OIL PALM TRUNK POLYMER COMPOSITE: MORPHOLOGY, WATER ABSORPTION, AND THICKNESS SWELLING BEHAVIOURS

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In this research, impregnated oil palm trunks (OPT) and polymer composites were prepared from a combination of dried oil palm trunks with phenol formaldehyde (PF) and urea formaldehyde (UF) resin in different resin percentages using an impregnation method. Time of impregnation was a parameter used to control the percentage of resin content in the oil palm trunks. These studies investigated the effect of resin content and types of resin on the physical properties of impregnated OPT. Water absorption tests revealed that OPT polymer composite with 75% PF resin loading had increases of 21% and 26% for OPT polymer composites with 75% UF resin loading. The thickness swelling of OPT polymer composites with 75% PF resin loading exhibited the lowest value of 3.30% as compared with OPT polymer composite with 75% UF resin loading, which exhibited a value of 4.30%. The dimensional stability of the OPT polymer composites with the highest resin loading was slightly lower when compared to rubberwood. Scanning electron micrographs show that PF resin placement in OPT polymer composites was better, and resin penetration retained the original dried OPT structure.

Keywords: Oil palm trunk polymer composite; Impregnation; Water absorption; Thickness swelling.

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INTRODUCTION

The oil palm (*Elaeis guineensis*) is a main agricultural commodity in Malaysia and generates more than 90 million tons of waste annually from the empty fruit bunch (EFB), oil palm trunks (OPT) and oil palm fronds (OPF) during the replanting process (Abdul Khalil *et al.* 2011). This agricultural boost makes Malaysia the world's largest producer with an estimated 60% of the world's oil and fat production (Bhat *et al.* 2011). It has also been reported that oil palm land cultivation area covers more than 4.05 million hectares but the oil only comprises 10% of the total biomass produced in the plantation.

Rubberwood timber is a relatively cheap source of raw material, as it is considered a 'by-product' in rubber plantations (Puasa *et al.* 2010). In the 1990s, rubberwood timber comprised more than 70 to 80% of the wooden furniture produced in Malaysia. The acreage of rubber plantation throughout the country is reducing year by year due to land acquisition for housing and industrial development, as well as conversion of rubber plantation to oil palm cultivation. Oil palm trunk was discovered as one of the potential raw materials to substitute rubberwood for wood-based industry. Oil palms are usually felled after the age of 25 years, either due to their decreasing yield or because they have grown too tall, which makes harvesting very difficult. For the disposal of oil palm stems, they are normally left to rot or are burned in the field. However, freshly felled stems with their high moisture content cannot be easily burned in the field. Leaving the stems in the field without further processing physically hinders the process of planting new crops, as the stem can take about five years to decompose completely. Meanwhile, they serve as breeding grounds for pests such as the rhinoceros beetle (*Oryctes rhinoceros*) and stem rotting fungi (*Ganoderma* spp.). The practice of disposing oil palm stems by burning is now considered unacceptable, as it creates air pollution and affects the environment (Lim and Gan 2005; Bhat *et al.* 2010; Abdullah 2010).

Utilization of OPT as an alternative source for future wood-based panel industries could reduce the environmental burden of wood consumption. Studies on the enhancement of OPT properties showed the potential to be utilized in value-added product such as high-performance panel products, pulp and paper making, and animal feed. In addition, research to improve the OPT characteristics has been done in dimensional stability, durability, strength, and thermal stability (Erwinsyah 2008; Bakar 1999; Bhat *et al.* 2011). The modification of OPT using the polymers has been done by Furono *et al.* (2004), Abdul Khalil *et al.* (2010), Bhat *et al.* (2010), and Erwinsyah (2008) to improve the swelling behaviors, mechanical properties, thermal stability and biological exposure. Moreover, the treatment of OPT using phenol formaldehyde resin by the impregnation method has been studied and shown to exhibit higher quality properties than dried OPT (Abdul Khalil *et al.* 2009; Bhat *et al.* 2010).

The cost of construction materials is increasing year by year because of high demand, scarcity of raw materials, and high price of energy. The use of alternative constituents in construction materials is now a global concern for energy saving and conservation of natural resources. A worldwide shortage of solid wood due to environmental concern is attracting utilization of fibrous materials in development of composites, and various waste materials are being considered (Ashori and Nourbakhsh 2010). Wood polymer composites can be utilized in different applications, such as in the automotive, construction, marine, electronic, and aerospace industries (Ashori 2008). The utilization of oil palm trunk polymer composites has enormous potential to be converted into high value-added and useful income-generating products. Intensive research is being carried out to generate technologies that convert OPT polymer composites for the commercial viable composite panel products; such efforts have also proven to be successful in most cases. Polymer composites are being used in almost every type of application in our daily life and are widely used in industrial applications. Therefore, the oil palm trunk could be regarded as the most viable alternative source that could be used for construction and building materials.

In this study, the outer parts of oil palm trunks were impregnated with two resins, phenol formaldehyde (PF) and urea formaldehyde (UF) resin. Different periods of impregnation have been evaluated as a means of gaining different content of resin percentage in the oil palm trunks (OPT). The main objective of this study was to use PF and UF resin to cover the empty spaces in the oil palm trunk that are located in parenchyma tissues and vascular bundles. Furthermore, the impregnated oil palm trunk will improve the dimensional stability and can be used for structural and non-structural applications.

EXPERIMENTAL

Materials

The 25-year-old oil palm trunks were taken from KL-Kepong Berhad Plantation in Kulim, Kedah. Only the bottom parts and peripheral region from oil palm trunks were chosen for drying and the impregnation process. The phenol formaldehyde and urea formaldehyde resin were obtained from Hexion Specialty Chemicals Sdn. Bhd. The specifications of both resins are listed in Table 1.

Methodology

The outer parts of the dried OPT lumber were cut into dimensions (500 x 50 x 50 mm^3) and later kiln-dried for 15 days to obtain approximately 13 to 15% moisture content. The dried OPT was impregnated with PF and UF at 10, 20, and 30 minute intervals to obtain different resin loadings (25%, 50%, and 75%) using a pressure vessel, as stated in Table 2. In the impregnation process, dried OPT was put into the chamber for the vacuum process at 3 bar pressure. The vacuum process was used to remove the air and water in intercellular cavities of the dried OPT. Then, the impregnation process with 5 bar pressure was carried out. After a period of time, the resin was evacuated from the chamber and the vacuum process was undertaken with 3 bar pressure for five minutes to release the excess resin on the surface of the OPT polymer composite. The impregnated OPT with PF and UF resins were cured for 2 hours in an oven at 150^oC and 130^oC, respectively.

Table 1. Properties of Phenol Formaldehyde and Urea Formaldehyde Resins

Characteristics	Phenol Formaldehyde	Urea Formaldehyde
Viscosity (cp)	50 - 100	160 - 220
pH	13 - 15	7.8 - 8.2
Specific Gravity	1.20 - 1.21	1.28 - 1.295

Table 2. Resin Loading With Specified Impregnation Time

Time of Impregnation (min)	Resin Loading of OPT Polymer Composite (%)
10	25
20	50
30	75

Water Absorption and Thickness Swelling

The absorbed water and thickness swelling of the samples were calculated as a percentage according to the procedure of BS EN 317:1993. The amount of absorbed water was calculated by using the following Equation 2,

$$A(\%) = \left(\frac{M_1 - M_2}{M_2}\right)x100 \quad (1)$$

where M_2 is the weight before the test and M_1 is the weight during measurement (g).

The thickness swelling was calculated by using Equation 3,

$$G(\%) = \left(\frac{A_1 - A_2}{A_2}\right)x100 \quad (2)$$

where A_2 is the thickness before the swelling, and A_1 is the thickness after swelling (mm).

Resin Loading

The percentage of resin loading in the OPT polymer composite was calculated based on weight gain after being cured. The amount of resin loading was calculated using the following equation,

$$R(\%) = \left(\frac{W_1 - W_2}{W_2}\right)x100 \quad (3)$$

where W_2 is the weight of dried OPT before impregnation and W_1 is the weight of cured impregnated OPT polymer composite (g).

Scanning Electron Microscopy (SEM)

A scanning electron microscope (Leo Supra, 50 VP, Carl Ziess, SMT, Germany) was used to analyze the morphological images of dried OPT and OPT polymer composites. A thin section of the sample was mounted on an aluminum stub using a conductive silver paint and was sputter-coated with gold prior to morphological examination. The SEM micrographs were obtained under conventional secondary electron imaging conditions with an acceleration voltage of 5 kV.

RESULTS AND DISCUSSION

Water Absorption Properties

Water absorption affected the physical properties of the composites and could affect the matrix structure and the fiber-matrix interface, resulting in changes of bulk properties such as dimensional stability, as well as mechanical and physical properties. Water absorption properties of OPT polymer composites with PF and UF resin loading, dried OPT, and rubberwood immersed for up to 10 days at ambient temperature are displayed in Fig. 1. After day 7, OPT polymer composites, dried OPT, and rubber wood showed stability in water absorption properties.

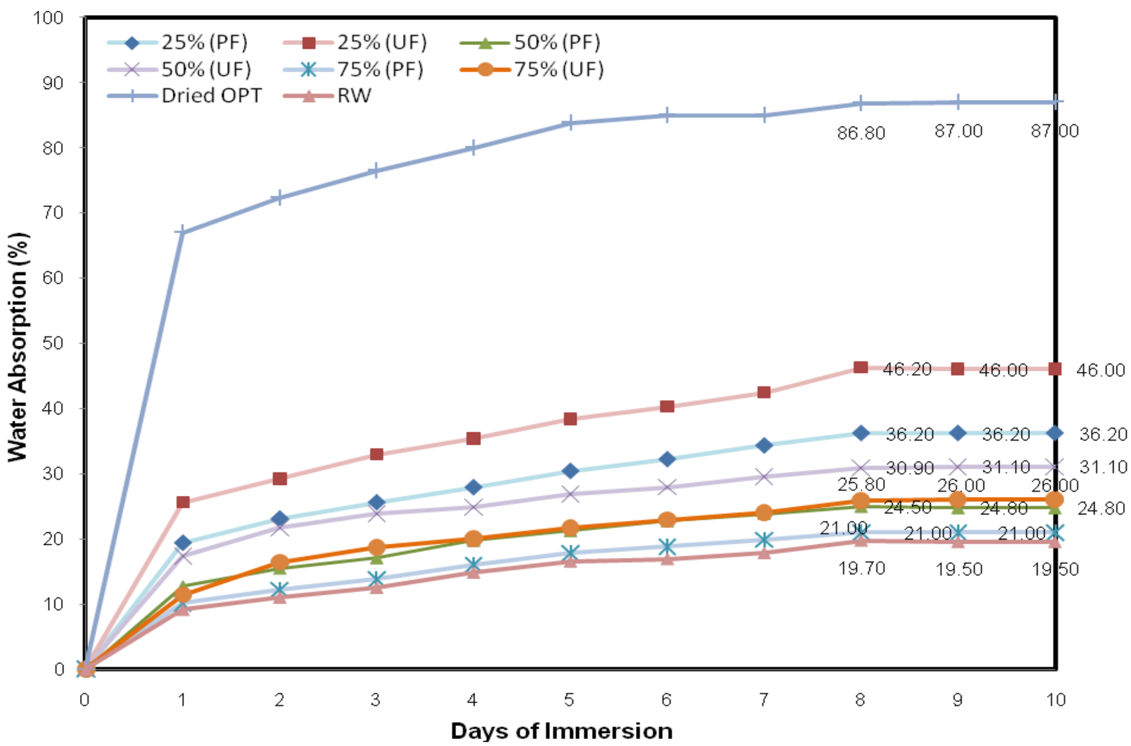

Fig. 1. Water absorption of OPT Polymer Composites at different resin loading, dried OPT, and rubberwood

The samples significantly absorbed water from day 1 until day 7 and constantly until day 10. The OPT polymer composites of PF resin loaded absorbed from 10 to 35% of water after being immersed for 10 days. It was observed that the highest water absorption was obtained in the case of dried OPT, while rubberwood showed the lowest water absorption. This was due to the fact that dried OPT contains a higher proportion of parenchyma tissues, which leads to the greater affinity to absorb water compared to the vascular bundles (Norralakmam 2007).

Figure 1 shows that the percentage of water absorption decreased when PF resin loading increased in OPT polymer composites. The percentage of water absorption of OPT polymer composites with 75% resin loading was comparable with rubberwood, which absorbed only 10 to 11% of water. This can be explained by the high resin content in OPT polymer composites covered by the parenchyma tissues, which reduces the ability of parenchyma to absorb water. Therefore, the 75% of resin loading in the OPT polymer composites is assumed to be sufficient to form stable solids which occupy void spaces in the parenchyma and penetrate into the cell wall.

The water absorption properties of OPT polymer composites with UF resin loading showed similarities with OPT polymer composites with PF resin loading. This study showed that water uptake capacity of the OPT polymer composites decreases with the increase of resin loading. The highest water absorption uptake was found in dried OPT, due to the presence of more hydroxyl group in the parenchyma tissue that enabled more hydrogen bonding formation. In addition, the parenchyma behaved like a sponge, making it easier for the dried OPT to absorb water. In addition, the porous structure of oil palm trunk fibers led to an initial capillary uptake which resulted in the large initial uptake in all cases.

The results also showed that the water uptake in OPT polymer composites decreased significantly after being impregnated as compared to dried OPT. The reduction of water absorption in OPT polymer composites with PF resin loading was better correlated to the replacement of the hydroxyl groups with carbon atoms in the PF chains, as reported by Abdul Khalil *et al*. (2010). Water absorption percentage of OPT polymer composites with UF resin showed slightly higher than OPT polymer composites with PF resin. Based on a previous study by Anthony (1996), urea formaldehyde resin is a highly hygroscopic material, which means that urea formaldehyde has the ability to release and absorb moisture easily.

The percentage increase was strongly dependent on the resin loading. Similar results were obtained by Dhakal *et al*. (2007), where the percentage of moisture uptake increased as the filler volume fraction increased for the hemp-reinforced unsaturated polyester composite. This was related to the situation in OPT polymer composites of 25 and 50% of resin loading, provided that there was more surface area on OPT fibers and parenchyma tissues to absorb moisture. In addition, a study by Sreekala and Thomas (2003) also mentions that after the oil palm fibers were coated by latex, the sorption at the capillary region decreased because the latex partially masked the pores on the fiber surfaces.

The reason for less water absorption of OPT polymer composites with PF resin loading as compared to OPT polymer composites with UF resin loading may have been due to better interfacial contact between fiber-matrix bonding. There were several factors that influenced water uptake, such as type of matrix and fiber, the orientation and distribution with respect to direction of water transport, and whether or not the absorbed water reacted chemically with the matrix (Abdul Khalil *et al*. 2007).

Thickness Swelling Properties

Several physical properties of wood are affected by the amount of moisture present in the wood. A study by Walker *et al*. (1993) stated that the amount of shrinkage depends on the basic density of the wood. The thickness swelling properties of OPT polymer composites with PF and UF resin loading, dried OPT, and rubberwood after being submerged in water for 10 days are shown in Fig. 2. The figure shows that OPT polymer composites with PF resin swell up between 2 and 5% as compared to dried OPT, which swelled up about 10%. In addition, OPT polymer composites with 75% of PF resin loading showed the lowest thickness swelling properties.

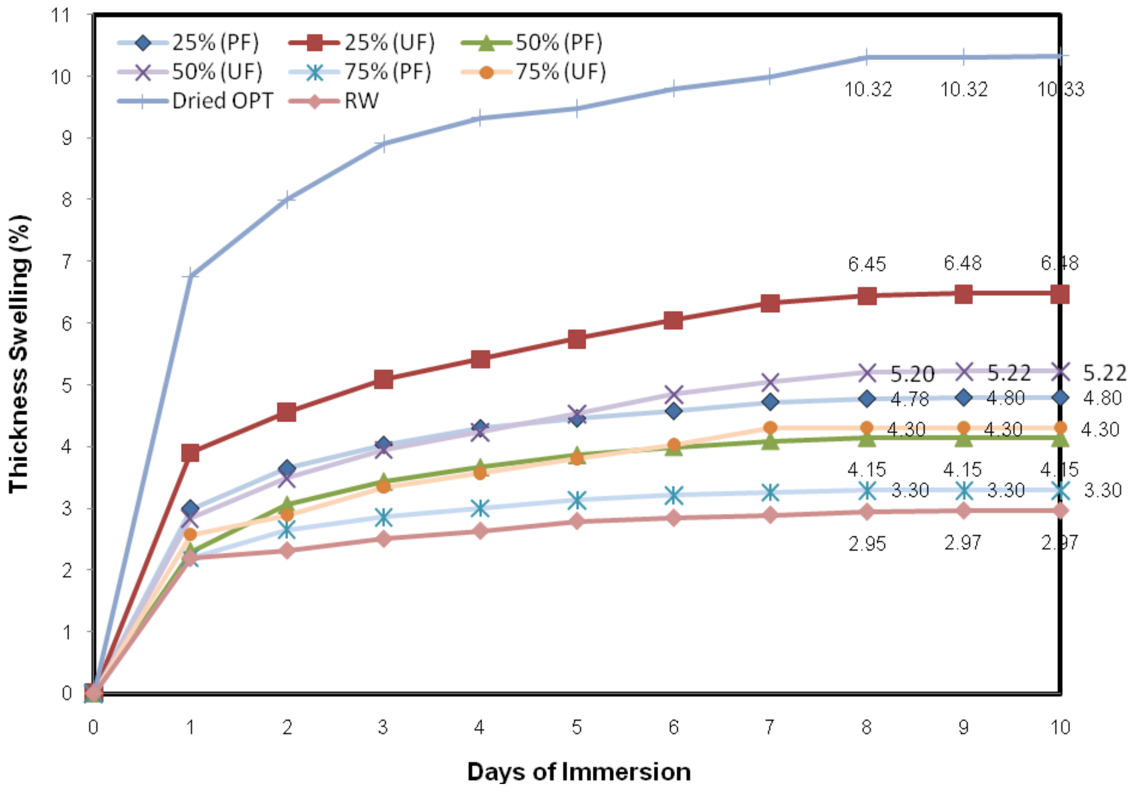

Fig. 2. Thickness swelling of OPT Polymer Composite at different resin loading, dried OPT, and rubberwood

It was observed that the increase of resin loading in OPT polymer composites developed resistance against water being absorbed. This result also showed that the swelling percentage of OPT polymer composites was slightly reduced after being impregnated with PF resin and led to better dimensional stability. However, rubberwood and dried OPT exhibited the lowest and the highest thickness swelling as compared to OPT polymer composite.

Similar to OPT polymer composites with PF resin loading, OPT polymer composites with 75% UF resin loading exhibited a lower thickness swelling than OPT polymer composites with 25 and 50% UF resin loading. However, compared with OPT polymer composites of PF resin, the OPT polymer composites of UF resin exhibited higher percentages on swelling properties. From these results, the thickness swelling of impregnated OPT with UF resin was between 2 and 6%. The dried OPT exhibited the highest thickness swelling compared with OPT polymer composites and rubberwood. However, the rubberwood still gave the lowest thickness swelling percentage.

The polar hydroxyl groups in fiber molecular structures are able to form hydrogen bonds with water molecules. The possibility of water being absorbed through the formation of hydrogen bonds increases with high volume of OPT fibers and parenchyma tissue. This was due to the presence of OH groups, which enhance the water absorption by forming hydrogen bonding with water molecules (Mishra and Naik 1998). The PF resin in OPT polymer composites reduced the porosity and minimized the dimensional changes. Therefore, the phenolic resin has been widely used to treat the oil palm trunks to increase the strength and dimensional stability (Ratanawilai *et al*. 2006).

Research has reported that treatment of wood with PF resin probably did not result in attachment or binding to the cell wall components but instead formed insoluble polymers that would not leach out in the water (Rowell and Banks 1985). Kajita and Imamura (1991) also found that unleachable resin solids, which are used in particleboards and wood, may improve water and moisture resistance. It was also observed that OPT polymer composites with 75% resin loading showed greater stability against water in contrast to the brittleness of the OPT polymer composites. Nikhom and Motoaki (2000) found that the resistance against water may be due to the existence of sufficient bonding strength together with the decrease in internal force generated by water. Moreover, forming wall polymers inside the cell wall enhanced the dimensional stability of the oil palm trunks (Furuno *et al.* 2004).

Morphological Study

The morphological analysis of dried OPT, as well as OPT polymer composites with 75% of PF and UF resin loading was carried out using a scanning electron microscope (SEM). The morphological detail of dried oil palm trunk structures, particularly parenchyma tissues, is illustrated in Fig. 3.

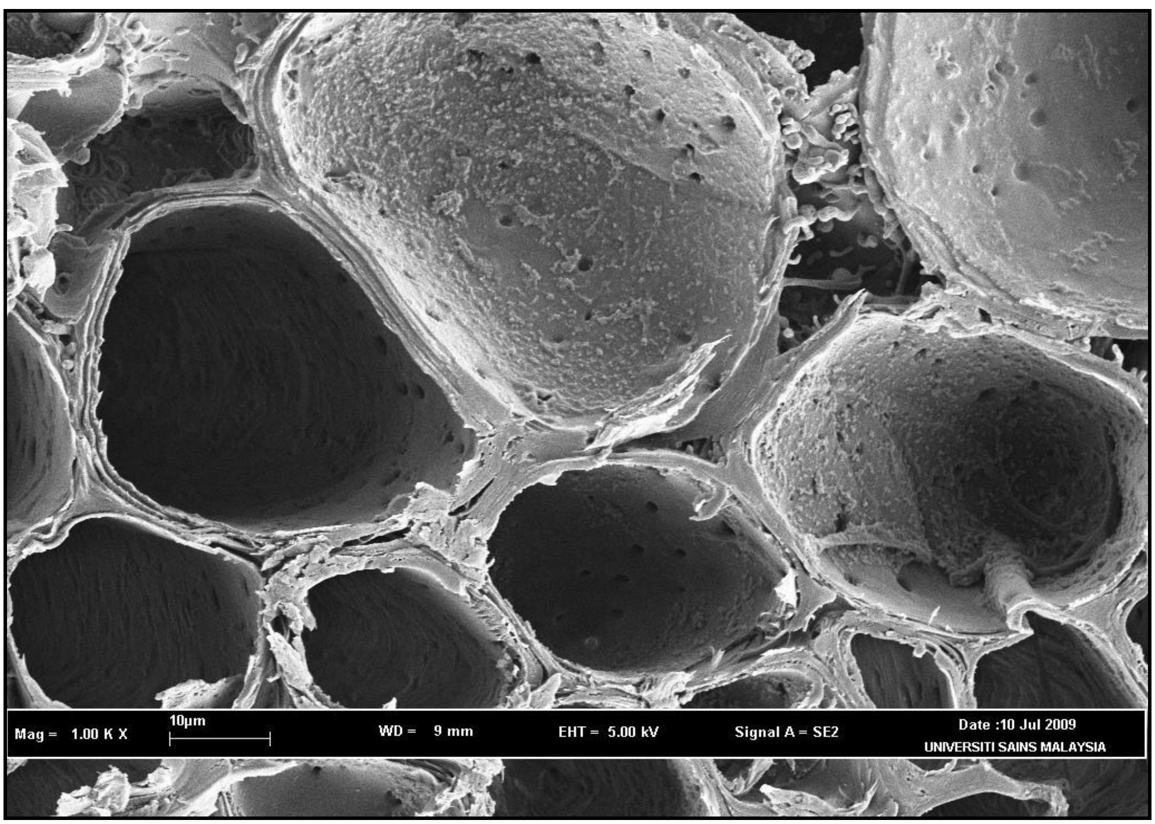

Fig. 3. Scanning electron micrograph (SEM) of parenchyma in dried oil palm trunk (1000x magnification)

The 'wood' of oil palm trunks consists of primary vascular bundles embedded in parenchyma ground tissues; such 'wood' plays an important role in the strengthening mechanism of composites when stress was transferred between the matrix (resin) and fibers. The highly porous morphology of dried oil palm trunks helps the resin to be located and filled within the void space, which will improve the characteristics of OPT polymer composite.

Based on Fig. 3, parenchyma tissues were found to be bowl-shaped and can provide a space for resin to fill it up. These cells function as the ground tissue that makes up the bulk of oil palm wood structures and is used as storage for food. Physically, this tissue is like a sponge, moist in green condition and very lightweight as well as easy to separate one cell to the others. Based on this fact, it can be logically accepted that ground parenchymatous tissue will be very hygroscopic. The moisture is easy to evaporate when the temperature is rising and also it is easy to absorb the moisture under high humidity conditions.

After the impregnation and curing process was completed, PF and UF resin were seen located in the parenchyma tissues. Figure 4 shows the microscopic image of PF resin, which is incorporated within the parenchyma cell. The parenchyma cells, which were fully covered by PF resin, were quite similar by attaining an elongated shape. However, the PF resin that was only located in the parenchyma cells displayed poor bonding. This result can be related to the reduction of dimensional stability in the physical properties of OPT polymer composites.

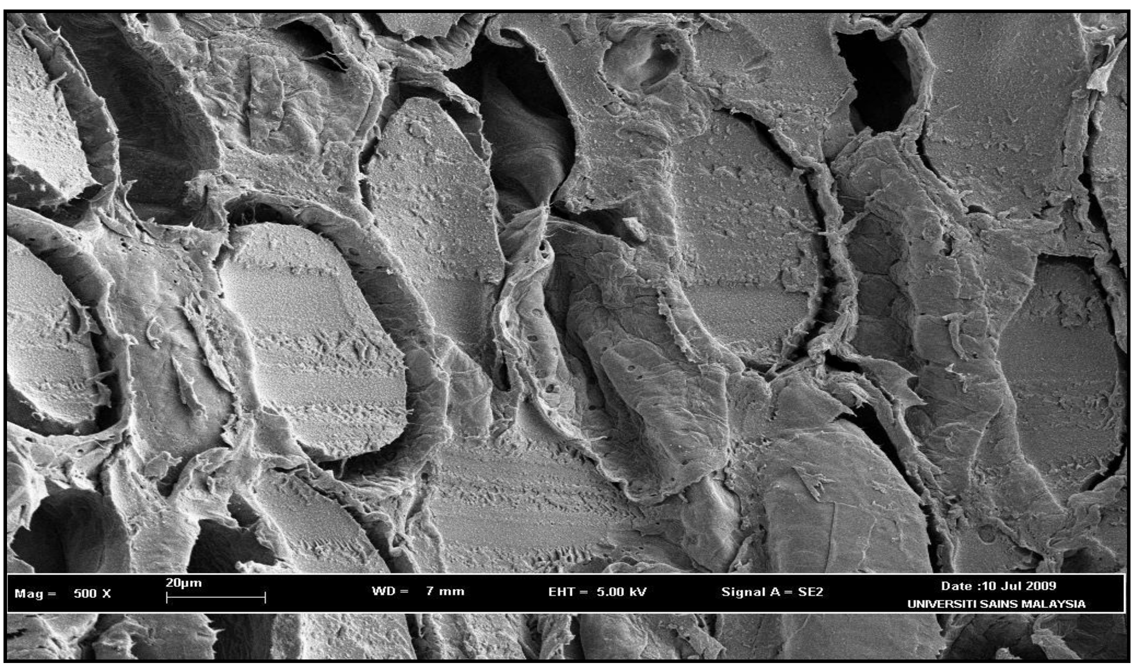

Fig. 4. Scanning Electron micrograph (SEM) of parenchyma fills up with phenol formaldehyde resin (500 x magnification)

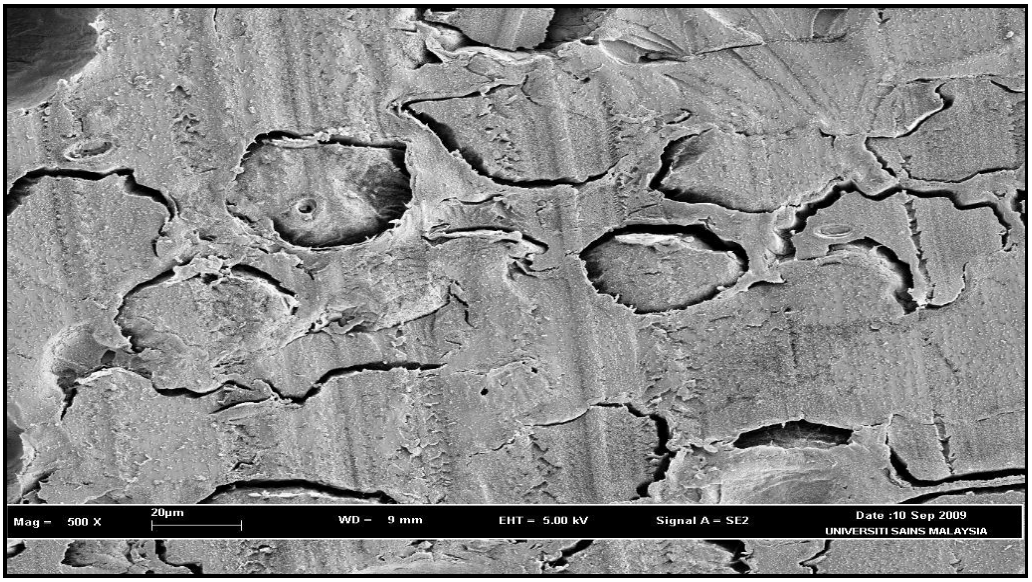

Fig. 5. Scanning Electron micrograph (SEM) of parenchyma fills up with urea formaldehyde resin (500 x magnification)

Meanwhile, a micrograph of OPT polymer composites impregnated with UF resin is displayed in Fig. 5. The parenchyma cells were fully covered with UF resin so as the actual parenchyma tissues could not be seen clearly. This was due to the curing process of resin in the OPT polymer composites. PF resin contains a higher amount of water than UF resin. In fact, the viscosity of UF resin was high when compared with PF resin and had a high amount of solid content. Therefore, during the curing process, the moisture in PF resin evaporated more slowly when compared to the UF resin, making the solid content of PF resin located fully in the parenchyma cells. The high pressure intakes during the impregnation process forced the resin to locate in OPT structures.

In resin penetration, optimum viscosity is an important factor. In case of high viscosity, slower wetting may occur, with very low penetration into the wood surface, hence poor dimensional stability properties.

CONCLUSIONS

1. The water absorption of dried OPT was observed to be higher than the water absorption determined in impregnated OPT polymer composites. However, rubberwood obtained the lowest water absorption in overall comparison. Both OPT polymer composites with 75% resin loading exhibited the lowest water absorption with 25% and 50% resin loading. The presence of resins resulted in improvement of water resistance properties.
2. The thickness swelling of dried OPT and rubberwood were found to be the highest and the lowest when comparing the thickness swelling of both OPT polymer composites. The average thickness swelling of OPT polymer composites was observed to be below 6%; this result indicated that the presence of resin gained better dimensional stability.

3. The morphological analysis of the dried OPT and OPT polymer composites with 75% resin loading illustrated better allocation of resin in OPT structures and poor interaction between cell wall and resin.

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