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Effects of Soaking Periods and Adhesive Concentrations on the Properties of Phenol Formaldehyde Resin Treated Oil Palm Wood

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ABSTRACT

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important and under-utilised non-wood biomass in Malaysia. This study examined the effect of low molecular weight phenol formaldehyde (Lmw-PF) resin impregnation on the mechanical and physical properties of oil palm trunk wood. The oil palm wood was treated using the following steps: by drying, resin impregnation, soaking and re-drying of specimens using different resin concentrations and treatment times. The determination of the modulus of elasticity, modulus of rupture and dimensional stability of treated oil palm wood were carried out using British standards. Results indicated that both resin concentration and soaking time significantly enhanced dimensional stability of the treated oil palm wood. Water absorption and thickness swelling of the treated wood displayed reduction with different soaking periods and resin concentrations with the best results of 7.37% and 5.08% respectively. Soaking had a significant effect on the bending properties of treated oil palm wood and showed 1.5 and 1.8 times improvement in modulus of elasticity and modulus of rupture respectively. It can be thus concluded that resin impregnation followed by soaking of oil palm wood is a viable method to improve its overall physical and mechanical properties as well as its dimensional stability.

Keywords: Durability, impregnation, oil palm wood, physical and mechanical properties, resin concentrations, soaking periods

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) was introduced to Malaysia from Africa as an ornamental plant. However, it found its way into commercial plantations and finally grew to become one of the most important commercial crops in Malaysia. Malaysia is the second largest producer and exporter of palm oil in the world, after Indonesia, with about 5.40 million hectares of planted area in 2014 (MPOB, 2014). Initially, the development of this crop was slow, but became an important crop for both countries. These vast plantations also produce huge amounts of underutilised lignocellulosic material. The average age for oil palm replanting is approximately 25-30 years. The production palm oil is only about 10% of the total biomass produced in oil palm plantations. The rest of the biomass is lignocellulosic materials, which consist of oil palm fronds (OPF), oil palm trunks (OPT) and empty fruit bunches (EFB). It is estimated that 14.4 million cubic metres of oil palm wood is produced annually due to replanting (Choo et al., 2013).

The outer portion of the trunks has better physical and mechanical properties compared with the inner portions (Choo et al., 2011; Balkis et al., 2012). However, oil palm trunk wood lacked in properties such as strength, durability, dimensional stability and machining when compared with other typical solid wood. Therefore, the treatment of oil palm wood (OPW) with a synthetic adhesive such as phenol formaldehyde would be considered as an alternative soluble to enhance the overall properties of this under-utilised species. Various studies have been carried out to improve the properties of OPW (Huang et al., 2014; Wahab et al., 2014; Zaidon et al., 2014). Impregnation and densification, similar to *compreg* (Amarullah, 2010; Chong et al., 2010; Faizatul et al., 2010; Bakar et al., 2013a, 2013b; Khairunnisha et al., 2014) were also applied to OPW to enhance its attributes.

In a typical resin impregnation process, adhesives can only penetrate into cell lumens and not cell walls. However, soaking which results in the diffusion of resin can enable the resin to penetrate into cell walls. This would further improve the overall dimensional stability and mechanical properties of OPW. Although there have been several studies carried out to evaluate properties of resin-treated OPW, there is little or no information on OPW treated with low molecular weight phenol formaldehyde (Lmw-PF) via a soaking process.

Therefore, the objective of this paper was to evaluate the mechanical properties and dimensional stability of OPW samples treated by impregnation and soaking using low molecular weight phenol formaldehyde (Lmw-PF).

MATERIALS AND METHODS

Mature oil palm trunks aged 25 years in Universiti Putra Malaysia's Agriculture Park were harvested and cut into 2 m long sections. The oil palm logs were sawed using polygon sawing method. As shown in Figure 1, the polygon sawing method was applied s to get the best homogenous

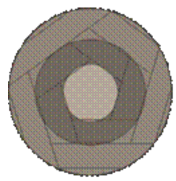


Figure 1. Polygon sawing as introduced and reported by Bakar et al., 2006

tangential lumbers from the outer parts of oil palm trunks (Bakar et al., 2006). A total of 45 samples with dimensions of 170 mm x 120 mm x 40 mm were used in this experiment.

The process consisted of five steps (Bakar et al., 2013b) - drying, resin impregnation, soaking, resin semi-curing, and curing (Figure 2). First, the lumbers were dried in a kiln at 15% moisture content (MC) and were then placed in an impregnation cylinder. Vacuum was applied for 15 minutes and the tank was then filled with Lmw-PF resin (10%, 15% and 20% concentrations) followed by an application of pressure at a level of 120 psi for 30 min. Treated samples were removed from the tank and soaked in Lmw-PF resin with concentration levels of 10% 15% and 20% for 6, 12, 18 and 24 hours respectively. Control samples did not undergo the soaking process. Next, samples were placed in an oven with a temperature of 150°C for 3 hours.

Cell wall penetration

The percentage of resin penetration into cell walls was based on the dry volume of

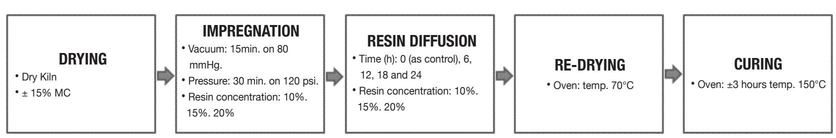


Figure 2. Five step impregnation and diffusion treatment process adapted from Bakar et al., 2013b

penetrated resin and the volume gain of treated samples. The calculation for cell wall penetration was derived from Hill (2006) as shown in Equation 1.

$$Vr = \frac{Wr}{Dr} \quad \text{[Equation 1a]}$$

$$Vg = Vf - Vi \quad \text{[Equation 1b]}$$

$$CWP = \frac{Vg}{Vr} \ x\ 100 \quad \text{[Equation 1]}$$

Where, V_r is the volume of resin (cell wall + lumen cell), W_r is the weight of resin, D_r is the density of solid resin, V_g is the volume gain (volume of resin in cell wall), V_f is the final volume (sample volume after treatment), and V_i is the initial volume (sample volume before treatment).

Water absorption (WA) and thickness swelling (TS)

The water absorption and thickness swelling of the samples with dimensions of 20 mm x 20 mm x 20 mm were calculated according to British Standard BS 373:1957

(1957). The amount of absorbed water was calculated using Equation 2.

$$Water\ absorption\ (\%) = \frac{W_f - W_i}{W_i}\ x\ 100$$
[Equation2]

where, W_f is the sample after a 24-hour immersion in water and Wi is the sample weight before immersion (g). The thickness swelling was calculated using Equation 3.

$$Thickness\ swelling\ (\%) = \frac{T_f - T_i}{T_i}\ x\ 100$$
[Equation 3]

where, T_f is the thickness of the sample after a 24 hour immersion in water and Ti is the thickness of the sample immersion (mm).

Static bending

According to British Standard BS 373:1957 (1957), sample sizes for the static bending test should be 20 mm x 20 mm x 300 mm. However, the sizes of the samples in this study were modified to 20 mm x 20 mm x 150 mm because of limitations in lengths. The Modulus of elasticity and modulus of rupture were calculated using Equations 4 and 5 respectively.

$$Modulus\ of\ Elasticity\ (MPa) = \frac{P_t L^3}{4Dbh^3}$$
[Equation4]

where, P_t is the load below the proportional limit (N), L is the span of the test specimen (mm), D is the deflection at mid-span resulting from Pt (mm), b is breadth or width of the test specimen (mm) and h is height or depth of the test specimen (mm).

$$Modulus\ of\ Ropture\ (MPa) = \frac{3P_m L^3}{2bh^3}$$
[Equation 5]

where, P_m is the maximum (breaking) load (N), L is the span of the test specimen (mm), b is breadth or width of the test specimen (mm) and h is height or depth of the test specimen (mm).

Data analysis

Data was analysed using the Statistical Analysis System (SAS) and mean separation was carried out using the Least Significant Difference (LSD) method. All statistical analysis was based on $p \leq 0.05$.

RESULTS AND DISCUSSION

Table 1 shows ANOVA for the properties of the *impreg* OPW. It can be observed that all properties were significantly affected by resin concentration and soaking period. The interaction between diffusion period and resin concentration only influenced the WA and TS.

Cell wall penetration of the samples

Figure 3 shows that almost all samples which were soaked had higher cell wall penetration (CWP) compared with samples treated with just impregnation. Soaked samples showed resin CWP ranging from 7.86% to 35.15%. The highest CWP value of 35.13% was found in samples which were soaked for 24 hours and 20% resin concentration, while the lowest corresponding value of 7.86% was obtained for samples that were not soaked and 10% resin concentration. The

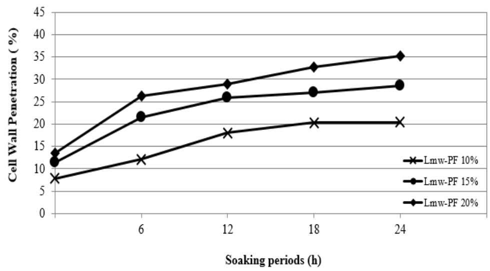


Figure 3. Cell wall penetration of *impreg* wood with different diffusion periods and different resin concentrations

CWP also increased with increased resin concentration. Irrespective of the soaking period, the mean CWP was 19.22% at 10% resin concentration and 34.49% at 20% resin concentration.

During the soaking process, resin can easily move from zones with higher concentration (in cell lumens) to zones with lower concentration (in cell walls) via diffusion (Hunt & Grant, 1967). Therefore, the additional soaking process after resin impregnation with Lmw-PF resin in this study showed that resin penetrated and bulked into cell walls.

Resin concentration also influenced resin penetration into cell walls. Figure 3 indicates that the higher the resin concentration, the higher the cell wall penetration. This could be because higher resin concentration contains more resin solids with an increased potential to allow resin penetration into cell walls.

Water absorption and thickness swelling of the samples

Table 1 shows the effect of soaking periods and resin concentrations on the water absorption (WA) and thickness swelling (TS) of OPW. It is clear that WA and TS of the samples were significantly influenced by soaking time and resin concentration. Mean WA values ranged from 7.37% to 17.41%. As can be seen in Figure 4, samples soaked for 24 hours at 20% resin concentration had the lowest WA of 7.37%, and samples that

Table 1
Summary of ANOVA for properties of Impreg OPW

Source	df	Pr> F				
					Static bending	
		CWP	WA	TS	MOE	MOR
Diffusion period	4				0.0001*	0.0001*
Resin concentration	2	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
Dif. period x resin concentration	8	0.1527^{ns}	0.0214*	0.0004*	0.1766^{ns}	0.1526^{ns}

* Significantly different at p≤0.05
ns Not significantly different at p>0.05;
df degree of freedom
CWP Cell wall penetration
WA Water absorption
TS Thickness swelling
MOE Modulus of elasticity

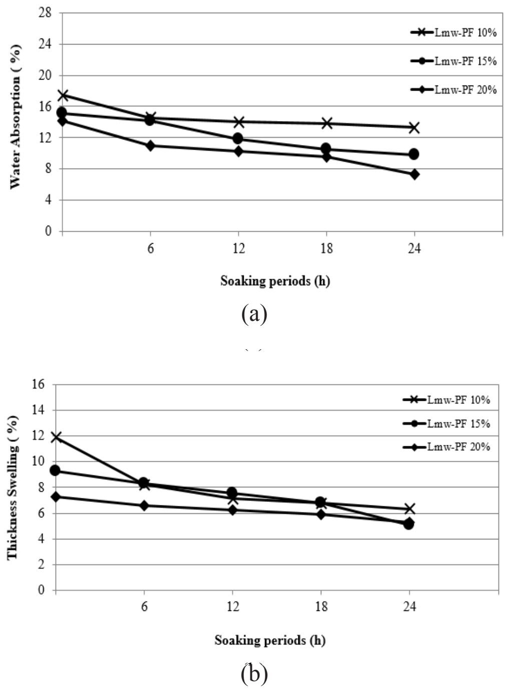


Figure 4. Dimensional stability of *impreg* OPW with different diffusion period and different resin concentration. (a) Water absorption (b)Thickness swelling

did not undergo soaking treatment at 10% resin concentration had the highest WA of 17.41%. Regardless of soaking periods, the WA was 14.64%, 12.27% and 10.48% for samples treated with 10, 15 and 20% resin concentrations respectively.

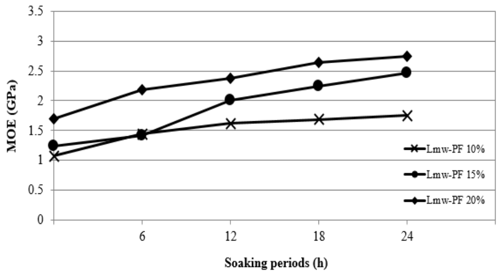
The lower WA in some samples is related to their enhanced dimensional stability. This could be due to resin replacing water in cell walls. According to several researchers (Kajita and Imamura, 1991; Furuno et al., 2004), Lmw-PF resin easily penetrates into cell walls and fully fills cell lumens and improves dimensional stability and decay resistance.

Table 1 shows that the thickness swelling (TS) of treated OPW was significantly affected by both resin concentration and soaking treatment. The mean TS values ranged from 5.08 to 11.89%. In general, the trend was similar to WA where the higher the soaking periods and resin concentrations, the lower the TS. Samples soaked for 24 hours at 15% resin concentration also had the lowest TS (5.08%) and the highest TS (11.89%) was shown by samples that were not soaked treated at 10% resin concentration (Fig. 4b). Regardless of soaking periods, samples treated using 10%, 15% and 20% resin concentration had mean TS of 8.07%, 7.39% and 6.26% respectively.

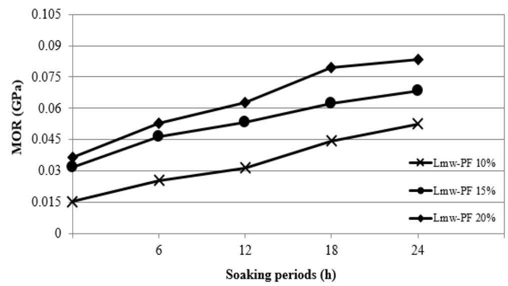
This result suggests that the additional soaking process after resin impregnation improves the dimensional stability of the material. The very low TS of treated OPW is considered as the effect of resin penetration into OPW cell walls and also cell lumens. Thus, this treatment can be used as an effective method to improve the dimensional stability of OPW. Abdullah et al. (2010) observed that increased WPG in OPW showed resistance against water absorption. The results showed that the thickness swelling of treated OPW was further reduced by the soaking treatment after impregnation leading to better dimensional stability.

Static bending of the samples

According to Figure 5, it is clear that higher resin concentrations result in higher Modulus of elasticity (MOE) and Modulus



(a)



(b)

Figure 5. Static bending values of *impreg* OPW with different diffusion periods at different resin concentrations. (a) MOE (b) MOR

of rupture (MOR) values than that of lower resin concentrations. All samples that had undergone soaking treatment also had higher MOE and MOR values compared with samples treated only with impregnation. The highest MOE value of 2.74 GPa was found for samples soaked for 24 hours with 20% resin concentration and the lowest value of 1.07 GPa was found in samples that were did not undergo soaking treatment with 10% resin concentration. The highest MOR (0.08 GPa) was at a soaking period of 24 hours with 20% resin concentration and the lowest (0.02 GPa) was found in samples that did undergo any soaking period and at 10% resin concentration. The mean MOR value was 0.03, 0.05 and 0.06 GPa for 10%, 15% and 20% resin concentration respectively.

The mean MOE and MOR values of soaked OPW was 1.5 and 1.8 times higher respectively compared with samples that were not subjected to the soaking treatment. The penetration of resin into cell walls increased the stiffness value (MOE) and the value of rupture (MOR) of soaked OPW. This is consistent with a study carried out by Bakar et al. (2013b) where MOE increased with higher resin concentrations. Deka and Saikia (2000) also discovered that MOE and MOR of treated soft-wood (*Anthocephalus cadamba* Miq.) increased due to resin that fully saturated the cell walls.

CONCLUSION

The soaking treatment of OPW with Lmw-PF improved both the physical and mechanical properties of the samples. The results of this study clearly showed that the physical and mechanical properties of OPW specimens improved with increasing diffusion periods and resin concentrations. Cell wall penetration and bending strength increased with the impregnation and diffusion process compared with samples treated only with the former (impregnation process). Higher resin concentrations were expected to fully fill cell lumens and increased penetration into cell walls due to the higher content of resin solids. Meanwhile, water absorption and thickness swelling was lower in samples that had undergone soaking treatment. Spaces that should have been filled by water molecules were occupied and bulked by resin, thus improving the dimensional stability of OPW. It can be concluded that impregnation further improves the properties of OPW specimens.

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