UNIVERSITI PUTRA MALAYSIA

FORMALDEHYDE EMISSION AND PROPERTIES OF COMPREGNATED WOOD TREATED WITH LOW MOLECULAR WEIGHT PHENOL FORMALDEHYDE WITH ADDITION OF UREA

RABI’ATOL ADAWIAH BINTI MOHD ALI

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master Science

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Chairman: Professor Zaidon Ashaari, PhD

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Phenol formaldehyde (PF) resin impregnation and compression at considerable high hot pressing pressure of jelutong and sesenduk is attractive for the improvement of strength properties, dimensional stability and decay durability. The formaldehyde emission (FE) from the treated materials is, however, very high especially when low molecular weight resin is used. Attempt to reduce the formaldehyde emission was made by introducing urea in the treating solution. In this study, urea was used to scavenge the excess formaldehyde produce from the PF-compregnated wood. The urea was preferable as scavenger since it is efficient in reducing formaldehyde emission and low manufacturing cost. The experimental design of this study included impregnation of jelutong (*Dyera costulata*) and sesenduk (*Endospermum diadenum*) strips with 20 %, 30 % and 40 % low molecular weight phenol formaldehyde (LmwPF, M_w 600) mixed separately with urea (30% based on solid PF), pre-curing at 60^{o}C for certain periods (7 h, 8 h and 9 h) and subsequently compressed to a compression ratio (CR) of 80 % in a hot press temperature of 150^{o}C for 20 min. The formaldehyde emission, physical and mechanical properties and durability of the *compreg* wood for each treatment combination was analyzed. Addition of urea into PF resin successfully reduced formaldehyde emission by 97 % for both *compreg* woods. The results also showed the dimensional stability of the *compreg* jelutong and sesenduk increased by 60 % and 52 % in anti swelling efficiency (ASE), respectively. When compared between strips treated with and without the presence of urea, the efficiency in preventing swelling of *compregs* treated with PF solution admixed with urea was more successful. Based on the *compreg* properties evaluated, the optimum treatment combination of fabricating jelutong and sesenduk was using 30 % PF mixed with 30% urea (based on solid PF), precuring at 60^{o}C for 8 h followed by compressing to 80 % CR at 150^{0}C for 20 min. This treatment combination was then applied to produce *compreg* laminates. Three layers laminated *compreg* jelutong and sesenduk were fabricated by assembling the impregnated strips perpendicular (cross) or parallel to each other, followed by compression in a hot press. Compared to the untreated solid wood of the same size, both parallel and cross laminated *compreg* wood had superior properties. The density of the *compreg* wood increased by 78 % to 117 % from its original densities. The modulus of rupture (MOR) and modulus of elasticity (MOE) were increased by 24 %, except for the parallel laminates of sesenduk which had lower values than the untreated solid wood. The study also revealed that shear strength at the bonding glueline was higher for the parallel than for the cross laminated *compreg* wood. Parallel *compreg* laminates had bonding shear strength comparable to that of solid wood. The treatment used in the study also rendered *compreg* laminates to be highly resistance towards towards white rot fungus (*Pycnoporous sanguineus)*.

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

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Penerapan dan pemampatan melalui resin phenol formaldehid (PF) pada suhu yang tinggi adalah menarik untuk memperbaharui sifat kekuatan, kestabilan dimensi dan daya ketahanan kayu menentang pereputan. Walau bagaimanapun, pelepasan formaldehid daripada bahan yang dirawat adalah sangat tinggi terutama apabila menggunakan resin yang berat bermolekul rendah. Percubaan untuk mengurangkan pelepasan formaldehid telah dilakukan dengan memasukkan urea ke dalam

larutan rawatan. Di dalam kajian ini, urea telah digunakan untuk mengurangkan formaldehid yang berlebihan daripada kayu yang diserap mampat dengan PF. Urea telah dipilih kerana efisyen mengurangkan pelepasan formaldehid dan kos pembuatan yang bersesuaian. Pemboleh ubah eksperimen termasuklah penyerapan oleh kepingan jelutong (*Dyera costulata*) dan sesenduk (*Endospermum diadenum*) melalui 20 %, 30 % dan 40 % phenol formaldehid yang mempunyai berat molekul rendah (berat molekul 600) dicampur secara berasingan dengan urea (30 % berdasarkan berat pepejal PF), pra pengeringan pada 60^{o}C selama beberapa jam (7, 8 dan 9 jam) dan seterusnya dimampatkan kepada purata kemampatan 80 % pada suhu 150^{o}C selama 20 minit. Pelepasan formaldehid, sifat fizikal dan mekanikal dan ketahanan kayu yang telah diserap mampat telah dianalisis. Penambahan urea ke dalam PF berjaya mengurangkan pelepasan formaldehid sebanyak 97 % bagi kedua-dua kayu serap mampat. Hasil kajian juga menunjukkan kestabilan dimensi kayu serap mampat jelutong dan sesenduk telah meningkat sebanyak 60 % dan 52 % dalam mengurangkan pengembangan. Apabila dibezakan antara kepingan yang dirawat dengan atau tanpa penggunaan urea, kecekapan dalam mengurangkan pengembangan oleh kayu serap mampat yang dirawat dengan larutan PF ditambah urea adalah lebih berjaya. Berdasarkan sifat kayu serap mampat yang telah dihuraikan, gabungan rawatan yang optimum untuk menghasilkan kayu jelutong dan sesenduk ialah 30 % kepekatan PF dicampur dengan 30 % urea (berdasarkan pepejal PF), 8 jam pra pengeringan pada 60^{o}C disusuli oleh pemampatan kepada 80 % purata kemampatan pada 150^{0}C selama 20 minit. Gabungan rawatan ini telah digunakan untuk menghasilkan lapisan kayu serap mampat. Tiga lapisan kayu jelutong dan sesenduk telah dihasilkan melalui penyatuan kepingan secara bertentangan dan selari antara satu sama lain, diteruskan dengan pemampatan oleh pemampatan panas. Apabila dibandingkan dengan kayu tanpa rawatan yang tidak dirawat yang mempunyai saiz yang sama, kedua-dua kayu lapis serap mampat mempunyai sifat yang lebih cemerlang. Ketumpatan kayu serap mampat telah meningkat sebanyak 78 % hingga 117 % daripada kayu yang tidak dirawat. Modulus pemecahan "MOR" dan modulus elastik "MOE" telah meningkat sehingga 24 %, kecuali lapisan selari sesenduk yang mempunyai nilai yang lebih rendah berbanding kayu yang tidak dirawat. Kajian juaga telah memperlihatkan kekuatan kericihan di garisan pelekatan adalah tinggi bagi kayu serap mampat selari berbanding bertentangan. Tambahan lagi, kayu serap mampat selari mempunyai kekuatan kelucutan setanding kayu pejal tidak dirawat. Rawatan yang telah digunakan dalam kajian ini telah mempunyai rintangan yang tinggi menentang kulat putih (*Pycnoporous sanguineus)*.

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I certify that a Thesis Examination Committee has met on 26th June 2012 to conduct the final examination of Rabi'atol Adawiah Binti Mohd Ali on her thesis entitled "Formaldehyde Emission and Properties of Compregnated Wood Treated with Low Molecular Weight Phenol Formaldehyde with Addition of Urea" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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RABI'ATOL ADAWIAH BINTI MOHD ALI

Date: 26 June 2012

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ANOVA	Analysis of Variance
ASE	Anti-swelling Efficiency
ASTM	American Standard Test Method
CR	Compression ratio
FE	Formaldehyde Emission
FRIM	Forest Research Institute Malaysia
FTIR	Fourier Transform Infrared
IARC	International Agency for Research on Cancer
LMW	Low Molecular Weight
LVL	Laminated Veneer Lumber
LMWPF	Low Molecular Weight Phenol Formaldehyde
MC	Moisture Content
Min	Minutes

MMA	Methyl Methacrylate
MOR	Modulus of Rupture
MOE	Modulus of Elasticity
MS	Malaysian Standard
PDA	Potato Dextrose Agar
PF	Phenol Formaldehyde
PPM	Part Per Million
RH	Relative Humidity
SPSS	Statistical Package for Social Science
TS	Thickness Swelling
UF	Urea Formaldehyde
UPM	Universiti Putra Malaysia
WA	Water Absorption
WHC	Water Holding Capacity

WL	Weight Loss
WPG	Weight Percent Gain

CHAPTER 1

INTRODUCTION

1.1 Background of study

Nowadays, human implement various sophisticated technologies to develop high quality forest products and maintaining sustainable forest management, simultaneously. In line with the increasing of human population and economic development especially in developing countries, global demand for timber products is rising. However, just few of us realized the population of natural forest has become distracted caused by the continuous development. Natural wood resources have been decreased year by year caused by illegal logging and unsustainable forest management. Wood technologist has been forced to develop new composites technology with good quality properties like particle board, oriented strand board, plywood, laminated veneer lumber and hardboard to optimize the using of wood. Regardless of some better properties than untreated wood, the products still has similar problem like solid wood.

An alternative in optimizing forest wood resources is to fully utilise the wood species available including low density wood. We always heard about timber named as teak, meranti, and chengal. They are the most valuable timber for Malaysian timber trade and wood products. Usually, exclusive and good quality furniture made from those materials. However, low density wood species which usually non durable like jelutong and sesenduk need to be treated in order to enhance its performance. Kempas *(Koompassia malaccensis)* a commercial timber which once was considered as nondurable species, has succeed through chemical preservation. Its service life now is six times longer than normal life span through preservative treatment (Stubbs 1967).

Another way to cater the lack of natural wood resources is by using chemically engineered material. The engineering material is preferable rather than solid wood due to its uniform strength and stability. Wood is not preferable because it's poor dimensional stability due to hygroscopicity towards moisture, low durability when attacked by biodeterioration agent and relatively low mechanical properties. Permanent stabilization of the dimensions of wood is needed for specialty uses. This can be achieved by depositing bulking agents within the swollen structure of the wood fibres. The deposition of the resin is called as impreg which mean the wood treated with thermosetting resin, fibre penetrating resin and cured without compression.

Impregnation involves treating wood or cellulosic material with monomer solution that diffuse into cell wall, and then followed by polymerization. The monomer solution usually diffuses into cell wall and ended with polymerization. Besides, Hill (2006) defines impregnation as method resulting in the filling of wood with inert material to obtain a greater performance product. The mechanisms of impregnant fixation occur through two mechanisms like monomer impregnation (subsequent polymerization within the cell wall) and diffusion of a soluble material into the cell wall (immobile). The resins that can be used in impregnation process are PF, UF, MMF and MF.

Successful treatment can be achieved by taking some factors into consideration (Hill, 2006):

i. The impregnant molecules must be smaller in size, so that it can swell the cell wall
ii. Choose molecules with a greater tendency to form/break hydrogen bonds
iii. The molecules can be introduced in carrier liquids, which swell the cell wall to a greater extent
iv. Allow sufficient time for the impregnant molecules to diffuse into the intracellular spaces
v. The impregnant molecules is nonleachable

For example, bamboo that was impregnated with resin caused increasing in strength properties and greater dimensional stability (Deka and Saila, 2000). Other than that, Ryu *et al.*, (1991) found that after applying PF resin above 40%, there was a little change in antishrink efficiency (ASE) values.

The physical and biological properties of wood could be enhanced through few mechanisms:

i. The material swell the cell wall
ii. The material occupies the cell wall, reduces hygroscopicity of wood
iii. The blocking of cell wall micropores reduce diffusion of water and other molecules into the cell wall
iv. Masking of hydroxyl content in the cell wall
v. Crosslinking might occur between bulking agent and cell wall constituents

Compressed wood products from low density species on have started in 1980s in order to utilize fast growing trees (Wang *et al*., 2000). *Compreg* is the process of impregnation of wood with certain monomer solution followed by compression under specific temperature and pressure to obtain a good connection between wood and synthetic resin polymer (Mclean, 1949). According to Stamm (1964), *compreg* product usually made of treated veneer in few layers and then being compressed to specific gravity and desire thickness. In contrast to impregnation process, the resin cures after hot pressing at high temperature and pressure. Before the compression begins, the resin is pre-cured upon medium temperature heat around 60 to 70 ^{o}C, providing semi polymerized resin in preventing a lot of resin squeezed out during the compression process. Gabrielli and Kamke (2009) stated that during compression process, less of the PF resin squeezed out from the samples caused by the slowed movement of the larger molecular size resin.

The most popular resin used in *compreg* process is PF resin since many researchers discovered excellent properties was bring out from wood treated with PF. At the softened stage, the compression applied will not rupture the cell wall while the resin will cure during the compression densification, simultaneously (Yano *et al*., 1997). For the wood veneer that has more than 3mm thick, it supposed to be dried to less than 2 percent moisture content to prevent checking of product. Compared to impreg, the advantage of *compreg* is its natural lustrous finish that can be developed on any surface by sanding with fine grit paper and buffing. It also has ability to mold by gluing blocks of resin treated wood at about 150^{o}C.

The compreg product usually has mechanical properties such as modulus of rupture (MOR), modulus of elasticity (MOE) and hardness greater than untreated wood mainly due to their high specific gravity (Stamm, 1964 and Kumar, 1994). Compreg product is also known as high resistant to decay, termites and mariner borers. Compare to untreated wood, it is more acid, electrical and fire resistance due to its greater density. Recently, addition of urea into PF has been introduced to improve curing, to lower the content of free formaldehyde and cost efficiently in minimizing resin (He and Riedl, 2003).

Compreg product is very resistant to decay, termites and marine borers. Thermal process can improve decay resistance by few ways such as formation of toxic compounds, chemical modification of wood components and breakdown of hemicelluloses (Weiland and Guyonnet, 2003). It could give better properties of wood like affecting drying speed, equilibrium moisture content, hygroscopicity, dimensional stability, surface quality, surface abrasion strength and shear modulus of wood (Welzbacher *et al*., 2008). It also has better fire resistance compare to untreated wood due to greater density.

Compregnation of wood with PF at considerably high pressure has been proved can enhance the bending strength, dimensional stability and durability against fungal attack (Yano *et al.*, 2001). Wood treatment using low molecular weight resin is the most successful and reported can improve the dimensional stability of composite products (Stamm and Beacheler, 1960). *Compreg* product normally has mechanical properties (Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and hardness greater than untreated wood due to higher specific gravity (Galperine *et al*., 1995). However, high pressure treatment needs high investment which has limited the application of this method in the wood industry. The final products are more expensive than other treated wood or wood based panel because of high production cost (Rowell and Konkol, 1987).

Even though PF resin is very well known in wood treatment industry, drawback of the formaldehyde emission released especially from low molecular weight phenol formaldehyde has become a worldwide major concern. Formaldehyde is a chemical made up of oxygen, carbon and hydrogen. It is colourless but yet producing strong smelling gas. It occurs naturally in the environment by decay process or emitted by all timber species. Naturally, formaldehyde present in air at background level of 0.03 ppm and up to 0.08 ppm in outdoor urban air. Formaldehyde is usually being used as ingredient in synthetic resin, industrial chemicals, preservatives and production of paints and varnishes.

Internal Agency for Research on Cancer a division of World Health Organization has classified formaldehyde to a known carcinogen. The properties of formaldehyde that can cause cancer are only evident at very high concentrations which are hundreds times greater than emission from plywood and laminated veneer lumber products. Formaldehyde emission has been established by IARC where formaldehyde emitted below 0.1 ppm is undetectable by smell. Formaldehyde emitted between 0.1 ppm to 0.5 ppm is detectable by smell and caused slightly irritation to eyes, nose and throat. Emission between 0.5 ppm to 1.0 ppm could irritate eyes, nose and throat to most people. Extremely discomfort could appear if the emission is above 1.0 ppm.

1.2 Problem statement and justification

The world today, especially Malaysia, is lacking of timber supply due to unsustainable forest management and illegal logging. One of the methods to solve the lacking of natural timber is by improving the mechanical properties of low density wood such as mahang, jelutong and sesenduk.

There is a need to enhance its mechanical properties before it can be used for value added products. *Compregnating* using low molecular weight Phenol Formaldehyde (PF) in low density wood can improve dimensional stability and some strength properties (Zaidon, 2009). Previous research has low molecular weight PF resins has become the best method to increase dimensional stability in wood products like plywood and laminated veneer lumber (Wan and Kim, 2006). It easily penetrates the wood cell and ultimately bulks the wood material to a greater extent, providing greater stability (Rowell, 1991).

Other than using PF itself, the using of urea as formaldehyde scavenger has been proven succeed to reduce the formaldehyde emission. Kim (1996) has added 20 % urea into PF resoles to treat the wood based composites. The analysis done showed that the urea added has lowered the formaldehyde emission, increased degree of polymerization, decrease water soaking but internal bonding and curing rates was decreased as the urea level increased. Furthermore, the cost manufacturing using urea is much lower than other formaldehyde scavenger.

REFERENCES

Ang, A.F., Ashaari, Z., Bakar, E.S, Sahri, M. H., Anwar, U. M. K. A., and Husin, H. 2009. Enhancing the Properties of Mahang (*Macaranga* spp.) Wood through Acrylic Treatment in Combination with Crosslinker. *Modern Applied Science* Vol 3, No 11.

Ang, A.F. 2010. Properties and Decay Resistance of Mahang (Macarangga sp.) Treated with Phenolic Resin and Acrylic Monomer using Vacuum-pressure Process, MSc Thesis, Universiti Putra Malaysia.

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

Anon. 2012. *Dyera costulata*. http://en.wikipedia.org/wiki/Dyera_costulata.

Anon. 2012. Woody Species *Endospermum spp*. www.prowebcanada.com/taxa

Anwar, U. M. K., Paridah, M.T., Hamdan, H., Sapuan, S. M. and Bakar, E. S. (2009). Effect of curing time on physical and mechanical properties of phenolic-treated bamboo strips. *Industrial Crops Products*. 29, 214-219.

Ashaari, Z., Barnes, H.m, Vasisth, R.C., Nicholas, D.D. and Lyon, D.E. 1990a. Effect of aqueous polymer treatments on properties. Part 1: Treatability and dimensional stability. *International Research group on Wood Preservation,* Doc. No. IRG/WP/3610.

Ashaari, Z., Bakar, E. S. And Paridah, M. T. 2010. *Compreg* Laminates from Low Density Tropical Hardwoods. *Proceedings of the International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe – Timber Committee* October 11-14, 2010, Geneva, Switzerland.

Behr, F.A. 1972. Decay and termite resistance of medium density fibreboards made from wood residue. *Forest Product. J.* 22(12) : 48-51.

Behr, J. and Nowak, D. 1992. Tobacco smoke and respiratory disease. Dept of Internal Medicine I, Section for Pulmonary Diseases and Institute and outpatient Clinic for Occupational and Environmental Medicine, University of Munich, Munich, Germany.

Blanchette, R.A. 1984a. Screening wood decayed white rot fungi for preferential lignin degradation. *Appl. Environ. Microbiol.* 48: 647–653.

Blanchette, R.A. 1984b. Selective delignification of eastern hemlock by Ganoderma tsugae. *Phytopathology* 74: 153–160.

Blanchette, R.A. and Reid, I. D. 1986. Ultrastructural aspects of wood delignification by Phlebia (Merulius) tremellosus. *Appl. Environ. Microbiol*. 52: 239–245.

BRE. 1989. Wet rots: recognition and control. *BRE digest 345, Department of Environment, UK*. 12p.

BSI (British Standard Institute). 1957. British Standard 373:1957: Methods of testing small clear specimens of timber. London: British Standard Institution.

Caesar, C. 1997. Raw material used in OSB production. *Asian Timber (August 1997).* Pp 38-40.

Carotenuto, G. and Nicolais, L. 1999. Kinetic study of phenolic resin cure by IR spectroscopy.*J. Appl. Polym. Sci.* 74, 2703–2715.

Chain, A. J., 1970. Termites: A Study in social Behavior. *Hutchinson and Co. Ltd. London.* 150 pp.

Charles, R. F., 2005. Wood Adhesion and Adhesives. USDA, Forest Service, *Forest Products Laboratory, Madison, WI.*

Chong K. F. 1980. Durabilityof Timber. *Timber Digest* No. 19.

Collins, N. M. 1988. Termite. In. Cranbrook, E (ed) Key Environments Malaysia. *Oxford: Pergamon Press.*

Collins, PJ. 1996. Current research activities on wood adhesives at CSIRO. *25th Forest Research Conference*, 18–21 November 1996, Victoria, Australia.

Desch, H. C. 1941. Manual of Malayan Timbers. *Mal. For. Rec.* No. 15 Vol. 1.

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

Eaton, R.A. and Hale, M.D.C. 1993. ***Wood: Decay, Pests and Protection***. Chapman and Hall, London. 546p.

Eaton, R.A. and Hale M.D.C. 1995. ***Wood: Decay, Pests and Protection.*** Chapman & Hill, London.

Ebewele, R. O., River, B. H. and Koutsky, J. A. 1986. Relationship between phenolic adhesive chemistry and adhesive joint performance: Effect of filler type on fraction energy. *J. Appl. Polym. Sci.* 1986, 31, 2275–2302.

Eddowes, P.J. 1980. Technical aspects of marketing unfamiliar species. Paper presented at 11th Commonwealth Forestry Conference. Trinidad and Tobago.

Edward, C. P. 1957. Bending Solid Wood to Form. *Agriculture Handbook No. 125. U. S. Department of Agriculture. Forest Service.*

Engku Abdul Rahman Chik. 1998b. Basic and Grade Stresses for Strength Groups of Malaysian Timbers. Malayan Forest Service Trade Leaflet No. 38. *The Malaysian Timber Industry Board and Forest Research Institute Malaysia, Kuala Lumpur*. 13 pp.

Erä, V. A., Salo, H., Kaps, T. and Linndberg, J. J. 1975. *Angew. Makromol. Chem.* 48, 185–187.

Fan, D., Li, J., Chang, J., Gou, J., and Jiang, J. 2009. Chemical Structure and Curing Behavior of Phenol–Urea–Formaldehyde Cocondensed Resins of High Urea Content. *Journal of Adhesion Science and Technology* vol. 23 issue 13-14 September 1, 2009. p. 1787-1797.

Flemmich, C.O. 1956. Destructive Agencies of Timber. *Malay forester* 19(3): 139-153 pp.

Forest Department Sarawak. 2012. http://www.forestry.sarawak.gov.my/modules/web/page.

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(5):349–361.

Gabrielli, C. P. and Kamke, F. A. 2009. Phenol-formaldehyde impregnation of densified wood for improved dimensional stability.

Galperin, A. S., Kuelshov, G. G., Tarashkevich, V. I. and Shutov, G. M. 1995. Manufacturing and properties of modified wood: A review of 25 years work. *Holzforchung.* 49(1): 45-50.

Hansom, O.P. 1983. Promotion of commercially less accepted species. Paper presented at *First UNIDO/FAO Consultation on the Wood and Wood Products Industry*, Helsinki, 19-23 September 1983.

Harris, W.V 1957. An Introduction to Malayan Termites. *Malay. Nat. J.* 12:20-32 pp.

He, G., and Riedl, B., 2003. Phenol-urea-formaldehyde cocondensed resol resins: Their synthesis, curing kinetics, and network properties. *J. Polym. Sci. Part B: Polym. Phys. 2003, 41,* 1929-1938.

Hill, C.A.S. 2006. Modifying the properties of wood. Pp. 19-44 in *Wood modification: Chemical, thermal and other processes.* London: John Wiley & Sons Ltd.

Hon, DNS. 2003. **Analysis of adhesives. *Handbook of adhesives technology***. (Eds. Pizzi A & Mittal KL). New York: Marcel Dekker Inc.

Hong, L. T and Liew, C. C. K. 1989. Protection of Rubberwood Timber. I. Impregnation With Boron Preservative. *International Research Group on Wood Preservation Doc.* No. IRG/WP/3551. IRG, Lappeenranta.

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

IARC (2004). International Agency for Research on Cancer, *Press Release Number 153*, 15 June 2004. http://www.iarc.fr/ENG/Press_Release/archieves/

Jackson, D. and Savory, J.G., 1968. The decay resistance of wood fibre building boards and particle boards. *Int. Baodetn Bull.*, 4, (2), 83-88.

Jeyanny, V., Ahmad Zuhaidi, Y., Suhaimi, W. C., and Amir, S. K. 2010. Site suitability assessment for sustainable forest plantation establishment of *Dyera costulata* in a West Malaysian tropical forest. *19 th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia.*

JIS (Japanese Industrial Standard). 2003. Japanese Industrial Standard: Particleboards. JIS A 5908. Tokyo, Japan.

Kajita, H. and Imamura, Y. 1991. Improvement of physical and biological properties of particleboards by impregnation with phenolic resin. *Journal of Wood Science Technology* 26: 63-70

Kajita, H. 1992. Report of grand-in-aid for scientific research (No. 01560193) from the Ministry of Education, Japan 360.

Kim, M. G., Watt, C., and Davis, C. R. 1996. Effects of Urea Addition to Phenol-Formaldehyde Resin Binders for Oriented Strandboard. *Journal of Wood Chemistry and Technology*. Volume 16, Issue 1.

Knop, A. and Pilato, L. A. 1985. Phenolic Resins. *Springer-Verlag: Berlin*.

Körnel , S., Niemz, P., Wienhaus, O., and Henke, R., 1992. "Orientierende Untersuchungen zum Nachweis des Klebstoffanteils auf Holzpartikeln mit Hilfe der FTIR-Spectroskopie," *Holz als Roh- und Werkstoff* 50, 67-72.

Kumar, S. 1994. Chemical modification of wood. *Wood and Fiber Science.* 26(2): 270-280.

Lim, S. C., Gan, K. S. and Choo, K. T. 2004. Identification and utilisation of lesser-known commercial timbers in Peninsular Malaysia 1: Ara, Bangkal, Bebusok and Bekoi. *Published by Timber Technology Centre (TTC), FRIM, Kepong, 52109 Kuala Lumpur* No. 29, 2004 ISSN:139-258.

Lisperguer, J.; Droguett, C. Bol Soc Chil Quim 2002, 47, 33.

Luna, M. L., Murace, M. A., Keil, G. D. and Otano, M. E. 2004. Patterns of Decay Caused by *Pycnoporus Sanguineus* and *Ganoderma Lucidum* (Aphyllophorales) Poplar Wood. *IAWA Journal*, Vol. 25 (4), 2004: 425–433.

Malaysian Timber Council (MTC). 2006. www.mtc.com.my.

Markessini, C., Athanassiadou, E., and Tsiantzi, S. 2010. Producing panels with formaldehyde emission at wood level. *7th European Wood-based Panel Symposium,* 13-15 October 2010, Hannover, Germany.

Marutzky R., 1989. Release of F by Wood Products. *In, Wood Adhesives: Chemistry and Technology* Volume Two. (Pizzi, A. eds) Marcel Dekker, INC. New York. Pp.307-388.

Mclean, G. K. 1949. Compreg-resin-treated densified wood, pp. 220-226. *In* 1949 Proceeding of the National Annual Meeting Forest Products Research Society, Volume 3. Forest Products Research Society, Madison.

McQuire, A.J. 1970. Radial permeability of timber. PhD Thesis, University of Leeds.

Md Iftekhar Shams and Hiroyuki Y., 2004. Compressive deformation of wood impregnated with low molecular weight phenol formaldehyde (PF) resin I: effects of pressing pressure and pressure holding. *Journal of Wood Science* vol. 50 issue 4 August 2004. p. 337 - 342

Md Iftekhar Shams and Hiroyuki Y., 2004. Compressive deformation of wood impregnated with low molecular weight phenol formaldehyde (PF) resin II: effects of processing parameters. *Journal of Wood Science* vol. 50 issue 4 August 2004. p. 343 – 350.

Menezzi, D. C. H. S., Souza, R. Q., Thompson, R. M., Teixeira, D. E., Okino, E. Y. A. and Costa, A. F. 2008. Properties after weathering and decay resistance of a thermally modified wood structural board. International Biodeterioration and Biodegradation 62 (4), 448-454.

Mohebby, B., Gorbani-Kokandeh, M. and Soltani, M. 2009. Springback in acetylated wood based composites.

Moslemi, A.A., 1935. **Particleboard.** Southern Illinois University Press, Ferrer & Simon, Inc, London and Amsterdam. Pp67-68

Malaysian Standard 544:Part 2:2001. Code of Practice for the Structural Use of Timber: Permissible Stress Design of Solid Timber.

Muller, G., Schopper, C., Vos, H., Kharazipour, A. and Polle, A. 2009. FTIR-ATR Spectroscopic Analyses of Changes in Wood Properties During Particle- and Fibreboard Production of Hard- and Softwood Trees. *BioResources* 4(1), 49-71.

Nicholas, D. D. and Siau, J. F. 1973. Factors influencing the treatability of wood. In Nicholas, D. D. (Ed.) *Wood Deterioration and its Prevention by Preservative Treatment.* Vol. II, Syracuse University Press, New York.

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

Otjen, L. and Blanchette, R. A. 1985. Selective delignification of aspen wood blocks in vitro by three white rot Basidiomycetes. *Applied Environmental Microbiology*. 50: 568–572.

Paridah, M. T., Loh, Y. F., Zaidon, A. and Bakar, E. S. 2009. *Proceeding the Fourth International Symposium on Veneer Processing and Products,* Espoo, Finland, pp. 267-275.

Paridah, M. T., Ong, L. L., Zaidon, A., Rahim, S., and Anwar, U. M. K. 2006. Improving The Dimensional Stability of Multilayered Strand Board Through Resin Imregnation. *J. Tropical Forest Sci.* 18 (3), 166-172.

Pizzi, A., 1983. **Wood Adhesives chemistry and technology**. *Marcel Dekker, Inc, New York and Basel.* Pp6-7. 59-176.

Pizzi, A., 1983. Wood Adhesives chemistry and technology. A. Pizzi (Ed), Vol. 1, pp. 177-246. *Marcel Dekker, New York, NY.*

Pizzi, A. and Smit, R. 1983. Phenol Formaldehyde Structures in Relation to their Adhesion to Wood Cellulose. *New York: Marcel Dekker Incorporated.*

Pizzi, A., Stephanou, A., Antunes, I. and DeBeer, G. 1993. Alkaline PF resins linear extension by urea condensation with hydroxybenzylalcohol groups. *Journal of Applied Polymer Science* Volume 50, Issue 12, 2201–2207.

Pizzi, A. and Mittal, K. L. 2003. Handbook of Adhesive Technology: Second Edition, Revised and Expanded. Boca Raton, CRC Press.

Poljansˇek, I., Sˇebenik, U., and Krajnc, M., 2005. Characterization of Phenol–Urea–Formaldehyde Resin by Inline FTIR Spectroscopy. *Acta Chim*. Slov., 5: 238-244.

Poulton Remedial Service. 2008. http://poultonpestcontrol.com/fungal_decay

Preston, A. F. And Jin, L. 1991. "The interaction of wood preservatives with lignocellulosic substrates. Part 1. Quaternary ammonium compounds," Holzforschung, 45 (6), 455-459.

Richards, O.W. and Davies, R.G., 1978. IMM'S Outlines of Entomology. *Chapman and Hall,* London.

Richardson, B. A. 1993. *Wood preservation*. 2nd Edition, E & FN Spon, London.

Roffael, E. 1993. Formaldehyde Release from Particleboard and other Wood Based Panels. Translated and Edited by Choo KC, Koh MP & Ong CL. *Malayan Forest Records* No. 37.

Roffael, E. 2002. On The Formaldehyde Release of Wood. *Third European Panel Products Symposium.*

Roger, R. M., Calle, N., Barbro, A. 2002. Emissions of Aldehydes and Ketones from a Two-Stroke Engine Using Ethanol and Ethanol-Blended Gasoline as Fuel. *Environmental Science Technology,* 36(8), 1656-1664.

Rowell, R. M. 2005. Chemical modification of wood. In: Rowell RM (ed) Handbook *of wood chemistry, wood composites,* Chap. 14. CRC Press, Boco Raton, pp 381–420.

Rowell, R.M., and Konkol, P., 1987. Treatments That Enhance Physical Properties of Wood. FPL, General Technical Report FPL-GTR-55, 12 pp.

Rowell, R. M. and Youngs, R.L. 1981. Dimensional stabilization of wood in use. USDA, Forest Serv. Res. Note. FPL-0243. Forest Products Laboratory, Madison, WI

Rowell, R. M. 1991. Chemical modification of wood. In: Hon, D. N.-S. and Shiraishi, N. (Eds.), Handbook on Wood and Cellulosic Materials. Marcel Dekker, New York, pp. 703–756.

Ryu JY, Takahashi M, Imamura Y & Sato T. 1991. Biological resistance of phenol-resin treated wood. *Mokuzai Gakkaishi* 37: 852−858.

Salamah, S. and Mohd Dahlan, J. 2008. Vacuum-Pressure Treatment Of Rubberwood *(Hevea Brasiliensis)* Using Boron-Based Preservative. *Journal of Tropical Forest Science* 20(1): 1–7.

Samarija-Jovanovic, S., Jovanovic, V., Konstantinovic, S., Markovic, G., and Marinovic-Cincovic., 2010. Thermal behavior of modified urea-formaldehyde resins. *Journal of Thermal Analysis and Calorimetry,* Volume 104 (3) Spinger Journals.

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

Seborg R.M., Millet M. and Stamm A.J. 1945. Heat-stabilized compressed wood. Staypak. *Mechanical Engineering* 67:25–31.

Shams, M. I., Kagemori, N. and Yano, H., 2004. Compressive deformation of wood impregnated with low molecular weight phenol formaldehyde (PF) resin I: effects of pressing pressure and pressure holding. *Journal of Wood Science* 50:337–342.

Shawkataly, A.K., and Hashim, R., 2004. Komposit panel berasaskan kayu. Penerbit Universiti Sains Malaysia, Malaysia. Pp 68-77.

Singh, M. and Yee, B.M. 2008. Environment Consious, Biomorphic Ceramics from Pine and Jelutong Wood Precursors. 26th Annual Conference on Composites, Advanced Ceramics, Materials and Structures: B: *Ceramic Engneering and Science Proceedings,* Volume 23, Issue 4.

Spear, P. J., 1970. Principle of Termite Control. In: Biology of Termite. (Krishna, K. and F.N. Weesner Eds). *Academic Press*, New York. Vol. II: pp 547- 604.

Stamm, A. J., and Bachelor 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., 1951. Forest Product Laboratory Resin-Treated Laminated, Compressed Wood-Compreg. USDA, FS. *Forest Products Laboratory*, Report No. 1381.

Stamm, A. J. 1964. Wood and cellulose science. Ronald, New York, pp 343–358.

Stephens, R. S. and Kutscha, N. P. 1987. "Effect of resin molecular weight on bonding flakeboard," *Wood and Fiber Science* 9(4), 353-361.

Stubbs, J.H. 1967. The pre-treatment of building timber in Malaysia. *Mal. For.* 30: 21-37.

Tomita, B. Ohyama, M. Itoh, A. Doi, K. and Hse, C-Y. 1994. Analysis of curing process and thermal properties of phenol-urea-formaldehyde cocondensed resins.

Tsoumis, G. 1991. Science and Technology of Wood: Structure, Properties and Utilization. New York: Van Nostrand Reinhold Press.

Wan, H. and Kim, M. G. 2006. Impregnation of southern pine wood and strands with low molecular weight phenol-formaldehyde resins for stabilization of oriented strandboard. *Wood Fiber Science* 38(2):314–324.

Wang, J.M., Zhao, G.J. and Lida, I., 2000. Effect of oxidation on heat fixation of compressed wood of China fir. Forestry Studies in China 2, 73–79.

Weiland, J.J., Guyonnet, R., 2003. Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy. *Holz als Roh- und Werkstoff* 61, 216–220.

Welzbacher, C.R., Wehsener, J., Rapp, A.O., Haller, P., 2008. Thermo-mechanical densification combined with thermal modification of Norway spruce (Picea abies Karst) in industrial scale – dimensional stability and durability aspects. *Holz als Roh- und Werkstoff* 66, 39–49.

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

Woodworkers. 2012. www.wood-database.com/lumber-identification/hardwoods/jelutong

Wright, J. and Deschamps, J. 1976-1977. Basidiomycetes xilófilos de la Región Mesopotámica. III. Los generos Bjerkandera, Gloeophyllum, Gloeoporus, Hirschioporus, Hydnolyporus, Phaeocoriolellus, Pycnoporus y Xerotinus. Rev. Invest. Agrop. INTA, Ser. 5, Pat. Veg., 13 (2): 27–70.

Young, S. 2004. Formaldehyde Emission from Solid Wood – Will It Become an Issue? 8th European Panel Products Symposium.

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. *Elsevier,* Volume 42, Issue 1, Pages 189–195.

Yano, H., Hirose, A. and Inaba, S. 1997. High-strength wood-based materials. *Journal of Material Science.* 16:1906–1909.

Zabel, R. A., and Morrell, J. J. 1992a. General features, recognition and anatomical aspects of wood decay. In: Wood Microbiology: decay and its prevention. *Academic Press*, Inc. San Diego, California. pp. 168–194.

Zaidon, A. 2009. Improvement of raw materials from underutilised timber species through chemical and densification treatments for value added laminated products. *End of Reports (unpublished) submitted to the Ministry of Science and Technology, Malaysia.* Report No. 06-01-04-SF0656 .