grain direction of adjacent layers oriented perpendicular to one another and an adhesive spread on these layers (Youngquist 1999). As shown in Fig. 7, the manufacturing of plywood consists of nine main processes. These are log storage, log debarking and bucking, heating the logs, peeling the logs into veneers, drying the veneers, gluing the veneers together, pressing the veneers in a hot press, plywood cutting, and sanding (United States Environmental Protection Agency [USEPA] 2002).

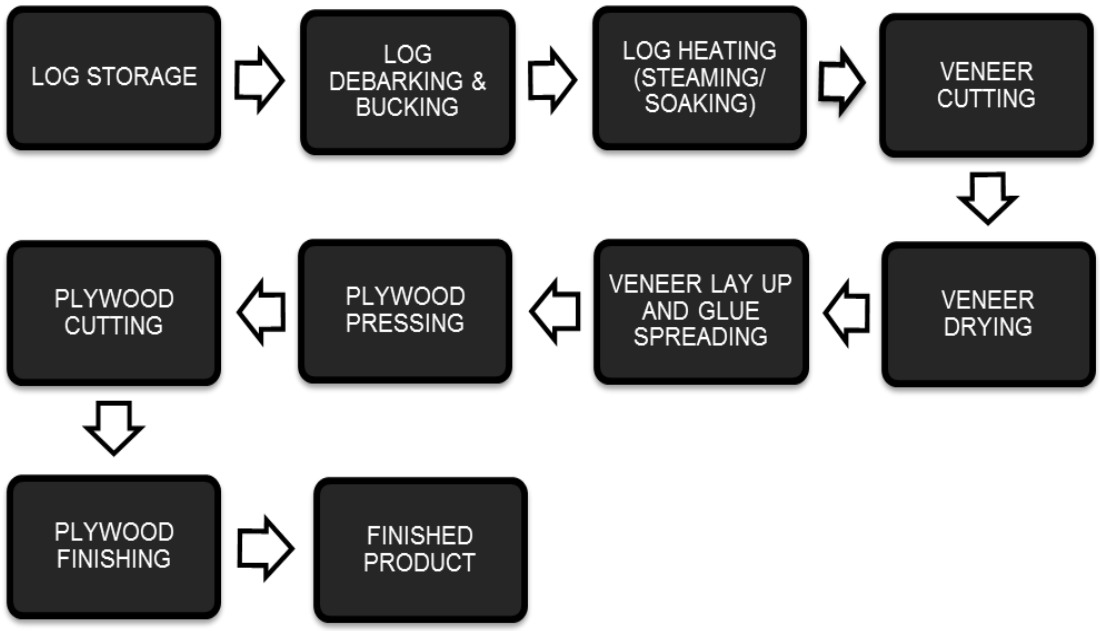


Fig. 7. A flow diagram for a plywood mill

A number of adhesives are commonly used in the production of plywood. These include protein extracted from plants and animals, for which the typical ingredients are water, dried blood, soya flour, lime, sodium silicate, and caustic soda, and phenol-formaldehyde and urea formaldehyde glues, which are thermosetting glues. Both protein and urea-formaldehyde are mainly interior glues, with less water resistance, that are used almost exclusively in the hardwood plywood industry. Phenol-formaldehyde is an exterior glue, with good water resistance, that is used for furniture and indoor paneling (Brady *et al*. 1998). However, the adhesives used in plywood have become a point of concern, as both urea formaldehyde and phenol formaldehyde are carcinogenic in very high concentrations. Therefore, many manufacturers are turning to low formaldehyde-emitting glue systems, denoted by an "E" rating for which "E0" possesses the lowest formaldehyde emissions or effectively zero formaldehyde emissions (Engineered Wood Products Association of Australasia [EWPAA] 2007).

Due to health concerns, researchers have developed new formaldehyde-free adhesives for the plywood industry that are environmentally friendly and harmless to human health. Soya-based adhesive provides better flexural strength to plywood (Buddi *et al*. 2015). Starch adhesives modified by blocked isocyanate result in good bonding strength (Tan *et al*. 2011). Recently, Tang *et al*. (2011) prepared a new formaldehyde-free adhesive by *in situ* chlorinating graft copolymerization. The main ingredients of this adhesive were maleic anhydride (MAH) grafted onto high-density polyethylene (HDPE) (forming PE-cg-MAH), which meets the standard of Type I plywood of GB/T 15104-94 (1994). Therefore, formaldehyde-free adhesives should be further explored and developed in the plywood industry.

QUALITY IMPROVEMENT OF PALM TRUNK PLYWOOD BY RESIN IMPREGNATION

Resin impregnation is used to improve the quality of plywood manufactured from OPT (Fig. 8). Impregnation can be defined as any technique using pressure or non-pressure to fill a wood substance with an inert material, resulting in a desired performance change (Hill 2006). The material occupies space within the cell wall and blocks microspores, thus increasing dimensional stability, reducing wood hygroscopicity and protecting the wood from decay and termites. Because the treatment significantly improves the appearance and properties, it can be used for making high quality OPT plywood.

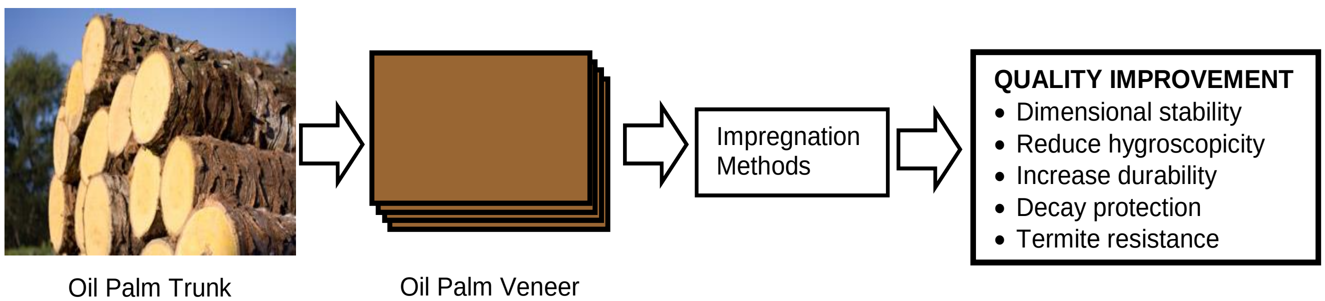


Fig. 8. Enhancement quality of oil palm trunk plywood

To improve the poor properties of OPT, palm trunk veneer has been made by resin impregnation (Table 2). The improvement of the physical and mechanical properties is influenced by several factors, including the type of adhesive (Abdul Khalil *et al*. 2010), lay up pattern of the plywood (Feng *et al*. 2011), resin content (Hoong *et al*. 2013), molecular weight of resin (Ab Wahab *et al*. 2012), pressing pressure (Hoong *et al.* 2012), hot pressing time (Hoong and Paridah 2013), and spread rate of adhesive (Feng *et al*. 2011).

Previous researchers used formaldehyde-based resins and adhesive for plywood manufacturing (Table 2). The major impact of the life cycle assessment (LCA) comes from the usage of phenol formaldehyde and urea formaldehyde in the production stages of the plywood industry (Ahmad Shamim *et al.* 2014). Consequently, formaldehyde causes health problems such as irritation of the skin, eyes, nose, and throat, and high levels of exposure may cause some types of cancers (USEPA 2015). Hence, formaldehyde-free adhesives should be developed to overcome these concerns.

In the variables studies, the lay-up pattern has been shown to have a more dominant influence on the bending strength and bond integrity than the adhesive spread rate. Oil palm trunk plywood, made from outer layer veneers, has a marked influence on the properties of plywood. Arranging veneers of low density in the core and those of higher density at the surface significantly increases the strength and stiffness (Feng *et al*. 2011). Thus, the lay-up arrangement should be emphasized for better quality palm trunk plywood.

The physical properties of palm trunk plywood are influenced by the resin concentration and veneer moisture content, while the mechanical properties and bonding performance of the pre-impregnated palm trunk plywood are influenced by the pressing time (Hoong and Paridah 2013). Hoong *et al*. (2012) used increased hot pressing pressure, finding that if the spongy oil palm veneer is more compact, there are reduced empty spaces in the veneer and increased plywood density. There is a clear positive correlation between the density and pressing pressure. Increased pressing pressure enhances the bonding strength in both dry and water boiled proof (WBP) test conditions.

There are limited studies related to palm trunk plywood using thermoplastic adhesives. Recently, a study by Hashim *et al.* (2011) reported better performance from laminated veneer lumber (LVL) manufactured from oil palm trunk using a cold setting adhesive, namely polyvinyl acetate (PVAc) and emulsion polymeric isocyanate (EPI). The utilization of PVAc and EPI, with and without toluene, on palm trunk LVL could be regarded as better in terms of thickness swelling and water absorption, such as those used in rubberwood LVL. However, palm trunk LVL is suitable for indoor purposes and dry conditions. Thus, the effect of thermoplastic resin impregnation, *e.g.*, with acrylonitrile butadiene styrene (ABS), should be investigated regarding the physical, chemical, and mechanical properties of palm trunk plywood. These studies will enhance the production of high quality palm trunk plywood as well as prompt the replacement of formaldehyde-based resins.

Table 2. Physical and Mechanical Properties of Palm Trunk Veneer

Reference	Resin treatment	Adhesive	Spread levels (g/m^2)	Physical Properties				Mechanical Properties			
				Density (g/cm^3)	Water absorption (%)	Thickness swelling (%)	Moisture Content (%)	MOR (MPa)	MOE (MPa)	Shear strength (Mpa)	Wood failure (%)
(Ab. Wahab *et al*. 2012)	40.4% PF	PF	220	0.45	-	-	-	-	-	1.1 (Dry test)	97
										0.6 (WBP test)	90
	49.7% MMwPF			0.64	-	-	-	-	-	2.0 (Dry test)	91
										1.3 (WBP test)	76
	41% LMwPF			0.63	-	-	-	-	-	1.8 (Dry test)	80
										1.0 (WBP test)	23
(Hoong *et al*. 2013)	40% PF	PF	300	0.516	-	-	-	30.3	3213	1.25 (Dry test)	100
										0.65 (WBP test)	100
	15% LMwPF			0.496	-	-	-	16.7	4952	0.38(Dry test)	10
										Delamination	0
	23% LMwPF			0.555	-	-	-	39.3	5612	0.75 (Dry test)	10
										Delamination	0
	32% LMwPF			0.557	-	-	-	48.2	6509	1.38 (Dry test)	50
										1.15 (WBP test)	20
	40% LMwPF			0.574	-	-	-	56.1	6364	1.51 (Dry test)	40
										1.20 (WBP test)	30
(Loh *et al*. 2011)	Untreated (outer layer)	Commer-cial UF (42.5% solid)	200	0.367	-	-	-	35.4	5435	1.084	-
	Untreated (inner layer)			0.315	-	-	-	27.0	2922	0.923	-
	15.9% LMwPF (outer layer)			0.565	-	-	-	72.3	8473	2.613	-
	19% LMwPF (inner layer)			0.393	-	-	-	39.7	4061	1.503	-
(Abdul Khalil *et al*. 2010)	Untreated	UF	300	0.6340	80.2384	20.1182	-	24.9	2190	1.24 (Interior test)	-
	Untreated	PF		0.6816	56.4502	10.6830	-	29.7	2368	1.40 (WBP test)	-
	Untreated	UF	500	0.5868	67.2277	16.7817	-	28.8	2240	2.14 (Interior test)	-
	Untreated	PF		0.6610	55.2346	10.1478	-	32.9	2723	1.76 (WBP test)	-

0

(Feng *et al*. 2011)	Untreated	UF	250	-	-	-	-	31.5	4264	0.61	91
	Untreated		300	-	-	-	-	22.4	2750	0.56	95
	Untreated		350	-	-	-	-	22.7	2879	0.61	90
	Untreated		400	-	-	-	-	34.0	4684	0.69	94
(Hashim *et al.* 2011)	Untreated	EPI (without toluene)	250	0.55	-	-	7.3	-	-	2.99 (Without pre-treatment)	99
										1.23 (Interior test)	70
										1.29 (WBP test)	70
										1.15 (CBR test)	69
	Untreated	EPI (with toluene)		0.52	-	-	8.4	-	-	2.28 (Without pre-treatment)	98
										1.59 (Interior test)	72
										1.99 (WBP test)	80
										1.24 (CBR test)	70
	Untreated	PVAc		0.55	-	-	8.1	-	-	4.80 (Without pre-treatment)	90
										1.92 (Interior test)	75
										2.16 (WBP test)	80
										1.63 (CBR test)	70
	Untreated	EPI (without toluene)	500	0.57	-	-	7.9	-	-	4.08 (Without pre-treatment)	100
										1.57 (Interior test)	70
										1.63 (WBP test)	60
										0.75 (CBR test)	30
	Untreated	EPI (with toluene)		0.53	-	-	7.5	-	-	3.27 (Without pre-treatment)	100
										1.77(Interior test)	60
										1.88 (WBP test)	70
										1.41 (CBR test)	70
	Untreated	PVAc		0.59	-	-	8.3	-	-	4.99 (Without pre-treatment)	96
										1.55 (Interior test)	50
										1.10 (WBP test)	60
										0.97 (CBR test)	60

CONCLUSIONS

1. Due to the abundance of oil palm waste in Malaysia, OPT is the best alternative raw material for plywood to reduce deforestation and environmental problems. In addition, the waste can be converted to a valuable product.
2. Because plywood is the second largest timber export item in Malaysia, palm trunk plywood can be promoted as an environmentally friendly and green product for the export market.
3. OPT is not truly a woody material because it does not have cambium. Instead, it is mostly secondary xylem and consists of primary vascular bundles randomly embedded in a parenchyma ground tissue. OPT has some limitations related to its properties, such as high hygroscopicity, low dimensional stability, and poor machining.
4. Resin impregnation can improve the physical and mechanical properties of veneer palm trunk plywood. Thermoplastic impregnation is the best alternative to formaldehyde resins and their associated health concerns.
5. Thermoplastic is used to act as a “self-adhesive,” as the impregnated veneers are joined and pressed together without glue spreading. This method reduces the cost and time of making high quality plywood.

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