# SURFACE MODIFICATION OF NAPIER STEM STRAND USED IN NON-WOOD LOW DENSITY PARTICLEBOARD

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**THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTERS OF ENGINEERING**

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**DECLARATION**

I hereby declare that the material in this thesis is my own except for quotations, accepts, equations, summaries and references, which have been duly acknowledged.

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# ABSTRACT

Napier stem (*Pennisetum Purpureum*) is a non-wood lignocellulosic biomass and was identified as a potential raw material for the production of particleboard because of its strong rigidity and wide availability. However, the composite polymer nature in Napier constituent and fibre morphology, particularly the lignin portion, presents resistance and recalcitrance to biological and chemical degradation during enzymatic hydrolysis, therefore fibre refining by pretreatment is a main process that significantly influences the overall fibre properties in Napier. Thus, Napier structure requires initial breakdown of the lignocellulosic matrix. In this study, Napier grass in the form of Napier stem strand (NpSS) was used to produce the low density standard particleboard for internal general purpose use. The objective of this study is to establish the operating conditions that bring the optimum properties of the NpSS particleboard with minimal variance. At the first stage of the study, the strands of Napier stem were alkali-treated using sodium hydroxide (NaOH) solutions to reduce the lignin content in native NpSS. The pretreatments were conducted using NaOH solutions of different concentrations of 5.5%(w/v), 8.0%(w/v), and 10.5%(w/v) and were incubated at controlled temperature of 70°C for five hours. Aspect ratio analysis (diameter examination), chemical analysis, Thermogravimetric Analysis (TGA), Fourier Transform Infrared Analysis (FTIR), and Scanning Electron Microscope (SEM) were used to examine the physical properties of the treated and the untreated NpSS. From the single-strand particle characterisation results and through a characterisation of Napier strand, the 10.5 wt. % alkali-treated NpSS exhibited the lowest lignin content. 93.78% of lignin was removed and 80.59% of cellulose and 63.57% of solid were recovered as compared to the control sample (untreated NpSS). Next, the second stage of the study was the board production using urea formaldehyde (UF) resin. For screening purpose, Taguchi approach was employed and the type of NpSS factor (categoric form), and the two numerical factors that consist of percentage of resin content and the hot press temperature were identified as the independent variables. Subsequently, Response Surface Methodology (RSM) of Central Composite Design (CCD) was employed using Design Expert (DE10) software to analyse the relationship between the three variables and their influence on the internal bond (IB) strength, static bending (MOE and MOR) strength, screw withdrawal (SW) strength, thickness swelling (TS) and water absorption (WA) properties were studied. The panels were produced with target thickness of 12 mm and density of 640 kg/m$^3$. A variety of mechanical and physical tests were performed in accordance to British Standard (EN310-317:1993, EN 320:2011). It was found that the formations of NpSS boards were best fit by a quadratic regression model for MOR and WA. Reduced cubic models were in compatible with IB, MOE, SW and TS.



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# ABSTRAK

## MODIFIKASI STRUKTUR MORPOLOGI BATANG RUMPUT NAPIER DAN APLIKASINYA DALAM PEMBUATAN PAPAN PARTIKEL BERKETUMPATAN RENDAH

*Batang Napier (Pennisetum Purpureum) adalah sejenis sumber lignoselulosik biomas bukan kayu yang telah dikenalpasti berpotensi sebagai bahan mentah yang boleh digunakan untuk pengeluaran papan partikel kerana sifat kekuatannya dan wujud secara banyak dan mudah didapati. Walau bagaimanapun, disebabkan sifat semulajadi komposit polimer dalam morfologi serat Napier, terutamanya bahagian lignin, yang memberikan ciri-ciri daya tahan terhadap tindakbalas biologi dan kimia semasa proses enzim mikrobial, rawatan fiber adalah satu proses utama yang memberikan signifikasi sifat-sifat gentian dalam Napier. Oleh itu, struktur Napier memerlukan aktiviti modifikasi bagi memperbaiki kualiti serat sesuai untuk pembinaan papan partikel. Dalam kajian ini, batang rumput Napier dalam bentuk serat batang (NpSS) telah digunakan untuk memfabrikasi papan partikel berketumpatan rendah bagi kegunaan am dalaman mengikut piawaian yang telah ditetapkan. Kajian ini juga bertujuan untuk mengenalpasti dan menentukan faktor-faktor penting bagi menghasilkan papan partikel berasaskan batang rumput secara optimum. Pada peringkat pertama kajian, batang Napier dirawat menggunakan larutan natrium hiroksida (NaOH) berkepekatan 5.5, 8.0 dan 10.5 wt. % dan telah diletakkan dibawah kawalan persekitaran (inkurbasi) suhu 70°C selama lima jam. Analisis nisbah aspek (penilaian diameter), analisis komposisi kimia, perubahan berat menerusi TGA analisis, perubahan fungsi kumpulan kimia menggunakan FTIR dan imbasan elektron mikroskop (SEM) dijalankan bagi mempastikan perubahan-perubahan kimia dan fizikal berlaku dalam batang Napier. Melalui keputusan ujian-ujian ini, didapati kepekatan larutan NaOH sebanyak 10.5% memberi impak yang paling utama iaitu pengurangan komposisi lignin sebanyak 93.78 %, dan pemerolehan selulosa sebanyak 80.59 % dan 63.57% kandungan ektrak telah didapati. Peringkat kedua kajian, mempamerkan pembuatan papan partikel menggunakan batang rumput Napier yang telah dirawat dengan 10.5% kepekatan NaOH dan urea-formaldehye (UF) resin. Pada peringkat permulaan pembinaan panel Napier, beberapa faktor yang dikenalpasti mempengaruhi sifat akhir papan telah ditapis menggunakan pendekatan Taguchi. Hasil daripada keputusan tapisan tersebut, tiga faktor telah dikenalpasti sebagai yang paling memberikan kesan iaitu jenis Napier (terawat dan tak terawat), tekanan suhu panas plat dan kuantiti peratus kandungan resin UF yang dicampurkan bersama serat Napier. Faktor-faktor ini kemudiannya dioptimumkan menggunakan pendekatan 'Response Surface Methodology' (RSM) melalui rekabentuk 'Central Composite Design' (CCD). Hasil daripada rekabentuk eksperimen yang telah dijalankan, beberapa respon seperti kekuatan regangan (IB), kekuatan statik (MOE dan MOR), kekuatan regangan skru (SW), pembengkakan ketebalan (TS) dan resapan air (WA) ke atas papan partikel Napier telah dijalankan menurut Piawaian British (EN310-312 :1993). Data-data yang telah diperoleh dianalisis menggunakan perisian Design Expert 10 (DE 10). Hasil daripada regressi model kuadratik, didapati ianya sesuai bagi MOR dan WA, manakala, model kubik menepati persamaan dalam IB, MOE, SW dan TS. Secara keseluruhannya keputusan kajian yang diperolehi menyeimbangi rekabentuk persamaan ramalan.*



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**LIST OF ABBREVIATIONS**

| | | |
|---|---|---|
| **BS** | - | British Standard |
| **DTG** | - | Derivative Thermal Degradation |
| **FTIR** | - | Fourier Transform Infrared |
| **IB** | - | Internal Bond |
| **MDF** | - | Medium Density Fibreboard |
| **MOE** | - | Modulus of Elasticity |
| **MOR** | - | Modulus of Rupture |
| **NaOH** | - | Sodium Hydroxide |
| **NpG** | - | Napier Grass |
| **NpSS** | - | Napier Stem Strand |
| **NWLB** | - | Non-Wood Lignocellulosic Biomass |
| **OSB** | - | Oriented Strand Board |
| **PB** | - | Particleboard |
| **SEM** | - | Scanning Electron Microscope |
| **SW** | - | Screw Withdrawal |
| **TGA** | - | Thermo-gravimetric Analysis |
| **TS** | - | Thickness Swelling |
| **UF** | - | Urea Formaldehyde |
| **WA** | | Water Absorption |



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## LIST OF SYMBOLS

| | | |
|---|---|---|
| **d** | - | Specimen Thickness |
| **f** | - | Screw Withdrawal Strength |
| **L** | - | Support Span |
| **lp** | - | Connector entry depth |
| **N** | - | Crosshead speed rate |
| **z** | - | Strain rate per minute |



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# CHAPTER 1

# INTRODUCTION

## 1.1 OVERVIEW

Huge numbers of the agricultural by product has always been a great matter due to the intensification in rate of landfill clearance that linked to out-dated systems to cope with the farming remainder. Therefore, one of the way out to shrink this problem is by reprocessing the generated biomass excess into particulate composites, such as particleboards (PB). The PB industry in Malaysia uses mostly wood chips, flakes and wafers from planted solid logs and timber, rubberwood and oil palm trunk (Amiruddin, Abrahman and Shariff, 2005). However, in view of Malaysia's agricultural affluent and the subsequent proliferation in not fully formed agricultural by product, a novel auxiliary of fibre and particles for PB production may be the prudent practice of using the agro engineering from the non-wood lignocellulosic biomass (NWLB) to supplant solid wood particles in the establishment of low density PB panels. Therefore questions regarding sustainable and marketable NWLB used to produce standard PB products for furniture industries attract the attention to evaluate the biomass from Napier grass (NpG) which exists in abundance. At the same time, as what has been reported by Norchahaya Hashim (2012), there are harsh fall in wood log supply and any other forest resources for PB raw material. For that reason, biomass from NpG is considered to be as one of the most potential NWLB and its characteristics will be investigated in the manufacturing of PB panel.



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## 1.2 Raw Materials for Particleboard Industry

Generally, the source of raw materials for the wooden industry in Malaysia come from the natural forests, plantations such as rubber logs and oil palm trunks, as well as the mill and agriculture residues as presented in Figure 1.2 (Bakar, Sultan, Azni, Hazwan, and Ariffin, 2018). In addition, PB is one of the most represented panel in the wooden board industry around the world and some countries use Spruce, Birch and Pine wood as a source of raw material (Melo, Stangerlin, Santana, and Pedrosa, 2014).

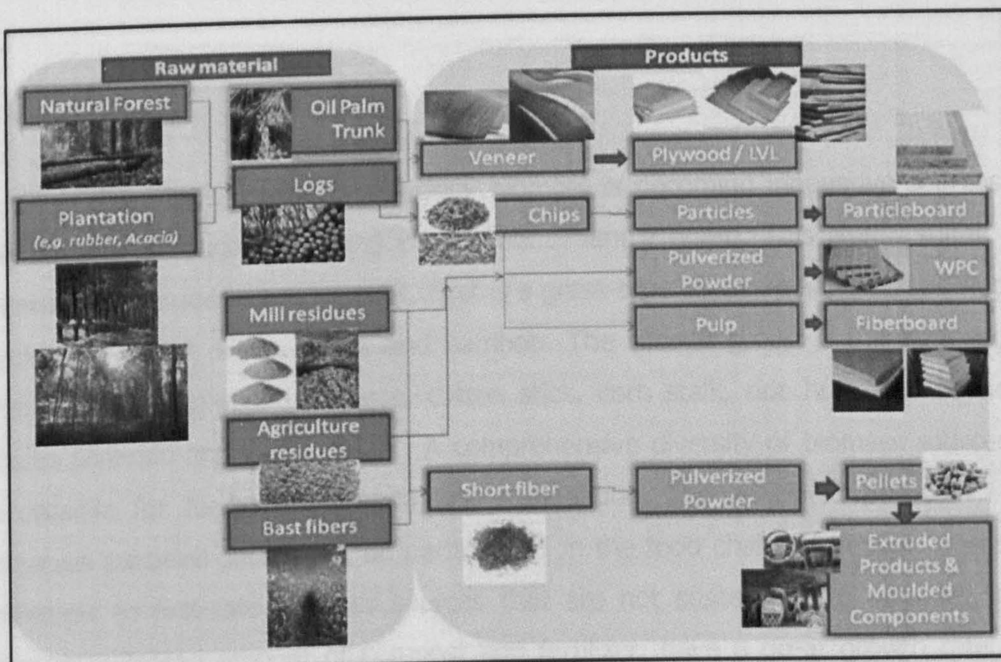


**Figure 1.2 : Current Supply Chain of Plywood, MDF and Particleboard**
Source : Bakar *et al.* (2018)

Even though wood is the utmost important fibre source of material for the production of PB, growing demand of forest resources for other expenditures has run to the deficiency of wood supply. Therefore, Malaysian government has encouraged researchers and industrialists to discover any other alternative raw materials from non- wood lignocellulosic biomass (NWLB) including harvesting residues and annual plants to produce PB (Othman and Samad, 2009). However



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the development of PB from these biomasses has been seriously debated over its sustainability as they are purposely extracted to create and contribute to other field of industries. According to Norchahaya Hashim (2012), Malaysia has an abundance of waste rice husks and EFB that mainly been used to produce good quality biochar which are believed to improve soils for positive and significant crop yield effects, while wood sawdust usually are burned and fermented to create methane and alcohol or used in bioreactors to make carbon and hydrogen for the production of alternative energy, fuels and industrial chemicals (Abdullah and Sulaiman, 2013). As a result, in term of competition, their production as alternative resources still could not fulfil the non-wood fibre development for PB panel.

For longer period, non-woody biomass is becoming innovative sources of material to produce green and environment-friendly board. This NWLB suited for making PB include two categories. First is a grass-type fibrous plant, such as Napier grass, jut kenaf, wheat straw and bamboo. The second group is the agricultural residues like sugarcane bagasse, cotton stick, corn stalk, rice husk and soybean sticks (Arevalo and Peijs, 2016) . A comprehensive diversity of biomass sources is accessible for further adaptation and exploitation. For principled purposes, the biomass particles should not be participated in the food chain. Moreover, it is also strategic to first-rate biomass sources that are not susceptible to diseases, one require a limited amount of compost and fertilizer, have a great growth rate per hectare annually and are preferably available all over the year.

Based on these criteria, the Napier grass (NpG) was proposed to be a potential biomass particles for further conversions and utilisation in PB panel. The basic work that need to be accomplished is to transform their morphology so that they can be adapted into PB panel production through an optimal methodological and cost-effective process.



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## 1.3 Problem Statement

By the year of 2020, it is estimated that annual exports of the timber logs is targeted to reach RM53 billion under the Third Industrial Master Plan (IMP3) (Norchahaya Binti Hashim, 2012) and because of that, it is predicted that there will be a shortfall and deficit of raw materials due to the decline in opening of state land forests and alienated land for development. Therefore, with the intention to maintain Malaysia's competitiveness as a topmost wood producer and to address the issues and challenges, alternative initiatives must be taken to ensure the resource of raw materials are accessible at reasonable prices. Lack of raw materials and manpower are the concern issue of how our wooden industry can move forward has been questioned comprehensively among the local furniture provider.

Khalil, Firdaus, Jawaid, Anis, and Ridzuan, (2010) revealed that, in 2007, 35% of rubber regions have been transformed to other yields and for expansion resolves. 25% of these rubber areas are being converted to oil palm which produced higher economic profits, 5% to supplementary crops consist of fruit trees, and another 5% have been advanced into building and infrastructural plans. Once these tree crops ripe, there would be a decline in the long period goods of rubber logs from plantations and farms.

According to Othman and Samad, (2009), it is reported that Malaysian PB mills are no longer able to obtain 100% rubber wood materials, therefore distressing their capability to produce homogeneous pale boards. They revealed that, from the time when the lacks of rubber wood logs, Malaysian board plants have to develop a mixture of wood materials. In 2008 on average the plants are utilising 40% Acacia (25% Acacia slabs-price at RM50/mt and another 15% Acacia log-at greater than RM100/mt), 20% mixed hardwood log and slabs (price



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RM80/mt), and the rest are taken up by rubber log (RM120/mt) (Norchahaya Binti Hashim, 2012). Price of combined hardwood logs is higher and more adhesive is desired in panel making then when using rubber wood, yet a manufacturer has to trade the hardwood PB board at nearly the equal rate as rubber wood PB boards. Consequently, this would lessen the revenue.

Currently, research regarding the use of NWLB fibre in manufacturing of PB with outcomes showing that this material has great possibility to replace traditional wood from timberlands has lead researchers to explore the suitability and more importantly to optimise the characteristics and process conditions to build PB from NWLB. Several studies have been conducted on the application of NWLB as reinforcing materials in specific applications for board industries. It was reported that NpG fibre-reinforced has been used in polyester laminates and were subsequently analysed their mechanical properties (M.Haameem et al., 2016). Besides that, NpG is also been studied to be converted into biogas production for renewable energy (Phitsuwan, Sakka and Ratanakhanokchai, 2016). However, there is still very lack of research done or reported so far on the NpG used as a building material in board productions.

Therefore, the present work was aimed to develop a suitable pretreatment system and through the optimization of process parameters to manipulate the characteristics and quality of NpG so that in the future this raw material can be utilised to manufacture a NWLB panel. Branch, (2013) studied the production and distribution of nine variety of Napier in the form of leaves and stem. He reported that Malaysia collectively produced huge volume of Napier residue annually. After Napier harvest, some quantity of the available stem is always left on the field to preserve soil health and productiveness and also to avoid soil destruction (water



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and wind). Excess stem available can be used in a sustainable approach for other economic purposes like board manufacturing.

Despite all the potential benefits of using Napier biomass as fibre source in building PB panel, there are also some trials that need to be overcome so as to make the process economically, possible and rewarding for investors, as well as to make PB effortlessly inexpensive by the users. Generally lignocellulosic biomass is a complex formation of cellulose, hemicellulose, and lignin (Arevalo and Peijs, 2016). Arevalo et al., (2016) stated that the lignin acts as an exterior crosslink bond hemicellulose and cellulose with cellulose positioned at the inner core of the structure which give resistance that generally known as "biomass recalcitrance" that need to be break down through pretreatment process. In the face of the potential of Napier becoming an advance as important sustainable biomass for PB production, it has attracted much attention on its multiple compositions and complex biopolymer structures. This could be a hindrance of the effective and efficient utilization of Napier biomass (Reddy et al., 2012). Therefore, it has been an important way to separate Napier biomass into individual components first and then utilize them in PB manufacturing.



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