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Properties of Resin Impregnated Oil Palm Wood (*Elaeis Guineensis* Jack)

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ABSTRACT

Oil palm wood (OPW) was treated with medium-molecular weight PF resin (mmw-PF) through a modified impregnation-compression method. The method consists of four steps, namely, drying, impregnation, heating, and hot pressing densification. The objective of the study was to optimize the impregnation variables. The overall density of the OPW increased, whereas the density gradient between the two OPW structural elements (namely, parenchyma tissues and vascular bundles) decreased. The weight percent gain (WPG) significantly increased even with a very short impregnation period (i.e. 1 hour). Young's Modulus of the compression parallel to the grain increased by 15 times (from 170 to 2600 MPa) and the shear strength increased by 7 times (from 1.9 to 13 MPa). The strength of the samples was increased exponentially against density increment. The treatment also made the two OPW structural elements to be strongly bonded that helped in enhancing the durability and machining characteristics of the material.

Keywords: Elais guineensis, oil palm wood, wood modification, properties enhancement, impregnation-compression method

INTRODUCTION

As the second largest palm oil producing country, huge amounts of oil palm biomass (fronds, trunks, and empty fruit bunches) are produced in Malaysia annually. More than 26.2 million tons of fronds, 7.0 million tons of trunks and 23% empty fruit bunches per ton of fresh fruit bunches are resulted annually. These huge residues are becoming a major concern because they cause many problems to the planters and are expensive to be disposed off (Bakar *et al.,* 2005, 2007).

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Malaysia and many other countries in the world are now facing problems of wood supply for wood industry. Many efforts have been done to use the oil palm biomass as an alternative material for wood substitution. Oil palm fronds and EFB have successfully been used for fibre-based and particle-based products in Malaysia, and oil palm fibre has been used for paper production in Indonesia. Oil palm stems, however, are still under utilized due to some inherent problems such as instability and density variation of the material (Bakar *et al.,* 2001, 2005).

Oil palm stems are among the three types of oil palm residues that offer the best properties that are comparable to those of wood. The stems can potentially produce oil palm wood (OPW). At the replanting age of 25-30 years, they can reach an average 50 cm in diameter and 10 m in length with 120-130 trees per hectare. This is equivalent to 230-250 m^3 of stems per hectare (Bakar *et al*., 2001). Therefore, huge amounts of OPW can be produced from matured oil palm stems.

As a monocotyledon plant, the best OPW is located at the periphery of the stem, which is in contrast to hardwood logs. Due to this difference, the sawing pattern in producing lumber from oil palm stems needs to be different from that of hardwood logs. The polygon sawing, as shown in Fig.1, is the most suitable sawing pattern. With such sawing pattern, the best tangential outer lumber can be resulted at the highest yield, with a recovery of about 30-35% to the volume of log (Bakar *et al.,* 2006, 2007).

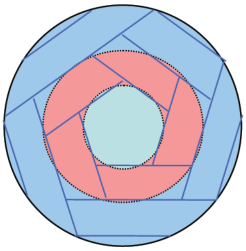

Fig.1: Polygon sawing used to saw the oil palm stem to produce the best tangential outer lumber

It was reported that OPW, even from the best outer lumber, has four main imperfections: very low in strength, very bad in dimensional stability, very low in durability, and very poor in machining characteristic. Hence, finding an effective method to modify the OPW properties has become our main concern (Bakar *et al.,* 2005, 2007).

A number of studies revealed that impregnation treatment and impregnation-and-compression treatment using Phenolic resin can improve the strength, dimensional stability and durability of wood, especially when low-molecular weight PF resins are used (Ibach, 2005; Furuno *et al.,* 2004).

Structurally, OPW consists of two main structures, namely; high-density vascular bundles scattered in thin-walled, low-density parenchyma ground tissues (Bakar *et al.,* 2008; Shirley, 2002) that amount to 70% of the total volume of the OPW (Istie, 2001). Because of that, OPW has a unique characteristic with high density gradient (between the vascular bundles and the parenchyma tissues) and low overall density. This unique characteristic is considered as the main cause to the mentioned material imperfections.

For OPW, we hypothesized that the impregnation-compression treatment is the most suitable treatment method (Bakar *et al.,* 2007). After the impregnation, the resin will penetrate more into the parenchyma tissues than the vascular bundles and reduce the density gradient between the two material structural elements. Furthermore, the compression densification will improve the structural element compactness and increase the overall density of the material. These effects are expected to not only improve the physico-mechanical properties of the material, but also the machining characteristic.

Therefore, the four-step impregnation-compression process was employed in this study (Bakar *et al.,* 2005, 2007). Fig.2 shows the diagram of the process. The objective of the study was to optimize the impregnation variables (i.e. resin concentration and impregnation period) to obtain an effective impregnation-compression treatment method for low-density OPW using mmw-PF.

MATERIALS AND METHODS

OPW outer lumbers of 50-mm thick were extracted from matured, 27-year old oil palm stems collected from University Agriculture Park of Universiti Putra Malaysia. The stems were sawn according to the Polygon sawing pattern as described by Bakar *et al.* (2006). The lumbers were dried to MC of 15 ± 1% and planed on both sides to a predetermined thickness of 40 mm. Only the lumbers with close density range (0.33 to 0.4 g/cm^3) were selected for the process. Immediately after being planed, the lumbers were cut short into samples of 40 mm x 100 mm x 100 mm for radial, tangential and longitudinal directions, respectively. The samples were impregnated under compression (120 psi) with mmw-PF under different solution concentrations and impregnating periods. The molecular weight of the resin was about 1000 (according to the supplier specification).

The density of each individual sample was recorded before the treatment. After being impregnated, the samples were re-dried or heated in an oven set at temperature of 80°C until they reached a target MC of about 50%. This re-drying stage was purposely made to make the resin become partially cured, so that the impregnated samples would not crack during the hot pressing densification, but allow the maximum resin load. Then, the samples were hot pressed at temperature of 150°C for 30 min (until which the resin is assumed

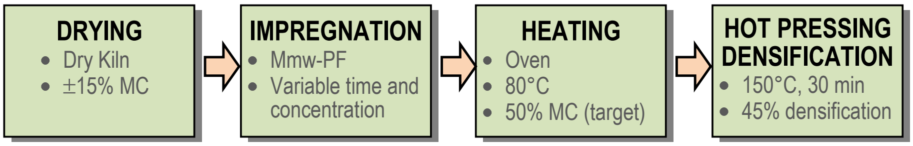

Fig.2: The four-step impregnation-compression treatment process

to be fully cured) until it reached a targeted compression level of 50%. Finally, the samples were conditioned and tested. The compression level was calculated as follows:

$$C = \frac{T_1 - T_2}{T_1} x100\%$$

Where, T_1 is the thickness before the compression and T_2 is the thickness after the compression.

RESULTS AND DISCUSSION

Density

Density is the most important parameter since it affects many other properties of material. The penetration of PF resin into the OPW structure followed by 50% compression increased the overall density of the sample from mean 0.37 g/cm^3 to 0.98-1.15 g/cm^3, which depended on the solution concentration and impregnation period. This was an increase of almost 3 times in density.

The thin-walled parenchyma tissues are more readily to absorb resin (during the impregnation stage) and experience greater level of densification (during hot pressing densification stage) than the vascular bundles. After the treatment, it can be expected that the parenchyma tissues would get greater density gain, and thus, reduce the density gradient between the parenchyma tissues and the vascular bundles. Reduction in this density gradient is expected to affect the other OPW properties to a great extent. Unfortunately, we do not have the apparatus to estimate the density of the two OPW elements for this moment.

PF resin can serve as a bulking and bonding agent in wood (Hill, 2006). These two functions were evident when the mmw-PF resin was impregnated in OPW. The bonding function of PF resin gave better compactness to the parenchyma tissues and the vascular bundles. This was expected as one reason why the treated OPW had much better machining characteristic than that of untreated OPW (Fig.3). The study on OPW planing also supports this result (Chong *et al.,* 2011).

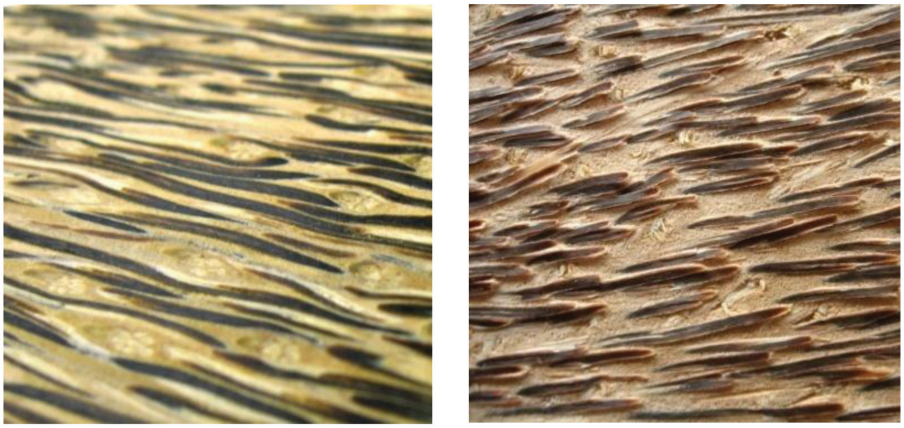

Fig.3: The planing surface of the treated OPW (left) and untreated OPW (right)

Weight Percent Gain (WPG)

The three-fold density increment in the treated OPW mentioned above was caused by two reasons: the 50% densification and the resin uptake. Densification reduced the volume of samples, whereas resin uptake increased the weight of the samples. A high resin uptake, also known as resin load, resin gain, or weight percent gain (WPG), is the main goal in every impregnation treatment of wood (Rowel, 2005). The effect of the treatment condition to WPG is discussed in this section.

The WPGs significantly increased by the increasing of the solution concentration, but they increased less significantly by the increasing of impregnation period (Fig.4). These results suggested that a WPG of 30%, a level which is considered as good enough for better OPW properties, could be obtained with a minimum impregnation period (1 hour) with liquid concentration of 15% to 20%. This is a very short period of impregnation as compared to more than one day needed for the impregnation of softwood with a low-molecular weight PF resin as reported by Furuno *et al.* (2004).

If WPG is the only parameter to consider, then the solution concentration of 20% with 1 hour impregnation period may be chosen. However, other parameters such as dimensional stability, strength and durability should also be taken into consideration. These are discussed in the following sections.

Anti Swelling Efficiency (ASE)

As mentioned earlier, the dimensional stability is one of the OPW weak points, especially when it is used in solid form (Bakar *et al.,* 2005, 2007). The Anti Swelling Efficiency (ASE) was evaluated to know the effective improvement of the treatment on dimensional stability.

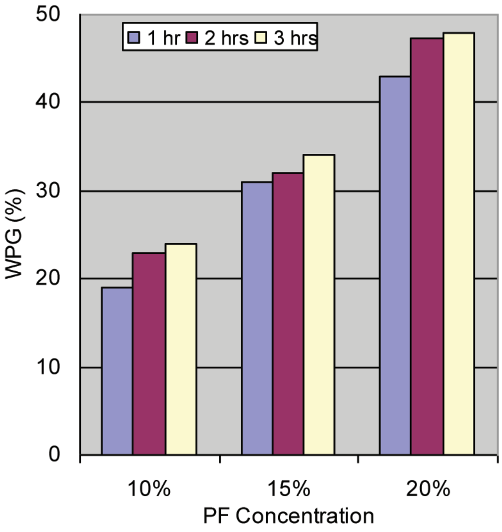

Fig.4: The relationships between PF concentrations and impregnation periods with WPG

An ASE value of 30% was attained by the treated OPW and there was no significant effect of increasing the solution concentration and impregnation period to this parameter (Fig.5). These results suggest that the impregnation with the mmw-PF resin under a concentration of 10 to 15% and an impregnation period of 1 hour were good enough to enhance the dimensional stability of OPW.

It is interesting to note that even though the PF resin used might not penetrate into the cell wall of fibre in the oil palm's vascular bundles (Bakar *et al.,* 2005), it could immediately penetrate into the parenchyma tissues as the bulking agent. This resin penetration helped not only in reducing the density gradient between the parenchyma tissues and vascular bundles, but also blocked the space and access of water that would have been occupied and penetrated by water during the water soaking test. The blocking effect of the resin seemed to be the main cause to this significant swelling reduction to the treated OPW.

The Strength

The strength is another weak point of OPW when it is used in solid form (Bakar *et al.,* 2005, 2007). Young's Modulus at the compression parallel to the grain and the shear strength were evaluated to know the effectiveness of the treatment. Both Young's Modulus and the shear strength were substantially increased. On average, the Young's Modulus increased from 170 to 2600 MPa (an increment of 15 times) and the shear strength increased from 1.9 to 13 MPa (almost 7 times of increment) after the treatment.

It is interesting to note that the Young's Modulus and the shear strength in the treated OPW were increased exponentially over the increment of density. For a better understanding, the specific strength, which is the strength value over the density of

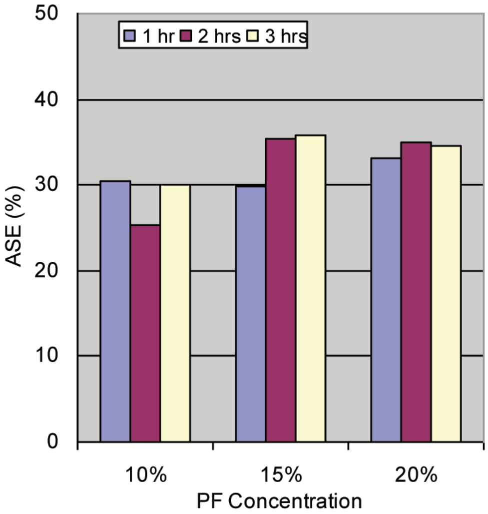

Fig.5: The relationships between PF concentrations and impregnation periods with Anti Swelling Efficiency

material, was evaluated. The specific Young's Modulus was increased by 5 times (from 459 MPa to 2500 MPa), while the specific shear strength was increased by 2.5 times (from 5.1 MPa to 12.5 MPa). Bulking and binding effects of the resin were expected to be the main reason to these exponential strength improvements.

After being impregnated with PF resin and followed by the hot-pressing densification, the whole density of OPW increased and the two material structural elements became strongly bonded. These two effects were expected to cause a significant improvement in the treated OPW strength. Even though only Young's Modulus and shear strength were tested in this study, we expected that other strength parameters were also improved to a large extent.

Durability

Another weak point of OPW is its durability, which belongs to the perishable durability class (Bakar *et al.,* 2005). The durability of the treated OPW was evaluated through a four-week block test method in accordance with the method described in ASTM D3345-93 (ASTM, 2006). The findings revealed that the mean weight loss of the samples due to the termite attack was substantially reduced from 27.9% (untreated) to only 9.6% (treated). A complete (100%) mortality of termite at the end of the test verified the validity of this test.

As mentioned earlier, OPW consists of two main structural elements, namely, vascular bundles and parenchyma tissues. The parenchyma tissues that amount to 70% of the total volume of the wood (Istie, 2001) contain high amount of starch, and thus, are lower in density and very susceptible to termite and fungal attack. However, the presence of PF resin in the treated OPW, which may be toxic to many fungi and insects, improved the durability of the material. This is in line with the finding from previous studies with both high- and low-molecular weight PF resins, that improved the durability class of OPW from perishable to durable (Bakar *et al.*, 2001, 2013).

Machining Characteristics

The other weak point of OPW is its bad machining characteristic (Bakar *et al.,* 2005, 2007). There was no observation made in this study related to this aspect. However, our previous studies revealed that the planing characteristics of OPW were improved from very bad (grade-5) to good (grade-2) (Bakar *et al.,* 2001) or from average (grade-3) to excellent (grade-1) (Chong *et al.,* 2010) after the treatment. Those two studies confirmed that the treatment could significantly improve the machining characteristics of OPW.

Overall, the treatment had substantially improved the properties of OPW, and solved all the four imperfections of the material. In addition, the treatment also gave an attractive red-brownish color to the treated OPW (Fig.3). Hence, with these properties, the material can be used as a high grade alternative material for solid wood.

CONCLUSION

It can be concluded that the four-step impregnation-and-compression process using mmw-PF resin can be used as a practical method to improve the quality of OPW. Based on the properties evaluated, the treated OPW can be proposed as a new high-grade solid wood alternative. On the sectoral aspect, this finding will help reduce the shortage of wood and the dependency of wood supply from forests, as well as solve the problematic oil palm waste disposal in the ground.

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