A Review on Quality Enhancement of Oil Palm Trunk Waste by Resin Impregnation: Future Materials

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Oil palm trunk (OPT) is a solid waste obtained in large quantities after the felling of oil palm trees and is available year-round. Scientists and industrialists face difficulties in utilizing these solid wastes for different applications due to great variations in their physical and mechanical properties. Because OPT consists of lignocellulosic materials, its cellulosic material is utilized in the production of panel products such as particleboard, medium density fibreboard, mineral-bonded particleboard, block board, and cement board. In order to control the OPT waste, it is essential to consider its alternative utilization inside buildings as lightweight construction materials and furniture. The impregnation of different resins in wood and non-wood materials can improve the quality of the OPT, making it possible to utilize OPT as raw materials for different applications. The enhanced properties and good appearance of impregnated OPT have found use in high-grade furniture and housing materials. In order to further evaluate its potential, this review has been compiled for the detailed study of various properties, characteristics, and applications of OPT.

Keywords: Quality enhancement; Oil palm trunk; Impregnation; Characteristic of oil palm trunk

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INTRODUCTION

The distribution of oil palm is restricted to tropical regions of the world, and it is mainly cultivated in Indonesia, Malaysia, and Thailand in Southeast Asia, Nigeria in Africa, Colombia and Ecuador in South America, and Papua New Guinea in Oceania (UNEP 2011). Oil palm is produced in 42 countries worldwide, covering a land area of about 27 million acres. Recently, it was reported that the production of oil palm has nearly doubled in the last decade and in the past 20 years has become one of the world's foremost fruit crops in terms of production (Abdul Khalil *et al.* 2010a). The palm oil is one of the leading vegetable oils produced at the global level (World Bank 2010). Malaysia and Indonesia are the two major palm oil-producing countries, having the largest area of planted oil palm in the world. In Malaysia, the total area of planted oil palm increased to about 3.87 million hectares in 2004 (Abdul Khalil *et al.* 2008), and other research stated that the total area of oil palm trees in Malaysia was 4.17 million hectares in the year 2006 (Anis *et al.* 2007). The total area of planted oil palm in Malaysia increased by 3.4 percent, to 4.85 million hectares, in 2010 (Brown 2011). In 2009, the total area of oil palm plantations reached more than 8.25 million hectares in Indonesia, spread across 22 provinces (Ministry of Agriculture Republic Indonesia 2010).

The waste or by-products obtained from palm oil mills consist of oil palm shell (OPS), oil palm empty fruit bunch (EFB), pressed fruit fibre (PFF), and palm oil mill effluent (POME). The waste obtained from plantation sites consists of oil palm trunk (OPT), oil palm frond (OPF), and pruning oil palm frond (POPF) (Subayinto *et al.* 2002). Pruning fronds generated from plantation sites are mainly used in inter-row mulching (Erwinsyah *et al.* 1997). Presently, Malaysia and Indonesia are the major palm oil-producing countries and generate huge amounts of biomass waste (Sumathi *et al.* 2008). In the year 2009, it was estimated that 421 Malaysian palm oil mills produced 19.47 million tonnes of EFB, 11.9 million tonnes of mesocarp fibre, 5.85 million of palm kernel shell, 10.95 tonnes OPT to cut, and millions of tonnes of fibres from oil palm trunks and fronds (Hoong 2011). In Indonesia, the availability of oil palm mill residues, such as EFB and mesocarp fibre, depends heavily on the amount of fresh fruit bunches (FFB) that are processed. Researchers reported that oil palm EFB and oil palm trunk produced 11.75 and 15.39 million tonnes of oil palm biomass, respectively (Erwinsyah 2008; Subiyanto *et al.* 2002; Hartono 2012). Overall, OPT biomass residue has greater potential for commercial exploitation than other types of oil palm biomass residues. It is predicted that Malaysia and Indonesia will generate more than 20 million tons of oil palm trunks in the year 2012.

Oil palm biomass will become an environmental problem if no effort is made to use it. When properly used, it will solve disposal problems and create value-added products. Therefore, the oil palm industry must be prepared to take advantage of this situation and utilize the available oil palm biomass in the best possible way, to convert waste to wealth (Basiron 2007). This biomass residue can be used as an alternative material for wood-based industries (Mohamad *et al.* 2005). Research has already been conducted worldwide in order to utilize and improve the economic value of biomass residue by producing lumber, furniture, and lightweight construction (Anon 2002). Malaysia has developed medium density fibreboard (MDF) from oil palm biomass (Subiyanto *et al.* 2002). Greater awareness about oil palm biomass-based products has increased their demand on a global level (Abdullah 2004).

Thus, the present review gives an overview of the utilization of OPT, and properties enhancement of OPT, including morphological, physical, mechanical, biological, and machining properties. Due to the nature of OPT, it is necessary to know its basic properties. Therefore, this review also discusses the characterization of impregnated OPT.

Oil Palm Trunks Utilization

Oil palm trunk biomass waste is collected during replanting, when trees exceeding the economical age are felled (Yuliansyah *et al.* 2009). OPT has been used as lumber, pulp and paper-producing materials, reconstituted boards, and bio-composites. OPT has also been utilized as a cellulosic raw material in the production of panel products such as particleboard (Teck and Ong 1985), medium density fibreboard, mineral-bonded particleboard, block board (Choon *et al.* 1991), and cement board (Schwarz 1985). OPT can be converted into value-added products to generate income for industries. The proper utilization of OPT also reduces the dependency on industrial raw materials from tropical forests and reduces waste of raw materials. By utilizing waste materials, capital input and product output can be maximized through replanting programmes. In other words, it can be said that alternative resources and products from OPT will fulfill the demand for alternative energy resources and provide the opportunity for a sustainable second generation of biofuels. Research on oil palm wastes, especially OPT, is important in reducing waste management problems and as an alternative raw material for wood products. OPT can be exploited for many types of value-added products on a commercial scale, such as the manufacture of composite panel products such as medium density fibreboard (MDF), block board, laminated veneer lumber (LVL), mineral-bonded particleboard, and plywood (Sulaiman *et al.* 2008; Laemsak and Okuma 2000; Chew and Ong 1985; Ho *et al.* 1985).

However, oil palm-based plywood mills utilize only about 40% of the OPT, and the other 60% is discarded as waste due to its insufficient properties (Rafidah *et al.* 2012). Recently, a study by Loh *et al.* (2011) showed that pre-treatment of oil palm veneers with low molecular weight PF resin significantly improved the surface characteristics and density and oil palm trunk. These further processes make it possible to obtain veneer for plywood manufacturing. The outer part of OPT can be used for plywood, while the inner part of OPT, which is not strong enough to use as lumber, is discarded in large amounts. The material is highly susceptible to degradation agents due to its high moisture content (around 80%) (Rafidah *et al.* 2012). Abdul Khalil *et al.* (2010b) investigated the development of hybrid plywood by utilizing OPT and oil palm EFB. Commercial production of oil palm lumber has been shown to be viable, but its acceptance in the market is limited because of its perceived poor machining properties due to the presence of high amounts of silica and variable density (Killman and Lim 1985). Ratnasingam *et al.* (2008) reported that oil palm lumber can be successfully machined using high cutting speeds. Abdul Khalil *et al.* (2012) studied sawn lumber from oil palm trunk and they stated that impregnated OPTCL (Oil Palm Trunk Core Lumber) showed better flexural, tensile, and compression properties than dried OPT. It has been found that OPT can be used to make laminated veneer lumber (LVL), furniture, and partition walls.

On the other hand, OPT materials have a number of weaknesses, particularly in terms of their dimensional stability, strength, durability, and machining properties. It was reported by Bakar *et al*. (1998; 1999a; 1999b) that the dimensional stability of the OPT has very low values, with variations of shrinkage in the range of 9.2 to 74%; also the strength is in the class III-V, and the durability falls in class V. These results indicate that only 1/3 to 3/4 of the outside part of the bottom of the OPT has better physical and mechanical properties. So, it could be used as lightweight building as well as furniture construction materials.

MORPHOLOGICAL AND ANATOMICAL PROPERTIES OF OPT

The trunk shape in the transverse direction is normally circular, and two parts may be distinguished, *e.g.*, the main part of the trunk and the cortex with the bark (Fig. 1). The main part of the OPT in the transverse direction exhibits brownish to blackish dots that spread over the trunk. This component increases in quantity from the central point to outer part and was hypothesized to be the main component to support structural features of the trunk. Bakar *et al.* (1999, 1998), Killmann and Choon (1985), and Lim and Khoo (1986) mentioned variations of physical and mechanical properties of OPT toward the

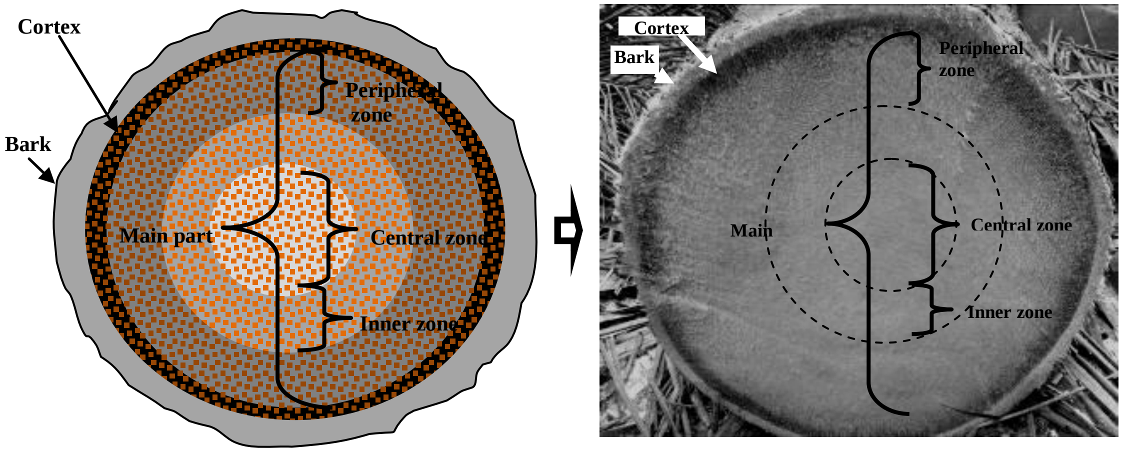

Fig. 1. (a) Schematic drawing, (b) actual end crosscut of OPT

the central point. The OPT can be divided into three different zones, *e.g.*, inner zone, central zone, and peripheral zone (Killmann and Choon 1985). Three different wood surfaces can be observed, which are cross, tangential, and radial surfaces. In green condition, the OPT's color was yellowish, but brownish in dry condition. The dried wood is very light in weight as compared to the green wood due to very high moisture content of OPT.

Oil palm trees are included in the monocotyledon class of plants. In contrast to dicotyledon plants, monocotyledons do not have a lateral meristem, so that monocotyledon growth is determined only by the apical meristem. This can be seen from the fact that the trunk diameter remains unchanged throughout the plant's life (Killmann and Choon 1985; Prayitno 1991). As a monocotyledonous species, the oil palm trunk structure is quite different compared to hardwood and softwood. Lim and Khoo (1986) reported that the distribution of fibrous strands depends on the number of bundles present. The peripheral part of OPT contains narrow layers of parenchyma and congested vascular bundles, which give rise to a sclerotic zone that provides mechanical support to the OPT.

The sclerotic zone normally consists of a large number of radially extended fibrous sheathed and vascular bundles; the strands are surrounded by silica bodies that can easily blunt a cutter knife (Lim and Gan 2005). The central zone is composed of slightly larger and widely scattered vascular bundles embedded in the thin walls of parenchymatous ground tissues.

The three main components of the wood structure are the vascular bundles, fibres, and parenchymatous cells. The number of vascular bundles decreases toward the central point or in the radial direction, and it fluctuates from the bottom to the top of the trunk (Fig. 2) (Erwinsyah 2008). The vascular bundle of OPT is surrounded by parenchymatous ground tissue, so that the woody material obtained from OPT is not comparable to the wood obtained from both dicotyledons and gymnosperms, which develop from the secondary xylem. The arrangement of OPT fibres is similar to the structure of common woods (softwood and hardwood), which are comprised of lumen, cell wall, and pits.

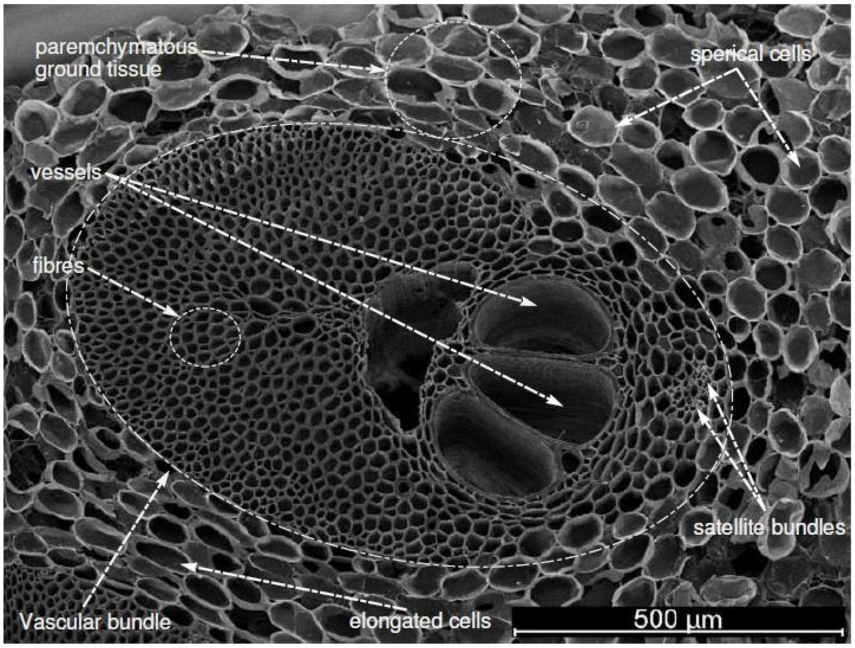

Fig. 2. The structure of the OPW (oil palm wood) in the field section of vascular bundles in the presence parenchymatous ground tissue, vessels, fibers and phloem (Source:http://www.qucosa.de/fileadmin/data/qucosa/documents/608/1211880694953-3697.pdf)

Various sizes and shapes of fibres can be distinguished in Fig. 3, *e.g.*, spherical, triangular, and rectangular (Erwinsyah 2008). The length of an oil palm fiber is shorter compared to rubberwood fiber (1.4 mm) (Shaari *et al.* 1991). Mansor and Ahmad (1990) mentioned that the oil palm trunk contains a high percentage of lignin, approximately 19%. Furthermore, studies by Erwinsyah (2008) showed that the length of oil palm trunk fibre is about 2.04 mm, with an average diameter of approximately 26.1 μm.

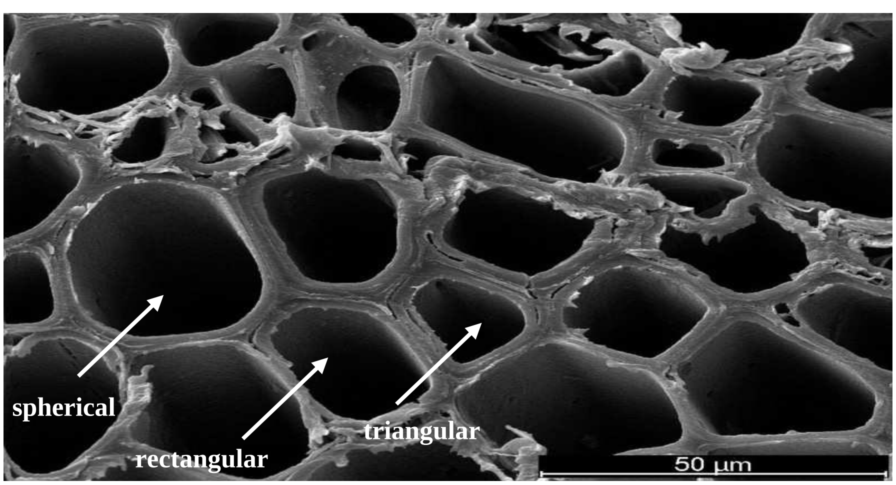

Fig. 3. The fibres vary in size and shape, *e.g.*, spherical, triangular, and rectangular (Source: http://www.qucosa.de/fileadmin/data/qucosa/documents/608/1211880694953-3697.pdf)

DRYING PROPERTIES

The variations of density and moisture content in the OPT makes it impossible to avoid drying defects (Lim and Gan 2005). OPT generally shows serious raised grain, warping, and collapse when dried. These severe drying defects were also obtained by other researchers upon drying of the OPT (Ho *et al.* 1985; Anis *et al.* 2005; Haslett 1990). This problem mostly occurred in the central region, which has low density and is virtually impossible to dry without excessive shrinkage and collapse (Fig. 4). According to Abdullah (2010), microwave drying is effective in reducing the time and in the removal of moisture. It was observed in the case of microwave drying that increasing drying time led to higher moisture removal, while oven drying did not show any significant change within the first 12 min.

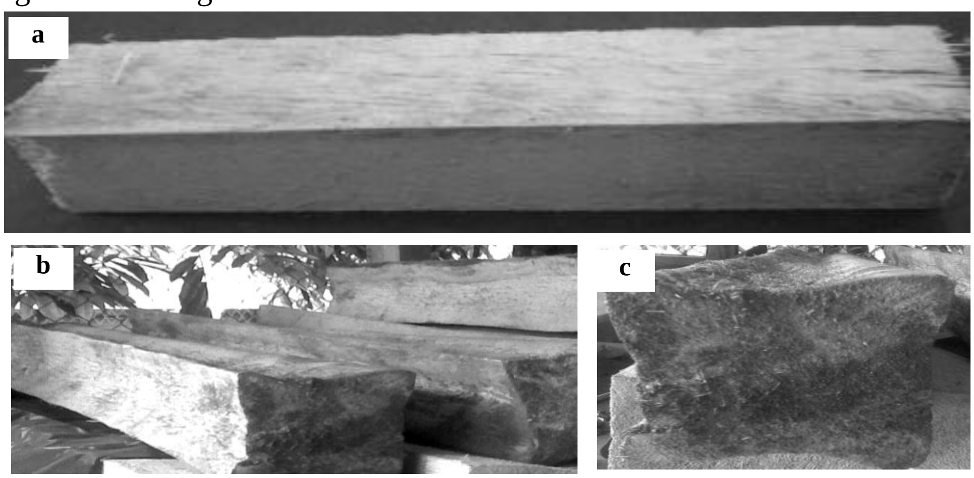

Fig. 4. OPTCL (a) fesh before drying, (b) trunk after drying, (c) shrunken surface of the trunk (original photograph)

CHRONOLOGICAL EVENTS AND APPLICATION

The impregnation of resin into wood or non-wood has been studied since the first half of the twentieth century. Based on a review of the literature, starting in 1936, researchers had already begun to use PF resins for impregnating wood (Stamm and Seborg 1936). With the development of oil palm plantations in various countries, especially Malaysia and Indonesia, the attention of researchers has turned to the study and the utilization of oil palm waste. Impregnation techniques have been carried out on OPT in order to improve the quality of the wood (Abdul Khalil *et al.* 2012). The history of impregnation of wood with resin and its related applications in various fields are shown in Table 1. On the other hand, impregnation by different chemicals, commonly known as chemical modification, considerably improved the wood or non-wood's properties. Research on the modification of wood with non-resins or chemicals was reported in the early 1950s (Stamm 1977). Early research on non-resin wood impregnation was reported by Goldstein and co-workers (Goldstein 1955; Goldstein and Dreher 1960). Goldstein's process used zinc chloride as the catalyst of choice and was applied to small sections of wood and veneers (Table 2).

Table 1. Chronological Order of Events in the Exploration of Impregnation with Various Resins and their Related Applications

Year	Event	Reference
1936	Redwood was impregnated with PF with 5.3 kg/cm^2 pressure; then it was cured for 3 days at 70 °C and 105 °C.	Stamm and Seborg (1936)
1939	Making plywood from veneer treated with a phenol formaldehyde resin-forming intermediate improved many of the properties.	Stamm and Seborg (1939)
1991	Phenol-formaldehyde resin treatment was used as a wood preservation technique to prevent biodeterioration.	Ryu *et al.* (1991)
2002	Wood was treated with thermosetting resins (UF, MF, and PF).	Deka *et al.* (2002)
2003	Melamine-formaldehyde resin was impregnated into softwood at the cellular level.	Gindl *et al.* (2003)
2004	In the impregnation process, the molecular weight of the resin was found to be very important.	Furuno *et al.* (2004)
2004	Effects of resin content, preheating temperature, pressing temperature, and pressing speed on the compressive deformation of oven-dried low molecular weight PF resin-impregnated wood were studied.	Shams and Yano (2004)
2006	Polymer impregnation improved adhesion of flattened bamboo and the resistance of polymer-impregnated bamboo to fungi.	Preechatiwong *et al.* (2006)
2006	The deformation behavior of resin-impregnated wood, up to 10 MPa, was significantly different among species. Low density wood species have an advantage as raw materials for obtaining high strength wood at low pressing pressure.	Shams *et al.* (2006)
2009	Impregnation of bamboo (*Bambusa vulgaris*) was done with polymeric resin FAA (formaldehyde, acetic acid, ethylic alcohol, and distilled water).	Júnior *et al.* (2009)
2009	The impregnated bamboo strips were pressed using a hot press at different pressing durations of 5, 8, 11, 14, and 17 min with LMWPF resin, improving the dimensional stability and strength properties of the strips.	Anwar *et al.* (2009)
2010	Impregnation of phenol formaldehyde (PF) resin into the oil palm trunk core (waste from the plywood industry) was done.	Abdul Khalil *et al.* (2010c)
2010	Kiln-dried oil palm trunk (OPT) was impregnated with phenol formaldehyde (PF) and urea formaldehyde (UF) resin using high-pressure vacuum.	Ul Haq Bhat *et al.* (2010)
2010	Impregnation with low molecular weight phenol formaldehyde (LMWPF) was done through a modified compreg method.	Way *et al.* (2010)
2010	Phenol formaldehyde (PF) resin impregnation was combined with the viscoelastic thermal compression (VTC) process.	Gabrielli and Kamke (2010)
2010	The vacuum pressure impregnation process with preservatives is the best method in treating bamboo against decaying fungi.	Adrianus *et al.* (2010)
2011	Low to high molecular weight resin of PF was shown to penetrate into $NaClO_2$-treated wood as estimated by weight gain contributing to the plasticization of the cell wall.	Shams and Yano (2011)
2011	Air-dry wood impregnated with low molecular weight phenol-formaldehyde resin mixed with urea reduced formaldehyde emissions.	Nur Izrean *et al.* (2011)
2011	Southern yellow pine was impregnated with a pyrolysis oil-based penetrant using both high pressure and vacuum impregnation systems.	Robinson *et al.* (2011)
2012	The outer part of oil palm trunk was impregnated with two resins, phenol formaldehyde and urea formaldehyde.	Abdullah *et al.* (2012)
2012	Impregnation with PF of microwave-dried core part of oil palm trunk was carried out.	Abdul Khalil *et al.* (2012)

Table 2. Chronological Order of Events in the Exploration of Impregnation with Various Chemicals and Its Related Applications

Year	Event	References
1950	Modification of wood with furfuryl alcohol	Hadi *et al.* (2005)
1955	Impregnation of wood with alkali and acids	Goldstein (1955)
1960	Wood impregnated with furfuryl alcohol	Goldstein and Dreher (1960)
1977	Furfurylated wood in small-scale production	Stamm (1977)
1989	Treating oil palm steam material with the two monomers methyl methacrylate (MMA) and glycidyl methacrylate (GMA) without further purification	Ibrahim (1989)
1994	The vacuum and pressure treatment of bamboo and rattan with monomers for the production of lignomers with improved technological properties and biological resistance	Liese (1994)
1998	Impregnated wood from Poland by styrene monomer using N-metylolmetacrilamide	Hadi *et al.* (1998)
2002	Impregnation of rubberwood using styrene as grafting monomer and glycidyl methacrylate (GMA) as cross-linker	Devi and Maji (2002)
2005	The impregnation technique performed to fill the oil palm trunk pores by a poly-blend of polypropylene/natural rubber and acrylic acid as a coupling agent	Suburian *et al.* (2005)
2005	Furfurylated wood appears to be resistant to termite attack	Hadi *et al.* (2005)
2009	The impregnation process by vacuum technique with borax, boric acid, zinc chloride, and di-ammonium phosphate on wood	Kurt and Özçifçi (2009)
2009	LVL impregnated with tanalith-C, creosot and sodium silicate	Uysal *et al.* (2009)
2009	The impregnation of rubberwood, kempas, keruing, and dark red meranti with copper naphthenate and trimethyl borate	Muhammed *et al.* (2009)
2010	The vacuum pressure impregnation process with preservative found to be the best method in treating bamboo against decaying fungi	Adrianus *et al.* (2010)
2010	Manufacture of composite materials from batai tropical wood (*Paraserianthes moluccana*) using different percentages of monomer solutions of poly vinyl alcohol (PVA) for impregnation	Islam *et al.* (2010)
2010	Impregnation chemicals on the combustion properties of 3-ply laminated veneer lumber (LVL)	Sahin Kol *et al.* (2010)
2010	The monomer N, N-dimethylacetamid to be used in the preparation of polymer-filled wood by impregnation	Hamdan *et al.* (2010)
2011	Southern yellow pine impregnated with a pyrolysis oil-based penetrant using both a high pressure and vacuum impregnation system	Robinson *et al.* (2011)
2011	Solution of NH_4NO_3 successfully impregnated into the microspores of different woodchips to formulate slow-release fertilizer (SRF) from pine, poplar, and oak	Ahmed *et al.* (2011)
2012	Impregnation with an aqueous solution of a methylated N-methylol melamine (NMM) compound of bamboo	Sint *et al.* (2012)
2012	Eucalyptus wood impregnated using methylolurea and carbomide	Wu *et al.* (2012)

The chemical modification of wood originally involved any chemical reaction between the hydroxyl groups of the principal wood components and a single chemical reagent. Devi and Maji (2002) impregnated styrene as a grafting monomer using glycidyl methacrylate (GMA) as a cross-linker into rubberwood. These modifications of wood have been studied in order to improve hygroscopic, mechanical, visco-elastic, and fire retardant properties and wood preservation techniques. Hadi *et al.* (1998) studied wood's resistance to termite attack by impregnating polystyrene and revealed that polystyrene-impregnated wood had greater resistance to termite attack. Hadi *et al.* (2005) studied the resistance of furfurylated wood to termite attack and the results indicated that a medium level of furfurylation (43% total weight increase due to furfurylation) was sufficient to prevent termite attack.

PROPERTIES OF IMPREGNATED OIL PALM TRUNK

Morphological Properties of Impregnated Oil Palm Trunk

Researchers have tried to understand the mechanisms of resin (matrix) impregnation into oil palm trunk by means of scanning electron microscopy (SEM). Previous studies revealed (using SEM) that the penetration of resin into the parenchyma can be visualized in order to gain insight into the wood structure (Abdul Khalil *et al.* 2012; Abdullah *et al.* (2012). Abdullah *et al.* (2012) reported that after impregnation and curing processes, resin was seen located in the parenchyma tissue. The parenchyma cells, which are fully covered by resin, can be seen in Fig. 5.

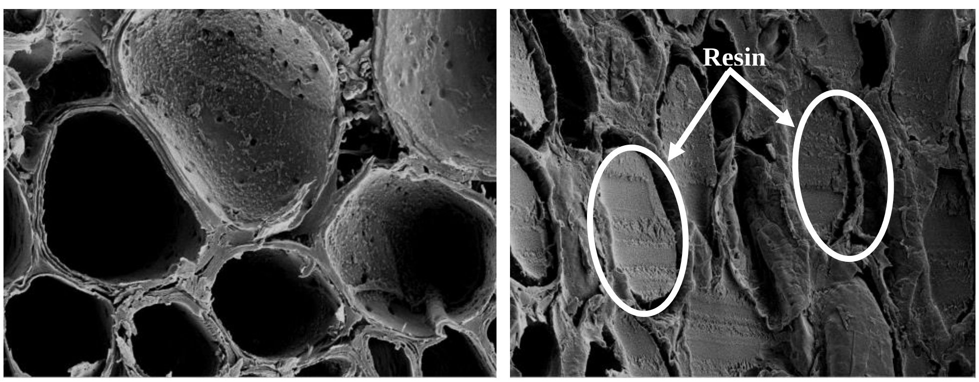

Fig. 5. Scanning electron microscopy of oil palm trunk impregnated of resin: (a) before impregnation, (b) after impregnation and curing processes (Ul Haq Bhat *et al.* 2010)

Physical Properties

Impregnation affects the most important physical properties, including the moisture content, density, and shrinkage swelling of oil palm trunk. Killmann and Choon (1985) stated that the moisture content of OPT varies between 100 and 500%. Lim and Khoo (1986) stated that moisture content increases up the height of the trunk and towards the center of the trunk. Meanwhile, Bakar *et al.* (1998) suggested that the variation in the moisture content of oil palm trunk ranged from 134.7 to 575.5%. According by Abdullah (2010), the moisture content of OPTL increased radially with the increase in the resin loading. Further, from these results, it was observed that OPTL with urea formaldehyde has lower moisture content compared with OPTL phenol formaldehyde resin. This may be due to the quality of moisture content in PF and UF resin, which contributed to the moisture content in OPTL.

The density of OPT values range from 200 to 600 kg/m^3, with an average density of 370 kg/m^3 (Lim and Khoo 1986). In another work, Bakar *et al.* (1998), who conducted an investigation based on the tenera variety of oil palm, found that the density varied between 0.11 to 0.40 g/cm^3. Erwinsyah (2008) suggested that the density of OPT ranged from 0.14 to 0.60 g/cm^3. Prayitno (1995) suggested that the oil palm trunk density has a wide variation between 0.28 and 0.75 g/cm^3. The density values gradually increase from the inner zone (center) to the peripheral zone (dominated by parenchyma tissue, thin cell wall) and in areas close to the skin (dominated by the vascular bundles, thick cell wall). The base of the trunk has the highest density, followed by the middle, and the top. The highest density value also has been recorded on the outer layer, and its value decreases towards the pith (Prayitno 1995). Bakar *et al.* (2005) state that there are two causes of differences in the density of the oil palm trunk. First, the outer part is dominated by the vascular bundles (51%) that have a high density, while the inner part is dominated by parenchyma tissue (70%) that has a low density.

In an interesting work by Abdullah *et al.* (2010) concerning oil palm trunk, they reported that the OPT density is low. The bottom part of OPT showed the highest average density, followed by middle and top parts. Ul Haq Bhat *et al.* (2010) used the outer parts of the OPT and impregnated them with PF and UF with different resin loadings (25%, 50%, and 75%) using a high-vacuum pump. The time of impregnation varied from 15 to 45 min for different resin loadings. The OPTL impregnated with PF and UF resins were cured for 2 h in an oven at 150 °C and 130 °C, respectively. From the results it is obvious that the density of OPTL was increased by the effects of the resins and the ratio of resin penetration into dried OPT. The density of OPTL with 75% PF resin loading showed the highest value. Further, Abdul Khalil *et al.* (2010c) investigated OPT impregnated with PF at different percentages (5, 10, 15, 20, and 25%) using a high-vacuum pump at 5 bar pressure at different time periods (for different matrix loading). Time of impregnation for each matrix loading was varied from 4 to 5 min. The resin-impregnated OPT cores were cured at 150 °C for 2 h. The physical properties of impregnated OPTL and OPTCL are given in Table 3.

Table 3. Physical Properties of OPTL and OPTCL Impregnated with Resin with Different Resin Loading

Sample	Resin loading (%)	Density (kg/m^3)	Water absorption (%)	Thickness swelling (%)
OPTL	PF 25	440 (50.25)	65.67 (5.66)	5.59 (1.12)
	PF 50	603 (55.24)	61.67 (5.24)	4.74 (1.33)
	PF 75	860(74.58)	54.70 (4.25)	3.65 (1.05)
	UF 25	430 (48.52)	70.49 (6.52)	6.53 (2.10)
	UF 50	600 (56.24)	63.40 (5.84)	5.10 (1.87)
	UF 75	810 (70.22)	58.10 (4.82)	4.40 (1.52)
OPTCL	PF 5	400	30.2	
	PF 10	480	28.5	
	PF 15	650	21.7	
	PF 20	580	26.2	
	PF 25	550	27.4	

Notes: OPTL = Oil palm trunk lumber; OPTCL = Oil palm trunk core lumber

Siburian *et al.* (2005) reported the impregnation of OPT using poly-blend polypropylene/natural rubber and acrylic acid. The impregnation technique was an attempt to fill the OPT pores by poly-blend polypropylene/natural rubber with acrylic acid as a coupling-agent. Dimensional stability rate and density after impregnation increased from 66.0725% and 0.56 g/cm^3 to 85.0225% and 0.862 g/cm^3. Szymonaa *et al.* (2011) reported the physical properties of OPL impregnated with 90% and 45% aqueous solutions of furfuryl alcohol (FA). The results revealed that OPL impregnation enhances the density of the modified samples. Bakar *et al.* (1998) stated that the volume shrinkage of OPT ranged from 25 to 74%. A study by Erwinsyah (2008) showed that the shrinkage in the central zone was about 19.6%, ranging from 13 to 23%, while the shrinkage value in inner and peripheral zones were about 16.7% (range 11 to 20%) and 16.8% (range 10 to 23%), respectively. A study by Ul Haq Bhat *et al.* (2010) stated that OPTL with PF resin swell up between 2 and 5% as compared to dried OPT, which swell about 10%. This result also showed that the swelling percentage of OPTL was slightly reduced after being impregnated with PF resin. Therefore, the phenolic resin has been widely used to treat the OPT to increase the dimensional stability (Ratanawilai *et al*. 2006).

Mechanical Properties

The mechanical properties of wood are measures of its resistance to exterior forces which tend to deform its mass. Strength is one of the primary criteria for selection of the material for structural applications. Bakar *et al*. (1999) reported that mechanical properties of oil palm trunk decrease close to the center of the base and top of the trunk because the influence of the depth (the diameter) is greater than the effect of altitude. In the horizontal section, all the mechanical properties decreased sharply from the edge to the center and sloping down from the center to the center trunk due to differences in specific gravity and density of vascular bundles in each section. Compared with wood, the MOE, MOR, compressive strength, shearing strength, and hardness of oil palm trunk's sliding exterior is almost equivalent to the strength of sengon wood (*Paraserianthes falcataria*), which puts it into strength class IV-V (Bakar *et al.* 1999). Rubberwood and coconut wood displayed better hardness properties than OPT. The impregnation was carried out in optimum conditions at a pressure of 1 kg/cm^2, impregnation duration of 15 min, and a poly-blend concentration of 10% (b/v).

Erwinsyah (2008) investigated impregnation of bioresin in OPT by two different treatments, *viz.*, bioresin heat and bioresin chemical techniques. The specimens were treated with bioresin at 180 °C and various impregnation times, *e.g.*, 150 and 300 seconds, and bioresin soluble in acetone at various concentrations (10 and 20%) and impregnation times (24 and 48 h). The treatment of OPT with bioresin using the heat technique displayed better mechanical strength than the untreated wood and the wood treated using the chemical technique. For example, the bending strength of heat-treated OPT in the inner zone was 20% higher than the untreated wood. The bioresin reinforcement experiments revealed that the proper technique for bioresin reinforcement is using heat rather than chemicals (acetone). The optimum conditions for the process were achieved with an impregnation time of 150 seconds and a process temperature of 180 °C. Ul Haq Bhat *et al.* (2010) reported that the flexural strength of OPTL impregnated with PF and UF resin increased after being treated by different resin loading percentages. The OPTL with 50% PF resin loading showed the highest flexural strength among OPTL. This is because polymerization of the PF resin and proper fiber-resin bonding was completed during the curing process. Meanwhile, the excess resin in 75% resin loading probably cured and led to the decrease of strength in OPTL, making it more brittle. The flexural modulus of OPTL increased as the PF resin loading increased, until 50%, and then slightly decreased at 75% resin loading. The OPTL with high resin contents were unable to withstand greater loads, displaying that the flexural modulus of the composites had decreased. The flexural modulus of OPTL with UF resin was comparable to OPTL with PF resin. After the resin loading exceeded 50% of OPTL, there was a considerable decrease in impact strength. The decrease in the impact strength of OPTL with 75% resin loading was related to matrix fracture. The impact strength of OPTL with PF resin was higher than OPTL with UF resin. This is because PF resin is associated more with proper interfacial adhesion between the OPTL and matrix. Moreover, the PF resin acts as a better stress-transferring medium than the UF resin in OPTL.

Abdul Khalil *et al.* (2010c) reported that tensile strength and flexural strength increased with an increase in the resin content, up to 15%, but the properties decreased with an increase in resin loading beyond 15%. Hartono *et al.* (2010) also conducted research using the inner part of OPT. Samples of the inner part of OPT were treated by 2% aqueous solution of $NaClO_2$ at 45 ^oC for 12 h, and then were immersed in aqueous solution PF using vacuum 1 MPa for 1, 6, and 12 h. The result showed that the average density of OPTS impregnated for a variety of times and concentrations of PF ranged from 0.56 to 0.82 g/cm^3, or an increase of 100 to 164%. The highest density was generated from the vacuum treatment time of 12 h and the concentration of 20% (0.82 g/cm^3). The mechanical properties are shown in Table 4.

Table 4. MOR and MOE of Impregnated OPT

Impregnation time	Concentration PF	MOR (MPa)	MOE (MPa)
1 hour	0	44.7	3004
	5	52.2	4036
	10	53.5	4196
	20	73.3	6255
6 hours	0	37.1	2544
	5	60.3	4666
	10	61.9	5289
	20	79.9	6482
12 hours	0	43.1	3087
	5	59.2	4942
	10	61.1	4947
	20	118.6	8623

Source: Hartono *et al.* (2010)

Machining Properties

Ho *et al.* (1985) mentioned that lumber from oil palm trunk does not have good machining properties. Further, Haslett (1990) stated that the main defects of oil palm lumber after the drying process are cupping, twisting, collapse, and checks (splits) between vascular bundles and parenchymatous tissue. Another study was reported by Way *et al.* (2010) on the machining properties of impregnated OPT by low molecular weight phenol formaldehyde resin (LMW-PF). The impregnated OPT were dried first with an oven set at 65 °C for 24 h, followed by microwave heating for another 8 to 10 min until a MC of 40% was reached. The impregnated OPT were subjected to hot-pressing densification to the pre-determined thickness of 2 cm at a temperature of 150 °C for 45 min. The treated OPT had much better planing quality (95% defect-free area) than the untreated OPT (0.5% defect-free area). The defect-free area of the treated OPT was just slightly lower than that of rubberwood (98.9%). The improvement in machining quality of the treated OPT, with a defective area of only 13.87%, made up of torn grain (4.03%), raised grain (9.17%), and very little fuzzy grain (0.67%), qualifies it to be grade 1 (excellent). The parenchyma tissue of treated OPT, due to resin penetration, became more compact and denser, which made them able to be cut cleanly by the knives in the cutter head without dusting. Furthermore, Sumardi (2000) reported that impregnation of oil palm with phenol formaldehyde using the resin loading 20, 30, and 40%, and pressure of 10 kg/cm^2 for 30, 60, and 90 min, respectively. The treated OPT's planing quality increased from grade 5 (untreated), to grade 3 (for resin loading 20 and 30%), and grade 2 (resin loading 40%).

Biological Properties

Decay and insect attack can weaken the performance of oil palm trunk and panel products. Chemical treatments can enhance the resistance of wood and non-wood materials. According to Wong *et al.* (1990), OPT impregnated by aqueous (28%) ammonia for 24 h at a reduced pressure of 10 mm Hg, then immediately densified by cold-pressing at 400 N/mm^2 for 10 min to a final lateral thickness of 17.5 mm showed significantly increased general decay resistance. Furthermore, an 85% increase in density was accompanied by a 50% increase in resistance against white rot (*Coriolus versicolor*) and a 73% increase against brown rot (*Gloeophyllum trabeum*) fungi. The fungal resistance of both control and densified specimens were consistently better against *G. trabeum* than *C. versicolor*.

The impregnated OPT showed a high resistance against dry wood termites. The PF and UF resins played an important role in the decay-termite test. The PF and UF resins acted as preservatives in the OPT. After being impregnated, the percentage of decay from dried OPT decreased significantly (by 40%). After 8 weeks of exposing the samples to termites, it was observed that all termites in the control survived until the end of the experiment, while the termites in resin-impregnated OPT only survived for 6 weeks. Bakar *et al.* (2008) found that PF is not toxic to the termites; rather the termites were dying because of undigested OPTL. Therefore, the OPTL indicated a high termite-decay resistance compared with dried untreated OPT and rubberwood. The highest resin loading (75%) exhibited the best resistance against termite decay, comparable to commercial preservatives (Ul Haq Bhat *et al.* 2010).

IMPREGNATION OF OIL PALM LUMBER FOR VARIOUS APPLICATIONS

In order to use procedures which may ultimately lead to the production of zero waste from OPT, it is important to employ alternative measures and methods of OPT utilization (filling materials) for applications inside buildings, such as lightweight materials and furniture. One of the most commonly used methods is impregnation. Based on recent literature, the use of phenol formaldehyde resin (PF) or non-resin (chemical) for impregnation improves the quality of the OPT. This treatment significantly improves properties, appearance, and can thus be used for high-grade furniture and housing materials (Bakar *et al.* 2005, 2007). Impregnation of PF into the OPT enhances dimensional stability (Ohmae *et al.* 2002; Rowell 2005; Furuno *et al.* 2004). Recently, Abdul Khalil *et al.* (2010c) revealed that PF-impregnated oil palm trunk core lumber (OPTCL) displayed good mechanical and physical properties compared with untreated OPTCL and rubber wood. Bhat *et al.* (2010) reported that OPTCL impregnated with PF and urea formaldehyde (UF) resin using high-pressure vacuum exhibited better physical and mechanical properties. Way *et al.* (2010) stated that impregnation of oil palm trunk with low molecular weight PF caused the material to become more readily machined, and the planing quality improved from grade 3 (average) to grade 1 (excellent). Ul Haq Bhat *et al.* (2010) reported that OPTL with PF resin had improved dimensional stability, increased density, and enhanced mechanical properties. Further studies by Abdul Khalil *et al.* (2010c) showed that the impregnation of OPTCL with phenol formaldehyde (PF) resin enhanced the mechanical properties. Noorbaini (2009) reported that oil palm trunk laminated veneer (OPT LV) bonded with EPI-VAc and PVAc adhesives display lower percentage of thickness swelling and water absorption as compared to OPTL. The physical and mechanical properties decreased after being exposed to cold, hot, and cyclic treatments.

The utilization of oil palm trunks was established on the belief that there is a critical need for finding alternative wood materials for consumption without global forest loss and climate change. There are a number of limitations in the use of OPL, particularly in terms of dimensional stability, strength, and durability. According to Kurt and Özçifçi (2009), when the surfaces are coated by varnish, the Brinell hardness decrease, and unimpregnated lumber results in a higher Brinell hardness value. The impregnation of oil palm lumber using a variety of fillers (resin and non-resin) is the most versatile material for building, light construction, furniture, and other uses (Fig. 6).

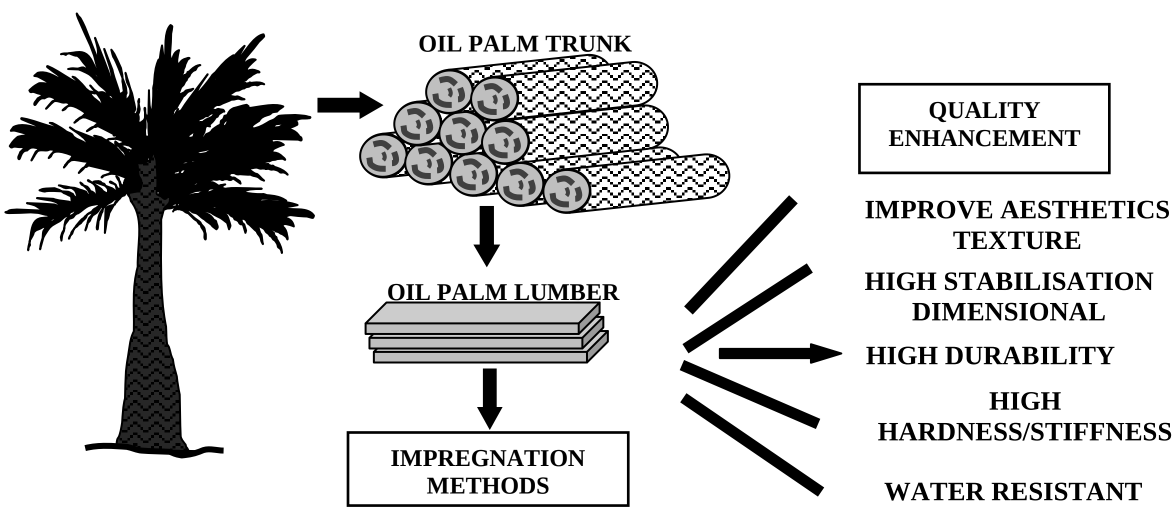

Fig. 6. Producing high quality products from low quality raw material

Wood modification, as described above, increases the quality, *e.g.*, aesthetic texture, dimensional stability, resistance to termite attack, water resistance, hardness, stiffness, *etc.* (Deka *et al.* 2002). Additionally, a study by Abdul Khalil *et al.* (2010c) reported that the use of modified oil palm trunk core as reinforcement in matrix improved the mechanical, physical, chemical resistant, aesthetic, and decay properties, compared with ordinary wooden lumber. Impregnated oil palm lumber has also been used to slow the UV degradation of the surface. Moreover, the treatment of wood by the compreg method using low molecular weight of phenol formaldehyde (PF) has been studied to obtain better wood characteristics (Shams *et al.* 2004).

CONCLUSIONS

1. Impregnation is the introduction of chemicals or fillers (bulking agent) into wood, using either pressure or non-pressure techniques. Almost all resins can be used as filler material. The best bulking agent among commercial synthetic resins is phenol formaldehyde (PF), which can be described as a water-soluble, thermoset resin having a low molecular weight.
2. Impregnation is effective in the treatment of wood with a thickness of no more than about 8 cm. Phenol formaldehyde resin impregnation can penetrate the cell wall and replace the water in the wood.
3. In impregnated wood, resin is polymerized and matured by heat to form a water-insoluble material in the wood structure, due to the bulking effect from resin or non-resin. Impregnated wood changes to a red-brown color after resin treatment.
4. The impregnation of wood depends on the molecular weight of the substance; low molecular weight resin penetrates easily into the cell walls, and high molecular weight resin only fills the cell lumina.
5. The impregnation fixation occurs through two mechanisms: monomer impregnation (subsequent polymerization within the cell wall) and diffusion of a soluble material into the cell wall (immobile). The stabilization mechanism is that resin is present in the cell wall so that the extent of cell wall swelling is reduced. The shrinkage cross-linking reaction occurs between resin and wood.

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