UNIVERSITI PUTRA MALAYSIA

OPTIMIZATION OF GLYOXALATION FOR ALKALI LIGNIN USED AS BULKING AGENT IN WOOD

ANG AIK FEI

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By

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

April 2016
DEDICATION

I specially dedicate this thesis to

My Supervisor
Prof. Dr. Zaidon Bin Ashaari

My Mother
Kua Ai Lian

My Father
Ang Boon Lip

My Wife
Gan Peg Kee

My Daughters
Ang Min Xuan & Ang Yu Xuan
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

OPTIMIZATION OF GLYOXALATION FOR ALKALI LIGNIN USED AS BULKING AGENT IN WOOD

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April 2016

Chairman : Zaidon Ashaari, PhD
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Bulking treatment through the impregnation of low molecular weight phenol formaldehyde (LmwPF) resin is a promising method to enhance the dimensional stability of wood. The development of bulking agent that made of modified alkali lignin, the glyoxalated alkali lignin is crucial to mitigate the concentrations of petrochemical derived phenol and carcinogenic formaldehyde. The objective of this study was to enhance the structural homogeneity and chemical reactivity of alkali lignin through sequential organic solvents fractionation and glyoxalation, and to enhance the dimensional stability of jelutong (Dyera costulata) wood using glyoxalated alkali lignin incorporated with low molecular weight phenol formaldehyde resin as bulking agent.

Low molecular weight lignin feedstock was obtained through base catalysed depolymerisation (BCD) treatments from an alkali lignin (OL) with a weight-average molecular weight ($M_w$) of 11646 g/mol at different combined severity factors. The homogeneity of the OL and BCD treated lignins was altered through sequential fractionation using organic solvents with different Hildebrand solubility parameters i.e. propan-1-ol, ethanol and methanol. The yield of OL and BCD treated lignins dissolved in propan-1-ol (F1), ethanol (F2), and methanol (F3) and their molecular weight distributions and chemical structures were determined and characterized by Gel Permeation Chromatography (GPC), Fourier transform infrared (FT-IR) spectroscopy and $^{13}$C-nuclear magnetic resonance (NMR) spectroscopy. The reactivity of the obtained low molecular weight lignin feedstock was then enhanced through glyoxalation using non-volatile and non-toxic dialdehyde, namely glyoxal, instead of formaldehyde. The proportion ratio of glyoxal to sodium hydroxide (NaOH) used in the glyoxalation process was optimised using response surface methodology (RSM) and central composite design (CCD). The glyoxalated alkali lignin (GL) synthesised using the optimum proportion ratio of glyoxal to NaOH was then incorporated with LmwPF resin to prepare bulking agent for wood bulking treatment. Oven dried jelutong (Dyera costulata) wood was evacuated under vacuum and then followed by soaking in 15, 20 and 25% concentrations of GL-LmwPF (67% solid of GL:33% solid of LmwPF based on the total solute content) and LmwPF resins, respectively at ambient temperature for 24 h. The impregnated wood was then curing at 180 °C for 30 min. The resin weight percent gain (WPG) and dimensional stability in terms of antiswelling efficiency (ASE), moisture excluding efficiency (MEE) and water absorption (WA) as well as
leachability of bulking agents for GL-LmwPF treated wood were determined and compared with untreated wood and wood treated solely with LmwPF resin. The formaldehyde release for both GL-LmwPF and LmwPF treated wood were also determined.

BCD treatments did not increase the yield of an OL dissolved in propan-1-ol or ethanol but did increase the yield of OL dissolved in methanol. Repolymerization of OL occurred during the BCD treatment. Lower molecular weight, more homogeneous OL tended to dissolve in propan-1-ol and ethanol, but their overall soluble lignin yields were low. The OL dissolved in methanol had higher molecular weight, was less homogeneous, and had a bulkier structure than OL dissolved in propan-1-ol or ethanol. Carbon-NMR and FT-IR spectroscopy analyses confirmed that F3 in OL exhibits optimum yield and appropriate chemical structures as well as molecular weight distributions for resin synthesis. For glyoxalation of alkali lignin, FT-IR spectroscopy revealed that lower molecular weight of lignin polymers was formed due to the crosslinking of lignin molecules via methylene (CH$_2$) bridges through the condensation reaction. RSM and CCD showed that the reactivity of GL reached highest when optimum amounts of glyoxal and NaOH, i.e., 0.222 and 0.353 mole, respectively, were used in the glyoxalation process. The WPG of GL-LmwPF treated wood was lower than LmwPF treated wood. GL-LmwPF treated wood exhibited positive ASE but the values were lower compared to LmwPF treated wood. The MEE and WA of GL-LmwPF treated wood were also inferior than LmwPF treated wood and untreated wood. GL-LmwPF resin was leached from treated wood whereas no leaching was found for LmwPF resin after 3 leaching cycles in distilled water. The formaldehyde release of GL-LmwPF resin treated wood was 25.76% lesser than wood treated with LmwPF resin. Wood treated with 25% GL-LmwPF resin yielded highest ASE value compared to 15 and 20% GL-LmwPF treated wood. Hence, wood treated with 25% GL-LmwPF resin together with external coatings could be used in several end applications such as parquet flooring, paneling and furniture component.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGOPTIMUMAN GLYOXALASI UNTUK LIGNIN ALKALI DIGUNAKAN SEBAGAI EJEN PUKAL DALAM KAYU

Oleh

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Rawatan pukal melalui pengisitepuan fenol formaldehid resin (LmwPF) berberat molekul rendah adalah satu kaedah yang berkesan untuk meningkatkan kestabilan dimensi kayu. Pembangunan ejen pukal yang diperbuat daripada lignin alkali yang diubahsuai iaitu lignin alkali glyoxalated adalah penting untuk mengurangkan kepekatan fenol yang diperolehi daripada petrokimia dan formaldehid yang berkasinogenik. Objektif kajian ini adalah untuk meningkatkan keseragaman struktur dan kereaktivitas kimia lignin alkali melalui pemerintikan berurutan dengan menggunakan pelarut organik dan glyoxalasi, dan untuk meningkatkan kestabilan dimensi kayu jelutong (*Dyera costulata*) menggunakan lignin alkali glyoxalated yang digabungkan dengan resin fenol formaldehid berberat molekul rendah sebagai ejen pukal.

Bahan mentah lignin berberat molekul rendah diperoleh melalui rawatan *base catalyzed depolymerisation* (BCD) daripada lignin alkali (OL) berberat molekul (mw) 11646 g/mol pada gabungan faktor tahap kekuatan yang berbeza. Kehomogenan struktur OL dan lignin-lignin yang dirawat dengan BCD dikawal melalui pemeringkatan berurutan dengan menggunakan pelarut organik yang mempunyai parameter keterlarutan Hildebrand yang berbeza iaitu propan-1-ol, etanol dan methanol. Hasil OL dan lignin-lignin yang dirawat dengan BCD yang terlarut dalam propan-1-ol (F1), etanol (F2), dan metanol (F3) dan taburan berat molekul serta struktur kimia mereka ditentukan dengan *Gel Permeation Chromatography* (GPC), spektroskopi *Fourier transform infrared* (FT-IR) dan spektroskopi 

13C-nuklear resonans magnetik (NMR). Kereaktivitas bahan mentah lignin berberat molekul rendah yang diperoleh kemudiannya dipertingkatkan melalui proses *glyoxalation* dengan menggunakan dialdehyde yang tidak merupau dan tidak toksik, iaitu glyoxal, daripada formaldehid. Nisbah bahagian glyoxal kepada natrium hidroksida (NaOH) yang digunakan dalam proses *glyoxalation* dioptimumkan dengan menggunakan kaedah *response surface methodology* (RSM) dan *central composite design* (CCD). Lignin alkali glyoxalated (GL) yang disintesis dengan nisbah kadar glyoxal kepada NaOH yang optimum kemudiannya digabungkan dengan resin LmwPF untuk penyediaan ejen pukal bagi rawatan pukal kayu. Kayu-kayu jelutong yang telah dikeringkan di dalam oven didedahkan di bawah vakum dan kemudiannya masing-masing direndamkan dalam resin GL-LmwPF (67% pepejal GL: 33% pepejal LmwPF berdasarkan jumlah kandungan bahan larut) dan LmwPF berkepekatan 15, 20 dan 25% pada suhu ambien selama 24 jam. Kayu-kayu yang telah diisitepuan
kemudian dimatangkan pada suhu 180 °C selama 30 minit. Kenaikan peratus berat resin (WPG) dan kestabilan dimensi dari segi antiswelling efficiency (ASE), moisture excluding efficiency (MEE) dan water absorption (WA) serta larut lesap bagi resin-resin LmwPF dan GL-LmwPF ditentukan dan dibandingkan dengan kayu yang tidak dirawat dan kayu dirawat dengan resin LmwPF. Perlepasan formaldehid dari kayu yang dirawat dengan kedu-dua resin GL-LmwPF dan LmwPF juga telah ditentukan.

Rawatan BCD tidak meningkatkan hasil OL yang terlarut dalam propan-1-ol atau etanol tetapi meningkatkan hasil OL yang terlarut dalam methanol. Repolimersasi OL berlaku semasa rawatan BCD dijalankan. OL dengan berat molekul yang lebih rendah, struktur yang lebih seragam cenderung untuk melarut dalam propan-1-ol dan etanol, tetapi secara keseluruhanannya hasil lignin yang terlarut dalam larutan-larutan tersebut adalah rendah. OL yang terlarut dalam metanol mempunyai berat molekul yang lebih tinggi, strukturnya adalah kurang seragam dan lebih mampat daripada OL yang terlarut dalam propan-1-ol atau etanol. Analisis spektroskopi 13Carbon-NMR dan FT-IR mengesahkan bahawa F3 dalam OL mempamerkan hasil yang optima dan struktur kimia serta taburan berat molekul yang sesuai untuk sintesis resin. Untuk proses glyoxalation lignin alkali, spektroskopi FT-IR menunjukan bahawa pembentukan polimer lignin dengan berat molekul yang lebih rendah adalah disebabkan oleh penyilangan antara molekul-molekul lignin melalui pembentukan lingkaran metilena (CH₂) secara tintak balas condensasi. RSM dan CCD menunjukkan bahawa kereaktivitas GL mencapai tertinggi apabila jumlah glyoxal dan NaOH yang optimum, iaitu, 0.222 dan 0.353 mol, masing-masing digunakan dalam proses glyoxalasi. WPG untuk kayu yang dirawat dengan GL-LmwPF adalah lebih rendah daripada kayu yang dirawat dengan LmwPF. Kayu yang dirawat dengan GL-LmwPF mempamerkan ASE positif tetapi nilai-nilainya adalah lebih rendah berbanding dengan kayu yang dirawat dengan LmwPF. MEE dan WA untuk kayu yang dirawat dengan GL-LmwPF adalah lebih lemah daripada kayu yang dirawat dengan LmwPF dan juga kayu yang tidak dirawat. Larut lesap resin GL-LmwPF dari kayu yang dirawat berlaku sedangkan larut lesap resin LmwPF tidak berlaku selepas 3 kitaran larut lesap dalam air suling. Perlepasan formaldehid dari kayu yang dirawat dengan resin GL-LmwPF adalah 25.76% lebih rendah daripada kayu yang dirawat dengan resin LmwPF. Kayu yang dirawat dengan 25% kepekatan resin GL-LmwPF menghasilkan nilai ASE yang tinggi berbanding dengan kepekatan 15 dan 20% resin GL-LmwPF. Oleh itu, kayu dirawat dengan 25% kepekatan resin GL-LmwPF diliputi dengan penyayat luar boleh digunakan dalam beberapa aplikasi akhir seperti lantai parket, panel dan komponen perabot.
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I certify that a Thesis Examination Committee has met on 6 April 2016 to conduct the final examination of Ang Aik Fei on his thesis entitled "Optimization of Glyoxalation for Alkali Lignin Used as Bulking Agent in Wood" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>ASE</td>
<td>Antiswelling Efficiency</td>
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<tr>
<td>BC</td>
<td>Bulking Coefficient</td>
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<tr>
<td>BCD</td>
<td>Base Catalysed Depolymerisation</td>
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<tr>
<td>CCD</td>
<td>Central Composite Design</td>
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<tr>
<td>CPF</td>
<td>Control PF</td>
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<tr>
<td>DMDHEU</td>
<td>Dimethyloldihydroxyethyleneurea</td>
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<tr>
<td>DMSO-d₆</td>
<td>Deuterated Dimethyl Sulfoxide</td>
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<tr>
<td>EFB</td>
<td>Empty Fruit Bunch</td>
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<tr>
<td>EMC</td>
<td>Equilibrium Moisture Content</td>
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<tr>
<td>FT-IR</td>
<td>Fourier Transform Infra-Red</td>
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<tr>
<td>GBI</td>
<td>Green Building Index</td>
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<tr>
<td>GL</td>
<td>Glyoxalated Alkali Lignin</td>
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<tr>
<td>GL-LmwPF</td>
<td>Glyoxalated Alkali Lignin-Low Molecular Weight Phenol Formaldehyde</td>
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<tr>
<td>GPC</td>
<td>Gel Permeation Chromatography</td>
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<tr>
<td>IAQ</td>
<td>Indoor Air Quality</td>
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<td>IARC</td>
<td>International Agency for Research on Cancer</td>
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<tr>
<td>IB</td>
<td>Internal Bonding</td>
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<tr>
<td>IMC</td>
<td>Initial Moisture Content</td>
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<tr>
<td>LEED</td>
<td>Leadership in Energy and Environmental Design</td>
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<tr>
<td>LmwPF</td>
<td>Low Molecular Weight Phenol Formaldehyde</td>
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<td>LPF</td>
<td>Lignin Substituted PF</td>
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<td>ML</td>
<td>Methanol-Fractionated Alkali Lignin</td>
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<tr>
<td>PEO</td>
<td>Polyethylene Oxide</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>PT</td>
<td>Press Time</td>
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<tr>
<td>MALDI-TOF</td>
<td>Matrix-Assisted Laser Desorption/Ionization Time-of-Flight</td>
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<tr>
<td>MC</td>
<td>Moisture Content</td>
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<tr>
<td>MEE</td>
<td>Moisture Excluding Efficiency</td>
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<tr>
<td>MDF</td>
<td>Medium Density Fibreboard</td>
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<tr>
<td>MF</td>
<td>Melamine Formaldehyde</td>
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<td>NMR</td>
<td>Nuclear Magnetic Resonance</td>
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<td>OL</td>
<td>Alkali Lignin</td>
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<td>OSB</td>
<td>Oriented Strand Board</td>
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<tr>
<td>PAM</td>
<td>Pertubuhan Akitek Malaysia</td>
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<tr>
<td>PF</td>
<td>Phenol Formaldehyde</td>
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<tr>
<td>PPM</td>
<td>Part per Million</td>
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<td>RH</td>
<td>Relative Humidity</td>
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<td>RSM</td>
<td>Response Surface Methodology</td>
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<td>S</td>
<td>Swelling Coefficient</td>
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<tr>
<td>SDS</td>
<td>Sodium Dodecyl Sulfate</td>
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<tr>
<td>SI</td>
<td>Severity Index</td>
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<tr>
<td>TGA</td>
<td>Thermogravimetry Analysis</td>
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<tr>
<td>UF</td>
<td>Urea Formaldehyde</td>
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<tr>
<td>VOCs</td>
<td>Volatile Organic Compounds</td>
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<tr>
<td>WA</td>
<td>Water Absorption</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<td>WPG</td>
<td>Weight Percent Gain</td>
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CHAPTER 1

INTRODUCTION

1.1 General Background

Wood chronically is a good material to be used for many applications because of its many excellent material properties. The natural beauty and high strength at low density of wood make it is the first choice of material to use in many applications such as roof truss, column, beam, wall cladding, flooring and so on compared to other materials. Although wood possess the excellent properties as mentioned above, but the drawbacks of wood such as the dimensional instability when it is exposed to various atmospheric conditions, susceptibility to biological attack and changes in appearance when exposed to weathering condition limits the potential end-uses of wood.

In fact, the drawbacks of wood can be enhanced through wood modification treatments. Wood modification treatment is a means of altering the material to overcome or ameliorate one of more of its advantages. Wood modification treatments involve the action of a chemical, biological or physical agent upon the material, resulting in a desired property enhancement during the service life of the modified wood (Hill 2006a). Wood modifications either by bulking, internal coating or croslinking have shown promising results to upgrade low quality timbers for potential applications (Ashaari et al. 1990a and 1990b; Nicholas and Williams 1987; Rowell and Youngs 1981). Some of the modified wood such as phenol formaldehyde resin-treated wood (Impreg and Compreg) and heat treated-compressed wood (Lignostone and Lignofol) have been introduced and commercialized since many years ago (Rowell and Konkol 1987).

One of the examples of wood modification using bulking principle is impregnation modifications. Impregnation or diffusion of wood with a single chemical or combination chemicals into wood cell walls followed by polymerization of the chemicals is the most adequate method to enhance the properties of wood with this implication. Impregnation of low molecular weight phenol formaldehyde (LmwPF) compound in the wood followed by full curing under heat may enhance the dimensional stability and strength properties of the treated material (Ang 2010; Furuno et al. 2004; Sham et al. 2004; Ryu et al. 1991; Rowell and Konkol 1987).

However, the utilization of LmwPF resin as bulking agent also brought some disadvantages such as phenol is derived from non-renewable petrochemicals while formaldehyde is a known carcinogen. By using so called ‘green’ materials, the strong exploitation of fossil resources can be mitigated, reduce the amount of carbon dioxide that enters the atmosphere and take upon the responsibility of using earth’s resources in a sustainable manner, thus improving resource management, indoor air quality (IAQ), and generally the overall performance and efficiency of human kind on earth. In Malaysia, the launching of green building rating tool, Green Building Index (GBI) in 2009 by the Pertubuhan Akitek Malaysia (PAM) was an approach to promote sustainability in the built environment and raise awareness among developers, architects, engineers, planners, designers, contractors and the public about environmental issues and our responsibility to the future generations. This was a message to show that the awareness to protecting the environment through energy...
savings, water savings and a healthier indoor environment is getting more important in Malaysia.

1.2 Problem Statement and Justification

Wood is an anisotropic material, which means it swells and shrinks to a different extent in the three anatomical directions–longitudinal (vertical direction), tangential (parallel to annual growth rings), and radial (perpendicular to the annual growth rings). Swelling of wood in contact with moisture exerts very large forces. When wood in use swells, the forces developed can cause serious damage. As mentioned earlier, the dimensional instability of wood can be enhanced through bulking treatment i.e. impregnation of low molecular weight phenol formaldehyde (LmwPF) compound (bulking agent) in the wood followed by full curing under heat which yielded treated products with cell walls bulked with insoluble resin polymer.

Although the impregnation modification with LmwPF resin has been studied extensively in past few decades ago (Paridah et al. 2006; Furuno et al. 2004; Wan Ariffin et al. 1992; Kajita and Imamura 1991), but the study of using lignin based-phenolic resin as bulking agent to enhance the properties of wood is rather poor. Phenol is derived from petrochemical benzene and formaldehyde from methanol that is prepared from natural gas. The availability of petrochemicals is finite as it is non-renewable resource and the prices of raw materials for LmwPF resin would increase because the fuel consumption increases as the world’s population grows (Sellers, 1985). Formaldehyde has been classified as a known carcinogen by the International Agency for Research on Cancer (IARC), a division of the World Health Organization (WHO). The emission of free formaldehyde from the resin during impregnation process and service life of the treated products will causes health problems to the consumers (Soljacic and Katovic 1988). It has been reported that the formaldehyde emission from LmwPF resin impregnated wood reduced when the wood is impregnated with lower concentration of LmwPF resin (Nur Izreen et al. 2011; Rabi’atol Adawiah et al. 2012). However, it is anticipated that the effectiveness in enhancing some the properties of wood would become inferior if using lower concentration of LmwPF resin as the effectiveness in enhancing the dimensional stability of wood through this method is very much associated with the ultimate cell wall bulking effect (ultimate polymer of chemicals deposited in cell wall) of the impregnated wood (Deka and Saikia 2000; Ang 2010; Rabi’atol Adawiah et al. 2012; Leemon et al. 2015).

The polyphenolic nature of lignin makes it a potential substitute for phenol in the production of ordinary formaldehyde-based resin. In addition, lignin is the most abundant natural and renewable organic polymer in the world after cellulose. Large quantities of isolated lignin can be recovered from various pulping or biomass conversion processes. Therefore, lignin is an inexpensive raw material that potential for the production of environmentally friendly thermosetting resin by substituting the phenol in the ordinary formaldehyde based thermosetting resins (Alonso et al. 2004; Khan and Ashraf 2007; Cetin and Ozmen 2002; El Mansouri et al. 2006; Cavdar et al. 2008). Therefore, impregnation of wood with partial glyoxalated alkali lignin (GL) substituted-LmwPF resin as bulking agent thus offers advantages by reducing the free formaldehyde emission with using lesser neat LmwPF resin while retaining the ultimate WPG in the impregnated wood as majority of the solid content deposited in
the impregnated wood (especially in the cell walls) was comprised of natural and renewable lignin polymer.

To process lignin into various end products, it would be advantageous to use material with a more homogenous structure, chemistry and purity (Stewart 2008). The homogeneity of lignin can be enhanced by sequential fractionation in different organic solvents (Wang et al. 2010; Li et al. 2012). The heterogeneity of lignin can be reduced because different parts of the lignin molecule have different hydrogen-bonding capacity (Hildebrand solubility parameter) in different organic solvents. Low-molecular weight lignin fragments are dissolved in organic solvents with weak or moderate hydrogen-bonding capacities with a wider range of Hildebrand solubility parameters than the higher-molecular weight lignin fragments (Schuerch 1952).

Apart from this, lignins also offer no advantages in terms of chemical reactivity. The low reactivity of lignins is the main obstacle limits their utilization in the production of resins (Vishtal and Kraslawski 2011). Hence, the reactivity of lignins needs to be enhanced in order to increase the possibility of using lignins as feedstock for the production of resins. Hydrolysis of lignin in an alkaline medium has been shown to increase the reactivity of lignin by liberating lower molecular weight phenolic compounds which possess more reactive sites and reduced steric hindrance effect (Cheng et al. 2013; El Mansouri et al. 2006; Thring 1994). Apart from this, depolymerisation of lignin macromolecule into lower molecular weight fragments is also important as one of the requirements for wood bulking treatment is that the molecular weight of bulking agents used should be low to ensure the penetration of bulking agents into wood cell walls (Norimoto 2000). It has been reported that hydroxymethylation is also one of the chemical modification methods applied to enhance the reactivity of lignin toward crosslinking agents such as formaldehyde (Lin et al. 2010; Mu et al. 2009; Malutan et al. 2008; Zhao et al. 1994). Hydroxymethylation enhances the reactivity of lignin by introducing reactive functional groups to the lignin molecules. Instead of using toxic and volatile formaldehyde as crosslinking agent in hydroxymethylation, non-toxic and non-volatile dialdehydes such as glyoxal also has been used as a replacement for formaldehyde (Navarrete et al. 2012; El Mansouri et al. 2011). Glyoxal can be obtained as a by-product from the generation of hydrogen peroxide required by manganese-dependent peroxidase enzymes (Kersten 1990; Hirayama et al. 1984).

Although the modifications of lignin to enhance its structural homogeneity and chemical reactivity may slightly increase the cost of processing, the cost of processing can be reduced by monitoring the concentration of chemicals used by developing the optimum treatment method. Furthermore, the treated products are very potential for commercialization because it is Green Building Index (GBI) and Leadership in Energy and Environmental Design (LEED) complaint material. The treated products could sell with better price as it is value-added product that renders superior performance under service life. The needs of developing thermosetting resin from renewable raw materials as bulking agent for impregnation modification are crucial in order to ensure that the sustainability of thermosetting resins raw materials for this modification.
1.3 Main Objective

The objective of this study was to enhance the structural homogeneity and chemical reactivity of alkali lignin through sequential organic solvents fractionation and glyoxalation, and enhance the dimensional stability of jelutong (*Dyera costulata*) wood using glyoxalated alkali lignin (GL) incorporated low molecular weight phenol formaldehyde (LmwPF) resin as bulking agent.

1.3.1 Specific Objectives

1. To obtain optimal yield of alkali lignin with more homogeneous structure through base catalysed depolymerisation (BCD) and sequential organic solvents fractionation treatments.

2. To optimise the ratios of glyoxal to sodium hydroxide used in the glyoxalation process based on the relative intensity of methylene (CH$_2$) bridge using response surface methodology (RSM).

3. To determine the molecular weight distributions and thermal stability of glyoxalated alkali lignin (GL).

4. To identify the functional groups in low molecular weight phenol formaldehyde (LmwPF) resin and GL-LmwPF admixture resin.

5. To evaluate the effectiveness of using GL-LmwPF admixture resin as bulking agent to enhance the dimensional stability of jelutong (*Dyera costulata*) wood.
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Nicholas DD, Williams AD. Dimensional stabilization of wood with dimethylol compounds. IRG/WP/3412 (1987).


