Treatment of Oil Palm Wood with Low-Molecular Weight Phenol Formaldehyde Resin and Its Planing Characteristics

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Abstract

In line with the Malaysian government calls to turn waste into wealth, oil palm wood (OPW) is establishing itself as a potential wood substitute. However, the OPW on its own has four imperfections, i.e.: low strength, low durability, poor dimensional stability, and poor machining characteristics. Previous studies have shown that the first three imperfections were able to be solved by impregnating with low molecular weight phenol formaldehyde (Lmw-PF) through modified compreg method. But, the machining behaviour of OPW remains uncovered. A planing test was carried out to evaluate the machining characteristics of the treated OPW. For comparison purpose, another set of test for the rubberwood and untreated OPW samples were also conducted. It is acknowledged that the planing quality of the treated OPW is of equal grade to that of rubberwood. In general, the planing of the treated OPW and the rubberwood fell into the Grade I (very good), compared to Grade III (average) for untreated OPW. The treatment significantly improves the machining characteristics of OPW, adding significant improvements on the physico-mechanical properties, durability, and appearance that have been proven in the previous studies, which make it can be used as a new, high-grade alternative for solid wood material.

Key words: Oil palm wood, low-molecular weight PF, modified compreg method, planing, high-grade material.

Introduction

Since early 1970s, plantation of oil palms have increased tremendously in Malaysia and Indonesia, the two largest producer countries, with a combined area share to about 85% of the global oil palm plantation areas. In Malaysia alone, the planted area have reached a total of 4.49 million hectares in 2008, which is capable of producing 17.73 million tons of palm oil and 2.13 tons of palm kernel oil annually (MPOB 2009). Oil palms are usually replanted again once they reach a mature age of 20~25 years as they are no longer considered commercially productive (Ismail and Mamat 2002). There are three main types of residues from an oil palm plantation, i.e. fronds, empty fruit bunches and trunks. The first two residues are produced throughout the year, whilst the trunks are produced during replanting season (Bakar *et al*. 2008). So far, all of these residues are still underutilized. The oil palm trunks (OPT), being the biggest residues among the three with an average production of 15 million cubic meters per annum (Kamaruddin *et al*. 2007), are considered as a liability as they are not only too expensive to dispose, but also disturb the replanting activities and may attract pests and diseases attact against the new seedling if they are not properly disposed. Therefore, in order to turn this liability into asset and transform the wastes into wealth, it is logical to utilize this underutilized lignocellulosic material as an alternative material for sawn timber.

Many efforts have been done to utilize the wood from the matured OPT (henceforth oil palm wood, OPW). Previous studies revealed that only the outer parts of the matured OPT can be used as solid wood, i.e. one-third of the most outer radius of the lower portions of the trunk (Bakar *et al*. 2000; Ratanawilai *et al*. 2006). Those parts of trunk actually produce the best quality OPW. However, solid OPW has four imperfections, i.e. very low in strength, very bad in dimensional stability, very bad in durability, and very poor in machining characteristic. A comprehensive treatment must be done to solve these problems. The treatment with modified compreg method is proven to be effective in solving the first three imperfections (Bakar *et al*. 2008), but OPW machining characteristic is yet understood.

As solid wood, the machining characteristic of a material is very important, especially when it will be used for furniture manufacturing. In fact, one of the recommended applications of the treated OPW is for furniture. Therefore, the machining characteristics of the material should be examined (Bakar *et al*. 2000). The objective of this study is to probe the machining characteristic of treated OPW in term of planing.

Materials and Methods

Materials Preparation

Numbers of matured (28-year old) oil palm trees from Taman Pertanian Universiti, UPM were selected as raw material. The bottom parts of trunks were cut short into two 2-meter length logs and the logs were sawn into 5-cm thick OPW lumbers. In order to have the best, homogeneous, tangential outer lumber, a polygon sawing (Figure 1) was employed to saw the logs as described by Bakar *et al*. (2006). Only selected outer OPW lumbers having relatively same density (410~450 kg/m^3) were used for this study. The lumbers were cut into common sizes (4cm x 12cm x 100cm for the thickness, width, and length respectively) before proceeding to the following treatment process.

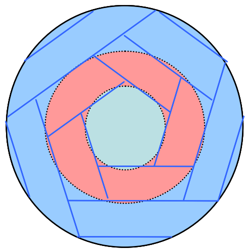

Figure 1. Polygon sawing pattern to saw OPT for best tangential outer lumber (Bakar *et al*. 2006).

Methods

A modified Compreg method was adopted for the treatment which consisted of four step processes: drying, resin impregnation, heating for resin semi-curing, and hot-pressing densification (Bakar *et al*. 2005). Firstly, the lumber were kiln dried to about 15% MC before being impregnated with low-molecular weight Phenol Formaldehyde resin (Lmw-PF) in an impregnation cylinder. The resin was diluted with distilled water to a solid content of 15% and impregnation was carried out at a tank pressure of 120 psi for 45 minute. The impregnated samples were then taken out from the cylinder and placed in standing rows for a few hours to drain out the excess resin before being partially re-dried and heated with an industrial oven and microwave. The objective of this re-drying or heating is to get the impregnated resin becomes semi-cured and bulks the OPW structure. For that purposes, the impregnated samples were re-dried first with the oven set at 65°C for 24 hours and followed by the microwave heating (6 magnetron force) for another 8~10 minutes until a targeted MC of 40% is reached. Finally, the samples were subjected to hot-pressing densification to the pre-determined thickness of 2cm at the temperature of 150ºC for 45 minutes.

Three set of samples (the treated OPW, untreated OPWs and rubberwood), each with 30 replications, were prepared and cut into a common sizes of 2cm x 10cm x 100cm, for the planing test. The test procedures were based on a modified ASTM D1666-87 standard. Due to the limitation of material, the number of replications for test samples was reduced from 50 samples to 30 samples for each treatment.

The planing tests were carried out with a standard single-faced planing machine (Sanjui SA16) equipped with 40cm long cutterhead, having 4 blades on it. The rotational speed of the cutterhead was 5500 rpm. Two 2.0-mm depth planings were made for each sample with a standard feed rate of 18 m/minute, giving a 0.8-mm knife mark interval. The first planing was excluded, and only the second planing was taken for observation to ensure that all the samples are same in condition. New blades were used for this test, and they were always kept sharp. In addition, to minimize the gradual dulling effect of the blades, the samples among the three material types were machined in a random order.

The surface qualities of individual samples were carefully examined based on the ASTM D1666-87 standard. The surface qualities were classified into five grades (Grade 1 = excellent; Grade 2 = good; Grade 3 = fair; Grade 4 = poor; Grade 5 = very poor) based on coverage and type of defects present on the surface as given in the standard (Abdurrachman *et al*. 1982). The defects that were observed were fuzzy grain, raised grain, and torn grain. The roughness of the machined surfaces was also examined with a surface roughness measuring machine as according ISO 4288. The values of surface roughness (R_a, R_{max}) give more quantitative information on how good or how bad is the surface quality on each machined material.

Results and Discussion

Defective Area

The results from the planing test on the three different test materials are summarized in Table 1. Proportion of defects for each material is obvious. The treated OPW has much better planing quality (95% defect free area) than the untreated OPW (0.5% defect free area). The defect free area of the treated OPW is just slightly lower to that of rubberwood (98.9%). The raised grain and torn grain were the main defects observed in both types OPW, but with different proportion. Fuzzy grains were also observed but to a much lesser extent. The three types defect, however, are distributed equally in the rubberwood, but at a very little extent.

Table 1. Planing performance of treated OPW, untreated OPW and rubberwood.

Defect types	Treated OPW	Untreated OPW	Rubber wood
Defect free area, %	86.13	41.66	91.8
Defective area, %	13.87	58.34	8.20
- Torn Grain, %	4.03	10.00	2.40
- Fuzzy Grain, %	0.67	4.67	5.80
- Raised Grain, %	9.17	43.67	0.00

Untreated OPW experienced very severe defects with more than half of it machined surfaces (58.34%) were covered with defects which consisted of raised grains (43.67%), torn grains (10.00%), and fuzzy grains (4.67%). Based on Abdurrachman criteria (1982), which classify the grade of the machined surface based on the percentage of defective areas, the planing of the untreated OPW falls into Grade 3 or average. Figure 2 shows the defect proportions and grade of planing of the untreated OPW and other two type materials.

The reasons for untreated OPW's poor planing have been reported by Bakar *et al*. (2005; 2008). OPW consists of two main structures, i.e. vascular bundles embedded in soft parenchyma tissues (Tomlinson 1961). The densities of vascular bundles greatly differ to those of parenchyma tissues with a difference up to a factor 3. This extreme density differences, between the two OPW structures, are considered as the main reason for the very bad OPW planing. When knives on cutterhead try to cut the denser, stronger vascular bundles, it cannot be properly cut but are deflected down the cutting plane due to insufficient support by the parenchyma tissues beneath. After the knives passing, the vascular bundles rose up, resulting raised grains. When the cutting continue, due to the cumulative deflections, the vascular bundles are then cut in a deeper cut and that, along with the existence of irregular slope grain (leaf-traces), causing the bundles to be torn out by the knives rotation and produce torn grains. The phenomena of raised grains and torn grains can be clearly observed from the machined surface as shown in Figure 3, and the existence of irregular slope grains or leaf traces can be observed from the workpiece edge as shown in Figure 4.

The treated OPW on the other hand shows a huge improvement in its machining quality with defective area of only 13.87% that made of torn grain (4.03%), raised grain (9.17%), and very little fuzzy grain (0.67%). With this amount of defective areas, the treated OPW fall into Grade 1 (excellent) according to Abdurrachman criteria (1982). Figure 5 shows the planing surface of the treated OPW with very fine surface finish.

Bakar *et al*. (2005) mentioned that reduction in density gradient between the vascular bundles and the parenchyma tissue as the main reason to the significant improvement on the planing quality of the treated OPW. Impregnation treatment of OPW with Lmw-PF followed by hot-pressing densification greatly increased the density of parenchyma tissues but not the vascular bundles. This is because the resin will penetrate more readily into thin-walled parenchyma cells than into the thick-walled cells in the vascular bundles. Therefore, the density of the parenchyma cells increased thus reduced its density differences over the vascular bundles. With this improved density, the parenchyma tissues become stronger and able to provide suffice support to the vascular bundles from deflection during planing. In addition, as the result of the densification process, the whole structure of the treated OPW become more compact and readily to be machined. Figure 5 shows the treated OPW with excellent surface finish after planing. The vascular bundles are able to adhere tightly to the parenchyma tissues, even the slope grains can be cut clear by the knife, producing very fine surface finish.

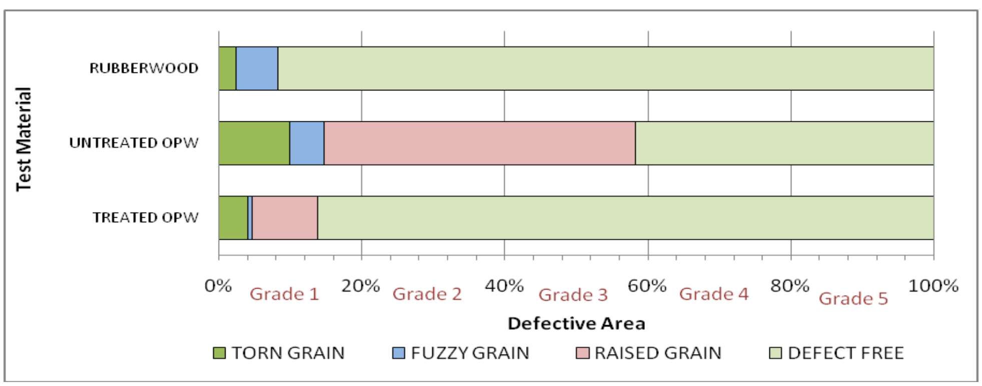

Figure 2. Types and proportions of defect on the planing of three different materials and their grade.

Figure 3. The planed surface of untreated OPW showing fuzzy grain (top), raised grain (middle) and torn grain (bottom).

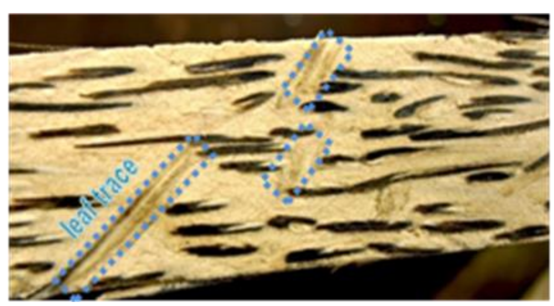

Figure 4. The slopping of vascular bundles (leaf trace) look on the workpiece edge that causes torn grains.

Figure 5. The planed surface of treated OPW showing very smooth surface.

The rubberwood as a references species fall into Grade I with 91.8% of its planed surface are defect free. This justify why rubberwood are highly sort after by the wood industry for furniture making. The defect types are mainly fuzzy grain (5.8%) and torn grain (2.4%), all with a minor extent and can be easily cleared off with a light sanding. Unlike OPW, where its "wood" are consist of primary vascular bundle embedded in parenchymatous ground tissues, rubberwood posess cambium, and its primary tissues are mostly secondary xylems which are more rigid due to the high fibre cells ratio than parenchyma tissues. This makes the rubberwood able to provide sufficient support for its surrounding tissues during the planing, resulting a better planing quality as compare to the untreated OPW.

Chips Formation

For deeper analysis, chip formations during the planing and its geometry on the three different wood samples were analyzed. These gave the first insight on the planing characteristic of each wood samples. For that purpose, the dust collector's hood was purposely removed from the machine to allow close observation on the exit chips.

Figure 6 shows that the formation of exit chip among the three types wood sample was obviously different. The exit chips were characterized with dusted particles mixed with relatively long strands at the untreated OPW. On the other hand, both dusted particles and long strands were not observed at the treated OPW and rubberwood. As expected, dust formation in the untreated OPW was due to the planing of soft, thin-walled parenchyma cells, whilst relatively long strands were resulted from the planing of vascular bundles.

As previously mentioned, OPW consisted of two main structures: i.e. high density vascular bundles embedded in soft, thin-walled parenchyma tissues. In untreated OPW, the two structures were greatly differ in its density and loosely adhered to each other. Therefore, knives in the cutterhead are unable to cut the material cleanly. Dried thin-walled parenchyma tissues were removed in broken dust-like particles (Figure 6a), whilst the vascular bundles were removed in relatively long strands (Figure 7a).

In the treated OPW however, due to resin penetration and hot-pressing densification during the treatment, parenchyma tissues become more compact and denser, which make them able to be cut cleanly by the knives in the cutterhead without dusting. The treatment also helps the parenchyma tissues and vascular bundles to reduce their density gradient and tightly adhered to each and other (Bakar *et al*. 2008). Because of that, both the parenchyma tissues and vascular bundles could be cleanly cut into small slivers as shown in Figure 7b. Similar phenomena, but with much wider slivers was observed in rubberwood planing (Figure 6c and 7c).

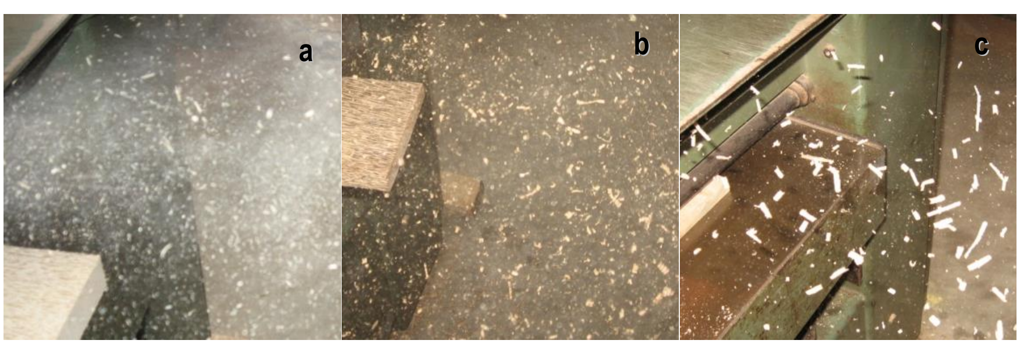

Figure 6. Comparison of exit particles in the planing of untreated OPW (a), treated OPW (b), and rubberwood (c).

Figure 7. Chip geometry of untreated OPW (a), treated OPW (b), and rubberwood (c).

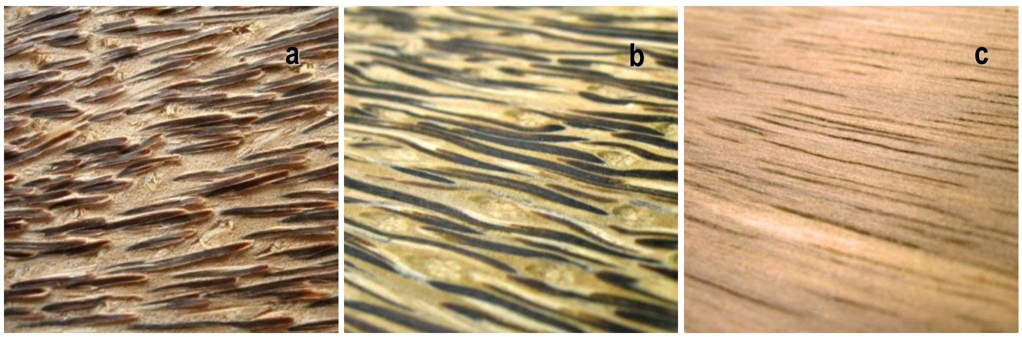

Figure 8. Comparison of planing surface finish between untreated OPW (a), treated OPW (b), and rubberwood (c).

Surface Roughness

Figure 8 shows qualitative comparison of the planing surface finish of the three type materials. The surface roughness values in Table 2 and profile in Figure 9 give more quantitative comparison on the surface finish quality among the three type materials in term of R_a and R_{max}. The R_a is arithmetic average of absolute profile wave, whilst the R_{max} is the maximum height of the profile.

Table 2. The planing surface roughness values of three different materials.

Wood material	R_a (µm)	R_{max} (µm)	R_z (µm)
Rubberwood	5.30 ^{B} (1.93)	79.33 ^{BB} (36.61)	47.16 ^{B} (18.09)
Treated OPW	8.06 ^{BB} (3.12)	77.88 ^{B} (23.14)	54.45 ^{BB} (16.62)
Untreated OPW	20.35 ^{A} (6.54)	159.28 ^{A} (41.61)	116.11 ^{A} (27.35)

*Notes:
- The mean value with the similar suffixes did not show significant differences at 0.05 confidence level.
- Values in the bracket are the standard deviation.

The rubberwood that had the least defective area (8.20%) and belong to Grade 1 had the R_a value of 5.30µm. The treated OPW that had 13.87% defective area and belong to Grade 1 had the R_a value that almost double to that of rubberwood (8.06µm). On the other hand, the untreated OPW that had 41.66% defective area and belong to Grade 3 had the Ra value about 4 times of that of rubberwood (20.35µm). This make a significant different between the treated OPW with untreated OPW, but do not between the treated OPW and rubberwood. The similar trend was also demonstrated in R_{max} but with much higher values, 79.33µm, 77.88µm and 158.28µm for rubberwood, treated OPW and untreated OPW respectively. The R_{max} value on the untreated OPW should be even greater since there had been some rejected data that had the profile height beyond the maximum range of measurable profile. Nevertheless, the profile of the planing surface in the untreated OPW shows deep-and-wide valleys (caused by knife over cuts on the parenchyma tissues) and high-and-wide peaks (caused by raised vascular bundles) which was not observed in the treated OPW and rubberwood.

In Figure 9, deep-and-narrow valleys in the profile of planing surface can be observed on both the treated OPW and rubberwood. It is consider being the vessel cell cavity. Unlike rubberwood or other hardwood species, OPW contains vessel cells inside the vascular bundle surrounded by protoxylem, protopholem and fiber (Bakar et al., 2008). According to Bakar *et al*. (2007), it is very difficult for the resin (Lmw-PF) to penetrate into vascular bundles during the treatment. Therefore, the vessels of the treated OPW would remain empty and result in the deep-and-narrow valley in the planing surface profile.

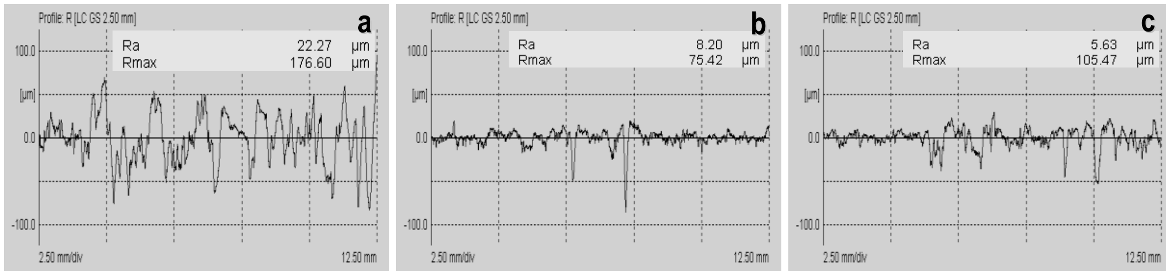

Figure 9. Comparison of planing surface profile among untreated OPW (a), treated OPW (b) and rubberwood (c).

Conclusions

From this study, it is concluded that the machining quality of treated OPW has vastly improved as compared to untreated one. After being impregnated with Lmw-PF and followed by hot-pressing densification, the material becomes more readily to be machined and the planing quality are improved from Grade 3 (average) to Grade 1 (excellent). In general, the planing quality of the treated OPW is comparable to that of rubberwood thus showing a plausible opportunity for this material to be a competitive wood substitute in furniture and flooring industry.

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