UNIVERSITI PUTRA MALAYSIA

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

NABIL FIKRI BIN LEEMON

IPTPH 2015 2
COMPARATIVE PERFORMANCE BETWEEN NATURAL *Endospermum diadenum* (Miq.) AIRY SHAW WOOD AND TREATED WOOD IMPREGNATED WITH NANOCLAY AND PHENOLIC RESIN

By

NABIL FIKRI BIN LEEMON

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

August 2015
All material contained within the thesis, including without limitation test, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made any material contained within the thesis for non-commercial purpose from the copyright holder. Commercial use of the material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia
COMPARATIVE PERFORMANCE BETWEEN NATURAL *Endospermum diadenum* (Miq.) AIRY SHAW WOOD AND TREATED WOOD IMPREGNATED WITH NANOCLAY AND PHENOLIC RESIN

By

NABIL FIKRI BIN LEEMON

August 2015

Chairman : Professor Zaidon bin Ashaari, PhD
Faculty : Institute of Tropical Forestry and Forest Product

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

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

Air-dry sesenduk (*Endospermum diadenum*) wood was impregnated with these admixtures using vacuum pressure process followed by curing at 150°C for 30 min. The strength properties, dimensional stability and formaldehyde emission were evaluated and compared with impreg wood treated with LmwPF per se. Scanning electron micrograph (SEM) showed that the admixture penetrated the wood cell wall to some extend but larger amount polymer matrix was found resided in the cell lumen. The results showed that the polymer retention and density of the admixture-impregnated samples were higher than the PF-
impregnated samples. This admixture had successfully bulked the cell wall of the wood and imparted higher dimensional stability. The modulus of rupture (MOR) and modulus of elasticity (MOE), compressive stress and hardness of the admixture-impregnated wood were more superior to the PF-impregnated wood. The admixture was also found able to reduce the formaldehyde emission of the admixture-impregnated wood by 3-5% compared to PF-impregnated wood.

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

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

Oleh

NABIL FIKRI BIN LEEMON

Ogos 2015

Pengerusi : Profesor Zaidon bin Ashaari, PhD
Fakulti : Institut Perhutanan Tropika dan Produk Hutan

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

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

Sesenduk (*Endospermum diadenum*) kayu telah dirawat dengan bahan campuran menggunakan proses tekanan vakum diikuti oleh pemejaan pada suhu 150°C selama 30 minit. Sifat-sifat kekuatan, kestabilan dimensi dan pelepasan formaldehid telah dinilai dan dibandingkan dengan kayu impregnasi dirawat dengan LmwPF. Pengimbas Mikrograf Elektron (SEM) menunjukkan bahawa campuran menembusi dinding sel kayu tetapi jumlah matriks polimer yang lebih besar didapati berada di bahagian sel lumen. Hasil kajian
menunjukkan bahawa kandungan polimer dan ketumpatan sampel campuran-impregnasi adalah lebih tinggi daripada sampel PF-impregnasi. Campuran ini telah berjaya menyumbat di dalam dinding sel kayu dan memberikan kestabilan dimensi yang lebih tinggi. Modulus pecah (MOR) dan modulus keanjalan (MOE), tegasan mampatan dan kekerasan untuk impregnasi campuran adalah lebih bagus berbanding impregnasi PF sahaja. Impregnasi campuran ini juga dapat mengurangkan 3%-5% pelepasan formaldehid berbanding dengan diimpregnasi menggunakan LmwPF sahaja.

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

In the name of Allah S.W.T. Most Beneficent and Most Merciful.

I would like to express my deepest appreciation, gratitude and sincere thanks to my supportive supervisor, Professor Dr. Zaidon Ashaari, for his invaluable guidance, advice, suggestion, support, constructive comments and advance throughout the course of this study. My appreciation also goes to my committee members, Assoc. Prof. Dr. Edi Suhaimi Bakar and Dr. Khairun Anwar Uyup for their patient and never losing track of me.

Not forgetting to express my sincere thanks to Director of Institute Tropical Forestry and Forest Products (INTROP) Professor Dr. Paridah Md. Tahir through her teaching about wood adhesive and assistance given when I could understand theoretically about thermosetting resin. Great appreciation is also extended to Wood Composite Laboratory and Wood Deterioration Laboratory staffs, i.e., Mr. Fakhruddin, Mr. Zamani Mr. Rizal, Mr. Wan, Mr. Lokman, and Mrs. Lina for helping on materials preparation and sorting specimens in this project.

My appreciation also to Professor Dr. Nor Yuziah (MAC), Dr. Rafaiah (FRIM), Dr. Ainun (INTROP), Dr. Adlin (UPM), Dr. Salim Hiziroglu (OSU), Farah (IBS), Wan (UKM), my friends (Anuar Ridzuan, Mohd Aizat, Mohd Fitri, Mohd Nazri, and Zulfadli) and many other whose name are not mentioned but help in this project. Not forgetting to Ministry of Higher Education (MoHE) for paying my tuition fee and also to Ministry of Science Technology and Innovation with research grants VOT 5450621 entitled increasing value of Sesenduk (Endospermum diadenum) wood through chemical modification and incorporation of nanoclay particles.

My greatest, and deepest gratitude goes to my family; my parents Sallehuddin Mohamed Nor and Kintan Alimen, and my sister Syafiqah Hani, for their love, support, patience, understanding, and encouraged me throughout this journey. To my wife, Nur Aqila Kamarol Zamal, thank you for your support and patient during my difficult time. Last but not least, appreciation to my parent in law (Kamarol Zamal and Khatijah) for their understanding of my situation and constant pray for my success.
I certify that an Examination Committee has met on 19 August 2015 to conduct the final examination of Nabil Fikri bin Leemon on his Master of Science thesis entitled "Comparative Performance between Natural *Endospernum diadenum* (Miq.) Airy Shaw Wood and Treated Wood Impregnated With Nanoclay and Phenolic Resin". In accordance with Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia and [P.U.(A) 106] 15 March 1998. The committee recommends that the candidate be awarded the Master of Science.

Members of the Examination Committee are as follows:

**H Ng Paik San, PhD**  
Senior Lecturer  
Faculty of Forestry  
Universiti Putra Malaysia  
(Chairman)

**Jegatheswaran a/l Ratnasingam, PhD**  
Professor  
Faculty of Forestry  
Universiti Putra Malaysia  
(Internal Examiner)

**Razak bin Wahab, PhD**  
Professor  
Faculty of Agro Industry and Natural Resources  
Universiti Malaysia Kelantan  
(External Examiner)

---

**ZULKARNAIN ZAINAL, PhD**  
Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

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

**Zaidon bin Ashaari, PhD**  
Professor  
Faculty of Forestry  
Universiti Putra Malaysia  
(Chairman)

**Edi Suhaimi bin Bakar, PhD**  
Associate Professor  
Faculty of Forestry  
Universiti Putra Malaysia  
(Member)

**Mohd Khairun Anwar bin Uyup, PhD**  
Senior Officer  
Wood Finishing Laboratory  
Forest Research Institute Malaysia  
(Member)

____________________                   *

**BUJANG BIN KIM HUAT, PhD**  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:
Declaration by graduate student
I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly 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 permission must be obtained from the 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 notes, learning modules or any other material as stated in Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the University Putra Malaysia (Research) Rules 2012. The thesis had undergone plagiarism detection software.

Signature: ________________________      Date: __________________

Name and Matric No: Nabil Fikri bin Leemon GS 36378
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.

<table>
<thead>
<tr>
<th>Signature:</th>
<th>Signature:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of Chairman of Supervisory Committee:</td>
<td>Name of Member of Supervisory Committee:</td>
</tr>
<tr>
<td>Professor Dr. Zaidon bin Ashaari</td>
<td>Associate Professor Dr. Edi Suhaimi bin Bakar</td>
</tr>
</tbody>
</table>

Signature: __________________________

Name of Chairman of Supervisory Committee: Dr. Mohd Khairun Anwar bin Uyup
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRAK</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>v</td>
</tr>
<tr>
<td>APPROVAL</td>
<td>vi</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xv</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xviii</td>
</tr>
</tbody>
</table>

## CHAPTER

### 1 INTRODUCTION

1.1 Background of Study  
1.2 Problem statement  
1.3 Research Aim and Objective

### 2 LITERATURE REVIEW

2.1 Scenario of Wood Industry in Malaysia  
2.2 Promotion of Lesser Known Species (LKS)  
2.3 Sesenduk  
2.3.1 Uses of *Endospermum Diadenum*  
2.4 Physical Properties of *Endospermum Diadenum*  
2.5 Mechanical Properties of *Endospermum Diadenum*  
2.6 Dimensional Stability of Lignocellulosic Materials  
2.7 Natural Durability of Lignocellulosic Materials  
2.7.1 Decaying of Lignocellulosic Materials by Rotting Fungi  
2.7.2 Destruction of Lignocellulosic Materials by Subterranean Termite  
2.8 Improving The Properties of Lignocellulosic Materials  
2.8.1 Wood Modification  
2.8.1.1 Wood Modification by Impregnation Treatment  
2.9 Phenol Formaldehyde Resin  
2.10 Formaldehyde Emission  
2.11 Layer Silicate  
2.12 Addition of Nanoclay in Polymer Matrix  
2.13 Dispersion of Nanoclay in Polymer Matrix  
2.14 Behaviour of Nanoclay in Polymer Matrix
Emission from Wood Specimens

4.2.8 Statistical Analysis

4.3 Results and Discussion

4.3.1 Summary of Analysis of Variance (ANOVA) of Impreg Wood

4.3.2 Weight Percent Gain

4.3.3 Density and Density Gain

4.3.4 Distribution of Resin and Admixture in Wood Structure

4.3.5 Bending Properties

4.3.6 Surface Hardness Properties

4.3.7 Compression Strength Properties

4.3.8 Dimensional Stability

4.3.9 Formaldehyde Emission (FE)

4.4 Conclusion

5 DURABILITY OF IMPREG WOOD AGAINST WHITE ROT AND SUBTERRANEAN TERMITE

5.1 Introduction

5.2 Experimental Procedure

5.2.1 Preparation of Samples

5.2.2 Decay Test

5.2.2.1 Preparation of Culture Media

5.2.2.2 Preparation of Soil Substrate

5.2.2.3 Preparation of Test Culture

5.2.3 Termite Test

5.2.3.1 Termite Collection

5.2.4 Statistical Analysis

5.3 Results and Discussion

5.3.1 Fungal Decay Test

5.3.2 Evaluation of Decay Resistance

5.3.3 Status of Test Blocks after Exposed to P. sanguines

5.3.4 Termite Resistance of Untreated and Impreg Wood Block

5.3.5 Evaluation of Termite Mortality

5.3.6 Status of Test Blocks after Exposed to C. curvignathus

5.4 Conclusion

6 CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Conclusion

6.2 Recommendation for future research

REFERENCES

APPENDICES

BIODATA OF STUDENT

LIST OF PUBLICATIONS
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Tables</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Grouped of fungus and species (Martinez et al., 2005)</td>
</tr>
<tr>
<td>2.2</td>
<td>The classes for durability of lignocellulosic materials in temperate, tropical and laboratory conditions (Findlay, 1985)</td>
</tr>
<tr>
<td>2.3</td>
<td>The classification for different type of wood modification (Norimoto and Gril, 1993)</td>
</tr>
<tr>
<td>3.1</td>
<td>Summary of ANOVA on physical properties of PF and PF/nanoclay admixture</td>
</tr>
<tr>
<td>3.2</td>
<td>The physical properties of PF and PF/nanoclay admixture</td>
</tr>
<tr>
<td>4.1</td>
<td>Dimension of mechanical test specimens</td>
</tr>
<tr>
<td>4.2</td>
<td>Summary of the analysis of variance (ANOVA) on properties of <em>impreg</em> wood</td>
</tr>
<tr>
<td>4.3</td>
<td>Properties of untreated and <em>impreg</em> wood at different treatment combinations</td>
</tr>
<tr>
<td>4.4</td>
<td>Correlation between density of <em>impreg</em> wood and WPG</td>
</tr>
<tr>
<td>4.5</td>
<td>Correlation between static bending properties of <em>impreg</em> wood and WPG</td>
</tr>
<tr>
<td>4.6</td>
<td>Correlation between SH properties of <em>impreg</em> wood and WPG</td>
</tr>
<tr>
<td>4.7</td>
<td>Correlation between CP of <em>impreg</em> wood and WPG and WPG</td>
</tr>
<tr>
<td>4.8</td>
<td>Correlation between dimensional stability properties of <em>impreg</em> wood and WPG</td>
</tr>
<tr>
<td>4.9</td>
<td>Correlation between FE properties of <em>impreg</em> wood and WPG</td>
</tr>
<tr>
<td>5.1</td>
<td>Rating system of termite damage</td>
</tr>
<tr>
<td>5.2</td>
<td>Summary of ANOVA on resistance of <em>impregs</em> against fungal decay and termite attacks</td>
</tr>
<tr>
<td>5.3</td>
<td>Mean weight loss of untreated and <em>impreg</em> wood after</td>
</tr>
<tr>
<td></td>
<td>xiii</td>
</tr>
</tbody>
</table>
16 week exposure to *P. sanguines*

5.4 Mean weight loss of untreated and *impreg* wood after 4 week exposure to *C. curvignathus*
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Transverse section of <em>Endospermum diadenum</em> (Nordahlia <em>et al.</em>, 2013)</td>
<td>6</td>
</tr>
<tr>
<td>2.2</td>
<td>A Model of different type of wood modification at the cellular level (Norimoto and Gril, 1993)</td>
<td>11</td>
</tr>
<tr>
<td>2.3</td>
<td>Process involved in the preparation of phenol formaldehyde (Pizzi, 2003)</td>
<td>14</td>
</tr>
<tr>
<td>2.4</td>
<td>Structure when cross-linking of a. Novolac and b. Resole type phenolic resin (Fink, 2003)</td>
<td>14</td>
</tr>
<tr>
<td>2.5</td>
<td>Structure of formaldehyde (Martzuky, 1989)</td>
<td>16</td>
</tr>
<tr>
<td>2.6</td>
<td>Different types of disperison arising from the interaction of layered silicates and polymers a. phase separated, b. intercalated and c. exfoliated (Alexandre and Dubois, 2000)</td>
<td>20</td>
</tr>
<tr>
<td>3.1</td>
<td>Flow process of synthesis of PF/nano clay admixture</td>
<td>22</td>
</tr>
<tr>
<td>3.2</td>
<td>Ultrasonication processor sonifier</td>
<td>23</td>
</tr>
<tr>
<td>3.3</td>
<td>Bruker AXS 8 Advance model</td>
<td>24</td>
</tr>
<tr>
<td>3.4</td>
<td>TEM Hitachi H7100 model</td>
<td>26</td>
</tr>
<tr>
<td>3.5</td>
<td>Occurrence of bubbles and nanoclay tactoids on the surface of the resin after sonicated at a. 25 kHz for 20 min and b. elimination of bubbles and nanoclay tactoids after sonicated at 50 kHz for 60 min</td>
<td>27</td>
</tr>
<tr>
<td>3.6</td>
<td>Gelling time of PF resin solution and PF/nano clay admixture</td>
<td>29</td>
</tr>
<tr>
<td>3.7</td>
<td>XRD analysis for 10% PF solution</td>
<td>30</td>
</tr>
<tr>
<td>3.8</td>
<td>XRD analysis for 15% PF solution</td>
<td>31</td>
</tr>
<tr>
<td>3.9</td>
<td>XRD analysis for 20% PF solution</td>
<td>31</td>
</tr>
<tr>
<td>3.10</td>
<td>The dark clouds line shows the nanoclay gallery in the 10% PF solution (yellow arrow)</td>
<td>32</td>
</tr>
<tr>
<td>3.11</td>
<td>The dark clouds line shows the nanoclay gallery in the 15% PF solution (yellow arrow)</td>
<td>32</td>
</tr>
</tbody>
</table>
3.12 The dark clouds line shows the nanoclay gallery in the 20% PF solution (yellow arrow)

4.1 Flow process of the treatment

4.2 Treated apparatus for impregnating wood with resin

4.3 Summary of flow process for impregnated wood

4.4 Schematic diagram for preparation of test specimens

4.5 Desiccators method to determine FE

4.6 Transverse section parts of untreated and impreg wood

4.7 MOR of untreated and impreg wood

4.8 MOE of untreated and impreg wood

4.9 Hardness of untreated and impreg wood

4.10 Compression Parallel untreated and impreg wood

4.11 WA of untreated and impreg wood

4.12 TS of untreated and impreg wood

4.13 ASE for impregs at different treatment combinations

4.14 Calibration curve of standard formaldehyde concentration vs. Absorbance using spectrometer

4.15 FE from impreg wood at different treatment combinations

5.1 Flow process of the durability test

5.2 Schematic diagram of producing test blocks from remnant of static bending samples

5.3 Soil cultured bottles with feeder strips after 3 weeks of exposure to P. sanguineus

5.4 Method of baiting termite (After Tamashiro et al., 1973)

5.5 Weight loss and increment in resistance to decay for untreated and impreg wood after 16 weeks exposure to P.sanguiness

5.6 Status of Test Block after Exposed to P. Sanguines
<table>
<thead>
<tr>
<th>Section</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7</td>
<td>Weight loss and increment in resistance to termite for untreated and <em>impreg</em> wood after 4 weeks exposure to <em>C. curvignathus</em></td>
</tr>
<tr>
<td>5.8</td>
<td>Daily mortality of <em>C. curvignathus</em> after exposing to untreated and <em>impreg</em> wood for 4 weeks</td>
</tr>
<tr>
<td>5.9</td>
<td>Status of test block after 4 wk exposure to <em>Coptotermes curvignathus</em> Holmgren through surface of a. 20% PF solution b. 15% PF solution, c. 10% PF solution and d. untreated sesenduk</td>
</tr>
</tbody>
</table>
# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ampere</td>
</tr>
<tr>
<td>AFM</td>
<td>Atomic force microscope</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>ASE</td>
<td>Anti-swelling Efficiency</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>AWPA</td>
<td>American Wood Preserves' Association</td>
</tr>
<tr>
<td>BS</td>
<td>British Standards</td>
</tr>
<tr>
<td>CR</td>
<td>Compression ratio</td>
</tr>
<tr>
<td>CP</td>
<td>Compression Strength parallel to grain</td>
</tr>
<tr>
<td>D</td>
<td>Density</td>
</tr>
<tr>
<td>DG</td>
<td>Density Gain</td>
</tr>
<tr>
<td>DMRT</td>
<td>Duncan Multiple Range Test</td>
</tr>
<tr>
<td>DSC</td>
<td>Differential scanning calorimetric</td>
</tr>
<tr>
<td>EMC</td>
<td>Equilibrium Moisture Content</td>
</tr>
<tr>
<td>EPMA</td>
<td>Electron probe microscopy analysis</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
</tr>
<tr>
<td>FE</td>
<td>Formaldehyde Emission</td>
</tr>
<tr>
<td>FRIM</td>
<td>Forest Research Institute Malaysia</td>
</tr>
<tr>
<td>h</td>
<td>Hours</td>
</tr>
<tr>
<td>IMP</td>
<td>Industrial Malaysian Plan</td>
</tr>
<tr>
<td>KHz</td>
<td>Kilohertz</td>
</tr>
<tr>
<td>kN</td>
<td>Kilo Newton</td>
</tr>
<tr>
<td>kPa</td>
<td>Kilopascal</td>
</tr>
<tr>
<td>Kv</td>
<td>Kilovolt</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>LKS</td>
<td>Lesser Known Species</td>
</tr>
<tr>
<td>LmwPF</td>
<td>Low Molecular Weight Phenol Formaldehyde</td>
</tr>
<tr>
<td>MC</td>
<td>Moisture Content</td>
</tr>
<tr>
<td>MDF</td>
<td>Medium Density Fiberboard</td>
</tr>
<tr>
<td>MF</td>
<td>Melamine Formaldehyde</td>
</tr>
<tr>
<td>Min</td>
<td>Minutes</td>
</tr>
<tr>
<td>MMA</td>
<td>Methyl Methacrylate</td>
</tr>
<tr>
<td>MMT</td>
<td>Montmorillonite</td>
</tr>
<tr>
<td>MPa</td>
<td>Mega Pascal</td>
</tr>
<tr>
<td>MOE</td>
<td>Modulus of Elasticity</td>
</tr>
<tr>
<td>MOR</td>
<td>Modulus of Rupture</td>
</tr>
<tr>
<td>MS</td>
<td>Malaysian Standard</td>
</tr>
<tr>
<td>MTC</td>
<td>Malaysian Timber Council</td>
</tr>
<tr>
<td>MTIB</td>
<td>Malaysian Timber Industrial Boards</td>
</tr>
<tr>
<td>Mw</td>
<td>Molecular Weight</td>
</tr>
<tr>
<td>NaOH</td>
<td>Sodium hydroxide</td>
</tr>
<tr>
<td>NC</td>
<td>Nanoclay</td>
</tr>
<tr>
<td>NICNAS</td>
<td>National Industrial Chemicals Notification and Assessment Scheme</td>
</tr>
<tr>
<td>nm</td>
<td>Nano meter</td>
</tr>
<tr>
<td>PDA</td>
<td>Potato Dextrose Agar</td>
</tr>
<tr>
<td>PE</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>PEG</td>
<td>Polyethylene Glycol</td>
</tr>
<tr>
<td>PF</td>
<td>Phenol Formaldehyde</td>
</tr>
<tr>
<td>PLA</td>
<td>Polylactic acid</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylenes</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>ppm</td>
<td>Part Per Million</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>RH</td>
<td>Relative Humidity</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for Social Science</td>
</tr>
<tr>
<td>TS</td>
<td>Thickness Swelling</td>
</tr>
<tr>
<td>TEM</td>
<td>Transmission Electron Microscopy</td>
</tr>
<tr>
<td>TGA</td>
<td>Thermo gravimetric analysis</td>
</tr>
<tr>
<td>UF</td>
<td>Urea Formaldehyde</td>
</tr>
<tr>
<td>UPM</td>
<td>Universiti Putra Malaysia</td>
</tr>
<tr>
<td>UV</td>
<td>Ultra Violet</td>
</tr>
<tr>
<td>WA</td>
<td>Water Absorption</td>
</tr>
<tr>
<td>WHC</td>
<td>Water Holding Capacity</td>
</tr>
<tr>
<td>WL</td>
<td>Weight Loss</td>
</tr>
<tr>
<td>WPG</td>
<td>Weight Percent Gain</td>
</tr>
<tr>
<td>XRD</td>
<td>X-ray diffraction</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

1.1 Background of Study

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

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

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

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

In order to support the wood-based industry for a long term, possible solution was to use underutilized or lesser known wood species as a new wood source.
Sesenduk (*Endospermum diadenum*) grows in the lowland to lower montane forest, particularly in secondary growth, along streams and on hills and slopes. Due to its poor properties in nature, it is still underutilized, but this wood can have value added by being made into wood suitable for different applications like flooring, panelling and furniture through proper treatment such as chemical modification.

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

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

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

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

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

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

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

1.2 Problem Statement

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

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

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

1.3 Research Aim and Objectives

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

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


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


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


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


