UNIVERSITI PUTRA MALAYSIA

COMPARATIVE PERFORMANCE BETWEEN NATURAL Endospermum diadenum (Miq.) AIRY SHAW WOOD AND TREATED WOOD IMPREGNATED WITH NANOCLAY AND PHENOLIC RESIN

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By

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Chairman : Professor Zaidon bin Ashaari, PhD
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Sesenduk (*Endospermum diadenum*) is a low density tropical hardwood that has not been fully utilized due to their poor properties in nature. One of the potential ways to improve its properties is through bulking treatment with phenol formaldehyde resin followed by either heating or compressing at high temperature. However, the treated materials release high formaldehyde when treated with low molecular weight phenol formaldehyde (LmwPF). Attempts to reduce formaldehyde emission by incorporating urea in the treatment system have been explored and the results showed that the treated material release lower formaldehyde emission compared to those treated without urea. However, some of the physical and mechanical properties were lower compared to the latter. Incorporation of nano particle to the phenolic matrix could possibly reduce the use of high concentration LmwPF in the treatment system and as a result would lower the formaldehyde emission. In addition, the properties of the treated could be better enhanced.

The aim of the study are to examine the characteristics of LmwPF resin and nanoclay admixture and to determine its effects on the performance of *impreg* wood. Montmorillonite nanoclay nanomer (0.5%-1.5% w/w based on solid PF) was dispersed in LmwPF resin (10%-25% w/v) using ultrasonication technique. The dispersion of nanoclay in LmwPF was examined using X-ray diffractometer (XRD) and Transmission electron microscopy (TEM). XRD and TEM analyses confirmed that the nanoclay dispersion in the resin was in exfoliated form. The results also showed that pH value were significantly affected by the addition of nanoclay in the PF resin. The gelling time of the admixture was reduced as the nanoclay content in the admixture increased.

Air-dry sesenduk (*Endospermum diadenum)* wood was impregnated with these admixtures using vacuum pressure process followed by curing at 150^{0}C for 30 min. The strength properties, dimensional stability and formaldehyde emission were evaluated and compared with *impreg* wood treated with LmwPF *per se.* Scanning electron micrograph (SEM) showed that the admixture penetrated the wood cell wall to some extend but larger amount polymer matrix was found resided in the cell lumen. The results showed that the polymer retention and density of the admixture-impregnated samples were higher than the PF-

impregnated samples. This admixture had successfully bulked the cell wall of the wood and imparted higher dimensional stability. The modulus of rupture (MOR) and modulus of elasticity (MOE), compressive stress and hardness of the admixture-impregnated wood were more superior to the PF-impregnated wood. The admixture was also found able to reduce the formaldehyde emission of the admixture-impregnated wood by 3-5% compared to PF-impregnated wood.

The durability of treated sesenduk wood against white-rot fungus (*Pycnoporous sanguineus)* and subterranean termites (*Coptotermes curvignathus* Holmgren) was evaluated based on weight loss after exposure for 16 weeks and 4 weeks, respectively. The results showed that wood treated with PF and PF/nanoclay admixture increased the resistance of the wood. For fungal decay test, the weight loss for PF-impregnated wood ranged from 2.24%-4.85% and admixture-impregnated samples from 2.11%-4.74%. The weight loss for untreated wood was 31.86%. A similar trend was also observed for the test against termite. The weight loss value ranges from 0.49%-3.40% and 0.37%-3.20% for wood treated with PF and admixture-impregnated wood compared with untreated wood (17.95%) respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PERBANDINGAN PRESTASI ANTARA KAYU *Endospermum diadenum* (Miq.) ASLI DAN KAYU DIRAWAT DENGAN NANOCLAY DAN RESIN FENOLIK

Oleh

NABIL FIKRI BIN LEEMON

Ogos 2015

Pengerusi : Profesor Zaidon bin Ashaari, PhD
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Sesenduk (*Endospermum diadenum*) adalah kayu keras tropika yang berketumpatan rendah dan belum digunakan sepenuhnya kerana sifat semula jadi mereka yang lemah. Salah satu cara yang berpotensi untuk memperbaiki sifat-sifatnya adalah dengan fenol formaldehid resin melalui rawatan pukal diikuti dengan pemanasan atau pemampatan pada suhu yang tinggi. Walau bagaimanapun, kayu yang telah dirawat melepaskan formaldehid tinggi apabila dirawat dengan berat molekul fenol formaldehid yang rendah (LmwPF). Percubaan untuk mengurangkan pelepasan formaldehid dengan menggabungkan urea dalam sistem rawatan telah dijalankan dan keputusan menunjukkan bahawa pelepasan bahan formaldehid adalah lebih rendah berbanding tanpa urea. Walau bagaimanapun, sebahagian daripada sifat-sifat fizikal dan mekanikal adalah lebih rendah berbanding dengan yang tanpa urea. Gabungan nano dengan bahan fenolik mungkin boleh mengurangkan penggunaan kepekatan tinggi LmwPF dalam sistem rawatan dan hasilnya akan mengurangkan pelepasan formaldehid. Di samping itu, sifat-sifat yang lain boleh dipertingkatkan.

Tujuan kajian ini adalah untuk mengenal ciri-ciri LmwPF resin dan campuran nanoclay bagi menentukan kesannya terhadap prestasi kayu impregnasi. Montmorilonit nanoclay nanomer (0.5%-1.5% w/w berdasarkan pepejal PF) telah disebarkan dalam resin LmwPF (10%-25% w/v) menggunakan teknik ultrasonikasi. Penyebaran nanoclay dalam LmwPF diperiksa menggunakan X-ray diffractometer (XRD) dan mikroskop elektron (TEM). Analisis daripada XRD dan TEM mengesahkan bahawa perebakan nanoclay dalam resin adalah dalam bentuk terkelupas. Keputusan juga menunjukkan bahawa nilai pH telah dipengaruhi oleh penambahan nanoclay dalam PF resin. Masa gel bahan campuran telah berkurang seiring peningkatan bahan nanoclay.

Sesenduk (*Endospermum diadenum*) kayu telah dirawat dengan bahan campuran menggunakan proses tekanan vakum diikuti oleh pemejalan pada suhu 150ºC selama 30 minit. Sifat-sifat kekuatan, kestabilan dimensi dan pelepasan formaldehid telah dinilai dan dibandingkan dengan kayu impregnasi dirawat dengan LmwPF. Pengimbas Mikrograf Elektron (SEM) menunjukkan bahawa campuran menembusi dinding sel kayu tetapi jumlah matriks polimer yang lebih besar didapati berada di bahagian sel lumen. Hasil kajian

menunjukkan bahawa kandungan polimer dan ketumpatan sampel campuran-impregnasi adalah lebih tinggi daripada sampel PF-impregnasi. Campuran ini telah berjaya menyumbat di dalam dinding sel kayu dan memberikan kestabilan dimensi yang lebih tinggi. Modulus pecah (MOR) dan modulus keanjalan (MOE), tegasan mampatan dan kekerasan untuk impregnasi campuran adalah lebih bagus berbanding impregnasi PF sahaja. Impregnasi campuran ini juga dapat mengurangkan 3%-5% pelepasan formaldehid berbanding dengan diimpregnasi menggunakan LmwPF sahaja.

Ketahanan kayu dirawat sesenduk terhadap kulat reput putih (*Pycnoporous sanguineus*) dan anai-anai bawah tanah (*Coptotermes curvignathus Holmgren*) dinilai berdasarkan berat selepas terdedah selama 16 minggu dan 4 minggu. Hasil kajian menunjukkan bahawa kayu dirawat dengan PF dan campuran PF/nanoclay meningkatkan rintangan kayu. Untuk ujian kulat reput, kehilangan berat untuk kayu PF-impregnasi adalah di antara 2.24%-4.85% dan campuran-impregnasi dari 2.11%-4.74%. Kehilangan berat untuk kayu yang tidak dirawat adalah 31.86%. Trend yang sama juga diperhatikan untuk ujian terhadap anai-anai. Nilai penurunan berat masing -masing adalah antara 0.49%-3.40% dan 0.37%-3.20% untuk kayu dirawat dengan PF-impregnasi dan campuran-impregnasi berbanding dengan kayu yang tidak dirawat (17.95%).

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I certify that an Examination Committee has met on 19 August 2015 to conduct the final examination of Nabil Fikri bin Leemon on his Master of Science thesis entitled "Comparative Performance between Natural *Endospermum diadenum* (Miq.) Airy Shaw Wood and Treated Wood Impregnated With Nanoclay and Phenolic ResiN". In accordance with Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia and [P.U.(A) 106] 15 March 1998. The committee recommends that the candidate be awarded the Master of Science.

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LIST OF ABREVIATIONS

A	Ampere
AFM	Atomic force microscope
ANOVA	Analysis of Variance
ASE	Anti-swelling Efficiency
ASTM	American Society for Testing and Materials
AWPA	American Wood Preserves' Association
BS	British Standards
CR	Compression ratio
CP	Compression Strength parallel to grain
D	Density
DG	Density Gain
DMRT	Duncan Multiple Range Test
DSC	Differential scanning calorimetric
EMC	Equilibrium Moisture Content
EPMA	Electron probe microscopy analysis
FAO	Food and Agriculture Organization of the United Nations
FE	Formaldehyde Emission
FRIM	Forest Research Institute Malaysia
h	Hours
IMP	Industrial Malaysian Plan
KHz	Kilohertz
kN	Kilo Newton
kPa	Kilopascal
Kv	Kilovolt

LKS	Lesser Known Species
LmwPF	Low Molecular Weight Phenol Formaldehyde
MC	Moisture Content
MDF	Medium Density Fiberboard
MF	Melamine Formaldehyde
Min	Minutes
MMA	Methyl Methacrylate
MMT	Montmorillonite
MPa	Mega Pascal
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MS	Malaysian Standard
MTC	MalaysianTimber Council
MTIB	Malaysian Timber Industrial Boards
Mw	Molecular Weight
NaOH	Sodium hydroxide
NC	Nanoclay
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
nm	Nano meter
PDA	Potato Dextrose Agar
PE	Polyethylene
PEG	Polyethylene Glycol
PF	Phenol Formaldehyde
PLA	Polylactic acid
PP	Polypropylenes

ppm	Part Per Million
PVC	Polyvinyl chloride
RH	Relative Humidity
SEM	Scanning Electron Microscopy
SPSS	Statistical Package for Social Science
TS	Thickness Swelling
TEM	Transmission Electron Microscopy
TGA	Thermo gravimetric analysis
UF	Urea Formaldehyde
UPM	Universiti Putra Malaysia
UV	Ultra Violet
WA	Water Absorption
WHC	Water Holding Capacity
WL	Weight Loss
WPG	Weight Percent Gain
XRD	X-ray diffraction

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Wood has been used by mankind throughout history because of its excellent material properties. Although the use of timber in some markets has decreased, the consumption of timber overall continues to rise. Although wood continues to be used for many applications because of its many excellent material properties (such as a good strength to weight ratio, aesthetic appearance etc.), it also suffers from a number of disadvantages. Dimensional changes in response to altering atmospheric conditions, susceptibility to biological attack and changes in appearance when exposed to weathering place restrictions on the potential end-uses of wood (Hill, 2006).

Excellent properties of wood are the cause of it has been used for millennia by mankind. This long evolution has allowed wood to become an integral part of the ecological cycle. However, some properties of wood are bane cause of dimensional instability with changing moisture, low durability and unsatisfying mechanical properties (Shams and Yano, 2011).

Dimensional instability is one of the major weaknesses in the processing and use of lumber. In order to enhance the properties of low density wood, a number of studies have been carried out through resin impregnation and compression (Zaidon *et al.,* 2009; Nur Izreen *et al.,* 2011; Rabi'atol Adawiyah *et al.,* 2012; Purba *et al.,* 2014; Ang *et al.,* 2014). There are many treatments that have been developed to eliminate the disadvantages of wood since the past few decades ago. These treatments which are also known as wood modification are a mean of altering the material to overcome one or more of its disadvantages. Wood modifications involve the action of chemical, biological or physical agents upon the material, resulting in a desired property enhancement during the service life of the modified wood. Modification of wood can involve active modifications, which result in a change to the chemical nature of the material, or passive modifications, where a change in properties is affected.

The world demand for wood products from tropical forest had been risen recently and this scenario is expected to continue in the years to come. Malaysia is one of the largest exporters of tropical wood products. The wood-based industry in Malaysia is one of the contributors to the export earner and significantly on economy's growth. However, the Malaysian wood industry is heading towards a declining of wood supply since 1995 (Abdul Rahim and Mohd Shahwahid, 2009). Department of statistics, Malaysia (2006) recorded that the logs production volume increased from 6.5 million m^3 in 1970 and decrease gradually to 4.4 million m^3 in 2005. This was due to the loss of potential tree crops as a result of heavy logging activity which than explicit the wood left for future source (Appanah and Harun, 1999).

In order to support the wood-based industry for a long term, possible solution was to use underutilized or lesser known wood species as a new wood source.

Sesenduk *(Endospermum diadenum*) grows in the lowland to lower montane forest, particularly in secondary growth, along streams and on hills and slopes. Due to its poor properties in nature, it is still underutilized, but this wood can have value added by being made into wood suitable for different applications like flooring, panelling and furniture through proper treatment such as chemical modification.

Impregnation with chemical is one of the examples of wood modification. Wood modified using this technology has been used in applications such as flooring. Impregnation of the wood cell wall with chemicals of various types is a very broad area. The impregnation involves the treating of wood with a monomer solution that diffuses into the cell wall, followed by subsequent polymerization. Property improvements occur primarily due to bulking of the cell wall by the impregnant (Hill, 2006).

Bulking treatments can be divided into three classes: nonbonded and leachable; nonbonded and nonleachable; and bonded and nonleachable. For nonbonded and water leachable, the wood cell wall can be bulked with concentrated solutions of salts or sugars. Solutions of manganese, sodium, barium, magnesium, and lithium chloride and solutions of sucrose, glucose, and fructose have been used to reduce the swelling of wood (Stamm *et al.,* 1939; Stamm, 1959). These chemicals make the wood even more hygroscopic, so the wood is usually finished with two coats of varnish to seal the chemical in the wood. These chemicals are also very soluble in water and are easily leached if the treated wood comes into contact with water (Rowell *et al.,* 1981).

Nonbonded and nonleachable is a treatment of wood with aqueous solutions of phenol-formaldehyde resin-forming compounds gives a bulked product where the chemicals are not attached or bonded to the cell wall components but form insoluble polymers which will not leach out in water. Bonded and nonleachable in a bulking treatment can be explained through chemical reactions whereas it is possible to add an organic chemical to the hydroxyl groups on wood cell wall components. This type of treatment reduces the hygroscopicity of the wood as described earlier and also bulks the cell wall with a permanently bonded chemical (Rowell *et al.,* 1981).

Several studies have been conducted through the use of Phenol Formaldehyde resin such Kajita and Imamura (1991) used low molecular weight formaldehyde resin (LmwPF) to improve the physical and biological properties of particle boards, Anwar *et al.,* (2006) and Loh *et al.,* (2011), respectively used this resin to enhance the properties of laminated bamboo and oil-palm stem veneer, while Nur Izreen *et al.,* (2011) and Rabi'atol Adawiyah *et al.,* (2012) used this resin to enhancing the properties of *Dyera costulata* and *Endospermum diadenum.*

PF resin with molecular weight (Mw) of 290-480 is able to penetrate into the cell wall and increase stability. However, if higher molecular weight PF resin is used, e.g. 820, the resin tends to be immobilized upon compressing and bigger portion will remain in the cell lumen. As a result, there will be an apparent lack of compaction even through the weight percent gain maybe about the same. Most of the cured resin will stay in the cell lumen and this does not provide significant stability to the wood (Furuno *et al.,* 2004). A study conducted by Ohmae *et al.,* (2002) found that wood treated with low molecular weight PF resin can obtain ASE values as high as 74% at 30% weight percent gain (WPG). This increase in dimensional stability appears to be caused both by bulking of the cell wall and a cross-linking of resin components within the cell wall.

A complete penetration of resin into wood is vital for an efficient treatment could be achieved through treating thin pieces of wood with LmwPF. Zaidon *et al.,* (2010) treated wood strips (5 mm thick) of sesenduk, jelutong and mahang with LmwPF (Mw600), followed by laminating and compressing them in a hot press to form three-layered compreg laminates. They found that the density of the 12 mm thick compreg laminates increased by two to three times compared with the control. The shear stress at the bonding line was slightly lower or comparable, while hardness was significantly higher than those of untreated control samples. The anti-swelling efficiency of the samples was 60–70%. Mechanical properties of such specimens were increased to some extent as a result of the treatment.

Although majority of the properties of PF-treated wood treated are enhanced, the use of LmwPF would release high amount of formaldehyde during soaking and hot pressing process. Since LmwPF resin contains substantial amounts of methylol groups in the oligomeric chains, some of these methylol groups is released as free formaldehyde upon being exposed to high temperature and humidity (Hoong *et al.,* 2010). Previous researches revealed that this problem can be overcome by incorporating urea in the treating resin, but the performance of the treated product was not as good as those treated without formaldehyde scavenger (Zaidon, 2009).

1.2 Problem Statement

Interests have, nowadays, shifted to using lower density timbers that have good appearance and acceptable properties comparable with those of commercial hardwood. Sesenduk (*Endospermum diadenum*), is a species which have not been fully utilized due to its poor properties. Previous study showed that compreg laminates had been successfully fabricated and have potential for high value added products such parquet flooring, furniture components and panelling (Zaidon *et al.,* 2010).

Phenol Formaldehyde (PF) resin impregnation at considerably high hot pressing pressure is one of the cost effective ways to improve strength properties, dimensional stability and durability of wood against decay (Zaidon *et al.,* 2010). The LmwPF managed to swell the cell wall without bonding to it. The increasing of molecular weight gives a significant reduction in the effectiveness of the resin in improving dimensional stability (Ryu *et al.,* 1993). However, high formaldehyde emission is expected from the treated product. One way to capture the free formaldehyde is by using the formaldehyde scavenger (Rabi'atol Adawiyah *et al.,* 2012). Urea is preferable due to its low cost and has been proven able to reduce the formaldehyde emissions from the *compreg* products made from low density wood, sesenduk (*Endospermum* *diadenum*) and mahang (*Macarangga spp*.) (Zaidon, 2009). The addition of urea can reduce the FE but it still beyond standard threshold limit. Mixing nano particle in phenol formaldehyde could possibly reduce the use of high concentration of resin in the treatment system and as a result would lower the formaldehyde emission and further increased the properties of the treated wood. Recent study by Lu and Zhao (2008) found that incorporating nanoclay in phenolic resin resulted in increment on strength properties of low density wood. Cai *et al.,* (2008) also found that addition of nanoclay in phenolic matrix significantly improved the properties of modified aspen wood.

It should also be noted that method to disperse nanoclay in phenol formaldehyde is crucial before the admixture can be impregnated into the wood structure. Nanoclay is difficult to disperse in resole type phenolic resin compared to novolac due to its three-dimensional structure (Lee and Giannelis, 1997). However, a better dispersion of clay platelets in resol type phenolic resin can be achieved using modified montmorillonite nanoclay (Byun *et al.,* 2001, Wang *et al.,* 2004). It is anticipated that the well dispersed nanoclay in the phenolic resin could serve as a novel resin system to replace the existing resin. This resin system could be used at a lower concentration yet at the same time increase the performance of the treated wood. It is anticipated that the performance of sesenduk (*Endospermum diadenum*) wood treated with low molecular weight phenol formaldehyde resin with and without addition of nanoclay enhance the performance of the product.

1.3 Research Aim and Objectives

The research attempts to enhance the properties of sesenduk (*Endospermun diadenum)* wood properties and at the same time reduce the amount of formaldehyde emission (FE) by impregnating the wood using low concentration of LmwPF/nano clay admixture.

The specifics objectives of the study are;

1. To investigate the characteristics and physical properties of LmwPF/nanoclay admixture synthesised using ultrasonication technique.
2. To determine the optimum treatment parameters on polymer loading of sesenduk wood treated with the admixture.
3. To determine the properties of the *impreg* wood and to correlate them with polymer loading.

REFERENCES

Abdul Rahman, A.S., and Mohd Shahwahid, H.O. (2009). Short and Long Run Effects of Sustainable Forest Management Practices on West Malaysian Log Supply: An Ardl Approach. *Journal of Tropical Forest Science*. 21(4): 369–376.

Abdul Samad, A.R., Mohd Ashhari, Z., and Othman, M.S. (2009). Sustainable forest management practices and West Malaysian log market. *Asian Social Science.* 5(6): 69-76.

Aboubakr, S.H., Kandil, U.F., and Taha, M.R. (2014). Creep of epoxy–clay nanocomposite adhesive at the FRP interface: A multi-scale investigation. *Int J Adhes Adhes*. 54: 1-12.

Adejoye, O.d., and Fasidi, I.O. (2009). Biodegradation of agro-wastes by some Nigerian white-rot fungi. *Bioresources*. 4(2): 816-824.

Adinoyi, M.J., Merah, N. Z., Gasem, M., and Al-Aqeeli, N. (2011). Effect of Sonication Time and Clay Loading on Nanoclay Dispersion and Thermal Property of Epoxy-Clay Nanocomposite*. Key Engineering Materials*. 471-472: 490-495.

Ahmed, B.M., French, J.R.J., and Vinden,P. (2004). Evaluation of borate formulations as wood preservativs to control subterranean termites in Australia. *Holzforschung*. 58(4): 446-454.

Alexandre, M., and Dubois, P. (2000). Polymer-layered silicate nanocomposites: preparation, properties and used of a new class of materials. *Mater. Sci. Eng.* 28: 1-63.

Amarullah, M., Bakar, E.S., Zaidon, A., Mohd Hamami, S., and Febrianto, F. (2010). Reduction of formaldehyde emission from phenol formaldehyde treated oil palm wood through improvement of resin curing state. *Journal of Tropical Wood Science Technology.* 8(1): 9-14.

Anognost, S.E., and Smith, W.B. (1996). Comparative Decay of Heartwood and Sapwood of Red Maple. *Journal of Wood and Fiber Scienc.* 29(2): 189-194.

Ang, A.F., Zaidon, A., Bakar, E.S., Hamami, S.M., and Jawaid, M. (2014). Possibility of Improving the Properties of Mahang Wood (*Macaranga* sp.) through Phenolic *Compreg* Technique. *Sains Malaysiana.* 43(3), 219-225.

Ani, S., Salamah, S., Dahlan, M.J., Salmiah, U., and Roszaini, K. (2005). Durability of timbers for indoor applications in Malaysia. *Timber Technology Buletin.* 37: 139-258.

Anonymous, *Standard Test Method for Laboratory Evaluation of Wood and Other Cellulosic Materials for Resistance to Termites*; (*ASTM D3345-*

74). American Society of Testing and Materials: Philadelphia, U.S.A., 1999.

Anonymous, *Standard Method of Testing Wood Preservatives by Laboratory Soil-Block Cultures*; (*AWPA I0-77*). American Wood-Preservers Association (I-8), 1977.

Anonymous, *Third Malaysia Industrial Master Plan (IMP3), 2006-2020*. Ministry of International Trade and Industries. Kuala Lumpur, Malaysia: MITI, 2006.

Anonymous. *Toxicological Profile for Formaldehyde (Draft)*. Agency for Toxic Substances and Disease Registry (ATSDR). Department of Health and Human Services: U.S.A., Atlanta, 1997.

Anwar, U.M.K., Hiziroglu, S., Hamdan, H., and Abd. Latif, M. (2011). Effect of outdoor exposure on some properties of resin-treated plybamboo*. J. Industrial Crops and Products.* 33: 140–145.

Anwar, U.M.K., Paridah, M.T., Hamdan, H., Zaidon, A., and Bakar, E.S. (2006). Impregnation of bamboo (Gigantochloa scortechinii) strips with low molecular weight phenol formaldehyde resin. *Journal of Bamboo and Rattan.* 5(374): 159-165.

Anwar, U.M.K., Paridah, M.T., Hamdan, H., Bakar, E.S., and Sapuan, S.M. (2008). Impregnation and Drying Process of Bamboo Strips Treated with Low Molecular Weight Phenol Formaldehyde (LMwPF) Resin. *J. Polym. Mater.* 25(2): 35-50.

Aparna, K. (2013). Evaluation of cooper ethanolamine boron based wood preservative to control wood destroying insects. *Mol. Entomol*. 4 (2): 6-12.

Appanah, S., and Harun, I. (1999). Some thoughts on future management and silvicultural treatment of Malaysian forests. JIRCAS-FRIM-JFES Research Meeting, 11-13 October, 1999. Kuala Lumpur.

Appiah-kubi, E., Kankam, C.K., and Adom-Asamoah, M. (2012). Bending and modulus elasticity properties of ten lesser-used timber species in Ghana using structural dimensions. *Ghana J. Forestry*. 28(1), 15-28.

Ashaari, Z., Barnes, H.M., Vasisth, R.C., Nicholas, D.D., and Lyon, D.E. (Eds.). (1990a). *Effect of aqueous polymer treatments on wood properties. Part 1: Treatability and dimensional stability.* Proceedings from International Research Group on Wood Preservation Doc. No. IRG/WP 3610. Rotorua, New Zealand.

Ashaari, Z., Barnes, H.M., Vasisth, R.C., Nicholas, D.D., and Lyon, D.E. (Eds.). (1990b). *Effect of aqueous polymer treatments on wood properties. Part 2: Mechanical properties.* Proceedings from International

Research Group on Wood Preservation Doc. No. IRG/WP. Rotorua, New Zealand.
Baharuddin, G. *Development Progress in Timber Procurement Policies Case Study.* International Tropical Timber Council. International Tropical Timber Organization (ITTO): Malaysia. 2009.

Bakar, E.S., Jun, H., Zaidon, A., and Adrian, C.C.Y. (2014). Durability of phenolic-resin-treated oil palm wood against subterranean termites a white-rot fungus. *International Biodeterioration and Biodegradation.* 85: 126-130.

Barnett, J.R., and Jeronimidis, G. (2003). *Wood Quality and its Biological Basis*. Oxford Blackwell: CRC Press.

Baronas, R., Ivanauskasa, F., Juodeikienėc, I., and Kajalaviciusc, A. (2001). Modelling of Moisture Movement in Wood during Outdoor Storage. *Nonlinear Analysis: Modelling and Control*, 6(2): 3-14.

Beckers, E.P.J., Militz, H., and Stevens, M. (Eds.). (1994). *Resistance of acetylated wood to basidiomycetes, soft rot and blue stain. .* Proceedings from International Research Group on Wood Preservation Doc. No. IRG/WP 94-40021: Bali, Indonesia.

Beckers, E.P.J., Militz, H., and Stevens, M. (Eds.). (1995). *Acetylated solid wood. Laboratory durability test (part II) and field tests*. . Proceedings from International Research Group on Wood Preservation Doc. No. IRG/WP 95-40048: Bali, Indonesia.

Bensadoun, F., Kchit, N., Billotte, C., Bickerton, S., Trochu, F., and Ruiz, E. (2011). A Study of Nanoclay Reinforcement of BiocompositesMade by Liquid CompositeMolding. *International Journal of Polymer Science.* 2011: 1-10.

Bilotti, E., Fischer, H.R., and Peijs, T. (2008). Polymer nanocomposites based on needle-like sepiolite clays: Effect of functionalized polymers on the dispersion of nanofiller, crystallinity, and mechanical properties. *Appl. Polym. Sci.* 107: 1116–1123.
Gindl, W., Dessipiri, E., and Wimmer, R. (2005). Using UV-Microscopy to Study Diffusion of Melamine-Urea-Formaldehyde Resin in Cell Walls of Spruce Wood. *Holzforschung*. 56(1): 103-107.

BSI. 1957. BS 373. Standard Test Methods for Mechanical Properties of Lumber and Wood-Based Structural Material, British Standard Institution: London.

Byun, H.Y., Choi, M.H., and Chung, I.J. (2001). Synthesis and characterization of resol type phenolic resin/layered silicate nancomposites. *Chem. Mater.* 13: 4221–6.

Cai, X., Riedl, B., Wan, H., Zhang, S.Y., and Wang, X.M. (2010). A study on the curing and viscoelastic characteristics of melamine urea formaldehyde resin in the presence of aluminium silicate nanoclays. *Composites Part A: Applied Science and Manufacturing.* 41(5): 604-611.

Cai, X., Riedl, B., Zhang, S.Y., and Wan, H. (2007). Effects of nanofillers on water resistance and dimensional stability of solid wood modified by melamine-urea-formaldehyde resin. *Wood Fiber Sci.* 39(2): 307–18.

Cai, X., Riedl, B., Zhang, S.Y., and Wan, H. (2008). The impact of the nature of nanofillers on the performance of wood polymer nanocomposites. *Composites: Part A.* 39: 727-737.

Candan, Z., and Akbulut, T. (2013). Developing Environmental Friendly Wood Composite Panels by nanotechnology. *Nano wood composites Bioresources.* 3: 3590-3598.

Carol, A. (2010). *Handbook of wood as an engineering material: Biodeterioration of Wood.* Madison: USDA Forest Service, Forest Product Laboratory.

Chang, H.T., and Chang, S.T. (2002). Moisture excluding efficiency and dimensional stability of wood improved by acylation. *Bioresource Technology.* 85: 201-204.

Collins, P.J. (Eds.). (1996). Proceedings from 25th Forest: *Current research activities on wood adhesives*. Victoria, Australia: CSIRO.

Dean, K., Krstina, J., Tian, W., and Varley, R.J. (2007). Effect of Ultrasonic Dispersion Methods on Thermal and Mechanical Properties of Organoclay Epoxy Nanocomposites. *Macromolecular Materials and Engineering.* 292(4): 415-427.

Deka, B.K., and Maji, T.K. (2010). Effect of coupling agent and nanoclay on properties of HDPE, LDPE, PP, PVC blend and Phargamites karka nanocomposite. *Composites Science and Technology.* 70(12): 1755-1761.

Deka, M., Saikia, C.N., and Baruah, K.K. (2000). Treatment of wood with thermosetting resins: Effects on dimensional stability, strength and termite resistance. *Indian Journal of Chemical Technology.* 7: 312-317.

Department of Statistics. Malaysia Economic Statistics— Time Series 2005. Department of Statistics, Kuala Lumpur. 2006.

Devi, R.R., and Maji, T.K. (2011). Preparation and Characterization of Wood/Styrene-Acrylonitrile Copolymer/MMT Nanocomposite. *Journal of Applied Polymer Science.* 122: 2099-2109.

Devi, R.R., and Maji, T.K. (2013). In situ Polymerized Wood Polymer Composite: Effect of Additives and Nanoclay on the Thermal and Mechanical Properties. *Journal of Materials Research.* 16(4): 954-963.

Djebbar, M., Djafri, F., Bouchekara, M., and Djafri, A. (2012). Adsorption of phenol on natural clay. *Appl Water Sci.,* 2: 77–86.

Dunky, M. (1998). Urea-formaldehyde (UF) adhesive resin for wood. *International Journal of Adhesion and Adhesives.* 18: 95–107.

Dupre, F.C., Foucht, M.E., Freese, W.P., Gabrielson, K.D., Gapud, B.D., Ingram, W.H., McVay, T.M., Rediger, R.A., Shoemake, K.A., Tutin, K.K., and Wright, J.T. *Cyclic urea-formaldehyde prepolymer for use in phenol formaldehyde and melamine-formaldehyde resin-based binders (US Patent 6379814).* United States Patent. Georgia-Pacific Resins: Atlanta. 2002.

Dong, J., Chen, L., Liang, B., Kong, J., Zhao, H., and Liang, F. (2009). Research and application progress of water soluble PF. *China Adhesive.* 18 (10): 37-41.

Eastin, I., and Wright, D. (1998). Developing a marketing strategy to introduce lesser-used timber species. *CINTRAFOR News*, 13(2): 1-3.

Eaton, R.A., and Hale, M.D.C. (1993). *Wood: decay, pest and protection*. London: Chapman and Hall.

Edwards, K. (2004). Materials Vol. 1 (pp. 263-264). In C.Vasile, and A.K. Kulshreshtha (Ed.), *Handbook of polymer blends and composites (4 Volumes*). UK: Rapra Technology.

Engku Abdul Rahman Chik. (1971). Basic and Grade Stresses for Strength Groups of Malaysian Timbers. *Malayan Forester.* 34(4): 131-134.

Erfurth, T., and Rusche, H. *The marketing of tropical wood: wood species from South American tropical moist forests*. Forestry department, Food and Agriculture Organization of the United Nations: Rome. 1976.

Evans, C.S., and Hedger, J.N. (2001). Fungi in Bioremediation. In: G.M. Gadd, (Ed.), *Degradation of plant cell wall polymers* (pp. 1-20). Cambridge: University Press.

FAO. (1986). *Wood preservation manual / Mechanical Wood Products Branch, Forest Industries Division, FAO Forestry Department*. Rome: Food and Agriculture Organization of the United Nations.

Fiala, B., and Maschwitz, U. (1991). Extrafloral Nectaries In The Genus Macaranga (Euphorbiaceae) In Malaysia: CoMparative Studies Of Their Possible Significance As Predispositions For Myrmecophytism. *Biological Journal of the Linnean Society.* 44: 287- 305.

Findlay, W.P.K. (1985). The nature durability of wood. In W.P.K. Findlay, (Ed.), *Preservation of timbers in the tropics* (pp. 1-13). Netherlands: Springer.

Fink, J.K. (2003). *Reactive Polymers Fundamentals and Applications: A Concise Guide to industrial polymer*. New York: William Andrew.

Firda, A.S., Bambang, S.M., and Yusram, M.M. (2011). Termite Resistant Properties of Sisal Fiberboards. *Insects.* 2: 462-468.

Foxworthy, F.W. and Woolly, H.W. *Durability of Malayan Timbers*. Malayan Forest Record No. 8, Caxton Press: Kuala Lumpur, Malaya. 1930.

Freeman, M. H., Shupe, T.F., Vlosky, R.P., and Barnes, H.M. (2003). Past, present, and future of preservative-treated wood. *Forest Products Journal.* 53(10): 8-15.

Furuno, T., Imamura, Y., and Kajita, H. (2004). The modification of wood by treatment with low molecular weight phenol-formaldehyde resin: a properties enhancement with neutralized phenolic-resin and resin penetration into wood cell walls. *Wood Science and Technology.* 37: 349-361.

Gabrielli, C.P., and Kamke, F.A. (2009). Phenol-formaldehyde impregnation of densified wood for improved dimensional stability. In Thuvander, F.L., Wallstrom, L.A., Berglund, K.A.H., and Lindberg (2001). Effects of an impregnation procedure for prevention of wood cell wall damage due to drying. *Wood science and Technology.* 34: 473-480.

Giannelis, E.P., Krishnamoorti, R., and Manias, E. (1999). Polymer-Silicate Nanocomposites : Model Systems for Confined Polymers and Polymer Brushes. *Advances in Polymer Science*, 138: 106-147.

Gindl, W., and Gupta, H.S. (2002). Cell-wall hardness and Young's modulus of melamine-modified spruce wood by nano-indentation*. Composites: Part A.* 33:1141–1145.

Gindl, W., Mauller, U., and Teischinger, A. (2003). Transverse compression strength and fracture of spruce wood modified by melamine-formaldehyde impregnation of cell walls. *Wood and Fiber Science.* 35(2): 239-246.

Gold, M.H., Youngs, H.L., and Gelpke, M.D. (2000). Manganese peroxidase. *Met. Ions Biol Syst*. 37: 559-586.
Gold, R.E., Howell, H.N., and Glenn, G.J. (1999). *Subterranean Termites*. The Texas A&M University System: Texas Agricultural Extension Service B-6080. 1999.

Hafezi, S.M., and Doosthoseini, K. (2014). The influence of silane coupling agent and poplar particles on the wettability, surface roughness, and hardness of UF-bonded wheat straw (Triticum aestivum L.)/poplar wood particleboard. *Journal of Forestry Research.* 25(3): 667-670.

Hafiza, A.W., Paridah, M.T., Yuziah, M.Y., Zaidon, A., Adrian, C.Y., and Azowa, I. (2003). Influence of resin molecular weight on curing and thermal degradation of plywood made from phenolic prepreg palm veneers. *The journal of adhesion.* 90(3): 210-229.

Hamid, N.H., Sulaiman, O., Mohammad, A., and Ludin, N.A. (2012). The Decay Resistance and Hyphae Penetration of Bamboo Gigantochloa scortechinii Decayed by White and Brown Rot Fungi. *Int. J. Forestry Res*. 10.1155/2012/572903.

Haupt, R.A., and Sellers, T. (1994). Characterizations of phenol-formaldehyde resol resins. *Ind. Eng. Chem. Res.* 33(3): 693.

Hetzer, M., and Dekee, D. (2008). Wood/polymer/nanoclay composites, environmentally friendly sustainable technology: A review. *Chemical Engineering Research and Design.* 86(10): 1083-1093.

He, G., and Riedl, B. (2003). Phenol-Urea-Formaldehyde Cocondensed Resol Resins: Their Synthesis, Curing Kinetics, and Network Properties. *Journal of Polymer Science: Part B: Polymer Physics.* 41: 1929-1938.

Hill, C.A.S., (2006). *Wood Modification: Chemical, Thermal and Other Processes*. London: John Wiley and Sons.

Hill, C.A.S., Papadopoulos, A.N., and Payne, D. (2004). Chemical modification employed as a means of probing the cell-wall micropore of pine sapwood. *Wood Sci. Technol*., 37(6):475-488.

Homan, W., Tjeerdsma, B., Beckers, E., and Joressen, A. (2000). Structural and other properties of modified wood. In Whistler (Ed.), *World Conference on Timber Engineering* (pp. 1-8). Canada: British Columbia.

Homan, W.J., and Jorissen, A.J.M. (2004). Wood modification developments. *Heron*, 49(4): 361-386.

Hon, D.N.S. (2003). Analysis of adhesives. In A. Pizzi and K.L. Mittal (Ed.), *Handbook of adhesives technology* (pp. 293-324). New York: Marcel Dekker.

Hooi Chiew, T. *Malaysia forestry outlook study*. FAO, Asia-pacific forestry sector outlook study II: Bangkok. 2009.

Hoong, Y.B., Paridah, M.T., Loh, Y.F., Koh, M.P., Luqman, C.A., and Zaidon, A. (2010). Acacia mangium tannin as formaldehyde scavenger for low molecular weight phenol formaldehyde resin in bonding tropical plywood. *Journal of Adhesion Tech.* 24: 1563-1664.

Huang, Y., Fei, B., Zhao, R.J. (2013). Effect of modification with phenol formaldehyde resin on the mechanical properties of wood from Chinese fir. *Bioresources*. 8(1): 272-282.

Imamura, A., Tamura, S., Shimozawa, N., Suzuki, Y., Zhang, Z., Tsukamoto, T., Orii, T., Kondo, N., Osumi, T., and Fujiki, Y. (1998a). Temperature-sensitive mutation in PEX1 moderates the phenotypes of peroxisome deficiency disorders. *Hum. Mol. Genet*. 7: 2089 – 2094.

Islam, M.S., Hamdan, S., Talib, Z.A., Ahmed, A.S., and Rahman, M.R. (2012). Tropical wood polymer nanocomposite (WPNC): The impact of nanoclay on dynamic mechanical thermal properties. *Composite Science and Technology.* 72: 1995-2001.

Jiang, W., Chen, S.H., and Chen, Y. (2006). Nanocomposites from Phenolic Resin and Various Organo-Modified Montmorillonites: Preparation and Thermal Stability. *Journal of Applied Polymer Science.* 102: 5336–5343.

Jiang-Ying, Y.U., Lian-Qi, W., and Xian-kun, C. (2003). Preparation and properties of phenolic resin/ montmorillonite intercalation nanocomposites. *Journal of Wuhan University of Technology –Mater. Sci. Ed*.18: 64–67.

Jianmin, X., Li, Y., Wang, W., and Xia, C. (2009). Preparation of montmorillonite modified phenolic resin for shell process. *China foundry, research and development.* 2009: 1672–6421

Kaboorani, A., Riedl, B., and Blanchet, P. (2013). Ultrasonication Technique: A method for dispersing nanoclay in wood adhesives. *Journal of Nanomaterials.* 2013: 1–9.

Kajita, H., and Imamura, Y., (1991). Improvement of physical and biological properties of particleboard by impregnation with phenolic resin. *Wood Sci. and Tech*., 26(1): 63-70.

Kaynak, C., and Tasan, C.C. (2006). Effects of production parameters on the structure of resol type phenolic resin/layered silicate nanocomposites. *European Polymer Journal.* 42: 1908–1921.

Kenzo, T., Yoneda, R., Matsumoto, Y., Azani, M.A., and Majid, N.M. (2008). *JARQ*. 42(4): 299-306.

Kevin, A., and Stan, L. (2006). *Wood Preservation*. Forest Product Laboratory, USA: Chemical Specialties.

Khairil, M., Wan Juliana, W.A., and Nizam, M.S. (2014). Edaphic Influences On The Tree Species Composition And Community Structure In A Tropical Watershed Forest, Peninsular Malaysia. *Journal of Tropical Forest Science*. 26(2): 284-294.

Kim, J.T., Lee, D.Y., Oh, T., and Lee, D. (2003). Characteristics of Nitrile – Butadiene Rubber Layered Silicate Nanocomposites with Silane Coupling Agent. *Journal of Applied Polymer Science.* 89: 2633–2640.

Kim, M.G., and Watt, C., (1996). Effects of Urea Addition to Phenol-Formaldehyde Resin Binders for Oriented Strandboard. *Journal of Wood Chemistry and Technology.* 16(1): 21-34.

Kim, S.S., Yu, H.N., Hwang, I.U., and Lee, D.G. (2008). Characteristics of wood–polymer composite for journal bearing materials. *Composite Structures*. 86: 279-284.

King, D.A., Davies, S.J., and Noor, N.S.M. (2006). Growth and mortality are related to adult tree size in a Malaysian mixed dipterocarp forest. *Forest Ecology and Management*. 223: 152–158.

Kulshreshtha, A.K., and Vasile, C. (2002). Handbook of polymer blends and composites. (C. V. A. K. Kulshreshtha, Ed.). Rapra Technology Limited.

Kumar, A., Gupta, A., Sharma, K.V., and Suriati, G.B. (2013). Influence of Aluminium Oxide nanoparticles on the physical and mechanical properties of wood composites. *Bioresources*. 8(4): 6231-6241.

Kord, B., Jari, E., Najafi, A., and Tazakorrezaie, V., (2012). Effect of nanoclay on the decay resistance and physicomechanical properties of natural fiber-reinforced plastic composites against white-rot fungi (Trametes versicolor). *Journal of Thermoplastic Composite Materials*. 2012/11/19/0892705712465302.

Koehler, P.G., and Tucker, C.L. (2003). *Subterranean Termites*. University of Florida: Institute of Food and Agricultural sciences (IFAS).

Labidi, S., Azema, N., Perrin, D., and Lopez-Cuesta, J.M. (2010). Organo-modified montmorillonite/poly(ε-caprolactone) nanocomposites prepared by melt intercalation in a twin-screw extruder. *Polymer Degradation and Stability*. 95(3): 382-388.

Landry, V., Riedl, B., and Blanchet, P. (2008). Nanoclay dispersion effects on UV coatings curing. *Progress in Organic Coatings*. 62(4): 400-408.

Lebaron, P.C., Wang, Z., and Pinnavaia, T.J. (1999). Polymer-layered silicate nanocomposites : an overview. *Applied Clay Science.* 15: 11-29.

Lee, E.C., Mielewski, D.F., and Baird, R.J. (2004). Exfoliation and dispersion enhancement in polypropylene nanocomposites by in-situ melt phase ultrasonication. *Polym. Eng. Sci.* 44: 1773–1782.

Lee, J., and Giannelis, E.P. (1997). ACS, Polym. Preprints, Div. *Polym. Chem.* 38: 688–689. Lei, H., Du, G., Pizzi, A., and Celzard, A. (2008). Influence of nanoclay on urea formaldehyde resins for wood adhesive and its model. *J. Apply. Polym. Sci.* 109(4): 2442-2451.

Lei, H., Du, G., Pizzi, A., Celzard, A., and Fang, Q. (2010). Influence of nanoclay on phenol-formaldehyde and phenol-urea formaldehyde resins for wood adhesives. *Wood Adhesives*. 225–234.

Lei, H. (2009). *Synthetic and Natural Materials for Wood Adhesive Resins*, (Unpublished Doctoral Thesis). University Henri Poincare, France.

Leonowicz, A., Matuszewska, A., Luterek, J., Ziegenhagen, D., Wojtas-Wasilewska, M., Cho, N.S., Hofrichter, M., and Rogalski, J. (1999). Biodegradation of lignin by white rot fungi. *Fungal Genetics and Biology*. 27: 175-185.

Levi, F.L.P. (1983). *A guide to the inspection of new houses for wood inhabiting fungi and insects*. Raleigh: NC Agricultural Extension Service.

Lim, S.C., and Chung, R.C.K. *A Dictionary of Malaysian Timbers.* Malayan forest records No. 37, Forest Research Institute Malaysia: Kepong. Kuala Lumpur. 2002.

Lim, S.C., Gan, K.S., and Choo, K.T. (2004). *Identification and utilization of lesser-known commercial timbers in Peninsular Malaysia 1: Ara, Bangkal, Bebusok and Bekoi*. FRIM, Kuala Lumpur: Timber Technology Centre.

Lim, S.C., Choo, K.T., and Gan, K.S. (1999). *Timber notes - light hardwoods VII : (Sentang, Sepetir, Sesendok, Terap, Terentang)*. FRIM, Kuala Lumpur: Timber Technology Centre.

Lin, Q., Yang, G., Liu, J., and Rao, J. (2006). Property of nano-SiO2/urea formaldehyde resin. *Frontiers of Forestry in China*. 2: 230–237.

Lin, Qiaojia, L., Jinghong, R., and Jiuping Y.G. (2005). Study on the property of nano-SiO2/urea formaldehyde resin. *Scientia silvae sinicae (China); Linye Kexue (China)*. 41(2): 129-135.

Linuma, A. (2009). Environmental sustainability concerns in wood production. Asia Plywood Company Sdn Bhd. Online at: http://www.asiaplywoodcompany.com/Environmental%20Sustainability%20Concerns%20in%20Wood.pdf

Liu, R., Cao, J., Xu, W., and Li, H. (2012). Study on the anti-leaching property of chinese fir treated with borate modified by phenol-formaldehyde resin. *Wood research*. 57(1): 111-120

Loh, Y.F., Paridah, M.T ., Hoong, Y.N., Bakar, E.S., Anis, M., and Hamdan, H. (2011). Resistance of phenolic treated oil palm stem plywood against subterranean termites and white-rot decay. *International Biodeterioration and Biodegradation.* 65: 14-17.

Lohrer, W., Nantke, H.J., and Schaaf, R. (1985). Formaldehyd in der Umwelt. *Staub Reinhalt. Luft.* 45: 239-247.

Lu, W., and Zhao, G. (2004). Design of wood/montmorillonite (MMT) intercalation nanocomposite. *Forestry Studies in China*. 6(1): 54-62.

Malaysian Adhesives and Chemicals, MAC Certificate of Analysis; Shah Alam, Selangor. 2000.

Mahfuz H., Uddin, M.F., Rangari, V.K., Saha, M.C., Zainuddin, S., and Jeelani, S. (2005). High strain rate response of sandwich composites with nanophased cores. *Applied Composite Materials*. 12, (3-4): 193–211.

Maloney, T.M. (1977). *Modern particleboard and dry process fibreboard manufacturing*. Miller Freeman, San Fransisco, USA: Backbeat Books.

Mamatha, B.S., Jagadish, R.L., and Aparna, K. (2013). Investigation on the use of nanoclay against white rot fungi. *Int. J. Fundamental Applied Sci*. 2(4): 69-71.

Markessini, C., Athanassiadou, E., and Tsiantzi, S. (Eds.). (2010). Proceedings from 7th European Wood-based Panel Symposium: *Producing panels with formaldehyde emission at wood level*. Hannover, Germany.

Marta, L., Miren, B., Maria, M., and Inaki, M. (2012). Influence of Cure Conditions on Properties of Resol/Layered Silicate Nanocomposites. *Polymer Engineering and Science*. 52: 1161–1172.

Martinez, A.T., Speranza, M., Ruiz-Duenas, F.J., Ferreira, P., Camarero, S., Guillen, F., Martinez, M.J., Gutierrez, A., and Rio, J.C. (2005). Biodegradation of lignocellulosics: microbial, chemical, and enzymatic aspects of the fungal attack of lignin. *International Microbiology*. 8: 195-204.

Martzuky, R. (1989). Release of Formaldehyde by Wood Products. In A. Pizzi (Ed.), *Wood Adhesives, Chemistry and Technology Volume 2* (pp. 307-315). New York and Basel: Marcel Dekker.

Masseat, K., Noor, M.M., Omar, M.K.M., Hamid, A.S., Hafiz, M.M., and Awang, K. (2010). Solid Wood and Veneer Study of 12-Year Old Sesenduk Clone. *Modern Applied Science*. 4(7): 1913-1852.

Masseat, K., Mahat, M.N., Kamal, I., Saleh, A.H., and Kadir, Y.A. (2015). New Clone of Sesenduk (FRIMSRP001). *Journal of Tropical Resources and Sustainable Science*. 3; 135-138.

Mauldin, J.K., and Karl, B.M. (1996). Disodium octaborate tetrahydrate treatments to slash pine for protection against formosan subterranean termite and Eastern subterranean termite (Isoptera: Rhinotermitidae). *J Econ. Ento*. 89(3): 682-687.

Messner, K., Fackler, K., Lamaipis, P., Gindl, W., Srebotnik, E., and Watanabe, T. (2003) Overview of white-rot research: where we are today. In B.

Goodell, D. D. Nicholas and T. P. Schultz (Ed.), *Wood Deterioration and Preservation*, (pp. 73-96). Washington: American Chemical Society.

Morgan, A.B., and Gilman, J.W. (2002). Characterization of Polymer-Layered Silicate (Clay) Nanocomposites by Transmission Electron Microscopy and X-Ray Diffraction : A Comparative Study. *Inorganic Materials*. 87: 1329-1338.

MS. 2005. 1787. Part 15. Wood-based panels -.Determination of Formaldehyde Emission by Desiccators Method. Malaysian Standard Institution. Shah Alam. 2005.

MTC, 2013. Natural Durability of Selected Malaysian Timbers. Malaysian Timber Council. online at: http://www.mtc.com.my/info/images/stories/pdf/natural.pdf.

MTIB. 1986. *100 Malaysian timbers*. Kuala Lumpur: Malaysian Timber Industry Board.

Myneni, R.B., Dong, J., Tucker, C.J., Kaufmann, R.K., Kauppi, P.E., Liski, J., Zhou, L., Alexeyev, V., and Hughes, M.K., (2001). A large carbon sink in the woody biomass of northern forests. *PNAS*. 98: 14784-14789.

Natali, M., Kenny, J., and Torre, L. (2010). Phenolic matrix nanocomposites based on commercial grade resols: synthesis and characterization. *Composites Science and Technology*. 70: 571– 577.

NICNAS. 2006. *National Industrial Chemicals Notification and Assessment Scheme*: Formaldehyde, Priority Existing Chemical Assessment Report No. 28: Australian Government.

Nieminen, S., Heikkinen, J., and Raty, J. (2013). Laser transillumination imaging for determining wood defects and grain angle. *Meas. Sci. Techno.* 24(12): 125401.

Nordahlia, A.S., Hamdan, H., and Anwar, U.M.K. (2013). Wood properties of selected plantation species: khaya ivorensis (african mahogany), azadirachta excelsa (sentang), endospermum malaccense (sesendok) and acacia mangium. *Timber Technology Buletin*. 51: 239 - 258.

Norimoto, M. (2001). Chemical modification of wood. In: *Wood and Cellulosic Chemistry*, 2nd ed. N. S. David, Hon and N. Shirasishi, pp. 270. United State of America: Marcel Dekker.

Norimoto, M., and Grill, J. (1993). Structure and Properties of Chemically Treated Woods. In: N. Shiraishi, H. Kajita, M. Norimoto, (Ed.), *Recent Research on Wood and Wood Based Materials, Current Materials Research*, (pp.135-154). London and New York: Elsevier Applied Science.

Nourbakhsh, A., Farhani, B.F., and Ashori, A. (2011). Nano-SiO2 filled rice husk/polypropylene composites: physico-mechanical properties. *Ind Crops Prod*. 33: 183–187.

Nunes, L., and Nobre, T. (2001). Strategies of Subterranean Termite control in Buildings. In P.B. Lourenco and P. Roca (Ed.), *Historical Constructions* (pp. 867-874). Brasil: Guimares.

Nur Izreen, F.A., Zaidon, A., Rabia'tol Adawiyah, M.A., Bakar, E.S., Paridah, M.T., Hamami, S.M., and Anwar, U.M.K., (2011). Enhancing The Properties Of Low Density Hardwood Dyera Costulata Through Impregnation With Phenolic Resin Admixed Wth Formaldehyde Scavenger. *Journal of Applied Scien*ce. 11(20): 3474-3481.

Nzokou, P., and Kam, D.P. (2004). Influence of wood extractives on moisture sorption and wettability of red oak (Quercus rubra), black cherry (Prunus serotina), and red pine (Pinus resinosa). *Wood and Fiber Science.* 36: 483–492.

Ohmae, K., Minato, K., and Norimoto, M. (2002). The analysis of dimensional changes due to chemical treatments and water soaking for hinoki (Chamaecyparis obtuse) wood. *Holzforschung*. 56(1): 98-102.

Ong, M.S., and Chew, L.T. *Utilization of underutilized species*. Paper presented at the national workshop on utilization of lesser-known timbers, Kuala Lumpur. August 1983.

Orwa, C.A., Mutua, Kindt, R., Jamnadass, R., and Anthony, S. *A tree reference and selection guide version 4.0*. The Agroforestry Database, World Agroforestry Centre: Kenya. 2009.

Oyagade, A.O., and Fasulu, S.A. (2005). Physical and mechanical propeties of Trilepisium madagascariense and Funtumia elastica wood. *Journal of Tropical Forest Scienc.* 17: 258-264.

Ozcifci, A., and Ayar, S. (2011). The effects of some impregnation parameters on modulus of rupture and modulus of elasticity of wood. *Wood research*. 52(2): 277-278.

Pandey, K.K., and Pitman, A.J. (2003). FTIR studies of the changes in wood chemistry following decay by brown-rot and white-rot fungi. *International Biodeterioration and Biodegradation*. 52: 151-160.

Pappas, J., Patel, K., and Nauman E.B. (2004) Structure and properties of phenolic resin/nanoclay composites synthesized by *in situ* polymerization. *Journal of Applied Polymer Science.* 95: 1169–1174.

Paridah, M.T., and Loh, Y.F. (2009). Enhancing the Performance of Oil Palm Stem Plywood via Treatment with Low Molecular Weight Phenol Formaldehyde. In: *Research on Natural Fiber Reinforced Polymer Composites*, pp. 281–299. Selangor: Universiti Putra Malaysia Press.

Paridah, M.T., Ong, L.L., Zaidon, A., Rahim, S., and Anwar, U.M.K. (2006). Improving the dimensional stability of multi-layered strand board through resin impregnation. *Journal of Tropical Forest Science.* 18: 166–172.

Pavlidou, S., and Papaspyrides, C.D. (2008). A reviewon polymer–layered silicate nanocomposites. *Progress in Polymer Scienc*e. 33(12): 1119-1198.

Peralta, R.C.G., Menezes, E.B., Carvalho, A.G., and Menezes, E.L.A. (2003). Feeding Preferences of Subterranean Termites for Forest Species associated or not to Wood Decaying Fungi. *Floresta e Ambiente*. 10(2): 58-63.

Pereira, C.M.C., Rodrigues, J., Correia, N., and Marques, A.T. (Eds.). (2005). Proceedings from 9th International Conference of Chemical Engineering: *Kinetic Studies of Unsaturated Polyester-Layered Silicate Nanocomposites at Different Temperatures*. University of Coimbra: Portugal.

Pizzi, A., and Mittal, K. L. (1994). *Advanced wood adhesives technology (1st Ed.)*. New York: Marcel Dekker.

Pizzi, A. (1983). *Wood Adhesives chemistry and technology Vol. 2*. New York: Marcel Dekker.

Pizzi, A. (1994). Phenolic Resin Adhesives. In A. Pizzi, and K.L. Mittal (Ed.), *Handbook of Adhesive Technology* (pp. 97-119). New York and Basel: Marcel Dekker.

Pizzi, A. (2003). Phenolic resin adhesive. In A. Pizzi, and K.L. Mittal (Ed.), *Handbook of Adhesive Technology* (pp. 329-346). New York and Basel: Marcel Dekker.

Purba, T.P., Zaidon, A., Bakar, E.S., and Paridah, M.T. (2014). Effects Of Processing Factors and Polymer Retention On The Performance Of Phenolic-Treated Wood. *Journal of Tropical Forest Science.* 26(3): 320-330.

Qutubuddin, S., and Fu, X. (2002). Polymer-Clay nanocomposites: Synthesis and Properties. In Morton Rosoff (Ed.), *Nano-Surface Chemistry* (pp. 653-673). New York: Marcel Dekker.

Rabi'atol Adawiah, M.A., Zaidon, A., NurIzreen, F.A., Bakar, E.S., Mohd Hamami, S., and Paridah, M.T. (2012) Addition of urea as formaldehyde scavenger of low molecular weight phenol formaldehyde treated compreg wood. *J. Trop. For. Sci.* 24: 265-274.

Ray, S., and Okamoto, M. (2003). Polymer/layered silicate nanocomposites: a review from preparation to processing. *Progress in Polymer Science*. 28(11): 1539-1641.

Rezaur, R.M., Hamdan, S., Saiful, I.M., and Saleh, A.A. (2012). Influence of Nanoclay/Phenol Formaldehyde Resin on Wood Polymer Nanocomposites. *J. Appl. Sci*.12: 1481–1487.

Roffael, E., *Formaldehyde release from particle board and other wood based panels.* Malayan forest records no. 37, Forest Research Institute Malaysia: Kepong, Kuala Lumpur. 1993.

Roh, S.C., Hyuk, J.K., and Chang, K.K. (2012) Nanocomposites of Novolac Type Phenolic Resins and Organoclays: The effects of the resin molecular weight and the amine salt structure on the morphology and the mechanical properties of the composites. *Macromolecular Research*. 20: 496–502.

Rokiah, H., Siti Hazneza, A.H., Othman, S., Norli, I., Mahmamad Hakim, I., Hasnah, H.J, and Samliah, U. (2009). Extractable Formaldehyde From Waste Medium Density Fibreboard. *Journal of Tropical Forst Science*. 21(1): 25-33.

Roumeli, E., Pavlidou, E., Papadopoulou, E., Vourlias, G., Bikiaris, D., Paraskevopoulos, K.M., and Chrissafis, K. (2012). Synthesis, characterization and thermal analysis of urea formaldehyde/nanoSiO2 resins. *Thermochimica Acta.* 527: 33–39.

Rowell, R.M. (2005). Chemical Modification of Wood. In: R. M. Rowell (Ed.), *Handbook of Wood Chemistry, Wood Composites* (pp. 381–420). Boco Raton: CRC Press.

Rowell, R.M. (2006). Acetylation of wood-journey from analytical technique to commercial reality. *For. Prod. J.* 56(9): 4-12.

Rowell, R.M., and Banks, W.B., *Water repellency and dimensional stability of wood (FPL Rep. 50)*. General Technical Reports, Forest Products Laboratory, U.S. Department of Agriculture: Madison. 1985.

Rowell, R.M., and Konkol, P., T*reatments that enhance physical properties of wood (FPL Rep. 55).* General Technical Reports, Forest Products Laboratory, U.S. Department of Agriculture: Madison. 1987.

Rowell, R.M., and Youngs, R.L.. *Dimensional stabilization of wood in use (FPL Rep. 0243)*. General Technical Reports, Forest Products Laboratory, U.S. Department of Agriculture: Wisconsin. 1981.

Rowell, R.M., and Ellis, W.D. (1978). Determination of dimensional stabilization of wood using the water-soak method. *Wood and Fiber*. 10(2): 104-111.

Ryu, J.Y., Takahashi, M., Imamura, Y., and Kajita, H. (1993). Effects of molecular weight and some other properties of resins on the biological resistance of phenolic resin treated wood. *Mokuzai Gakkashi*. 39(4): 486-492.

Ryu, J.Y., Takahashi, M., Immamura, Y., and Sato, T. (1991). Biological resistance of phenol resin treated wood. *J. Japan Wood Res. Soc*. 37: 852–858.

Rozman, H.D., Kumar, R.N., Khalil, H.P.S., Abusamah, A., and Abu, R. (1997). Fibre Activation With Glycidyl Metacrylate and Subsequent Copolymerization With Diallyl Phthalate. *European Polymer Journal*. 33(8): 1213-1218.

Salari, A., Tabarsa, T., Khazaeian, A., and Ahmadreza, S. (2012). Effect of nanoclay on some applied properties of oriented strand board (OSB) made from underutilized low quality paulownia (Paulownia fortunei) wood. *J. Wood Sci*. 58: 513–524.

Salari, A., Tabarsa, T., Khazaeian, A., and Ahmadreza, S. (2013). Improving some of applied properties of oriented strand board (OSB) made from underutilized low quality paulownia (Paulownia fortunie) wood employing nano-SiO2. *Industrial Crops and Products*. 42: 1– 9.

Scheffer, T.C., and Morrell, J.J. (1998). *Natural Durability of Wood: A Worldwide Checklist of Species*. Corvallis: College of Forestry, Forest Research Laboratory, Oregon State University.

Schmidt, K., Grunwald, D., and Pasch, H. (2006). Preparation of phenol–urea–formaldehyde copolymer adhesives under heterogeneous catalysis. *Journal of Applied Polymer Science*. 102: 2946–2952.

Schwarze, F.W.M.R., Engels, J., and Mattheck, C. (2000). Fungal strategies of wood decay in trees. Springer-Verlag, Berlin Heidelberg.

Sergio, M., Martínez, S., Gutierrez S.G., Carlos, F., Garza, R., Tania, J., Galvan, V., Juan F., Cordero, C., Carlos, E., and Luna, H. (2013). Purification and Partial Characterization of a Thermostable Laccase from Pycnoporus sanguineus CS-2 with Ability to Oxidize High Redox Potential Substrates and Recalcitrant Dyes. In Y. Patil and P. Rao (Ed.), *Applied Bioremediation - Active and Passive Approaches*. (394) Intech: Creative Community.

Shams, M.I., Kagemori, N., and Yano, H. 2006. Compressive deformation of wood impregnated with low molecular weight phenol formaldehyde (PF) resin IV: species dependency. *J. Wood Sci*. 52:179-183.

Shams, M.I., and Yano, H. (2011). Compressive deformation of phenol formaldehyde (PF) resin-impregnated wood related to the molecular weight of resin. *Wood Science and Technology.* 45: 73–81.

Shary, S., Ralph, S.A., and Hammel, K.E. (2007). New insights into the ligninolytic capability of a wood decay ascomycete. *Applied and Environmental Microbiology*. 73: 6691-6694.

Shawkataly, A.K., and Hashim, R., (2004). *Komposit panel berasaskan kayu.* Pulau Pinang, Malaysia: Universiti Sains Malaysia.

Simpson, W., and Tenwolde, A., *Physical properties and moisture relations in wood (FPL Rep.113)*. Forest Products Laboratory, U.S. Department of Agriculture, Forest Service: Madison. 1999.

Smith, D.M., and Allen, S.J. (1996). Measurement of sap flow in plant stems. *J. Exp. Bot.* 47(12): 1833-1844.

Soerianegara, I., and Lemmens, R.H.M.J. (1993). *Plant resources of South-East Asia No 5, (1), Timber trees: Major commercial timbers*. Wageningen, Netherlands: Pudoc Scientific Publishers.

Soljacic, I., and Katovic, D. (1988). The effect of heating on the release of formaldehyde from durable-press finished fabrics. *Journal of Society of Dyers and Colourists*. 104(10): 384-386.

Spear, M., and Walker, J. (2006). Primary wood processing: Principles and Practice. In J. Walker (Ed.), *Dimensional Instability* (pp. 95-120). The Netherlands: Springer.

Stamm, A.J. (1959). Dimensional stabilization of wood with thermal reactions and formaldehyde crosslinking. *Tappi*. 42(1): 39-44.

Stamm, A.J. (1964). *Wood and Cellulose Science*. New York: Ronal Press.

Stamm, A.J. (1977). Dimensional changes of wood and their control. In: I.S. Goldstein (Ed.), *Wood Technology: chemical aspect* (pp. 115-139). Washington: ACS Symposium.

Stamm, A.J. and Baechler, R.H. (1960). Decay resistance and dimensional stability of five modified woods. *Forest Product Journal.* 10: 22-26.

Stamm, A.J., and Seborg, R.M. (1941). Resin treated laminated, compressed wood. *Trans. Am. Inst. Chem. Eng.* 37: 385–397.

Stamm, A.J., and Seborg, R.M., *Resin treated wood impreg (FPL Rep. 1380).* Forest Products Laboratory, U.S. Department of Agriculture, Forest Service: Madison. 1962.

Stamm, A.J., and Seborg, R.M., *Resin treated wood impreg (FPL Rep. 1380).* Forest Products Laboratory, U.S. Department of Agriculture, Forest Service: Madison. 1962.

Stephen, R.S., and Kutscha, N.P. (1987). Effect of resin molecular weight on bonding of flakeboard. *Wood and Fiber Science.* 19: 353-356.

Sundin, E.B. (Eds.). (1985). Proceedings from 19th International Particleboard/Composite Materials Symposium: *The formaldehyde situation in Europe*. Washington State University, Pullman: Washington.

Tabarsa, T., Jahanshahi, S., and Ashori, A. (2011). Mechanical and physical properties of wheat straw boards with a tannin modified phenol formaldehyde adhesive, *Composites: Part B*. 42: 176-80.

Tamashiro, M., Fujii , J.K., and Lai, P.Y. (1973). A simple method to observe, trap and prepare large numbers of subterranean termites for laboratory and field experiments. *Environ. Entomol.* 2: 721-722.

Tasan, C.C., and Kaynak, C. (2009) Mechanical Performance of Resol Type Phenolic Resin/Layered Silicate Nanocomposites. *Polym. Compos.* 30: 343–350.

Taylor, A.M., Gartner, B.L., and Morrell, J.J. (2002). Heartwood formation and natural durability—a review. *Wood and Fiber Science.* 34: 587–611.

Tho, Y.P. (1992). *Termites of Peninsular Malaysia*. Forest Research Institute Malaysia: Kirton.

Uddin, F., (2008). Clays, Nanoclays, and Montmorillonite Minerals. *Metallurgical and Materials Transactions A.* 39: 2804-2814.

Vaughan, T.L., Shapiro, J.A., Burt, R.D., Swanson, G.M., Berwick, M., Lynch, C.F., and Lyon, J.L. (1996). Nasopharyngeal cancer in a low-risk population: defining risk factors by histological type. *Cancer Epidemiol Biomarkers Prev*. 5(8): 587-593.

Vaughan, T.L., Stewart, P.A., Teschke, K., Lynch, C.F., Swanson, G.M., Lyon, J. L., and Berwick, M. (2000). Occupational exposure to formaldehyde and wood dust and nasopharyngeal carcinoma. *Occup. Environ. Med.* 57(6): 376-384.

Vaughan, T.L., Strader, C., Davis, S., and Daling, J.R. (1986). Formaldehyde and cancers of the pharynx, sinus and nasal cavity: I. Occupational exposures. *Int. J. Cancer.* 38(5): 677-683.

Vukusic, S.B., Katovic, D., Schramm, C., Trajkovic, J., and Sefc, B. (2006). Polycarboxylic acids as non-formaldehyde anti-sweeling agents for wood. *Holzforschung*. 60(4): 439-444.

Willeitner, H., and Liese, W. (1992). *Wood protection in tropical countries: A manual on the knowhow*. Rossdorf, Germany TZ-Vertriebs-Ges: GTZ (GmBH) Technical Cooperation.

Wang, H., Zhao, T., Yan, Y., and Yu, Y. (2004). Synthesis of resol-layered silicate nanocomposites by reaction exfoliation with acidmodi Wed montmorillonite. *J. Appl. Polym. Sci*. 92; 791–7.

Wang, S., Qiu, H., Zhou, J., and Wellwood, R., *Phyllosilicate Modifided Resins for Lignocellulousic Fiber Based Composite Panels (US 20080234423)*. United States Patent, Alberta Research Council: Alberta. 2008.

Wagener, R., and Reisinger, T.J.G. (2003). A rheological method to compare the degree of exfoliation of nanocomposites. *Polymer*. 44 (24): 7513–7518.

Wahab, N.H.Ab., Paridah, M.T., Yunus, N.Y.M., Ashaari, Z., Yong, C.C.Y., and Ibrahim, N.A. (2013). Influence of Resin Molecular Weight on Curing and Thermal Degradation of Plywood Made From Phenolic Prepreg Palm Veneers. *The Journal of Adhesion*. 90(3): 210-229.

Waldermar, J.H., and Andre, J.M. (2004). Wood modification developments. *Heron*. 49: 361-386.

Wallstrom, L., and Lindberg, K.A.H. (1999). Measurement of cell wall penetration in wood of water-based chemicals using SEM/EDS and STEM/EDS technique. *Wood Sci. Technol*. 33: 111–122.

Wellon, J.D. (1981). Bonding in wood composites. In: J. F Olicver (Ed.), *Adhesion in cellulosics and wood composites* (pp.127-146). New York: Plenum Press.

Weslin, J., Djupstrom, L.B., Schroeder, M., and Widenfalk, O. (2011). Long-term priority effects among insects and fungi colonizing decaying wood. *Journal of Animal Ecology*. 80, 1155–1162

West, R.D., and Malhotra, V.M. (2006). Rupture of nanoparticle agglomerates and formulation of Al2O3-epoxy nanocomposites using ultrasonic cavitation approach: effects on the structural and mechanical properties. *Polymer Engineering and Science*. 46(4): 426–430.

Weyerhaeuser, *Material Safety Data Sheet, Medium-Density Fiberboard* (*WC333–06)*. Weyerhaeuser Material Safety Data Sheet, Wood Composites MSDS: Washington. 2003.

Wu, G., *Low-volatile and strongly basic tertiary amino alcohols as catalyst for the manufacture of improved phenolic resins (US 5623032).* United States Patent, Angus Chemical Company: Buffalo Grove. 1997.

Wu, Z., Zhou, C., and Qi, R. (2002). The Pr e pa ration of P he n o l i c Res i n/Monmorillonite Nanocomposites by Suspension Condensation Polymerization and Their Morphology. *Polym. Compos.* 23: 634.

Xia, H., and Wang, Q. (2003). Preparation of conductive polyaniline/nanosilica particle composites through ultrasonic irradiation. *Journal of Applied Polymer Science*. 87(11): 1811–1817.

Xu, L., James, L., and Lee. (2005). Kinetic Analysis and Mechanical Properties of Nanoclay Reinforced Unsaturated Polyester (UP) Resins Cured at Low Temperatures. *Polymer Engineering and Science*. 45(4): 496-509.

Yang, T.H., Lin, C.J., Wang, S.Y., and Tsai, M.J. (2005). Characteristics of particleboard made from recycled wood-waste chips impregnated with phenol formaldehyde resin. *Build Environ.* 42(1): 189–195.

Yano, H. (2001). Potential strength for resin-impregnated compressed wood. *J. of Materials Science.* 20: 1127-1129.

Yano, H., Hirose, A., and Inaba, S. (1997). High-strength wood-based materials. *J. Mat. Sci.* 16: 1906–1909.

Yasuda, R., and Minato, K. (1995). Chemical modification of wood by non-formaldehyde crosslinking reagents. *Wood Science and Technology.* 29(4): 243-251.

Yap, M.G.S., Chia, L.H.L., and Teoh, S.H. (1990). Wood polymer composites from some tropical hardwood. *J. Wood Chem. Technol.* 10(1): 1–19.

Yazaki, Y. (Eds.). (1996). Proceedings from 25th Forest Products Conference: *What comes after phenolic-type adhesives for bonding wood to wood?*. Victoria, Australia: CSIRO Division of Forestry and Forest Products.

Young, S. Formaldehyde Emission from Solid Wood-will it become an issue? Timber test laboratories. Unpublished data.

Zabel, R.A., and Morrell, J.J. (1992). *Wood microbiology*. USA: Academic Press.

Zaidon, A., Edi, S.B., and Paridah, M.T. (Eds.). (2010). Proceedings from The International Convention Of Society Of Wood Science And Technology And United Nation Economic Commission For Europe: *Compreg Laminates Made From Low Density Tropical Hardwood*. Geneva, Switzerland.

Zaidon, A. Improvement of raw materials from underutilised timber species through chemical and densification treatments for value added products. Ministry of Science and Technology, Malaysia (2009); Rep. No. 06-01-04-SF0656.

Zaidon, A., Moy, C.S., Sajap, A.S., and Paridah, M.T. (2003). Resistance of CCA and boron-treated rubberwood composites against termites, Coptotermes curvignathus Holmgren. *Pertanika Journal Science and Technology.* 11: 65–72.

Zeng, Q.H., Yu, A.B., Lu, G.Q., and Paul, D.R. (2005). Clay-based polymer nanocomposites: Research and commercial development. *Journal of Nanoscience and Nanotechnology.* 5: 1574–1592.

Zhao, G., and Lu, W.H. (2008). Structure and characterization of Chinese fir (Cunninghamia lanceolata) wood/MMT intercalation nanocomposite (WMNC). *Frontiers Forests in China.* 3: 121- 126.

Zhang, H., Zhang, J., Song, S., Wu, G., and Pu, J. (2011). Modified nanocrystalline cellulose from two kind of modifiers used for improving formaldehyde emission and bonding strength of urea formaldehyde adhesive. *Bioresources*. 6(4): 4430-4438.

Zelalem, G., Pradeep, P., and Omprakash, S. (2014). The influence of physical and mechanical properties on quality of wood produced from pinus patula tree grown at arsi forest. *Journal of Plant and Animal Sciences*. 2(4): 32-41.

Zuhaidi, A.Y., and Noor, M.M. (2002) .Sentang. In B. Krisnapillay (Ed.), *A Manual for Forest Plantation Establishment in Malaysia* (pp. 199–204). Kuala Lumpur: Forest Research Institute Malaysia.