EFFECTS OF SURFACE TREATMENT ON THE WETTABILITY AND FINISHING PROPERTIES OF Acacia mangium WILLD. WOOD

REDZUAN BIN MOHAMMAD SUFFIAN JAMES

IPTPH 2019 5

EFFECTS OF SURFACE TREATMENT ON THE WETTABILITY AND FINISHING PROPERTIES OF *Acacia mangium* WILLD. WOOD

By

REDZUAN BIN MOHAMMAD SUFFIAN JAMES

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

November 2018

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

EFFECTS OF SURFACE TREATMENT ON THE WETTABILITY AND FINISHING PROPERTIES OF *Acacia mangium* WILLD. WOOD

By

REDZUAN BIN MOHAMMAD SUFFIAN JAMES

November 2018

Chairman : Professor Paridah Md. Tahir, FASc
Institute : Tropical Forestry and Forest Product

Furniture manufacturers who are using *Acacia mangium* wood often experienced difficulties in getting high glossy and attractive finished surface. Such problem may be attributed to poor surface wettability as well as the anatomical structure of the wood itself. This study evaluates the effects of surface treatment on both the wettability and finishing properties of *A. mangium* wood. The *A. mangium* lumber was segregated into sapwood and heartwood prior to sanding. Two types of solvent, methanol (MeOH) and sodium hydroxide (NaOH), were used to treat the wood surface using different concentrations: 2%, 4%, 6%, 8%, 10%, 12% and, 14%. The treated surfaces were evaluated for surface roughness and contact angle according to ISO 4287 and ASTM D7334-08 respectively. The results show that untreated sapwood of *A. mangium* has significantly rougher surface compared to heartwood upon treatment with MeOH and NaOH, the surface roughness. NaOH-treated surface has relatively lower contact angle than MeOH-treated, and experienced a complete wetting within 4.2 s for sapwood and 6.8 s for heartwood. Nevertheless, the surface looks darker and the grain is less visible. Meanwhile, MeOH-treated surface took 6.4 s for sapwood and 15.1 s for heartwood to completely wet the wood surface but retained it's original colour. Moreover, the wood grain was clearer and much enhanced. Based on both wettability and appearance, the best results were given by MeOH having 8% concentration. Evaluation on the effects of 8% MeOH pretreatment prior to coating was carried out for different coating systems i.e. nitrocellulose (NC), acid catalyst (AC) and polyurethane (PU). The coated surfaces were tested for adhesion test-cross cut, scratch resistance test, abrasion test, impact resistance test, surface roughness, and gloss measurements test according to the relevant standards. The results revealed that Acacia wood surface treated with 8% methanol resulted in superior finished surface compared to untreated panels except for gloss. Among the coating systems, AC and PU appears to be more compatible with MeOH compared to NC as shown by applying 8% methanol on the *A. mangium* surface prior to coating with AC or PU improved the quality of

the finished *A. mangium* wood meeting the minimum requirements stipulated in the standards.

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

KESAN RAWATAN PERMUKAAN TERHADAP TAHAP KESERAPAN DAN SIFAT KEMASIAPAN PADA KAYU *Acacia mangium* WILLD

Oleh

REDZUAN BIN MOHAMMAD SUFFIAN JAMES

November 2018

Pengerusi : Profesor Paridah Md. Tahir, FASc
Institut : Perhutanan Tropika dan Produk Hutan

Pengeluar perabot yang menggunakan kayu *Acacia mangium* untuk tujuan kemasiapan kebiasaannya akan mengalami kesukaran untuk mendapatkan permukaan yang berkilap dan menarik. Masalah ini berkemungkinan disebabkan tahap penyerapan yang lemah dan juga struktur anatomi kayu itu sendiri. Kajian ini bertujuan untuk mengkaji kesan rawatan terhadap tindak balas daya serapan dan kemasiapan kayu *A.mangium*. Kayu *A. mangium* telah dibahagikan kepada dua iaitu kayu gubal dan kayu teras, dan kedua kayu ini telah digosok menggunakan kertas pasir. Dua jenis pelarut iaitu methanol (MeOH) dan sodium hydroxide (NaOH) dengan pelbagai nisbah bancuhan: 2%, 4%, 6%, 8%, 10%, 12% & 14% telah digunakan. Permukaan yang telah dirawat akan diuji tahap kekasaran dan sudut penyerapannya berdasarkan piawaian ISO 4287 dan ASTM D7334-08. Keputusan ujian berkenaan menunjukkan bahawa kayu gubal *A. mangium* yang tidak dirawat mempunyai kekasaran permukaan yang lebih berbanding pada kayu teras yang menerima rawatan oleh MeOH dan NaOH, tahap kekasaran permukaan NaOH menunjukkan sudut penyerapan yang rendah berbanding permukaan kayu yang dirawat oleh MeOH iaitu mencatatkan masa 4.2 saat untuk kayu gubal dan 6.8 saat untuk kayu teras untuk menyerap sepenuhnya. Namun begitu, permukaannya bertukar menjadi lebih gelap dan ira kayu kurang kelihatan. Sementara itu, permukaan yang dirawat menggunakan MeOH pula mengambil masa 6.4 saat untuk kayu gubal dan 15.1 saat untuk kayu teras untuk menyerap sepenuhnya dan ia mengekalkan warna kayu tersebut. Tambahan pula, ia kayu menjadi lebih jelas dan menyerlah. Berdasarkan kepada kedua-dua tahap serapan dan rupa, keputusan terbaik adalah pada nisbah 8%. Ujian terhadap rawatan methanol 8% terhadap penglitup telah dijalankan dengan menggunakan system pernglitup yang berbeza iaitu nitrocellulose (NC), acid catalyst (AC) dan polyurethane (PU). Permukaan penglitup berkenaan telah diuji dengan ujian rekatan (garisan bersilang), ujian ketahanan calar, ujian geseran, ujian impak, ijian kekasaran permukaan dan ujian kelipan berpandukan piawaian yang telah ditetapkan.

Keputusan menunjukkan bahawa kayu *A. mangium* yang telah dirawat menggunakan 8% MeOH adalah lebih baik kemasiapannya berbanding kayu yang tidak dirawat kecuali pada tahap kilapan. Berdasarkan kepada semua jenis system penglitup, AC and PU telah menunjukkan kesesuaian dengan MeOH berbanding dengan AC. Penggunaan 8% MeOH terhadap permukaan kayu *A. mangium* dengan menggunakan penglitup AC atau PU mampu untuk meningkatkan kualiti kemasiapan kayu *A. mangium* dan ianya telah memenuhi keperluan asas seperti yang terdapat pada piawaian.

ACKNOWLEDGEMENTS

First and foremost, Alhamdulillah and thanks to Allah for giving me opportunity to complete the research successfully.

I would like to express my deep and sincere gratitude to my research supervisor, Professor Dr. Paridah Md Tahir for giving me the opportunity to do research and providing invaluable guidance throughout this research. Her dynamism, vision, sincerity and motivation have deeply inspired me. She has taught me the methodology to carry out the research and to present the research works as clearly as possible. It was a great privilege and honor to work and study under her guidance. I am extremely grateful for what she has offered me. I am extending my heartfelt thanks to my committee members, Dr. Ummi hani Abdullah and Dr. Khairun Anwar Hj. Uyup for their acceptance and patience during discussion we had on research work and thesis preparation.

I would like to thank the Ministry of Education under grant Public Private Research Network (PPRN) whose funding provided financial support for my research. I would also like to thank Nusantara Kraft Sdn. Bhd. for providing us the *Acacia mangium* wood and other technical details. In addition, I would like to extend my thanks to the staffs of Institute of Tropical Forestry and Forest Product (INTROP, UPM) and Coating and Finishing Laboratory (MKK, FRIM), En Yaakob Mansuri, En Faizul Jemari and Pn Siti Rafidah Mahmood that always spared time for helping me analyze data provided necessary enthusiasm for me to push forward.

I am extremely grateful to my parents, Mohammad Suffian James Abdullah and Mawor Musaini for their love, prayers, caring and sacrifices for educating and preparing me for my future. I am very much thankful to my wife, Norwahyuni Mohd Yusof for her love, understanding, prayers and continuing support to complete this research work. Also, I express my thank to my siblings, family in law for their support and valuable prayers. My special thanks go to my friend at INTROP and Faculty of Forestry for their keen interest shown to complete this thesis successfully.

Finally, my thank go to all the people who have supported me to complete the research work direct or indirectly.

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

Paridah Md. Tahir, FASc
Professor
Institute of Tropical Forestry and Forest Products
Universiti Putra Malaysia
(Chairman)

Ummi Hani Abdullah, PhD
Senior Lecturer
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Mohd Khairun Anwar Hj. Uyup, PhD
Senior Research Officer
Forest Products Division
Forest Research Institute Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Univeriti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been fully referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permissions must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No: Redzuan Bin Mohammad Suffian James (GS47833)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Professor Dr. Paridah Md Tahir

Signature: _____
Name of Member of Supervisory Committee: Dr. Ummi Hani Binti Abdullah

Signature: _____
Name of Member of Supervisory Committee: Dr. Mohd Khairun Anwar Bin Hj Uyup

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	Percentage
°	Degree
°C	Degree celcius
µl	microlitre
µm	micrometre
AC	Acid catalyst
ANOVA	Analysis of variance
ASTM	American Society of Testing Materials
BS	British Standard
CA	Contact angle
df	Degree of freedom
EN	European Standard
g	Gram
ha	Hectare
HCL	Hydrochloric acid
INTROP	Institute of Tropical Forestry and Forest Product
kg/m^3	Kilogram per cubic meter
LSD	Least significant different
MC	Moisture content'
MeOH	Methanol
ml	Milliliter
mm	Millimeter
MOE	Modulus of elasticity
MOR	Modulus of rupture
N	Newton
NC	Nitrocellulose
NaOH	Sodium hydroxide
ns	No significant
OD	Oven dried
pH	Potential of hydrogen
PU	Polyurethane
RF	Resorcinol formaldehyde
RH	Relative humidity
SAS	Statistical analysis system
SEM	Scanning electron microscopic
SG	Specific gravity

CHAPTER 1

INTRODUCTION

1.1 Background of Study

For many years, the Malaysian export furniture has been placed within the top ten of the world's furniture export (MATRADE, 2017). According to Malaysian Timber Council (2018), the wooden furniture was reported as the highest contributor to Malaysia's export of timber followed by plywood, sawn timber, fibreboard and etc. The export of Malaysian major timber products is tabulated in Table 1.1.

Table 1.1: Malaysia: Export of major timber products (Jan-Feb 2018)

Type of Products	Million (RM)	Percentage (%)
Wooden Furniture	1,189,2	99.83
Plywood	642.2	0.05
Sawn timber	578.0	0.05
Fibreboard	179.2	0.02
Builder's Joinery & Carpentry	175.4	0.02
Mouldings	126.7	0.01
Chipboard / Particleboard	69.3	0.002
Wooden Frame	19.4	0.0001
Rattan furniture	1.7	0.0001
Other Products	180.7	0.02
Total	1,191,172.60	100

(Source: Malaysian Timber Council, 2018)

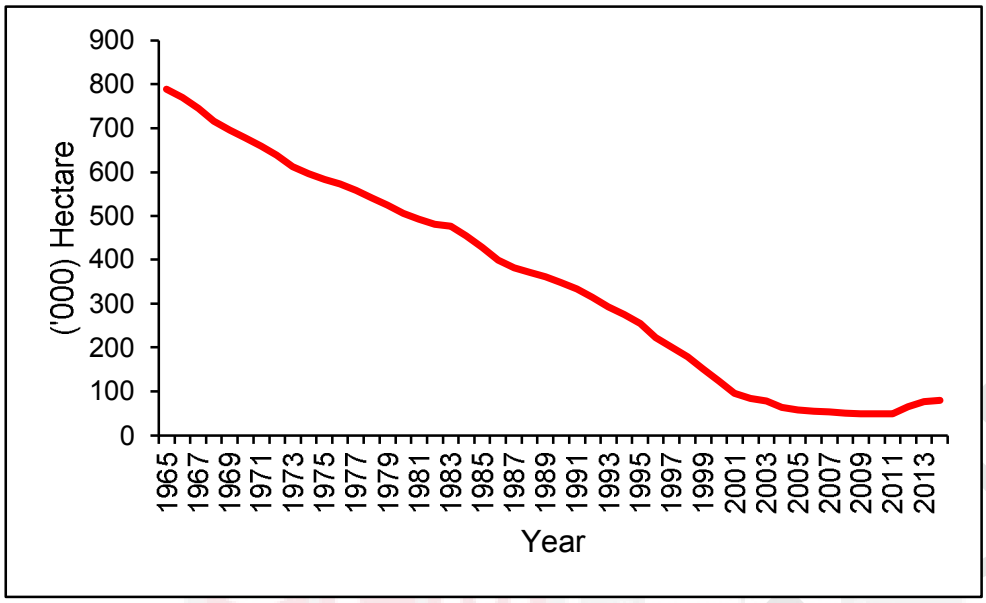

Figure 1.1: Rubberwood Plantation Area (Estate) From Year 1965 to 2014
(Source: Malaysian Timber Council, 2018)

There are about 600 furniture and wood working mills that are export oriented. About 80% of these mills utilise rubberwood as the main raw material (Jegatheswaran Ratnasingam et al., 2016; MASKAYU, 2012a; Sulaiman et al., 2009; Zaidon et al., 2007). Despite the increase use of rubberwood, the rubberwood planted areas have decreased tremendously (Figure 1.1) which inevitably raises the prices of rubber logs (Table 1.2).

Table 1.2: Average domestic price of logs by species (in RM per cubic metre)

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Meranti	592	606	612	650	751	802	820	818	604	653
Mersawa	613	698	700	700	746	750	760	758	588	599
Merbau	794	788	800	927	1175	1,200	1228	1246	1012	1316
Rubberwood	105	105	129	104	155	163	157	130	73	91

(Source: Forestry Department Peninsular Malaysia, 2016)

Other than rubberwood, a huge amount of *Acacia mangium* trees have been planted in Peninsular Malaysia, Sabah and Sarawak. Sarawak has the largest *A. mangium* plantation area, with about 289,816 ha in 2012 that makes up 74% of the planted area. This amount is expected to increase to a targeted area of 700,000 ha by the year 2020 (Perkasa, 2009; Jusoh & Adam, 2012). *A. mangium* has been acknowledged as one of the popular fast growing species found in South-East Asian forest plantations (Vijayanathan et al., 2011). According to Tsukamoto and Sabang (2005), *A. mangium* can be one of the potential resources for timber and/or pulp chip production. It has a very short rotation (fast growing species) and can be managed by using coppice system of 2-5 years

(Hashim et al., 2015). In addition, *A. mangium* can be easily planted in degraded areas (Nadhari et al., 2014; Awang & Taylor, 1993).

The popularity of *A. mangium* wood is due to its excellence in strength and machining properties, thus can be used for medium to high end value-added products such as furniture and indoor components (Lim et al., 2003). However, *A. mangium* was reported as low-priced wood due to knots, cross grain structure and relatively fair in permeability and wettability. Such properties are crucial for any wood particularly in finishing process (Lehman & Mishawaks, 1944). As the result, the finished surface often sagged and paint tailings often occurred due to lack of penetration by the lacquers (personal communication with Nusantara Kraft Sdn. Bhd., 2017). The low wettability of *A. mangium* wood surface was also experienced in bonding. Alamsyah et al. (2007) reported that *A. mangium* laminated board bonded with resorcinol formaldehyde (RF) resin has poor bonding shear strength. This problem was associated with poor wettability of *A. mangium* that prevents any liquid to sufficiently penetrate the wood surface. Hence a pretreatment is needed to improve the surface wettability of *A. mangium.*

Surface treatment of wood is done by treating the wood surfaces with polar liquid such as methanol (MeOH) and sodium hydroxide (NaOH). Such treatment involves only the surface to reduce its surface tension and increase surface compatibility with coating and adhesives (Bulian & Graystone, 2009). Some of the surface treatment agents that have been used were sodium hydroxide, hydrogen peroxide, lime (natural) and ethanol (Ayeni et al., 2013). To become friendly to industrial applications, a pretreatment agent must be effective, economical, easy-to-use, and easy to apply. Connected to that, the study to evaluate the ability of MeOH and NaOH as pretreatment solvents to increase the surface wettability and consequently the finishing properties of *A. mangium* was attempted.

1.2 Problem Statement

High quality finished surface of *A. mangium* wood with excellent surface properties and aesthetically durable are needed for the production of *A. mangium* furniture. However, *A. mangium* wood has low wettability properties hence making finishing a difficult task. Wood components, probably extractives, appear to affect the curing of resin (Alamsyah et al., 2008). One of the main problems is the finished surface often sagged and shows paint tailings due to lack of penetration by the lacquers. In addition, the finished surface has an uneven colour as the colour of sapwood and heartwood of *A. mangium* is distinctly differentiated (Nordahlia et al., 2013). Such defects are detrimental to the furniture quality and often led to rejection by buyers. Moreover, the main purpose of finishing is to produce attractive and scratch-abrasive-resistant surface of wood. However, with the existing coating system used for *A. mangium,* the results were quite unsatisfactorily.

1.3 Significance of Study

This study attempted to increase the wettability of *A. mangium* by a slight treatment of the wood surface using bleaching process. Studies have shown that the surface wettability of lumber can be improved by wiping it with a proper amount of solvent that have the ability to remove the contaminants on the surface and improve the wettability of the laminae surface by destroying the H-bonding in wood-cellulose and reduce the surface tension (Haque et al., 2017). Consequently, the penetration of coating materials into the substrate would become much easier.

1.4 Objective of Study

The objectives of this study are:

- To determine the effect of surface pretreatment on the wettability of *A. mangium* wood.
- To evaluate the finishing properties of surface-treated *A. mangium* wood coated with different finishing systems.

1.5 Organization of the Chapters

This thesis is organized into five chapters. The first chapter gives a general overview of *A. mangium* and wood finishing, problem statement, justification, and objectives of this study. The second chapter reviews on the relevant literature associated to the topic, which includes the *A. mangium* species in Malaysia, wood finishing, surface treatments, and application of finishing.

The third chapter focuses on the basic properties of *A.mangium,* which includes the moisture content, pH buffering capacity, surface roughness and wettability of wood. The effects of wood surface treatment by MeOH and NaOH wiped method were evaluated with surface roughness and contact angle test and the results were discussed.

Chapter four discusses the finishing properties of methanol-treated *A. mangium* sprayed with nitrocellulose (NC), acid catalyst (AC), and polyurethane (PU) towards control sample and treatment sample. The results were then compared in terms of physical and mechanical properties. The final chapter summarizes the whole thesis and gives a conclusion and some recommendations for future work.

REFERENCES

Alamsyah, E. M., Nan, L. C., Yamada, M., Taki, K., & Yoshida, H. (2007). Bondability of tropical fast-growing tree species I: Indonesian wood species. *Journal of Wood Science, 53*(1), 40-46.

Alamsyah, E. M., Yamada, M., & Taki, K. (2008). Bondability of tropical fast-growing tree species III: curing behavior of resorcinol formaldehyde resin adhesive at room temperature and effects of extractives of Acacia mangium wood on bonding. *Journal of Wood Science, 54*(3), 208-213.

Arisman, H., & Hardiyanto, E. B. (2006, February). Acacia mangium-a historical perspective on its cultivation. In *Aciar Proceedings* (Vol. 124, p. 11). ACIAR; 1998.

ASTM. (1994). D4060 Standard test method for abrasion resistance of organic coatings by the taber abraser. West Conshohocken, PA.: ASTM International.

ASTM. (2008). D7334-08 Standard practice for surface wettability of coatings, substrates and pigments by advancing contact angle measurement. *Annual Book of Standards 06.01*, 820-822.

Awang, K., & Taylor, D. A. (1993). *Acacias for rural, industrial and environmental development.* Paper presented at the Proceedings of the Second Meeting of the Consultative Group for Research and Development of Acacias (COGREDA), held in Udorn Thani, Thailand.

Ayeni, A. O., Hymore, F. K., Mudliar, S. N., Deshmukh, S. C., Satpute, D. B., Omoleye, J. A., & Pandey, R. A. (2013). Hydrogen peroxide and lime based oxidative pretreatment of wood waste to enhance enzymatic hydrolysis for a biorefinery: Process parameters optimization using response surface methodology. *Fuel, 106*, 187-194. doi: 10.1016/j.fuel.2012.12.078

BS. (1980). BS 3962:Part 6 1980. Finishes for wooden furniture-Assessment of surface to mechanical damage. BSI Standard Limited London: BSI Standard Limited. London.

BS. (2013). BS EN ISO 2409. 2013. Paints and varnishes – Cross-cut test. BSI Standard Limited. London.: BSI Standard Limited. London.

Budakci, M., & Cinar, H. (2004). Colour effects of stains on wood with knots, cracks and rots. *Progress in Organic Coatings*, *51*(1), 1-5

Bulian, F., & Graystone, J. (2009). *Wood coatings: Theory and practice*: Elsevier.

Busscher, H., Van Pelt, A., De Boer, P., De Jong, H., & Arends, J. (1984). The effect of surface roughening of polymers on measured contact angles of liquids. *Colloids and Surfaces, 9*(4), 319-331.

Çakıcıer, N., Korkut, S., & Korkut, D. S. (2011). Varnish layer hardness, scratch resistance, and glossiness of various wood species as affected by heat treatment. *BioResources, 6*(2), 1648-1658.

Chen, C. M. (1970). Effect of extractive removal on adhesion and wettability of some tropical woods. *Forest Products Journal*, *20*(1), 36-41.

Csanády, E., Magoss, E., & Tolvaj, L. (2015). Surface Roughness of Wood. 183-236. doi: 10.1007/978-3-319-22419-0_4

Eckelman, C. A. (1997). *Wood moisture calculations*. Purdue University, Department of Forestry & Natural Resources.

Farmer, R. H. (2013). *Chemistry in the Utilization of Wood: Pergamon Series of Monographs on Furniture and Timber*(Vol. 9). Elsevier.

Flexner, B. (1996). *Understanding wood finishing*: Rodale Press.

Forestry Department Peninsular Malaysia. (2016). Average Domestic Price of Logs by Species (in RM per cubic metre). from https://www.forestry.gov.my/index.php/en/2016-06-07-02-31-39/logs-price

Forestry Department Peninsular Malaysia. (2017). Plantation Information of Acacia mangium.

Gardner, D. J., Generalla, N. C., Gunnells, D. W., & Wolcott, M. P. (1991). Dynamic wettability of wood. *Langmuir, 7*(11), 2498-2502.

Gupta, B. S. (2006). Development of a coating technology for wood plastic composites.

Hashim, M., Hazim, M., & Syafinie, A. (2015). Strategic Forest Plantation Establishment in Malaysia For Future Product Development and Utilisation. *Intl J Agric For Plantat, 1*, 14-24.

Haque, M. A., Akhtar, M., Halilu, A., & Yun, H. D. (2017). Validation and extended application of cellulose microfibril swelling enzyme assay method to alkali induced swelling of cellulose. *J. Chem. Eng. Bioanal. Chem*, *2*, 62-69

He, G., & Yan, N. (2005). Effect of wood on the curing behavior of commercial phenolic resin systems. *Journal of applied polymer science, 95*(2), 185-192.

Hiziroglu, S. (1996). Surface roughness analysis of wood composites: a stylus method. *Forest Products Journal, 46*(7, 8), 67.

Hiziroglu, S., & Graham, M. (1998). Effect of press closing time and target thickness on surface roughness of particleboard. *Forest Products Journal, 48*(3), 50.

Hse, C.-Y. (1972). Wettability of southern pine veneer by phenol formaldehyde wood adhesives. *Forest Products Journal, Vol. 22 (1): 51-56*.

Hse, C.-Y., & Kuo, M.-L. (1988). Influence of extractives on wood gluing and finishing-a review.

ISO. (2011). BS EN ISO 1518-1. 2011. Paints and varnishes. Determination of scratch resistance. Constant-loading method.

ISO (1998). 4287: 1997: Geometrical Product Specifications (GPS)--Surface texture: Profile method--Terms, definitions and surface texture parameters. *International Organization for Standardization*.

Jakub, S., & Martino, N. (2005a). Wood surface roughness-what is it. *Trees and timber research institute, Ivalsa/Cnr.(http://www. boku. ac. at/physik/coste35/Rosenheim/article/art_Sandak_COST_E35_Rosenheim_2005. pdf.)*.

Jakub, S., & Martino, N. (2005b). *Wood surface roughness-what is it.* Paper presented at the Rosenheim Workshop, BOKU University of Natural Sources and Applied Life Sciences.

Jewitt, J. (2004). Selecting a Finish. Retrieved January 18, 2013.

Johns, W. E., & Niazi, K. A. (2007). Effect of pH and buffering capacity of wood on the gelation time of urea-formaldehyde resin. *Wood and Fiber Science, 12*(4), 255-263.

Jusoh, I., & Adam, N. S. (2012). Acacia mangium Plantation in Sarawak and its Wood Quality.

Keey, R. B. (2005). Colour development on drying. *Maderas. Ciencia y tecnología, 7*(1), 03-16.

Kim, S. (2010). Control of formaldehyde and TVOC emission from wood-based flooring composites at various manufacturing processes by surface finishing. *Journal of Hazardous Materials*, *176*(1-3), 14-19

Krisnawati, H., Kallio, M., & Kanninen, M. (2011). *Acacia mangium Willd.: ecology, silviculture and productivity*. CIFOR.

Kúdela, J., & Liptáková, E. (2006). Adhesion of coating materials to wood. *Journal of Adhesion Science and Technology, 20*(8), 875-895.

Laina, R., Sanz-Lobera, A., Villasante, A., López-Espí, P., Martínez-Rojas, J. A., Alpuente, J., . . . Vignote, S. (2017). Effect of the anatomical structure, wood properties and machining conditions on surface roughness of

wood. *Maderas. Ciencia y tecnología*(ahead), 0-0. doi: 10.4067/s0718-221x2017005000018

Lehman, E. A., & Mishawaks. (1944). Wood finishing: Google Patents.

Liang, T., & Wang, L. (2015). An environmentally safe and nondestructive process for bleaching birch veneer with peracetic acid. *Journal of Cleaner Production, 92*, 37-43.

Lim, S., Ten Choo, K., & Gan, K. (2003). *The characteristics, properties and uses of plantation timbers-rubberwood and Acacia mangium*: Timber Technology Centre, FRIM.

Lu, K.-T. (2006). Effects of hydrogen peroxide treatment on the surface properties and adhesion of ma bamboo (Dendrocalamus latiflorus). *Journal of Wood Science, 52*(2), 173-178.

Malanit, P., Barbu, M., & Frühwald, A. (2009). The gluability and bonding quality of an asian bamboo (*"Dendrocalamus asper"*) for the production of composite lumber. *Journal of Tropical Forest Science*, 361-368.

Malaysian Timber Council. (2018). TIMBER EXPORT STATISTICS. 2018 Performance Of The Malaysian Timber Trade.

Maloney, T. M. (1977). Modern particleboard and dry-process fiberboard manufacturing.

MASKAYU. (2012a). *Malaysian Timber Industry Board: Kuala Lumpur*.

Malaysia External Trade Development Corporation. (2017, October 10). Retrieved from http://www.matrade.gov.my/en/about-matrade/media/press-releases/4063-malaysia-s-furniture-sector-recognised-globally-2

Nadhari, W. N. A. W., Hashim, R., Hiziroglu, S., Sulaiman, O., Boon, J. G., Salleh, K. M., ... & Sugimoto, T. (2014). Measurement of some properties of binderless composites manufactured from oil palm trunks and Acacia mangium. *Measurement*, *50*, 250-254

Neese, J., Reeb, J., & Funck, J. (2004). Relating traditional surface roughness measures to gluebond quality in plywood. *Forest Products Journal, 54*(1), 67.

Nordahlia, A., Hamdan, H., & Anwar, U. (2013). Wood properties of selected plantation species: *Khaya ivorensis* (african mahogany), *Azadirachta excelsa* (sentang), *Endospermum malaccense* (sesendok) and *Acacia mangium.*

Nurhazwani, O., Jawaid, M., Tahir, P. M., Abdul, J. H., & Hamid, S. A. (2015). Hybrid particleboard made from bamboo (Dendrocalamus asper) veneer

waste and rubberwood (Hevea brasilienses). *BioResources, 11*(1), 306-323.

Nussbaum, R. M., & Sterley, M. (2007). The effect of wood extractive content on glue adhesion and surface wettability of wood. *Wood and Fiber Science, 34*(1), 57-71.

Paridah, M., Hafizah, A. N., Zaidon, A., Azmi, I., Nor, M. M., & Yuziah, M. N. (2009). Bonding properties and performance of multi-layered kenaf board. *Journal of Tropical Forest Science*, 113-122.

PERKASA. (2009). "Seminar on viability assessment of indigenous tree species and propagation techniques for planted forest development in Sarawak".

Petrič, M. (2013). Surface Modification of Wood. *Reviews of Adhesion and Adhesives, 1*(2), 216-247. doi: 10.7569/raa.2013.097308

Poth, U., Moller, D., & Dobbelstein, A. (1982). *U.S. Patent No. 4,315,053*. Washington, DC: U.S. Patent and Trademark Office.

Ratnasingam, J., Ramasamy, G., & Ioras, F. (2016). The influence of log felling season on the extent of discoloration in rubberwood sawn timber during the kiln drying process. *BioResources, 11*(2), 5003-5012.

Ratnasingam, J., & Scholz, F. (2006). Optimal surface roughness for high-quality finish on rubberwood (Hevea brasiliensis). *Holz als Roh-und Werkstoff, 64*(4), 343-345.

Rokeya, U. K., Hossain, M. A., Ali, M. R., & Paul, S. P. (2010). Physical and mechanical properties of (Acacia auriculiformis x A. mangium) hybrid acacia. *J Bangladesh Acad Sci*, *34*(2), 181-187.

Safta, E., Chen, F. B.-H., Forrest, H. R., & Muselman, G. D. (2002). Abrasion resistant coatings: Google Patents.

Scrinzi, E., Rossi, S., Deflorian, F., & Zanella, C. (2011). Evaluation of aesthetic durability of waterborne polyurethane coatings applied on wood for interior applications. *Progress in organic coatings, 72*(1-2), 81-87. doi: 10.1016/j.porgcoat.2011.03.013

Sonmez, A., Budakci, M., & Bayram, M. (2009). Effect of wood moisture content on adhesion of varnish coatings. *Scientific Research and Essays, 4*(12), 1432-1437.

Sulaiman, O., Hashim, R., Subari, K., & Liang, C. (2009). Effect of sanding on surface roughness of rubberwood. *Journal of Materials Processing Technology, 209*(8), 3949-3955.

Tanaka, S., Kano, S., Lat, J., Effendi, W. M., Tan, N., Arifin, A., . . . Kendawang, J. (2015). Effects of Acacia mangium on morphological and

physicochemical properties of soil. *Journal of Tropical Forest Science*, 357-368.

Tenorio, C., Moya, R., & Quesada-Pineda, H. J. (2012). Kiln drying of Acacia mangium wood: colour, shrinkage, warp, split and check in dried lumber. *Journal of Tropical Forest Science*, 125-139.

Tsukamoto, J., & Sabang, J. (2005). Soil macro-fauna in an Acacia mangium plantation in comparison to that in a primary mixed dipterocarp forest in the lowlands of Sarawak, Malaysia. *Pedobiologia, 49*(1), 69-80. doi: 10.1016/j.pedobi.2004.08.007

Vijayanathan, J., Yahya, A. Z., Yaacob, A., Kassim, A. S., & Chik, S. W. (2011). Impact of thinning of Acacia mangium plantation on soil chemical properties. *Malaysian Journal of Soil Science, 15*(1), 75-85.

Wålinder, M. (2000). Wetting phenomena on wood: factors influencing measurements of wood wettability. *KTH-Royal Institute of Technology, Department of Manufacturing Systems, Wood Technology and Processing, Stockholm, Sweden.*

Yuan, Y., & Lee, T. R. (2013). Contact angle and wetting properties *Surface science techniques* (pp. 3-34): Springer.

Zaidon, A., Norhairul Nizam, A., Mohd Nor, M., Abood, F., Paridah, M., Nor Yuziah, M., & Jalaluddin, H. (2007). Properties of particleboard made from pretreated particles of rubberwood, EFB and rubberwood-EFB blend. *Journal of Applied Science, 7*(8), 1145-1151.