PROPERTIES OF BINDERLESS PARTICLEBOARD PANELS MANUFACTURED FROM OIL PALM BIOMASS

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The objective of the study was to investigate physical and mechanical properties of experimental particleboard panels manufactured from oil palm (*Elaeis guineensis*) biomass without using any adhesives. Different parts of oil palm, including the core and mid sections of trunks, fronds, bark, and leaves, were used to make the panels with an average target density of 0.80g/cm^3. Based on the test results, it seems that panels made from bark and leaves did not have satisfactory strength and dimensional stability. However, the panels having particles from the core portion of the trunks exhibited the highest modulus of rupture and internal bond strength but lowest in thickness swelling and water absorption values among the samples. The panels made with particles of mid-section of trunks and fronds followed the samples having core portion trunks material. Three types of raw material, namely fronds, mid-, and core-parts of the trunks appeared as though they could have potential to manufacture particleboard panels with acceptable properties based on requirements stated in Japanese Industrial Standard (JIS). Similar to the above findings, surface quality of the samples were also found acceptable for the panels made from three types of particles. Based on the results of this work, oil palm in the form of biomass could be considered as an environmentally friendly alternative raw material to manufacture binderless particleboard panels.

Keywords: Oil palm biomass; Particleboard; Binderless; Mechanical properties; Physical properties

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INTRODUCTION

The oil palm (*Elaeis guineensis*) has remarkable commercial value because of the oil that can be obtained from the mesocarp of its fruit. The first commercial oil palm plantation in Malaysia was constructed in 1917 in Selangor (Salleh et al. 2007; Sumathi et al. 2008). Currently, Malaysia is the largest producer of palm oil in the world. Plantation of oil palm areas has been increasing, resulting in substantial residue within the harvesting sites. It is estimated that overall, the oil palm industry generates at least 30 million tons of lignocellulosic biomass per year in the form of trunks, fronds, empty fruit bunches, and leaves (Salleh et al. 2007; Khushairi and Rajanaidu 2000). These resources are not used effectively, and open burning and land filling are common practices used to eliminate oil palm residues. Recent strict regulations on open burning are intended to restrict such practices, which not only cause environmental pollution, but also produce adverse impacts on the ecosystem. The oil palm contains lignocellulosic material (Akmar and Kennedy 2001), which could be ideal for producing value-added composite panels in a similar approach to that with other non-wood resources such as bamboo, kenaf, rice straw, wheat straw, and coffee husk (Wang and Sun 2002; Sumardi et al. 2005; Okuda and Sato 2008; Bekalo and Reinhardt 2009).

Composite panels, including particleboard and fiberboard, are widely used as substrates for thin overlays in the furniture industry. It is necessary to use adhesives to bind the wood chips together for assembly of the composite panels. The most widely commercially used adhesives are urea formaldehyde and phenol formaldehyde (Sulaiman et al. 2009; Sulaiman et al. 2008; Hashim et al. 2005). The choice of adhesive generally depends on the end use of the composite. Urea formaldehyde, which is the most commonly used interior adhesive in the wood composite industry, has a main advantage of its low cost. Even though it is inexpensive and used at a level of only 8% to 10% of the weight of oven dry of the raw material, it still contributes 60% to the overall cost of final product (Hashim et al. 2005; Laemsak and Okuma 2000). Moreover, one of the main concerns of urea formaldehyde resin is its formaldehyde emission that causes important health and environmental problems (Halvarson et al. 2009; Hashim et al. 2009; Hashim et al. 2010). Therefore, manufacturing composite panels without any adhesive, known as binderless panels, constitutes an attractive alternative way to eliminate not only hazardous concepts of the resin, but also reduce overall production cost.

Production of binderless boards has been developed based on the concept of wet process fiberboard, in which the bonding between fibers is inherited from the natural binders existing in different types of raw materials under heat and pressure. Suchsland et al. (1985) studied binderless fiberboards using fibers made by Bauer and Masonite pulping methods. The work showed that the bonding mechanism could be due to the presence of lignin, and other different types of bonds could be involved. Laemsak and Okuma (2000) attempted to use steam-exploded oil palm fibers to manufacture binderless medium density fiberboard. Angles et al. (2001) studied the effect of adding acid to the pretreated fibers for the production of binderless panels made from spruce and pine by steam explosion. The results showed that the mechanical and physical properties of the panels increased, reaching their maximum values, first, and later reduced as pre-treatment was increased. The internal bond strength, thickness swell, and water absorption was improved with the addition of lignin into the panels. The results also showed that boards with higher internal bond strength had high content of cellulose and moderate content of lignin.

Hunt and Supan (2006) compared the fiber types from recycled corrugated containers and refined small-diameter whole tree chips for binderless fiberboard. The panels with 1.0g/cm^3 density manufactured using a temperature of 163ºC and a pressure 1175 kPa pressure for 10 minutes met the minimum requirement for a typical commercial hardboard panels. Van Dam et al. (2004) studied the production for high density high performance binderless board from whole coconut husk. The coconut husk underwent steam explosion, extrusion, was milled, and hot pressed. The results of the study indicated that good mechanical and physical properties affected the fiber cell wall thickness. Salvado et al. (2003) developed binderless fiberboard from *Miscanthus sinensis*. The work also used steam-exploded fibers in making experimental panels. The samples were pressed at varied temperatures ranging from 195 to 245ºC and pressed using a pressure range between 1.9 and 14.6 MPa. The boards satisfied the relevant standard specification. Addition of kraft lignin in the production of such binderless boards have been carried out by Velasquez et al. (2003) and showed that the specimens had improved properties.

Okuda and Sato (2004) manufactured and studied the mechanical properties of binderless fiberboards from kenaf core. The boards were pressed using a temperature of 180ºC, and a pressure of 5.3 MPa for 10 minutes. In this study, it was determined that such panels met the relevant Japanese Industrial Standard. Geng et al. (2006) produced binderless fiberboards using black spruce bark that was treated with 1% sodium hydroxide (NaOH), pre-heated with steam, and with steam pressure applied to the fibers. The work indicated that pre-heating of the fibers is important in order to achieve satisfactory results. The binderless fiberboards made from banana bunch after steam explosion was reported by Quintana et al. (2009). The results satisfied the requirements of the corresponding standard specification.

Studies on binderless particleboards of different types of raw materials have been reported (Mobarak et al. 1982; Shen 1986; Widyorini et al. 2005; Xu et al. 2006). Mobarak et al. (1982) studied the mechanism of binderless lignocelluloses of bagasse. The work showed that bonding of the particles was achieved as a result of the ability of the particles to compress closely together. Shen (1986) patented the process for manufacturing binderless composite products from sugar-containing lignocellulosic material, such as sugarcane and sorghum stalks. The panels were molded at a temperature of at least 180ºC. The adhesion was accomplished by the presence of free sugar, carbohydrates, or saccharides that serve as bonding and bulking agents. Widyorini et al. (2005) manufactured binderless panels by using a steam injection process. The panels were made by applying steam with a temperature of 183ºC at a pressure of 1.0 MPa for the time span ranging from 0.75 to 15 minutes. It was found that the bonding quality of panels, made without using adhesives, were functions of both raw material and manufacturing parameters, including morphological and chemical properties of the particles. Xu et al. (2003) manufactured and evaluated the properties of low-density binderless particleboard from kenaf core by steam-injection pressing, and showed that the boards had suitable sound and thermal properties.

Similarly, it appears that underused fiber resources from different parts of the oil palm including fronds, leaves, bark core, and middle parts of the trunks could potentially be used to manufacture different types of panel products. Therefore, the objective of this study was to manufacture experimental particleboard panels using the above materials of the oil palm. Both physical and mechanical properties of such panels made without adhesives were evaluated to determine if they are comparable to those made from other raw materials.

EXPERIMENTAL

Raw Material and Preparation of Samples

Oil palm biomass in the form of trunks, fronds, and leaves was obtained from a local plantation in Northern Malaysia. Three types of materials, i.e., core-part, mid-part, and bark particles, were produced from the trunks. Fronds and leaves were also cut from the trees. All five different types of particles were reduced to chips in the field using a commercial chipper (Viking GE-105). Chips were then reduced to coarse particles in a laboratory-type hammer mill. An oven was used to decrease the moisture content of the material to 7-8%. All coarse particles were ground into fine particles of less than 1 mm size, employing a Wiley Mill. Random samples of particles obtained from different parts of the oil palm were also screen analyzed on a Retsch AS 200 device for classification of size. The particles used to manufacture experimental panels had sizes of less than 1.0 mm. Figure 1 illustrates the screen analysis of the particles used in this work.

Production of Binderless Panels and Testing

A total of twenty single-layer panels, four from each biomass, with dimensions of 20.05 cm x 20.05 cm x 0.48 cm, were manufactured for the experiments with modification of panels. Manually formed mats were compressed in a computer-controlled hot press using a temperature of 180°C and a pressure of 5.0 MPa for 20 min. All panels had a target density of 0.80 g/cm^3. Pressed panels were cut into test samples based on Japanese standard after they had been conditioned in a climate chamber with a temperature of 20°C and relative humidity of 65%. Nine MOR and three IB samples were cut from each panel to evaluate their mechanical properties. Both tests were carried out on an Instron Testing System Model UTM-5582, equipped with a load cell capacity of 1,000 kg. Six samples with a size of 5 cm by 5 cm were used for determination of thickness swelling (TS) and water absorption (WA). The thickness of each sample was measured at four points midway along each side at 1 cm from the edge. The samples were submerged in distilled water for 24 hours before thickness measurements were taken at the same location to calculate thickness swelling values. Each sample was also weighed to an accuracy of 0.01 g to determine water absorption values. In addition to TS and WA properties, surface roughness characteristics were also evaluated. Three samples of each type of panel with a size of 5 cm by 5 cm were used for roughness measurements. Three measurements with a tracing span of 15 mm were taken from each side of the samples using a portable stylus-type T-500 Hommel tester. The profilometer consisted of a main unit and a pick-up that had a skid-type diamond stylus with a 5 μm tip radius and 90° tip angle. Various roughness parameters such as average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}), could be calculated from the digital information. The definitions of these parameters have been presented in detail in previous studies (Hiziroglu 1996; Hiziroglu and Graham 1998; Mummery 1993).

Spectroscopic Study

A Fourier transform infrared (FT-IR) spectrophotometer was used to characterize the functional groups presence in raw materials and after the panels was made. Pellets were prepared by mixing approximately 5 mg powder of each sample type with 95 mg of finely ground potassium bromide (KBr) and pressed into pellets about 1 mm thick. The FTIR spectrum of each sample was then analyzed using the Nicolet infrared spectrophotometer (Avatar 360 FTIR E.S.P) between 4000 cm^{-1} and 470 cm^{-1} wave number, with a resolution of 4 cm^{-1} to detect the functional groups of the compounds of each material.

Field Emission Scanning Electron Microscopy (FESEM)

Samples with 0.5 cm by 0.5 cm cross-sections were taken from oil palm trunks as well as pressed panels to determine the micrographs from their surface, and also individual parenchyma cells were used to evaluate their microstructure employing FESEM. Both types of samples were gold-sputtered using sputter coater model Polaron SC 515 ± 20 nm. A LEO Supra 50 Vp field emission scanning electron microscope (FESEM), with ultra high resolution, was used to take micrographs of the samples.

RESULTS AND DISCUSSION

Mechanical and Physical Properties

Average MOR and IB values of the specimens are depicted in Figs. 2 and 3. Samples made from core particles of the trunks had an average value of 10.86 MPa and 0.53 MPa for MOR and IB, respectively. These values were the highest among all the samples, which could be related to the pseudoplasticity and viscoelasticity of the core-part of starch-rich parenchyma cells, found in trunks. The panels made with particles from the fronds and the mid-part of the trunks had lower strength values; however samples made from fronds had the second highest MOR value of 8.45 MPa. The hemicellulose content of oil palm fronds is 1.5 to 3.0 times higher than that of typical hardwood species (Laemsak and Okuma 2000). This might create an enhanced bonding between particles during the pressing stage, resulting in acceptable bending properties. Panels made from particles of bark and leaves did not exhibit satisfactory mechanical properties. The Japanese Industrial Standard, JIS A-5908, Type-8 (JIS – A 5908 2003) minimum requirements for MOR and IB are 8.0 MPa and 0.15 MPa, respectively.

As Fig. 2 shows, panels made from core-part and frond particles satisfied the Japanese Standard requirements for particleboard MOR. The core-part and frond particles, as well as panels made from particles of the mid-part of the trunks, also satisfied the requirements for IB strength (Fig. 3). Panels made from bark and leaves performed poorly, as can be seen in Figs. 2 and 3. These findings are comparable to the results of a previous study that investigated the properties of binderless particleboard made with bagasse particles (Widyorini et al. 2005).

Thickness swelling and water absorption of the different panels ranged from 20% to 130% (Fig. 4). A typical Type-8 particleboard should not have more than 12% thickness swelling based on Japanese Industrial Standard (JIS A-5908). Therefore, none of the samples satisfied the TS requirements. The lowest TS value of 20% was found for panels made from core trunk particles. Panels made from non-trunk particles had substantially higher thickness swelling, which might be related to the non-fibrous structure of such particles (Hashim et al. 2001; Murai et al. 2009; Mansor and Ahmad

1990; Tomimura 1992). Steam or chemical treatments of these particles could probably improve their physical properties (Xu et al. 2003; Sun et al. 2005; Sekino et al. 1999).

Figure 5 shows typical roughness profiles of the samples. The roughness of the samples manufactured from particles of the core-parts had the smoothest R_a value of 4.57 µm, while panels made from 100% bark particles had the roughest R_a value of 9.95 µm, as shown in Fig. 6.

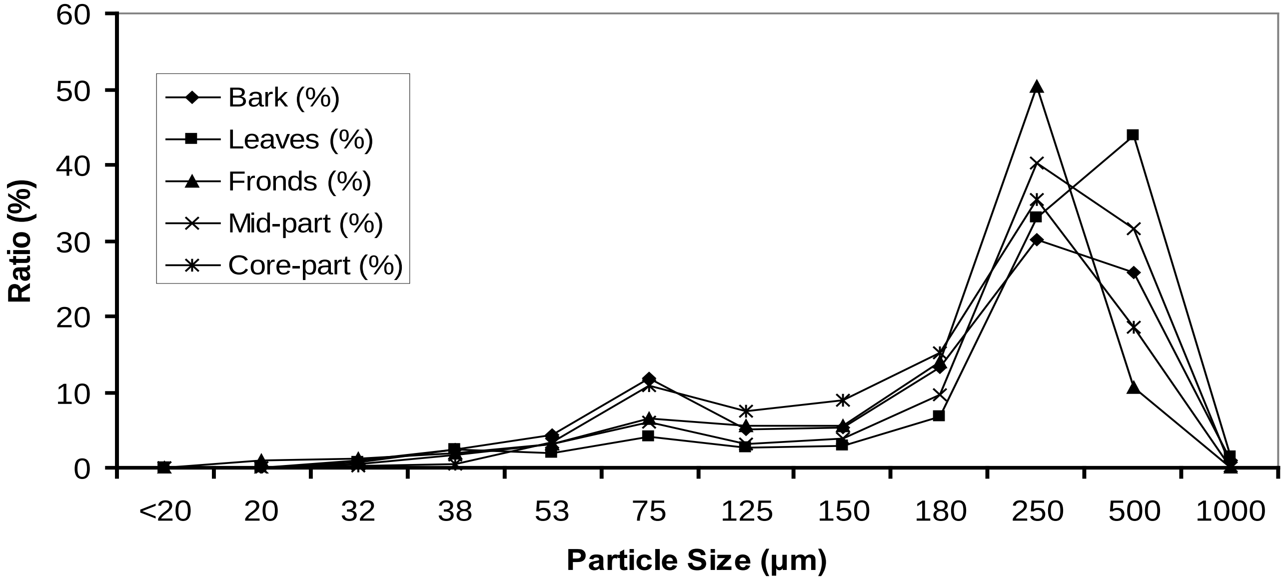


Fig. 1. Distribution of particle size

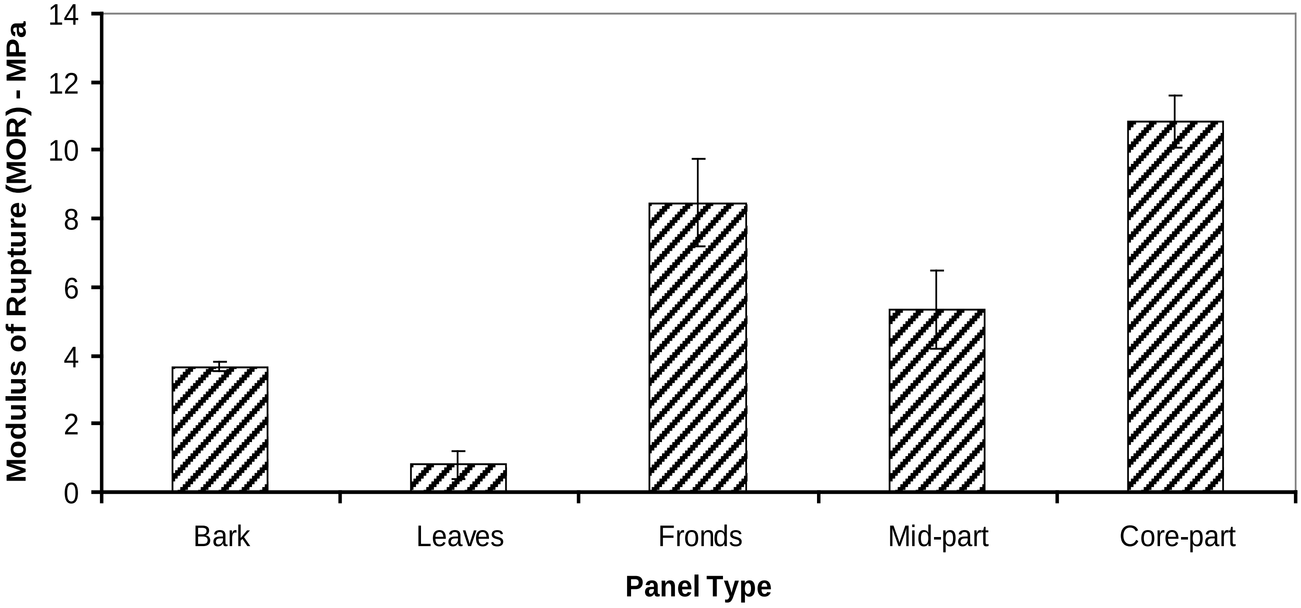


Fig. 2. Average modulus of rupture values of the samples

Overall roughness characteristics of the samples were comparable to those of commercially manufactured particleboards evaluated in a previous study (Hiziroglu and Suzuki 2007). In general, commercially manufactured particleboard panels are sanded to have uniform thickness and to improve their surface quality. The panels made from oil palm were not sanded prior to roughness measurement. If they had been sanded, the surface roughness would have been much better for overlaying application. Based on the quantitative evaluation of surface quality, such experimental panels could be overlaid with thin overlay papers to increase their value (Sulaiman et al. 2009).

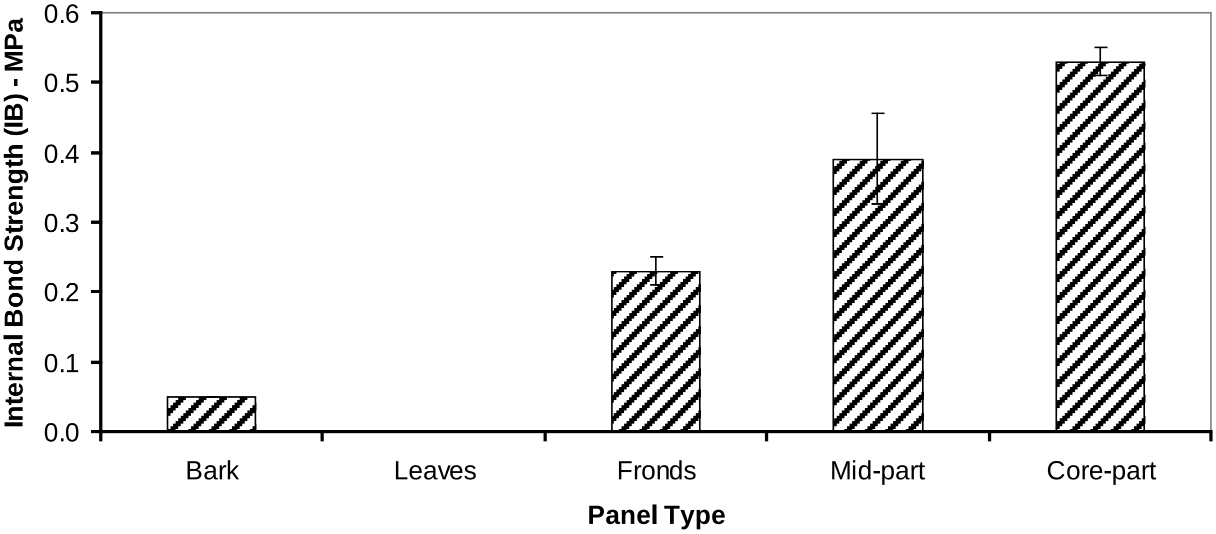


Fig. 3. Average internal bond values of the samples

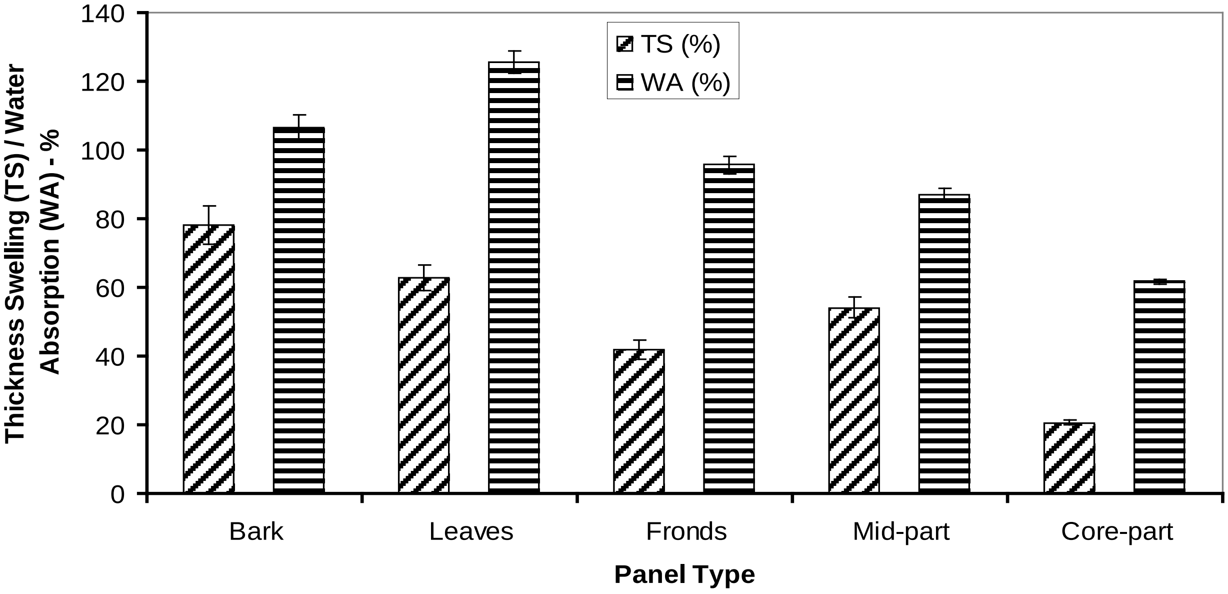


Fig. 4. Thickness swelling and water absorption of the samples

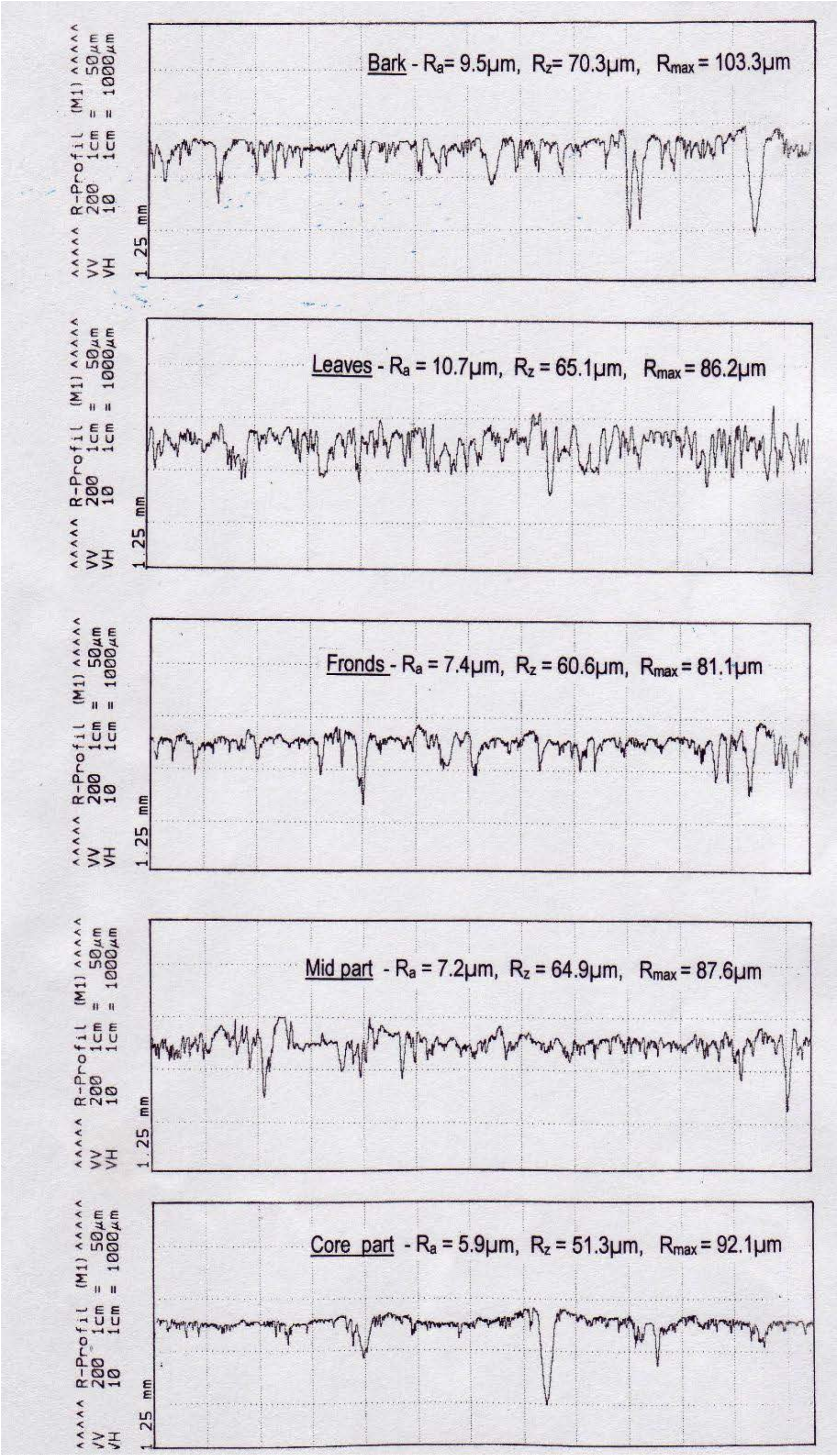


Fig. 5. Typical roughness profiles of the samples

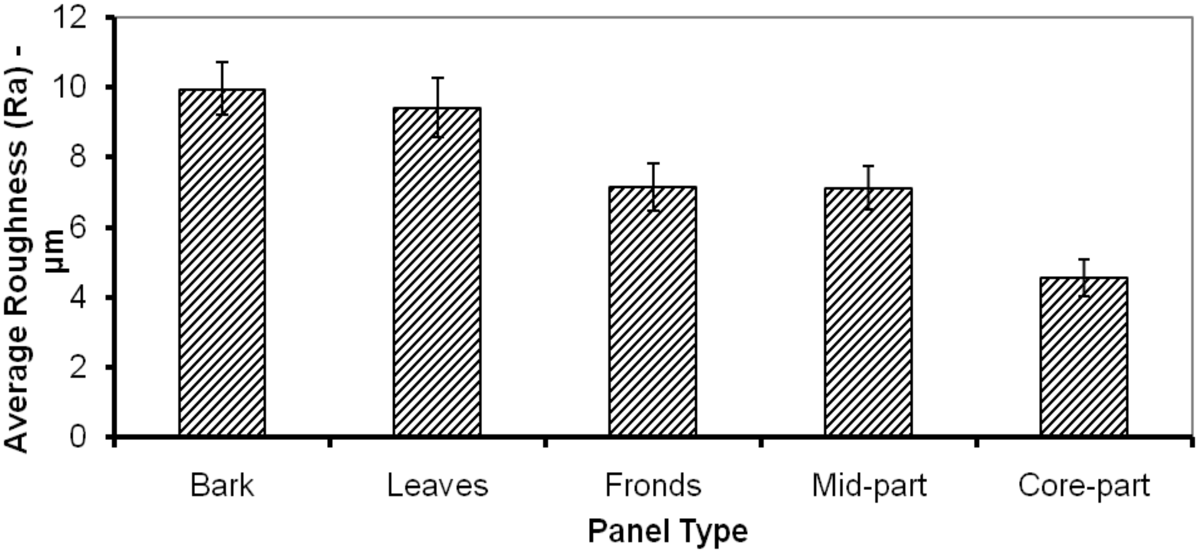


Fig. 6. Average surface roughness of the samples

Fourier Transform Infrared Spectrophotometry

Fourier transform infrared (FT-IR) spectra for all particle types are given in Fig. 7. In general, the spectra corresponding to particles before and after their having been compressed in a panel were found to be the same.

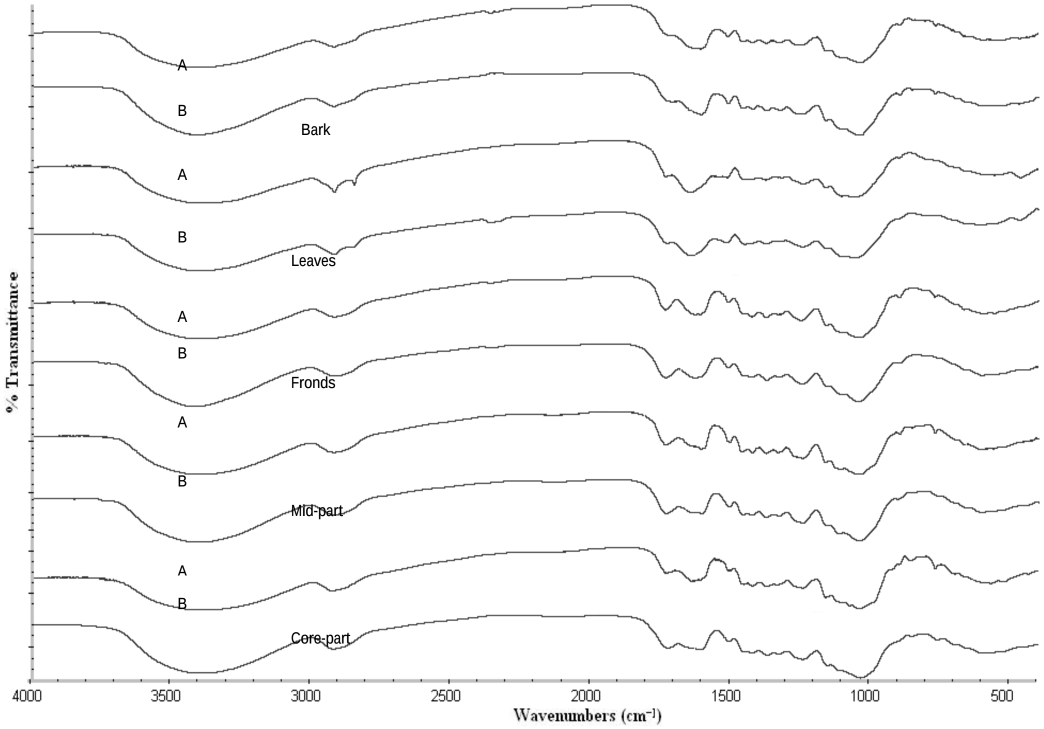
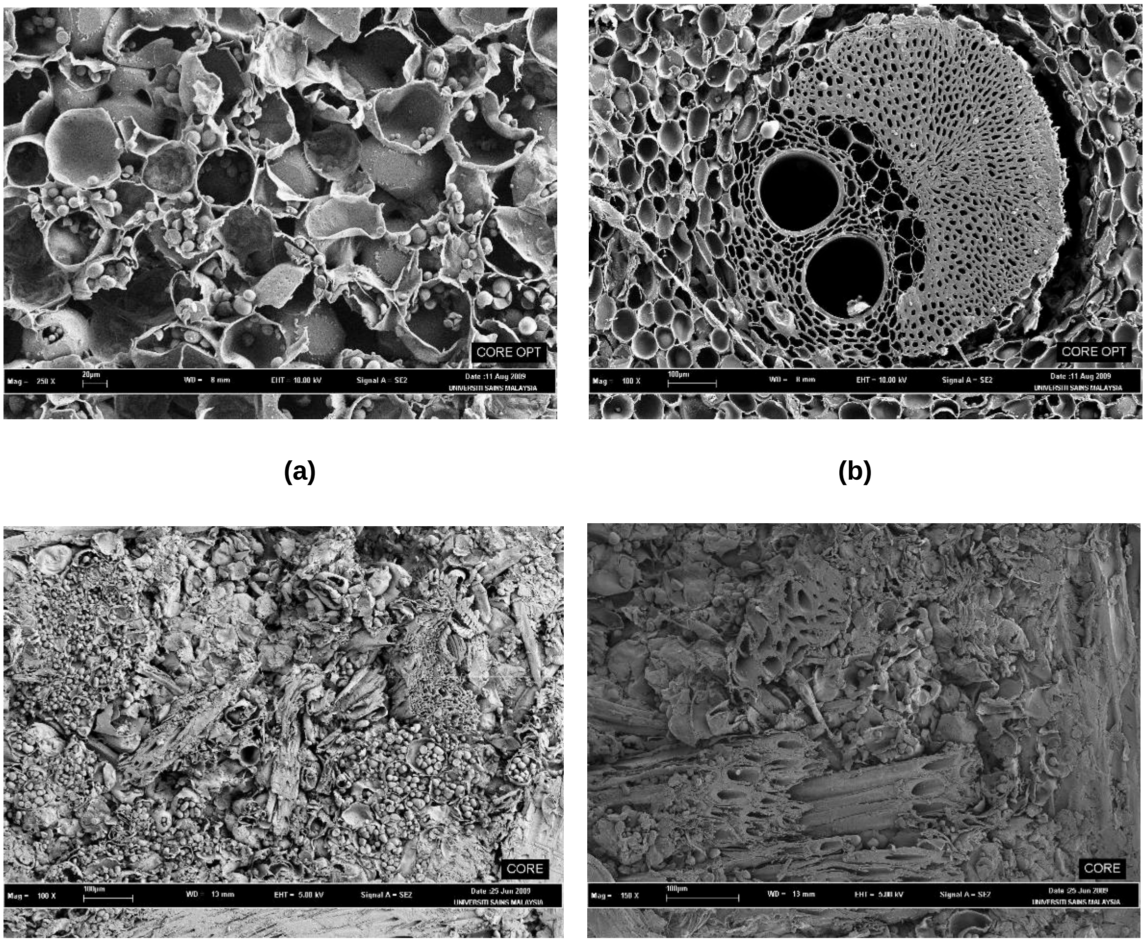


Fig. 7. FTIR spectra of different parts of oil palm trunk before (a) and after (b) board making

A broad absorption band appearing in the region of 3384 to 3421 cm^{-1}, and in each of the spectra, corresponds to O-H groups stretching of cellulose and lignin constituent of the oil palm biomass, respectively, present in all particle types that may affect bonding of the boards (Peng et al. 2009; Ibrahim et al. 2005; Zhong and Xia 2008). The peak at 1039 cm^{-1} is associated with hemicelluloses and a typical of arabinoxylan (Peng et al. 2009). The peak at 1633 cm^{-1} represents carbonyl-stretching (C=O) stretching of amide groups (Siddiqui et al. 2009). A previous study reported that the peak at 2919 cm^{-1} represents the C=O stretching frequency of the carboxylic group in hemicelluloses (Ahmad et al. 2007). The peak at about 1608 cm^{-1} corresponds to the stretching vibrations of C=C bonds in aromatic groups (Siddiqui et al. 2009). The peak at 1050 derives from –C-O-C stretching (Ahmad et al. 2007).

Field Emissions Scanning Electron Microscopy

Micrographs taken with the FESEM are shown in Fig. 8. Parenchyma cells in Fig. 8a appear as thin cubical cells with abundant starch particles in the lumen.



(a) **(b)**

(c) **(d)**

Fig. 8. Field emission scanning electron micrographs (FESEM) of oil palm particles before (a and b) and after (c and d) compression of the panels

The starch granules vary in shape, ranging from ovoid, elliptical, truncated end, and bell-shaped. The wall of the parenchyma cells is thin, in contrast to the thick cell wall of fibers, shown in Fig. 8b. Fibers are longitudinal cells with pointed ends and thick cell walls, similar to those found in hardwood species. Other cells such as those comprising the vessel, phloem, and xylem can also be seen within the vascular bundles in Fig. 8a. During the formation of the panels, the particles were randomly mixed, resulting in a matrix of these cells. After the boards were manufactured, the cells were compressed as illustrated in Figs. 8c and 8d. This effect was particularly strong for the parenchyma cells. The presence of starch and other residual saccharides in the cell lumen probably helped in the bonding of the board. However, the presence of starch could lead to poor moisture resistant of the board and need further study to overcome this problem. The walls of the parenchyma cells and the vascular bundles seem to be closer to each other; which enhanced the adherence properties of the cells. Therefore, binderless particleboard panels from the oil palm could be considered as a solution to a significant ecological problem, via the conversion of such biomass into a value-added product. A particular limitation of these experimental panels is their dimensional stability; steam treatment, chemical treatment, or a combination of both, could be alternatives to enhance the thickness swelling and water absorption properties. Detail studies of this process to overcome this issue are being investigated as a part of an ongoing research project.

CONCLUSIONS

1. This work showed that particles from some different parts of the oil palm could be used to produce particleboard panels without any adhesive.
2. The core-parts, mid-parts, and fronds could be used to produce binderless boards with acceptable MOR and IB strength.
3. Panels made from bark and leaves performed poorly in terms of MOR and IB strength.
4. All panels performed poorly when tested for water absorption and thickness swelling.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Universiti Sains Malaysia for the research assistant support of Ms. Wan Noor Aidawati Wan Nadhari and the Japan International Research Center for Agricultural Science (JIRCAS) for partially sponsoring this research.

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Article submitted: December 1, 2011; Peer review completed: January 8, 2012; Revised version received and accepted: January 27, 2012; Published: January 30, 2012.