PROPERTIES OF THERMALLY-COMPRESSED OIL PALM TRUNKS (*ELAEIS GUINEENSIS*)

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Received May 2013

CHOOWANG R & HIZIROGLU S. 2015. Properties of thermally-compressed oil palm trunks (*Elaeis guineensis*). The objective of this work was to evaluate the properties of thermally-compressed oil palm trunks (*Elaeis guineensis*) using hot press process. Samples were compressed at three press temperatures, i.e. 140, 180 and 220 °C under maximum pressure of 2 MPa for 8 min. Average oven-dry density of compressed samples increased from 0.34 to 0.71 g cm^{-3} compared with control samples. Both the modulus of rupture and modulus of elasticity of samples also increased with densification. The hot pressing increased hardness and brittleness of the samples but caused some loss of hardness when higher temperatures were used. The thermally-compressed samples had higher thickness swelling values than control samples due to spring back of cell wall when they were soaked in water. The combination of compression and heat resulted in specimens with smooth surfaces. The increased surface density reduced adhesive bond strength of samples. Contact angle measurement of samples using water decreased with increasing temperature due to cracks of cell walls of parenchyma cells after compression at high temperature. Thermally-compressed oil palm wood samples appeared to possess better mechanical properties but thickness swelling was adversely affected. The pressure, temperature and duration of hot pressing need to be optimised for specific applications.

Keywords: Compression, surface roughness, shear strength, wettability

INTRODUCTION

Oil palm (*Elaeis guineensis*), which originates from Africa is widely planted in South-East Asia, especially in Indonesia, Malaysia and Thailand. It is one of the most important agroforestry cash crops. It was introduced to Thailand in 1968. The plantation area of oil palm in Thailand is around 690,516 ha and has been increasing (Prasertsan & Prasertsan 1996, Office of Agricultural Economics 2012). Oil palm is harvested at age 25 to 30 years for replanting. Most oil palm trunks are left in the field to rot. The trunks are the main waste from oil palm plantations and their production rate has been estimated at 41.07 ton ha^{-1} of oven-dry weight (Khalid et al. 1999). Oil palm trunks have 22.6% lignin, 21.2% hemicellulose, 39.9% cellulose, 1.9% ash, 3.1% wax and 11.3% other constituents (Yuliansyah et al. 2010). Its low density and high porosity are its main disadvantages, limiting structural utilisation. A study on the mechanical properties of oil palm trunks as roof truss in low cost housing found that oil palm trunks might have potential if special design procedures were closely followed (Jumaat et al. 2006). Various studies on oil palm have investigated value-added composite panels (Abdul Khalil et al. 2010, Ahmad et al. 2010, Hashim et al. 2010, Hoong et al. 2012). There are numerous studies on how heat treatment affects the properties of wood (Bekhta et al. 2009, Bekhta & Niemz 2003, Boonstra & Tjeerdsma 2006, Ozcan et al. 2012). Although some physical properties of wood improve including dimensional stability, generally heat treatment has an adverse effect on mechanical properties (Bekhta & Niemz 2003, Yoshihara & Tsunematsu 2007). It is well known that heat treatment causes breakage of lignin–polysaccharide complex and release of organic acids from hemicelluloses reduces the strength of heat-treated samples (Tjeerdsma & Militz 2005, Boonstra & Tjeerdsma 2006). Wood densified with heat and compression has some advantages over wood treated with only heat (Boonstra & Blomberg 2007, Bami & Mohebby 2011). Bekhta et al. (2009) who studied surface roughness of hot-pressed beech and alder veneer sheets found that surface quality improved with compression. Thermally-compressed Douglas fir veneer had better surface quality with increasing pressure and temperature (Candan et al. 2010).

Low density and porous structure are two main disadvantages of oil palm trunk. However, densifying with heat and compression can improve such shortcomings so that the trunks can be used for different applications. Densification of solid wood and veneer sheets has been used for many years in various applications (Kutnar et al. 2008, Bekhta et al. 2012). Densified wood not only enhances mechanical properties but also improves surface quality. Serbong et al. (1953) concluded that densification significantly improved overall strength characteristics of specimens. The objective of this study was to evaluate the properties of thermally-compressed oil palm wood using hot press process. Data from this study could provide preliminary information on the use of compressed oil palm trunks.

MATERIALS AND METHODS

Oil palm wood was obtained from Muang district, Surat Thani province, south of Thailand. It had an average oven-dry density of 0.34 g cm^{-3}. Dimensions of specimens were 350 mm (grain) × 150 mm (tangential) × 25 mm (radial). The oil palm wood samples were stored in an air-conditioned room at 20 °C and 65% relative humidity (RH) until their moisture content reached equilibrium at 10 to 12%. The samples were then compressed in the radial direction of board by a laboratory hot-press at three different press temperatures, namely, 140, 180 and 220 °C. The pressing duration was 8 min at 2 MPa initial pressure. A thermocouple located in the core of each sample was used to determine the temperature at the centre of the sample during hot pressing. When the temperature reached 100 °C, the pressure was reduced to 1 MPa temporarily to allow steam vent out from the sample, and then raised back to 2 MPa for the rest of the pressing. A total of nine compressed panels, three for each temperature, were used. The amount of compression is quantified by

$$\text{Compression ratio} = (T_b - T_a)/T_b \times 100$$

where T_b = initial thickness and T_a = compressed thickness (Fang et al. 2012). The uncompressed control and compressed samples were conditioned for 2 weeks in a chamber at 20 °C and 65% RH. The modulus of rupture (MOR) and modulus of elasticity (MOE) of the samples were determined for 18 samples, six from each press temperature. The test samples were 20 mm wide and 300 mm long. A Universal testing machine was employed for the bending tests at crosshead speed of 6.30 mm s^{-1}. Hardness of samples was determined employing a Janka test using 11.2 mm diameter steel sphere. The steel ball was used to indent the sample surface perpendicular to the grain. Comten testing unit was used for the hardness test (BS 1957).

From each treatment, 50 mm × 50 mm samples were used to determine the oven-dry density and thickness swelling after soaking for 2 and 24 hours. The same samples were also used for roughness measurement using a stylus profilometer. Four measurements with a tracing length of 15 mm were taken across grain orientation from each hot-pressed side of the sample using a profilo meter. Three roughness parameters, average roughness (R_a), mean peak-to-valley height (R_z) and maximum roughness (R_{max}), were calculated to evaluate effects of hot pressing temperature on the surface quality (Hiziroglu 1996, Hiziroglu & Kosonkorn 2006).

Polyvinyl acetate adhesive was used in bonding shear strength tests. The adhesive was applied to a hot-pressed surface of each sample in the amount of 120 g m^{-2} using a brush. The pair of samples was cold pressed using pressure of 2.04 MPa for 2 min, before they were conditioned overnight at 20 °C and 65% RH. Comten testing unit was used for the shear test of adhesive bonding. Six pairs were shear strength tested for control samples and those pressed at each temperature level (Kasemsiri et al. 2012). In general, wettability of a surface plays an important role in effective utilisation of wood-based products. Therefore, contact angle values of control and treated samples were evaluated. A 1 µL drop of deionised water was deposited on the surface by a dispenser device and the contact angle was measured within 2 s. A computer program of the equipment was employed to determine the contact angle of each sample.

The micrograph of the specimens was examined using scanning electron microscope (SEM). Micrographs of cross-sections of control and samples hot pressed at 220 °C were taken before and after water soaking. The 5 mm × 5 mm × 5 mm cubes for SEM imaging were cut from dried samples and covered with a thin layer of gold by ion sputter coater for 3 min.

RESULTS AND DISCUSSION

The test results of control and thermally-compressed oil palm samples indicated that the average compression ratio was 60% (result not shown). Overall the bending characteristics were improved by hot pressing (Figure 1). A study had also reported positive effects of hot pressing on mechanical properties of solid wood (Yoshihara & Tsunematsu 2007). Probably, densification of oil palm due to hot pressing is the main structural characteristic affecting the bending strength of samples. Linear relationship between density and bending properties of wood and wood-based panels has been well established (Hunt et al.

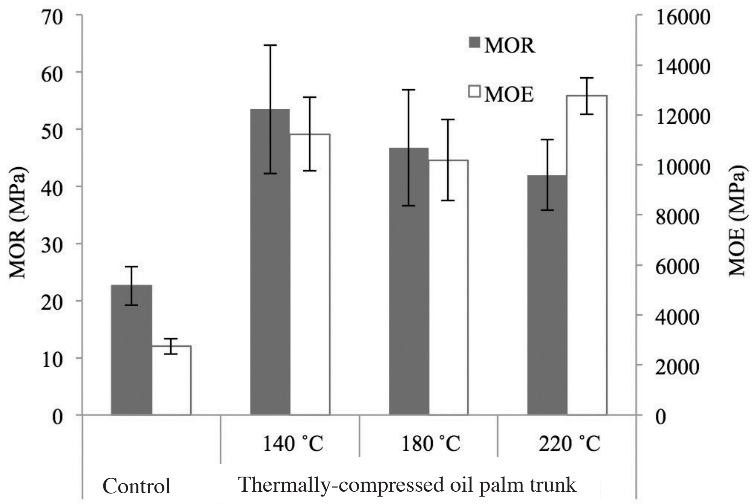

Figure 1 Modulus of rupture (MOR) and modulus of elasticity (MOE) of control and hot-pressed oil palm wood

Table 1 Oven-dry density (g cm^{-3}) of control and hot pressed oil palm wood

Control	Hot-pressed oil palm wood		
	140 °C	180 °C	220 °C
0.34	0.72	0.68	0.73
(0.03)	(0.02)	(0.06)	(0.03)

Values in parentheses are standard deviations

2008, Kiaei & Yeylaki 2011). Control samples in this study had an average oven-dry density of 0.34 g cm^{-3} and hot pressed samples, 0.71 g cm^{-3} (Table 1). However, the MOR of hot-pressed oil palm samples decreased with increasing temperature, while samples compressed at 220 °C had the highest MOE value (Figure 1). This could be due to degradation of wood polymers that led to high cellulose crystallinity at pressing temperatures above 200 °C (Hakkou et al. 2005).

Hardness of samples also improved with hot pressing. Hot pressing at 140 °C resulted in 5.6 times harder samples than control samples (Figure 2). The Janka hardness values of the samples decreased with increasing press temperature. This could be caused by increased brittleness of samples when the amorphous regions of polysaccharides decreased with treatment at high temperature (Phuong et al. 2007).

Oil palm has very porous anatomical structure and can easily absorb water without having substantial swelling. Control samples had very low thickness swelling after 2 and 24 hours water soaking (Figure 3). Samples hot pressed at 140 and 180 °C had significant spring back during soaking, resulting in large values of thickness swelling. For samples hot-pressed at 140 and 180 °C, the average thickness swelling was 43.71% after 2-hour soaking. SEM micrographs also confirmed that cells were significantly compressed and disfigured in dry and soaked samples (Figure 4). Such compressed cells expanded and absorbed a large amount of water during soaking. However, samples exposed to 220 °C had much lower thickness swelling than the other hot-pressed samples. This could be related to fixation of the parenchyma cell wall and degradation of some hemicelluloses at high temperature.

According to surface roughness measurements, hot pressing significantly improved the overall surface quality of samples. Figure 5 illustrates typical roughness profiles and roughness parameters of the samples. The average value of R_a was 19.48 μm for control sample and hot pressing at 140 °C resulted in 2.76 times smoother surfaces, with further improvement for hot pressing at 220 °C (Figure 6). Hot pressing has been reported to significantly improve

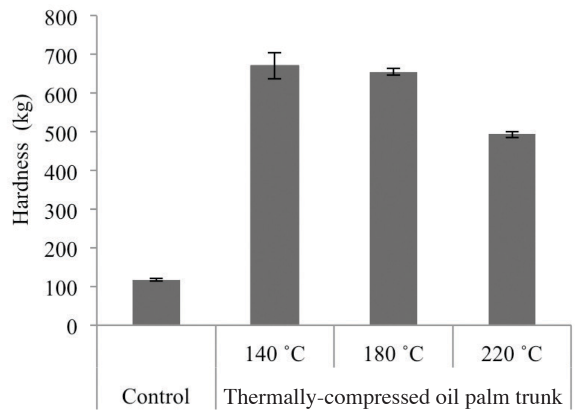

Figure 2 Hardness of control and hot-pressed oil palm wood

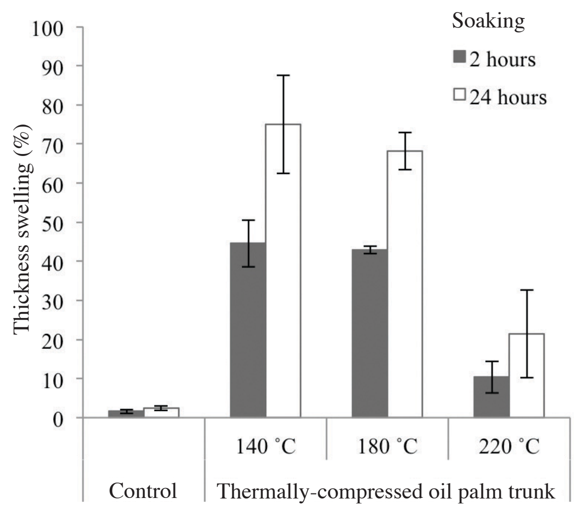

Figure 3 Thickness swelling of control and hot-pressed oil palm wood soaked for 2 and 24 hours

surface quality of Douglas fir and Eastern red cedar (Candan et al. 2010, Kasemsiri et al. 2012). Hot pressing of oil palm trunks may be a practical approach to flatten the parenchyma cells that cause high surface roughness. Hot pressing also softens the surface with heat and levels pits and falls. Generally, smoother surface requires less finishing materials. This reduces the overall cost of finishing.

Surface quality is an important factor affecting adhesive bond strength. Shear tested bond strength of control samples was maximum at 162.60 MPa (Figure 7) because the adhesive

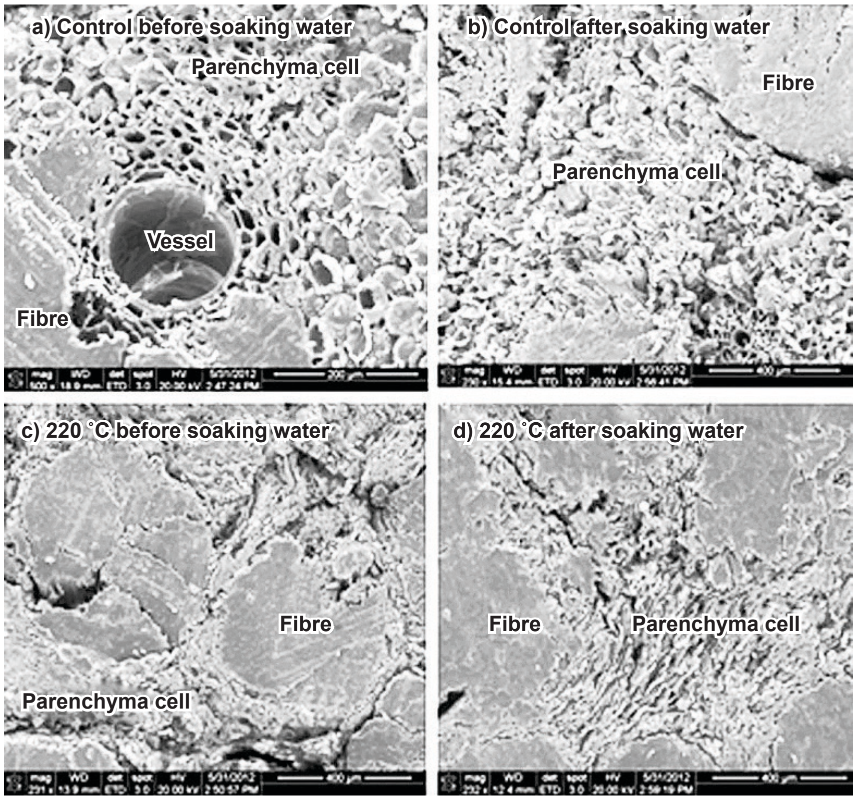

Figure 4 Micrographs of cross-sections of control and hot-pressed samples (220 °C), before and after water soaking

penetrated deep into the voids of the rough surfaces and created interlocking between specimens (Ahmad et al. 2009). However, the bond strength between hot-pressed surfaces was poorer, especially at 220 °C, because compressed smooth surfaces had little penetration of adhesive into samples (Figure 7). Based on visual observation, most of the failure took place within the wood in approximately 80% of the samples.

The contact angle of control samples was 87.6°, which was consistent with results of Ahmad et al. (2009). The angle decreased with compression temperature, with the lowest value at 220 °C. The parenchyma cells contain compressible starch granules and many pits on the primary cell wall weaken the wall. Due to this, after compression at high temperature, cell walls have cracks, especially on the sample surface (Hashim et al. 2011). The increase in affinity to water molecules causes comparatively small contact angles.

The micrographs of control and hot-pressed samples are illustrated in Figure 4. Vascular bundles consisting of fibre and vessel cells were surrounded by parenchyma cells. The vessel and parenchyma cells collapsed with hot pressing. After soaking in water, parenchyma cells in the hot-pressed sample had little spring back because of lock in by components that were molten at temperature of 220 °C and then solidified with cooling.

CONCLUSIONS

The mechanical properties of oil palm trunk could be improved with hot pressing. The main structural change was densification by crushing the parenchyma cells. Micrographs of compressed samples revealed that vascular bundles specifically on the surface layers of samples had collapsed and lumens had been closed. Surface smoothness of samples improved with increasing press temperature. Contact angle and bond strength values decreased with hot pressing temperature, resulting in the lowest values for samples compressed at 220 °C. However, thickness swelling of samples during soaking in water increased with hot pressing.

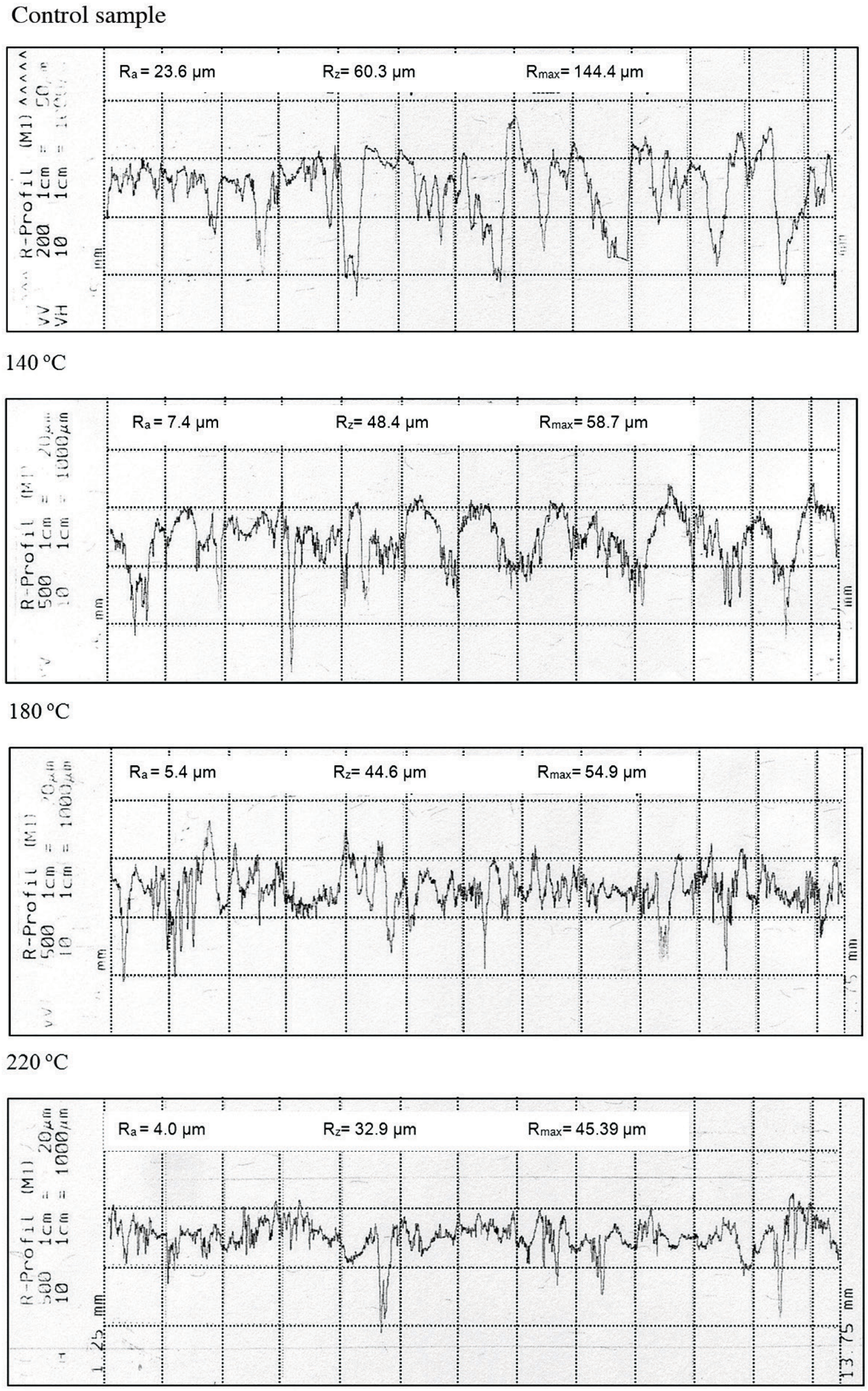

Figure 5 Representative surface roughness profiles at different hot press temperatures; R_a = average roughness, R_z = peak-to-valley height, R_{max} = maximum roughness

ACKNOWLEDGEMENTS

This research was financially supported by Prince of Songkla University, Surat Thani Campus Collaborative Research Fund. The visit of R Choowang to Oklahoma State University was funded by Prince of Songkla University.

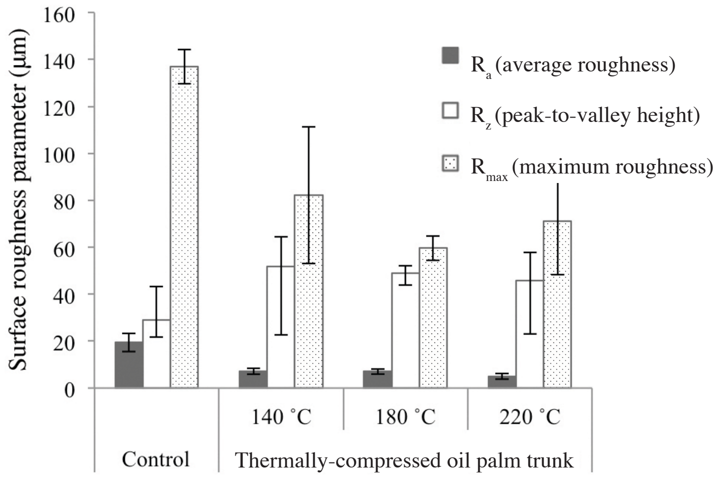

Figure 6 Surface roughness of control and hot-pressed oil palm wood

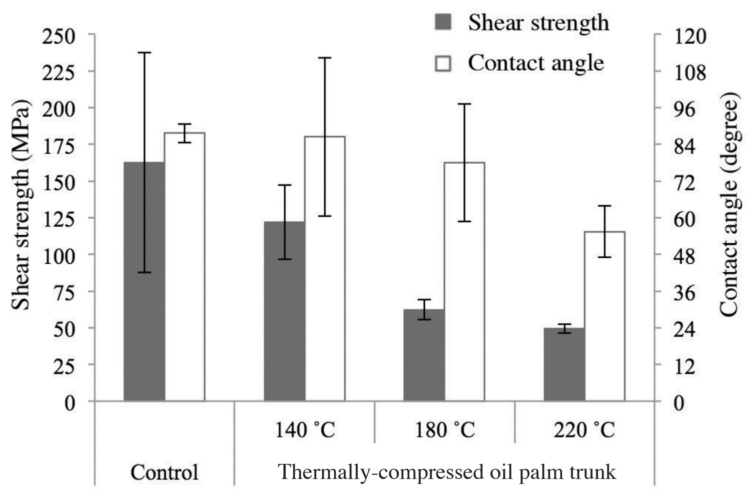

Figure 7 Shear tested bond strength and contact angle of control and hot-pressed oil palm wood

REFERENCES

Abdul Khalil HPS, Fazita Nurul MR, Bhat AH, Jawaid M & Fuadnik NA. 2010. Development and material properties of new hybrid plywood from oil palm biomass. *Material and Design* 31: 417–424.

Ahmad M, Rafatullah M, Sulaiman O, Ibrahim MH, Chii YY & Siddique BM. 2009. Removal of Cu(II) and Pb(II) ions from aqueous solutions by adsorption on sawdust of meranti wood. *Desalination* 247: 636–646.

Ahmad Z, Saman HM & Tahir PM. 2010. Oil palm trunk fiber as a bio-waste resource for concrete reinforcement. *International Journal of Mechanical and Materials Engineering* 5: 199–207.

Bami LK & Mohebby B. 2011. Bio resistance of poplar wood compressed by combined hydro-thermo-mechanical wood modification (CHTM): soft rot and brown rot. *International Biodeterioration and Biodegradation* 65: 866–870.

Bekhta P, Hiziroglu S & Shepelyuk O. 2009. Properties of plywood manufactured from compressed veneer as building material. *Material and Design* 30: 947–953.

Bekhta P & Niemz P. 2003. Effect of high temperature on the change in color, dimension stability and mechanical properties of spruce wood. *Holzforschung* 57: 539–546.

Bekhta P, Niemz P & Sedliacik J. 2012. Effect of pre-pressing of veneer on the glueability and properties of veneer-based products. *European Journal of Wood and Wood Products* 70: 99–106.

Boonstra MJ & Blomberg J. 2007. Semi-isostatic densification of heat-treated radiate pine. *Wood Science and Technology* 41: 607–617.

Boonstra MJ &Tjeerdsma B. 2006. Chemical analysis of heat treatment softwoods. *Holz als Roh- und Werkstoff* 64: 204-211.

BS (British Standard). 1957. *Methods of Testing Small Clear Specimens of Timber, BS 373*. British Standards Institution, London.

Candan Z, Hiziroglu S & McDonald AG. 2010. Surface quality of thermally compressed Douglas fir veneer. *Material and Design* 31: 3574–3577.

Fang C, Mariotti N, Cloutier A, Koubaa A & Blanchet B. 2012. Densification of wood veneers by compression combined with heat and steam. *European Journal of Wood and Wood Products* 70: 155–163.

Hakkou M, Petrissans M, Zoulalian A & Gerardin P. 2005. Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. *Polymer Degradation and Stability* 89: 1–5.

Hashim R, Saari Sulaiman O, Sugimoto T, Hiziroglu S, Sato M & Tanaka R. 2010. Effect of particle geometry on the properties of binderless particleboard manufactured from oil palm trunk. *Material and Design* 31: 4251–4257.

Hashim R, Said N, Lamaming J, Baskaran M, Sulaiman O, Sato M, Hiziroglu S & Sugimoto T. 2011. Influence of press temperature on the properties of binderless particleboard made from oil palm trunk. *Material and Design* 32: 2520–2525.

Hiziroglu S. 1996. Surface roughness analysis of wood composites: a stylus method. *Forest Products Journal* 46: 67–72.

Hiziroglu S & Kosonkorn P. 2006. Evaluation of surface roughness of Thai medium density fiberboard (MDF). *Building and Environment* 41: 527–533.

Hoong YB, Loh FY, Hafizah Nor AW, Paridah MT & Harun J. 2012. Development of a new pilot scale production of high grade oil palm plywood: effect of pressing pressure. *Material and Design* 30: 215–219.

Hunt JF, O'dell J & Turk C. 2008. Fiberboard bending properties as a function of density, thickness, resin, and moisture content. *Holzforschung* 62: 569–576.

Jumaat MZ, Rahim AHA, Othman J & Midon MS. 2006. Strength evaluation of oil palm stem trussed rafters. *Construction and Building Materials* 20: 812–818.

Kasemsiri P, Hiziroglu S & Rimdusit S. 2012. Characterization of heat treated eastern red cedar (*Juniperusvirginiana* L.). *Journal of Materials Processing Technology* 212: 1324–1330.

Khalid H, Zin ZZ & Anderson JM. 1999. Quantification of oil palm biomass and nutrient value in a mature plantation. I. Above-ground biomass. *Journal of Oil Palm Research* 11: 23–32.

Kiaei M & Yeylaki M. 2011. Relationship between number of annual rings in sample cross-section and static bending strength of cypress wood by linear and power models. *World Applied Sciences Journal* 13: 347–353.

Kutnar A, Kamke FA & Sernek M. 2008. The mechanical properties of densified VTC wood relevant for structure composites. *Holz Roh-Werkst* 66: 439–446.

Office of Agricultural Economics. 2012. *Agricultural Statistics of Thailand*. Ministry of Agriculture and Cooperative, Bangkok.

Ozcan S, Ozcifci A, Hiziroglu S & Toker H. 2012. Effect of heat treatment and surface roughness on bonding strength. *Construction and Building Materials* 33: 7–13.

Phuong LX, Shida S & Saito Y. 2007. Effect of heat treatment on brittleness of *Styraxtonkinensis* wood. *Journal of Wood Science* 53: 181–186.

Prasertsan S & Prasertsan P. 1996. Biomass residues from palm oil mills in Thailand: an overview on quantity and potential usage. *Biomass and Bioenergy* 11: 387–395.

Serbong RM, Tarkow H & Stamm AJ. 1953. Effect of heat upon the dimensional stabilization of wood. *Journal of Forest Products* 3: 59–67.

Tjeerdsma BF & Militz H. 2005. Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dry heat-treated wood. *Holz als Roh- und Werkstoff* 63: 102–111.

Yoshihara H & Tsunematsu S. 2007. Bending and shear properties of compressed Sitka spruce. *Wood Science and Technology* 41: 117–131.

Yuliansyah AT, Hirajima T, Kumagai S & Sasaki K. 2010. Production of solid biofuel from agricultural wastes of the palm oil industry by hydrothermal treatment. *Waste Biomass Valor* 1: 395–405.