UNIVERSITI PUTRA MALAYSIA

IMPREGNATION OF BAMBOO (*Gigantochloa scortechinii*) WITH PHENOLIC RESIN FOR THE PRODUCTION OF DIMENSIONALLY STABLE PLYBAMBOO

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By

MOHD KHAIRUN ANWAR BIN UYUP

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

March 2008

Specially dedicated to:

My Father
HJ UYUP B. HJ SIAM

My Beloved Late Mother

HJH SITI ESAH BT. YASIN
(Al-Fatihah)

and

My Family

Suhana Mohd Salleh
Muhamad Rizqan
Muhamad Aqimi

Your love has made me a better and stronger person.
You are always in my heart.

Abstract of thesis to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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MOHD KHAIRUN ANWAR BIN UYUP

March 2008

Chairman: Associate Professor Paridah Md. Tahir, PhD.

Faculty: Forestry

Low molecular weight phenol formaldehyde (LMwPF) resin was used to enhance the dimensional stability of bamboo strips (*Gigantochloa scortechinii*). Resin was impregnated into bamboo strips via vacuum process before the strips were converted into plybamboo. The present study was undertaken to develop a process to produce high dimensionally stable plybamboo. The work included evaluation of resin impregnation process, establishment of suitable drying/curing technique and final pressing of phenolic-treated bamboo strips. Evaluation of bonding properties, dimensional stability and mechanical properties of phenolic-treated plybamboo were also conducted. The bamboo strips were taken from basal and middle portions of bamboo culm. To treat the bamboo strips with LMwPF resin, firstly, a vacuum period of 1 hour was

applied before the strips were soaked in resin for at least 90 minutes. The samples were later dried in an oven at 60°C for 9 hours. The mean weight percent gain (WPG) and moisture content (MC) of dried phenolic-treated bamboo strips were 14.5% and 7%, respectively. Drying the phenolic-treated bamboo strips for > 9 hours resulted in cupping of the strips.

Phenolic-treated strips were then hot pressed for 5, 8, 11, 14 and 17 minutes at 14 kgm^{-2} and 140°C. Water absorption (WA), thickness swelling (TS) and linear expansion (LE) of the strips decreased when the curing time was extended from 5 minutes to 17 minutes but antishrink efficiency (ASE) increased. The mean value of modulus of rupture (MOR) for untreated strips (177 Nmm^{-2}) was significantly lower than the phenolic-treated strips (224 Nmm^{-2}) after 17 minutes pressing time. However, no significant difference was observed in modulus of elasticity (MOE) and compression parallel to grain. Results showed that the optimum pressing time for phenolic-treated strips was 11 minutes.

This work also established an optimum pressing time to produce high dimensionally stable plybamboo. For this, phenolic-treated bamboo strips were glued together edge-to-edge using phenol resorcinol formaldehyde (PRF) resin to produce a veneer. The veneers were then assembled perpendicular to each other to form a 3-ply (12 mm) and 5-ply (20 mm) plybamboo using phenol formaldehyde resin as a binder. The plybamboos were hot pressed at an optimum pressing condition of 140^{o}C (pressure 14 kgm^{-2}) for 22 (3-ply) and 33 (5-ply) minutes. The bonding strength of the plybamboo obtained in this study met the minimum requirement of MS 228-1991. WA, TS, and LE of phenolic-treated plybamboo were significantly lower compared to those of untreated plybamboo.

The MOR, MOE and compression parallel to grain of the phenolic-treated plybamboo were significantly higher compared to those of untreated plybamboo. For 3-ply, the values were 164 and 127 Nmm^{-2} for MOR, and 19767 and 16778 Nmm^{-2} for MOE, and 60 and 41 Nmm^{-2} for compression parallel to grain, respectively. Similarly, for 5-ply phenolic-treated plybamboo the MOR, MOE and compression parallel to grain of were 38%, 30% and 33% respectively higher than those of untreated plybamboo. Generally, the treatment of bamboo strips with LMwPF resins were found to significantly improve the properties of plybamboo made from them.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia bagi memenuhi syarat untuk memperolehi keperluan untuk ijazah Falsafah ke Doktoran

IMPREGNASI BULUH (*Gigantochloa scortechinii*) MENGGUNAKAN PEREKAT FENOL BAGI MENGHASILKAN BULUH LAPIS YANG BERDIMENSI STABIL

Oleh

MOHD KHAIRUN ANWAR BIN UYUP

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Fenol formaldehid yang berjisim molekul rendah (LMwPF) telah digunakan untuk mempertingkatkan mutu kestabilan dimensi bilahan buluh semantan (*Gigantochloa scortechinii*). Perekat tersebut telah dipadatkan ke dalam bilahan buluh melalui kaedah vakum sebelum dijadikan buluh lapis. Kajian ini adalah untuk menghasilkan buluh lapis yang stabil dimensinya. Kajian meliputi proses pemadatan, pengeringan/pematangan perekat dan penekanan bagi bilahan buluh yang dirawat. Penilaian kekuatan lekatan, kestabilan dimensi dan kekuatan buluh lapis telah dijalankan. Bilahan buluh diambil dari dua bahagian iaitu pangkal dan tengah.

Kaedah yang optimum untuk merawat buluh dengan LMwPF ialah secara vakum selama satu jam diikuti rendaman bagi tempoh 90 minit dan dikeringkan pada suhu 60°C di dalam ketuhar selama 9 jam. Purata peratus kenaikan berat (WPG) ialah 14.5% manakala kandungan kelembapan selepas 9 jam pengeringan ialah 7%. Pengeringan bilahan buluh rawat melebihi 9 jam akan menyebabkan bilahan buluh menggeleding.

Bilahan buluh yang dirawat ditekan panas pada tekanan 14 kgm^{-2} bersuhu 140°C untuk jangka masa 5, 8, 11, 14 and 17 minit. Kadar penyerapan air (WA), pengembangan ketebalan (TS) dan kadar pengembangan arah bertentangan (LE) telah menurun manakala keupayaan menentang pengembangan (ASE) meningkat apabila masa pematangan bertambah daripada 5 kepada 17 minit. Nilai purata kekuatan pecahan (MOR) untuk bilahan yang tidak dirawat (177 Nmm^{-2}) lebih rendah berbanding bilahan buluh yang dirawat (224 Nmm^{-2}) selepas 17 minit ditekan panas. Manakala kadar kekuatan kenyalan dan tekanan bagi kedua-dua bilah buluh ini tiada perbezaan yang nyata. Kadar optimum tekan panas untuk bilah yang dirawat ialah 11 minit.

Kajian ini juga bagi mendapatkan masa tekanan panas yang optimum untuk menghasilkan buluh lapis berdimensi tinggi. Di bahagian tepi bilah buluh yang dirawat kemudian dilekatkan antara satu sama lain dengan menggunakan fenol resorsinol formaldehid (PRF) bagi menghasilkan sekeping lapisan.

Lapisan kemudian disusun bertentangan antara satu sama lain dan digam dengan menggunakan fenol formaldehid bagi menghasilkan buluh lapis yang berketebalan 12 mm (3 lapis) dan 20 mm (5 lapis). Masa optimum bagi penekanan panas buluh lapis ialah 22 minit (3 lapis) dan 33 minit (5 lapis). Kekuatan lekatan untuk semua buluh lapis (sama ada dirawat atau tidak) telah mencapai piawaian minimum dalam MS 228-1991. Kestabilan dimensi (kadar resapan, pengembangan ketebalan dan kadar pengembangan bagi buluh lapis dirawat adalah nyata berbeza berbanding buluh lapis yang tidak dirawat.

Kekuatan rekahan, modulus kekenyalan dan tekanan menunjukkan buluh lapis yang dirawat lebih kuat berbanding buluh lapis yang tidak dirawat. Bagi buluh lapis tiga lapisan, nilainya ialah 164 berbanding 127 Nmm^{-2} untuk kekuatan kepecahan, 19767 berbanding 16778 Nmm^{-2} bagi modulus kekenyalan serta 60 berbanding 41 Nmm^{-2} bagi tekanan. Keadaan yang sama juga berlaku bagi buluh lapis lima lapisan dimana kekuatan rekahan, modulus kekenyalan dan tekanan bagi buluh yang dirawat mempunyai nilai lebih tinggi sebanyak 38%, 30% dan 33%, berturutan berbanding buluh lapis yang tidak dirawat. Secara keseluruhan, rawatan menggunakan fenol formaldehid yang berjisim molekul rendah (LMwPF) memberikan kesan penambahbaikan yang amat ketara terhadap ciri-ciri buluh lapis yang telah diuji.

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Semoga ALLAH S.W.T membalas jasa baik kalian. Amin.

I certify that an Examination Committee met on 17 March 2008 to conduct the final examination of Mohd Khairun Anwar Bin Uyup on his Doctor of Philosophy thesis entitled "Impregnation of Bamboo (*Gigantochloa scortechinii*) with Phenolic Resin for the Production of Dimensionally Stable Plybamboo" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Digree) Regulations 1981. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledge. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

MOHD KHAIRUN ANWAR BIN UYUP

Date: 21 April 2008

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ASE	Antishrink efficiency
CBR	Cyclic boil resistance
CL	Concentrated loading
CCA	Copper-chrome-arsenic
BC	Bulking coefficients
BB	Bamboo board
DSC	Different Scanning Calorimetry
EMC	Equilibrium moisture content
F/P	Formaldehyde to phenol
GPC	Gel permeation chromatography
GLM	General linear model
HCl	Hydrogen chloride
IR	Infrared spectroscopy
L	longitudinal
LSD	Least Significant Different
LMwPF	Low molecular weight phenol formaldehyde
LE	Linear expansion
MUF	Melamine urea formaldehyde
MEE	Moisture excluding efficiency
MMF	Methylolated melamine and formaldehyde
ml	Mililiter
MOR	Modulus of rupture
MOE	Modulus of elasticity

M_n	Number-average molecular weight
M_v	Viscosity-average molecular weight;
M_w	Weight-average molecular weight,
Mz	Average molecular weight
MWD	Molecular weight distribution
na	Not available
OSB	Oriented strand board
NaOH/P	Sodium hydroxide to phenol
NaOH	Sodium hydroxide
PF	Phenol formaldehyde
PRF	Phenol resorcinol formaldehyde
R	Radial
RH	Relative humidity
SAS	Statistical analysis system
SG	Specific gravity
SGL	Single glueline
SEM	Scanning electron microscope
T	Tangential
TS	Thickness swelling
UF	Urea formaldehyde
UL	Uniform loading
WA	Water absorption
WB	Wood board
WPG	Weight percent gain

CHAPTER 1

INTRODUCTION

1.1 Background

Bamboo has received tremendous attention as an alternative raw material due to its fast growth, availability, attractive and unique appearance and toughness (Tewari, 1992). Bamboo in its natural form is mainly used as construction material such as floorings, walls and other household items and utensils. Bamboo is one of the most easily available resources in rural areas. Fourteen out of 59 species are commonly used by the Malaysian bamboo industry for making poultry cages, vegetable baskets, incense sticks and joss papers, skewers and chopsticks, woven blind and handicrafts (Azmy *et al.,* 1994; Aminuddin, 1995).

Bamboo can potentially be converted into engineered products such as cement-bonded particleboard, particleboard, medium density fibreboard, laminated bamboo board, plybamboo, bamboo mat board, bamboo curtain board etc. Most bamboo producing countries such as China and India, lack the processing technology needed to produce high quality end products (Zhu, 1995). Commercialised products available on the market are laminated bamboo, bamboo mat, sliver board, bamboo particleboards, parquetry and plybamboo