# *EFFECT OF CARBOXYLIC ANHYDRIDE TREATMENTS ON PHYSICAL AND MECHANICAL PROPERTIES OF Hevea brasiliensis Mull.Arg., Acacia mangium Willd. AND Elaeis guineensis Jacq. WOOD*

**MOHD AFIQ BIN MOHTAR**

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**By**

**MOHD AFIQ BIN MOHTAR**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master Science**

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**EFFECT OF CARBOXYLIC ANHYDRIDE TREATMENTS ON PHYSICAL AND MECHANICAL PROPERTIES OF *Hevea brasiliensis* Mull.Arg., *Acacia mangium* Willd. AND *Elaeis guineensis* Jacq. WOOD**

By

**MOHD AFIQ BIN MOHTAR**

**February 2015**

**Chairman : Norul Hisham Hamid, PhD**

**Faculty : Faculty of Forestry**

The objectives of the study was to investigate the reactivity of acid anhydride treatments, to determine the physical and mechanical properties and anti-swelling efficiency(ASE) as well as its relation between the properties. The rubberwood (*Hevea brasiliensis*), acacia (*Acacia mangium*) and oil-palm wood (*Elaeis guineensis.*) were modified with acetic, propionic and butyric anhydride in this study.

The sample were cut into size of 300 mm X 100 mm X 25 mm (L X W X T) and vacuum impregnated before being reacted using a microwave. The scanning electron microscopy(SEM) observations shows that no damage occur to the cell wall structures during the modification procedure takes place while the fourier transform infra-red(FTIR) analysis indicates that the bonding of cell wall polymer hydroxyl group with anhydride did happened.

The results showed that the Oil palm wood(OPW) retained the highest anhydride solution followed by rubberwood and acacia with regardless of anhydrides. In contrast to uptake, the weight percent gain(WPG) was highest in rubberwood followed by OPW and acacia, regardless of anhydride. Overall, the modified rubberwood had a higher bulking coefficient (BC) followed by acacia and OPW. The result of density increment shows that the wood density was increased due to the modification process for all species. The void volume changes were negative for all wood species, except for acacia modified with acetic and butyric anhydride.

Generally, treatment of wood with anhydride did not give any improvements to modulus of rupture(MOR) and modulus of elasticity(MOE). The compression strength was improved in modified rubberwood and acacia, but not in modified OPW. The hardness was not improved with either treatment with anhydride and this trend was consistent with all wood species. Regardless of anhydride, the impact strength was improved in modified rubberwood and OPW, but not in the case of acacia. Generally, modified rubberwood and acacia with propionic anhydride gave the highest ASE ($4^{th}$ cycle). Overall, the maximum improvement in terms of dimensional stability and

mechanical properties was achieved in modified rubberwood and acacia with butyric anhydride.

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

**KESAN RAWATAN ASID ANHYDRIDE KARBOKSILIK KE ATAS SIFAT-SIFAT FIZIKAL DAN MEKANIKAL KAYU *Hevea brasiliensis* Mull.Arg., *Acacia mangium* Willd. DAN *Elaeis guineensis* Jacq.**

Oleh

**MOHD AFIQ BIN MOHTAR**

**Febuari 2015**

**Pengerusi :Norul Hisham Hamid, PhD**

**Fakulti :Perhutanan**

Objektif kajian yang dilakukan adalah untuk menyiasat ke-reaktifan oleh rawatan asid anhydride terhadap kayu, menentukan sifat fizikal, mekanikal dan anti pengembangan serta kaitan antara sifat-sifat tersebut. Kayu getah, acacia dan kayu minyak sawit telah di rawat dengan acetic, propionic dan butyric anhydride di dalam kajian ini.

Sampel kayu telah di potong kepada saiz 300 mm X 100 mm X 25 mm (L X W X T) dan telah di impreknasi secara vakum sebelum di tindak balas menggunakan ketuhar gelombang mikro. Permehatian melalui imbasan mikroskop electron menunjukkan tiada kerosakan berlaku terhadap sel kayu sewaktu proses modifikasi di jalankan dan analisa daripada fourier transform infra-red (FTIR) menunjukkan bahawa ikatan antara polimer sel kayu hidroksil dengan anhydride berlaku.

Keputusan menunjukkan bahawa kayu minyak sawit mendapat penyerapan anhydride yang tertinggi di ikuti dengan kayu getah dan akasia tanpa mengira jenis anhydride. Berbeza dengan penyerapan anhydride, peratus pertumbuhan berat adalah yang tertinggi untuk kayu getah di ikuti dengan kayu minyak sawit dan akasia tanpa mengira jenis anhydride. Secara keseluruhannya, kayu getah yang di ubahsuai menunjukkan kadar pengembangan effisyen yang tinggi di ikuti dengan akasia dan kayu minyak sawit. Keputusan peningkatan ketumpatan menunjukkan ketumpatan kayu meningkat di sebabkan oleh proses modifikasi untuk ketiga-tiga spesis. Perubahan ruang kosong adalah negative untuk semua spesis kecuali akasia yang di tindak balas dengan acetic dan butyric anhydride.

Secara umumnya, rawatan kayu menggunakan anhydride tidak memberikan peningkatan terhadap modulus ruptur dan modulus keanjalan. Kekuatan mampatan meningkat untuk kayu getah dan akasia yang di ubahsuai tetapi tidak meningkat untuk kayu minyak sawit. Tidak mengira jenis anhydride dan spesis, sifat kekerasan juga tidak meningkat. Kekuatan impak meningkat meningkat untuk kayu getah dan kayu minyak sawit tetapi tidak untuk kayu akasia. Secara umumnya, kayu getah dan akasia yang telah di ubahsuai dengan propionic anhydride memberikan kadar pengembangan

effisyen kitaran ke-empat yang tinggi. Kesimpulannya, penigkatan maksima dalam erti kestabilan dimensi dan sifat mekanikal dapat di capai oleh kayu getah dan akasia yang di ubahsuai dengan butyric anhydride.

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

**Norul Hisham Hamid, PhD**
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Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

**Mohd Hamami Sahri, PhD**
Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

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**TABLE OF CONTENTS**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| ASE | Anti-Swelling efficiency |
| BC | Bulking Coefficient |
| BS | British Standard |
| CCA | Copper Chrome Arsenic |
| df | Degree of Freedom |
| EMC | Equilibrium Moisture Content |
| FTIR | Fourier Transform Infra-Red Spectroscopy |
| IB | Internal bonding |
| IR | Infra-Red |
| L | Length |
| l | Longitunal |
| MOE | Modulus of Elasticity |
| MOR | Modulus of Rupture |
| MV | Molar Volume |
| NS | Not Significant |
| PU | Percent Uptake |
| r | Radial |
| RH | Relative Humidity |
| SEM | Scanning Electron Microscope |
| SG | Specific Gravity |
| T | Thickness |
| t | Tangential |
| $V_{rel}$ | Volume Increase |

| | |
|---|---|
| W | Width |
| WPG | Weight Percent Gain |

## LIST OF SYMBOLS

| | |
|---|---|
| $CH_3$ | Methyl |
| $C_2H_5$ | Ethyl |
| $C_3H_7$ | Propyl |
| cm | Centimeter |
| $cm^{-1}$ | Wavenumber |
| $cm^3mol^{-1}$ | Cubic Centimeters Per Mole |
| g | Gram |
| in/min | Inch Per Minute |
| J | Joule |
| $kg/m^3$ | Kilogram Per Meter Cube |
| kN | Kilo Newton |
| Mhz | Megahertz |
| Mm | Milimeter |
| mm/min | Milimeter Per Minute |
| Mpa | Mega Pascal |
| OH | Hydroxyl |
| W | Watt |
| % | Percent |
| °c | Degree Celsius |
| ° | Degree |
| µm | Micrometer |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Wood is a renewable material and has been used for many applications such as furniture, outdoor applications and building materials. It has been used since the beginning of human existence. However, it has been used without modification for the most part. Wood continues to be used for many applications due to its many excellent properties such as good strength to weight ratio, attractive appearance, thermal insulator, reusable, recycle and recoverable but it also suffers from several disadvantages. Dimensional changes due to the cyclic humidity changes, susceptibility to biological attack and surface eroded when exposed to extreme whether restricts the potential end-uses of wood. Wood modification tends to solve or counter these disadvantages by changing the wood properties. According to Hill (2006), many wood properties are determined by its chemical constituents. In consequence, wood modification aims to change the chemical configuration of wood which the process known as chemical modification. The main objective of wood modification is to alter and to improve desire properties such as decay resistance, dimensional stability, weathering performance, and mechanical properties.

Chemical modification of wood can be defined as any chemical reaction between some reactive part of a wood cell wall component and a simple single chemical reagent, with or without catalyst that forms a covalent bond between the two components (Rowell, 1991). The chemicals are including acetic, butyric and propionic anhydrides. Chemical modification of wood by using acetic anhydride is called acetylation and has been extensively studied all over the world. It has been reported that acetylation is a very effective way for enhancing wood properties. Wood properties can be improved considerably by converting hydrophilic hydroxyl (OH) groups into larger more hydrophobic groups. Dimensionally stable of material is created because the cell wall itself will be permanently in swollen state that will attract no or very little water (Homan and Jorissen, 2004).

Recent studies by Larsson and Simonson (1999) reported that, microwave heating can be used for the acetylation of wood in lumber thickness which aimed to reduce reaction time and to provide a uniform heating pattern in wood. However, chemical modification using a microwave heating has not been studied on rubberwood, acacia and oil palm wood. The reaction of these woods with anhydrides and its effect on anatomy, chemical structure, dimensional stability, physical and mechanical properties are still not completely known. A specific research on this subject is crucially needed so that these woods can be used beyond its natural limits.

The aim of this study is to modify rubberwood (*Hevea brasiliensis*), acacia (*Acacia mangium*) and oil-palm wood (*Elaeis guineensis*) with carboxylic acid anhydrides

(acetic anhydride, butyric anhydride and propionic anhydride). The target output from this research is not only to help releasing the great demands of timber from natural forest but also to promote the use of low quality wood as a main material for high end furniture and building materials.

## 1.2 Problem Statement

Rubberwood, acacia and oil-palm wood are three wood species that has abundant resources in Malaysia. The resource is ready able and sustainable. However, these three wood species need to undergo pre-treatment processes to make it possible to be used especially outdoor applications. For example, rubberwood need to be treated with wood preservatives such as Copper Chrome Arsenic (CCA) and creosote to improve its decay resistance, dimensional stability, strength and durability. As well as acacia and oil-palm wood, which need to be coated, apply wax during forming process for reconstituted woods or impregnation with phenolic resin to enhance the performance of wood.

However, such treatments are not permanent, which the coating may be failed by cracking, the chemical leach out and erode during the lifetime of the product. The loss of performance occurs because the treating agent is not chemically bonded to or otherwise immobilized within the wood structure. During the lifetime of the treated product may be a very low hazard associated with in service use, this may well change at the end of life of the product. Therefore, potential loss of the preservative into the environment may become a problem in disposal or recycling situations. When this occurs, the biocidal action of the preservatives remains and this can cause a negative impact to the environment.

Chemical modification of wood with anhydride provides a process that alters the properties of the material such that during the lifetime of a product no loss of the enhanced performance of the wood should occur. These modification processes with anhydride requires a lot of time using conventional heating to acquire the optimum properties wood and obtain maximum performance possible. However, using microwave, the reaction temperature of 120-130°C can be reached in a comparatively short time and provide a uniform heating.

Acetic anhydride has been widely used in chemical modification experiments and the results compared to other chemical were also better while wood treated with anhydride leave no harm to the environment (Rowell, 2006). Wood treated with anhydride provides consistent and optimum result for Anti-Swelling Efficiency (ASE) and biological resistance. However, the effect of modification on strength properties such as static bending, compression, hardness and impact strength were dependent on the degree of modification as well as species.

Therefore it is necessary to study the effect of carboxylic acid anhydride treatments on physical and mechanical properties rubberwood, acacia and oil-palm wood so that the

properties can be determined and indirectly can be used beyond its limitation without give any harm to the environment.

## 1.3 Research Objectives

The general objective of this study is to improve the physical and mechanical properties of rubberwood, acacia and oil palm wood. The specific objectives of the study are:

1) To investigate the reactivity of carboxylic acid anhydride treatments on the rubberwood, acacia and oil palm wood through scanning electron microscopy (SEM) observation and fourier transform in-frared (FTIR) analysis.

2) To determine the effect of carboxylic acid anhydrides treatments on the basic, physical and mechanical properties and dimensional stability of modified wood.

3) To determine the correlation (pearson's) of modified and unmodified wood between basic, physical and mechanical properties.

## 1.4 Significance of Research

The rubberwood, acacia and oil palm wood are the three main wood resources after natural forest timber in Malaysia. However, a pre-treatment for these three species is necessary to ensure that their performance is acceptable for high end-multipurpose product applications and those treatments were time consuming and involving a lot of money. Chemical modification of wood with anhydride using microwave can provide a uniform heating while reduce reaction time but also prevent the environment from negative impacts. The purpose of this research is to determine whether the physical and mechanical properties of rubberwood, acacia and oil-palm wood can be improved through chemical modification with anhydride using microwave heating method. The results of this study will determine whether the improved properties of wood can meet with the industrial specification, requirements and acceptable used by local wood industries. This study will also be beneficial to the Malaysia economic growth by maximising the utilization of lignocellulosic material.

## REFERENCES


Abdul Khalil, H. P. S., Alwani, M. S., Ridzuan, R., Kamarudin, H., and Khairul, A. (2008). Chemical composition, Morphological Characteristics , and Cell Wall Structure of Malaysian Oil Palm Fibers. *Polymer Plastics Technology and Engineering*. 47:273-280.

Baysal, E., Ozaki, S. K. and Yalinkilic, M. K. (2004). Dimensional stabilisation of wood treated with furfuryl alcohol catalysed by borates. *Wood Science and Technology*. 38(6): 405-415.

Beckers, E. P. J. and Militz, H. (1994).Acetylation of solid wood.Initial trials on lab and semi industrial scale. In: *Second Pacific Rim Bio-Based Composites Symposium*, Vancouver, Canada. (pp. 125-135).

Birkinshaw, C. and Hale, M.D. (2002). Mechanical properties and fungal resistance of acetylated fast grown softwood. I .Small specimens.*Irish forestry*. 59 (1-2): 49-58.

Bongers, H. P. M. and Beckers, E. P. J. (2003).*Mechanical properties of acetylated solid wood treated on pilot plant scale*. In: Proceedings of the First Europen Conference on Wood Modification, Ghent, Belgium, Van Acker, J. and Hill, C.A.S. (Eds.). pp. 341-350.

BS 373:1957 Methods of Testing Small Clear Specimens of Timber.

Cetin, N. S. and Ozmen, N. (2001). Dimensional changes in Corsican and Scots pine sapwood due to reaction with crotonic anhydride. *Wood Science and Technology*. 35(3): 257-267.

Chang, H. T. and Chang, S. T. (2001).Comparisons of the photostability of esterified wood.*Polymer Degradation and Stability*. 71(2): 261-266.

Chang, H. T. and Chang, S. T. (2002).Moisture excluding efficiency and dimensional stability of wood improved by acetylation.*Bioresource Technology*. 85(2): 201-204.

Chang, H. T. and Chang, S. T. (2003). Improvements in dimensional stability and lightfastness of wood by butyrylation using microwave heating .*Journal of Wood Science*. 49(5): 455-460.

Dinwoodie, J. M. (2000). *Timber: its Nature and Behaviour*, 2nd edn. E. and F.N. Spon, London, UK.

Hamid, N. H. and Hale, M. (2012). Decay threshold of acetylated rattan against white and brown rot fungi. *International Wood Products Journal*. 3(2): 96-106.

Haygreen, J. G. and Bowyer, J. L. (1982).*Forest Products and WoodScience*: an Introduction,4thedn. Iowa State University Press, USA.

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

Hill, C. A. S. and Jones, D. (1996). The dimensional stabilisation of Corsican pine sapwood by reaction with carboxylic acid anhydrides. *Holzforschung*. 50(5): 457-462.

Hill, C. A. S. and Jones, D. (1999). Dimensional changes in Corsican pine sapwood due to chemical modification with linear chain carboxylic anhydrides. *Holzforschung*. 53(3): 267-271.

Hill, C. A. S. and Ormondroyd, G. A. (2004). Dimensional changes in Corsican pine (Pinusnigra Arnold) modified with acetic anhydride measured using a helium pycnometer. *Holzforchung*. 58(5): 544-547.

Homan, W.J. and Jorissen, A. J. M., (2004).*Wood modification development*. Netherlands.

Imamura, Y. (1989). High-durable particleboards by chemical modification.*Wood Ind*. 44: 634-636.

Jebrane, M., Pichavant, F. and Sebe, G. (2011).A comparative study on the acetylation of wood by reaction with vinyl acetate and acetic anhydride.*Carbohydrate Polymers*. 83(6): 339-345.

Jorissen, A., Bongers, F., Kattenbroek, B., & Homan, W. (2005).*The influence of acetylation of Radiata pine in structural sizes on its strength properties*. In H. Militz& C. A. S. Hill (Eds.), Proceedings of Second European Conference on Wood Modification (pp. 108-116). Gottingen, Germany.

Kollman, F. F. and Cote Jr., W.A. (1968).*Principles of wood science and technology*, vol 1.Solid wood. Springer, Berlin Heidelberg, New York, pp 55-78.

Korai, H. (2001). Effects of low bondability of acetylated fibers on mechanical properties and dimensional stability of fiberboard.*Journal of Wood Science*. 47(6): 430-436.

Koshijima, K. and Watanabe, T. (2003).*Association Between Lignin and Carbohydrates in Wood and Other Plant Tissues*. Springer Series in Wood Science, Springer-Verlag, Berlin, Germany.

Lande, S., Westin, M. and Schneider, M. H. (2004).*Environmental friendly wood protection furfurylated wood as an alternative to wood preservation*. In: International Conference on Environmentally-Compatible Forest Products, Opporto, Portugal, Jorge, F. C (Ed.). (pp.163-175).

Larsson, P. and Simonson, R. (1994). A study of the strength, hardness and deformation of acetylated Scandinavian softwoods. *HolzalsRoh- und Werkstoff*. 52(2): 83-86.

Larsson Brelid, P., Simonson, R. and Risman, P. O. (1999).Acetylation of wood using microwave heating.Part 1.Studies of dielectric properties.*HolzalsRoh- und Werkstoff*: 57(4): 259-263.

Larsson, P. and Simonson, R. (1999).Acetylation of solid wood using microwave heating.Part 2. Experiment in laboratory scale. *HolzalsRoh- und Werkstoff*. 57(5): 383-389.

Larsson Brelid, P., Simonson, R., Bergman, O. and Nilsson, T. (2000).Resistance of acetylated wood to biological degradation.*HolzalsRoh- undWerkstoff*. 58(5): 331-337.

Li, J.Z., Furuno, T., Katoh, S. and Uehara, T. (2000).Chemical modification of wood without solvents or catalysts.*Journal of Wood Science*. 46(3): 215-221.

Minato, K., Takazawa, R. and Ogura, K. (2003). Dependence of reaction kinetics and physical and mechanical properties on the reaction systems of acetylation II: physical and mechanical properties. *Journal of Wood Science*. 49(6): 519-524.

Mohebby, B. and Militz, H. (2002).*Soft rot decay in acetylated wood.Chemical and anatomical changes in decayed wood*.International Research Group on Wood Preservation, Doc. No. IRG/WP 02-40231.

Pandey, K. K., Hughes, M. and Vuorinen, T. (2010). Modified pine wood. *BioResources*. 5(2): 598-615.

Panshin A. J., and DeZeeuw, C. (1980).*Textbook of Wood Technology*, fourth ed. McGrawhill Inc.

Papadopoulos, A. N. (2008). The effect of acetylation on bending strength of finger jointed beech wood (Fagussylvatica). *HolzRohWerkst*. 66(1) 309–310.

Papadopoulos, A. N., and Pougioula, G. (2010). Mechanical behavior of pine wood chemically modified with a homologous series of linear chain carboxylic acid anhydrides. *Bioresource Technology*. 101(3): 6147-6150.

Papadopoulos, A. N., Militz, H. and Pfeffer, A. (2010). The biological behaviours of pine wood modified with linear chain carboxylic acid anhydrides against soft for fungi. *International Biodeterioration and Biodegradation*. 64(4): 409-412.

Poula, C. P., Dmitry, V. E. and Carlos, P. N. (2005). Chemical compositions and structural features of the macromolecular components of plantation Acacia Mangium wood. *J. Agric. Food Chemistry*. 53: 7856-7862.

Prakash, G.K., Pandey, K.K., Ram, R.K.D., and Mahadevan, K.M., (2006). Dimensional stability and photostability of octanolyted wood.Institute of Wood Science and Technology, Bangalore, India.*Holzforschung*. Vol. 60: pp. 539-542.

Rafidah, S. K., Hill, C. A. S. and Ormondroyd, G. A. (2006).Dimensional stabilization of Rubberwood (HeveaBrasiliensis) with acetic or hexanoic anhydride.*Journal of Tropical Forest Science*. 18(4): 261-268.

Ramsden, M.J., Blake, F.S.R. and Fey, N.J. (1997).The effect of acetylation on the mechanical properties, hydrophobicity and dimensional stability of Pinussylvestris.*Wood and Science Technology*. 31(2): 97-104.

Reiterer, A. and Sinn, G. (2002). Fracture behaviour of modified spruce wood: a study using linear and non-linear fracture mechanics. *Holzforschung*. 56(2): 191-198.

Rowell, R. M. (1980). Distribution of reacted chemicals in southern pine treated with methyl isocyanate. *Wood Science*. 13(2): 102-110.

Rowell, R. M. (1982). Distribution of acetyl groups in southern pine reacted with acetic anhydride. *Wood Science*. 15(2): 172-182.

Rowell, R. M., (1983). *Chemical modification of wood*. Commonwealth Forestry Bureau, Forest Product abstract. Review article. 6(12): 363-382.

Rowell, R.M., (1984). *Penetration and reactivity of cell wall components*. In: The Chemistry of Solid Wood, Rowell, R.M. (Ed.). Advances in Chemistry Series, 207, American Chemical Society. pp.175-210.

Rowell, R. M. (1991). *Chemical modification of wood*.Wood and Cellulosic Chemistry. New York : Marcel Dekker, Inc, (15):703-756.

Rowell, R.M. (2005). *Chemical modification of wood,* In Handbook of Wood Chemistry and Wood Composite (Ed. Rowell, R.M.).Taylor and Francis, Boca Raton, FL, Ch. 14, pp.381-420.

Rowell, R.M. and Banks, W.B. (1985).*Water repellency and dimensional stability of wood*. USDA Forest Service General Technical Report FPL 50. Forest Products Laboratory, Madison, WI.

Rowell, R.M. and Banks, W.B. (1987).Tensile strength and toughness of acetylated pine and lime flakes.British*Polymer Journal*. 19(5): 479-482.

Rowell, R. M. and Ellis, W. D. (1978).Determination of the dimensional stabilization of wood using the water-soak method.*Wood and Fiber*. 10(4): 104-111.

Rowell, R. M., Simonson, R. and Tillman, A.-M.(1986). A simplified procedure for the acetylation of chips for dimensionally stabalized particleboards products.*PaperijaPuu*. 68(10): 740-744.

Rowell, R.M., Tillman, A.M., and Zhengtian, L., (1986).Dimensional stabilization of flakeboard by chemical modification.*Wood Science and Technology*, (20):83-95.

Rowell, R. M., Simonson, R. and Tillman, A. -M. (1990).Acetyl balance for the acetylation of wood particles by a simplified procedure.*Holzforschung*.44(4): 263-269.

Rowell. R. M., Simonsen, R., Hess, S., Plackett, D.V., Cronshaw, D. and Dunningham, E. (1994). Acetyl distribution in acetylated whole wood and reactivity of isolated cell wall components to acetic anhydride.*Wood and Fiber Science*. 26(1): 11-18.

Sander, C., Beckers, E. P. J., Militz, H. and Van Veenendaal, W. (2003).Analysis of acetylated wood by electron microscopy.*Wood Science and Technology*. 37(1): 39,46.

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

Thong, H. L. and Choh, S. H. (1994).*Rubberwood: Processing and Utilisation*. Forest Research Institute Malaysia, Kepong.

Yoshida, Y., Kawai, S., Imamura, Y., Nishimoto, K. Sato, T. and Nakaji, M. (1986). Production technology for acetylated low-denstiy particleboard. I. Mechanical properties and dimensional stability. *MokuzaiGakkaishi*. 32(12): 965-971.

Youngquist, J. A., Rowell, R. M. and Krzysik, A. (1986). Mechanical properties and dimensional stability of acetylated aspen flakeboard. Holz*alsRoh- und Werkstoff*. 44(12): 453.457.

## LIST OF PUBLICATIONS

1. Effect of Linear Chain Carboxylic Acid Anhydrides on Physical and Mechanical Properties of Rubber (*Hevea brasiliensis*), Acacia, (*Acacia spp*.), and Oil Palm (*Tinnera spp*.) Woods

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