UNIVERSITI PUTRA MALAYSIA

STRENGTH AND DIMENSIONAL STABILITY OF PHENOLIC-TREATED BAMBOO - LAMINATED PANEL

NOR FADHLIA FARHANA BINTI A. RAHMAN

IPTPH 2016 9

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By

NOR FADHLIA FARHANA BINTI A. RAHMAN

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

November 2015

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A million thanks to

Abah
Ab. Rahman bin Harun

Ma
Norizan binti Ahmad
And
Mohd Aswadi
Mohd Amirul Ashraf
Nurul Nabila
Nur QalesyaUmairah

…
FAMILY
Is a gift that lasts forever,
Where life begins and loves never ends!

In The Name Of Allah, the Most Gracious and Merciful
Read! In the name of Allah
Who created,Created man out of a (mere) clot of congealed blood,
Read! And thy Lord is Most Bountiful,
He who taught by the pen
Taught Man that which he knew not
Quran XXVI: The Clot, 1-5

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

STRENGTH AND DIMENSIONAL STABILITY OF PHENOLIC-TREATED BAMBOO - LAMINATED PANEL

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NOR FADHLIA FARHANA BINTI A. RAHMAN

November 2015

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

Laminated plybamboo panels were prepared using bamboo (*Gigantochloa scortechinii*) slivers that have been treated with phenol formaldehyde (PF) resin. The main purpose of the study was to develop a strong and dimensionally stable bamboo laminated panel. The epidermis and inner layer of the bamboo strips were removed and finally dressed using a sliver machine into 2-mm thick slivers. Bamboo slivers were dried to 12% moisture content in a kiln drying set at 40ºC and 60% relative humidity (RH) for a week. Phenol formaldehyde resin of medium molecular weight (MMwPF), MW1500, was used to pre-treat the bamboo slivers. Two methods were used; vacuum impregnation and soaking.

A process for the treatment of bamboo slivers comprising impregnating with MMwPF resin were subjected into a vacuum pressure at 42 cmHg for 15 min, followed by applying the external pressure at 2.5 kg/cm^2 for 30, 60 or 90 min. Meanwhile, in the soaking treatment, the slivers were submerged in MMwPF resin for 30, 60 or 90 min. The phenolic-treated bamboo slivers were pre-cured at 60ºC for 6 h. Following this, the phenolic-treated bamboo slivers were assembled perpendicularly into 3-layered plybamboo panel and hot pressed at 140 ± 5ºC and pressure 40 kg/cm^2 for 15 min.All the boards were trimmed and cut into test specimens and then conditioned at 20 ± 3ºC and RH 65 ± 3% for a week prior to testing. The weight percent gain (WPG), contact angle, buffering capacity and thermogravimetric analysis (TGA) of phenolic-treated bamboo slivers were determined. The bonding shear strength of 3-layered plybamboo was also evaluated according to British Standard European Norm BS EN 314.

The results showed that vacuum-impregnated bamboo slivers had significantly higher WPG compared to the soaked slivers. An examination on the bamboo sliver surfaces demonstrated that phenolic treatment had increased the contact angle of the bamboo

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surfaces, suggesting a relatively lower wettability. Compared to the control, such reduction is an advantage as it prevents over penetration of adhesive into the cells due to high porosity of the surface. Buffering capacity study revealed that phenolic-treated bamboo slivers have a greater resistance toward alkaline and was more sensitive towards acid. The thermal stability of phenolic-treated bamboo sliver was found to be significantly higher than the untreated.

The results also showed that irrespective of the treatment methods used, modulus of rupture (MOR) and impact strength were significantly affected (at $p \leq 0.01$) by the treatment method, whereas treatment duration does not indicate any significant effect. A notable improvement in the dimensional stability of treated sample was shown by the reduction of water absorption (WA), thickness swelling (TS) and linear expansion (LE). Treatment with phenolic resin was found to markedly increase the anti-swelling efficiency (ASE) (at $p \leq 0.05$) of the phenolic-treated plybamboo suggesting a reduction in irreversible swelling.

Conversions of phenolic-treated bamboo slivers into 3- and 5-ply bamboo boards appear to have different effects. The 3-ply phenolic-treated plybamboo had greater flexural strength properties (MOR and MOE) and shear bond strength compared to the 5-ply. In the 5-ply phenolic-treated plybamboo however, demonstrated a greater compressive strength. It was also recognized that the 3-ply phenolic-treated plybamboo at [0°/45°/0°] significantly generate higher MOR. Nevertheless, the 3- and 5-ply phenolic-treated plybamboo had comparable bonding shear properties when arranged at [0°/0°/0°] and [0°/0°/0°/0°/0°], respectively. In addition, the angle configuration at [45°/90°/45°] and [45°/90°/45°/90°/45°] in the 3- and 5-ply phenolic-treated plybamboo, respectively, gave relatively lower MOR values.

The overall results revealed that vacuum impregnation was effective compared to soaking. Based on this study, vacuum impregnation for 90 min resulted in significant improvements in the physical and mechanical properties of phenolic-treated plybamboo. Also, this study showed that the angle configuration of the bamboo slivers had greater influence over the mechanical properties of the plybamboo. The WA, TS and LE were found to be much lower in the 3-ply plybamboo indicating a much stable board.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah SarjanaSains

KEKUATAN DAN KESTABILAN DIMENSI FENOLIK-TERAWAT PANEL BULUH BERLAMINASI

Oleh

NOR FADHLIA FARHANA BINTI A. RAHMAN

November 2015

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

Panel buluh lapis berlaminasi telah dihasilkan dengan menggunakan kepingan buluh (*Gigantochloa scortechinii*) yang telah dirawat dengan resin fenol formaldehid (PF). Tujuan utama kajian ini adalah untuk menghasilkan panel buluh berlaminasi yang kuat dan stabil dimensinya. Epidermis dan lapisan dalam bilahan buluh telah dibuang dan akhirnya dibentuk dengan menggunakan mesin bilah kepada kepingan berketebalan 2-mm. Kepingan buluh dikeringkan sehingga ke kandungan lembapan 12% di dalam pengering kiln pada suhu 40ºC dan kelembapan relatif (RH) 60% selama seminggu. Resin fenol formadehid bermolekul sederhana (MMwPF), MW1500 digunakan untuk pra-rawatan kepingan buluh. Dua kaedah yang digunakan adalah: tekanan vakum dan rendaman.

Proses rawatan kepingan buluh yang melibatkan impregnasi dengan resin MMwPF telah dimasukkan ke tekanan vakum pada 42 cmHg selama 15 minit, disusuli dengan penggunaan tekanan luar pada 2.5 kg/cm^2 selama 30, 60 atau 90 minit. Manakala, bagi rawatan rendaman, kepingan telah direndam di dalam resin MMwPF selama 30, 60 atau 90 minit. Kepingan buluh yang dirawat-fenolik kemudian di pra-matangkan pada suhu 60°C selama 6 jam. Berikutan ini, kepingan buluh yang dirawat-fenolik disusun secara serenjang kepada 3 lapisan buluh lapis dan ditekan panas pada suhu 140±5ºC dan tekanan 40 kg/cm^2 selama 15 minit. Kesemua bod dipotong tepi dan dipotong mengikut spesimen ujikaji dan di hawa dingin pada 20±3°C dengan RH 65±3% selama seminggu sebelum diuji. Peratus berat pertambahan (WPG), sudut lekatan, keupayaan penimbal dan analisis thermogravimetrik (TGA) kepingan buluh yang telah dirawat dengan fenolik ditentukan. Ikatan ricih buluh lapis dinilai mengikut Piawaian British European Norm BS EN 314.

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Hasil keputusan menunjukkan bahawa kepingan buluh yang telah di vakum-impregnasi mempunyai WPG yang tinggi signifikasi berbanding dengan kepingan yang telah direndam. Pemeriksaan terhadap permukaan kepingan buluh mendapati bahawa rawatan fenolik telah meningkatkan sudut lekatan permukaan buluh, secara relatif merumuskan kadar pembasahan yang rendah. Berbanding dengan sampel kawalan, pengurangan ini adalah satu kelebihan dimana ia menghalang penembusan gam yang berlebihan ke dalam sel disebabkan oleh permukaan berongga tinggi. keupayaan penimbal mendedahkan bahawa kepingan buluh yang dirawat-fenolik mempunyai daya rintang yang tinggi terhadap alkali dan lebih sensitif terhadap asid. Kestabilan haba dari kepingan buluh yang dirawat-fenolik didapati lebih tinggi berbanding dengan tidak dirawat.

Berhubung dengan kaedah rawatan yang telah digunakan, nilai purata kekuatan pecahan (MOR) dan kekuatan hentaman sangat dipengaruhi oleh kaedah rawatan (pada $p \leq 0.01$), dimana tempoh rawatan tidak menunjukkan kesan yang signifikasi. Penambahbaikan yang ketara dari kestabilan dimensi bagi sampel yang dirawat ditunjukkan daripada kadar pengurangan penyerapan air (WA), pembengkakan ketebalan (TS) dan pengembangan linear (LE). Rawatan dengan resin fenolik menunjukkan peningkatan ketara di dalam kecekapan anti-bengkak (ASE) (pada $p \leq 0.05$) kepingan buluh yang menjadi petunjuk kepada pengurangan pembengkakan semula.

Penukaran kepingan buluh yang dirawat-fenolik kepada bod buluh 3- dan 5-lapis didapati mempunyai kesan-kesan yang berbeza. Buluh lapis 3-lapis yang dirawat-fenolik mempunyai sifat kekuatan (MOR dan MOE) dan kekuatan ikatan ricih yang baik jika dibandingkan dengan 5-lapis. Walaubagaimanapun, buluh lapis 5-lapis yang dirawat-fenolik menunjukkan kekuatan mampatan yang tinggi. Ianya juga dapat dikenal pasti bahawa buluh lapis 3-lapis yang dirawat-fenolik pada [0°/45°/0°] menghasilkan MOR yang tinggi. Namun, buluh lapis 3- dan 5-lapis yang dirawat-fenolik mempunyai sifat ikatan ricih yang setanding bila masing-masing disusun pada [0°/0°/0°] dan [0°/0°/0°/0°/0°]. Tambahan lagi, pada sudut konfigurasi [45°/90°/45°] dan [45°/90°/45°/90°/45°] bagi papan lapis 3- dan 5-lapis yang dirawat-fenolik, memberikan nilai MOR yang rendah.

Keseluruhan hasil dapatan mendapati bahawa vakum impregnasi sangat berkesan berbanding dengan rendaman. Berdasarkan kajian ini, vakum impregnasi pada 90 min telah memberikan penambahbaikan yang signifikasi terhadap sifat fizikal dan mekanikal buluh lapis yang dirawat-fenolik. WA, TS dan LE didapati sangat rendah pada buluh lapis 3-lapis menunjukkan bod yang stabil.

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ACKNOWLEDGEMENTS

I would like to express my deep appreciation to the chairman of the supervisory committee, Prof. Dr. Paridah Md. Tahir for her untiring guidance on my research and assistance throughout the course of this study. I will always be grateful to Prof. Paridah's advice, detailed assistance, dedication and kind encouragement. Her keen love to research always inspires me for the future study. I would always like to express my sincere gratitude to Dr. Khairun Anwar Uyup, for his guidance and assistance throughout the duration of this project. Appreciation is also extended to the members of the supervisory committee, Dr. H'ng Paik San.

I also indebted to Forest Research Institute Malaysia (FRIM), especially to the Head of Department, Dr. Hamdan, Dr Tarmizi and Dr. Suffian for providing the facilities, the use of the bamboo machining section, and testing facilities, not forgetting the management of Malayan Adhesive and Chemical (MAC) Sdn. Bhd, for the supply of phenol formaldehyde resin used in the study. I also extend my thanks to the help rendered by Mr. Nizam and Mr. Yaakob who's offered kind helps during the sample preparation. A million thanks to family and friends (Thenmoli, Khaulah, Naziratulasikin, Amirah Fikri, Aizat Ghani, Fazilah Musa, Elini odzlan, Irma raihana, Hayati and other colleagues) for their moral support and encouragement.

Finally, special thanks are due to Universiti Putra Malaysia for providing the scholarship for the author study, and Kementerian Pengajian Tinggi Malaysia for partly sponsoring this study.

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I certify that a Thesis Examination Committee has met on 24 November 2015 to conduct the final examination of Nor Fadhlia Farhana bt. A. Rahman on her thesis entitled "Strength and Dimensional Stability of Phenolic-Treated Bamboo-Laminated Panel" 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 Master of Science.

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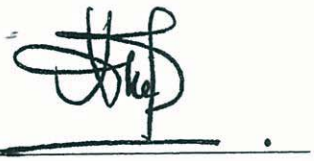

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the supervisory committee were as follows:

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASE	Anti-shrink efficiency
ASTM	American Society for Testing and Materials
BS	British Standard
BGB	Bamboo glubam beam
CBR	Cyclic boil resistance
Df	Degree of freedom
EMC	Equilibrium moisture content
FGS	Flat guadua sheets
GLB	Glued laminated bamboo
EN ISO	European Norm International Organization for Standardization
$LE_{\perp}$	Linear expansion perpendicular to the grain
LE_{ll}	Linear expansion parallel to the grain
LMWPF	Low molecular weight phenol formaldehyde
LSD	Least significant difference
LVL	Laminated veneer lumber
LOSP	Light organic solvent preservatives
LBL	Laminated bamboo lumber
MC	Moisture content
MMWPF	Medium molecular weight phenol formaldehyde
MOE	Modulus of elasticity
MOR	Modulus of rupture
MW	Molecular weight
OPS	Oil palm stem

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OPTL	Oil palm trunk lumber
OPW	Oil palm wood
OSB	Oriented strand board
PF	Phenol formaldehyde
PSL	Parallel strand lumber
PRF	Phenol resorcinol formaldehyde
RH	Relative humidity
SAS	Statistical Analysis System
SEM	Scanning electron microscopy
SGL	Single glue line
TGA	Thermogravimetric analysis
THM	Thermo-hydromechanical
TS	Thickness swelling
UF	Urea formaldehyde
UTM	Universal Testing Machine
VPI	Vacuum-pressure impregnation
WA	Water absorption
WPG	Weight percent gain
VPSEM	Variable Pressure Scanning Electron Microscope

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CHAPTER 1

INTRODUCTION

1.1 Background

The bamboo composite materials such as plybamboo and particle bamboo mat board can be made into potential walling material either as sheathing or stressed skin construction for prefabricated houses (Jagadeesh and Ganapthy, 1995). Several products have gone into commercial production, including mat plywood, sliver board, bamboo particleboard and parquet. Meanwhile, in Malaysia, bamboo strips have been found suitable for laminated board, and overlay rubber wood parquet products because of the toughness of the material and uniqueness of its appearance (Zaidon *et al.,* 2000). The excellent mechanical and physical properties of bamboo, makes bamboo as an ideal raw material for the manufacture of plybamboo and furniture as well as for structural application and general construction (Nordahlia*et al.,* 2011).

More than 28 bamboo based panel-products in combination with wood and other inorganic material have been developed by various researchers in the world (Ganapathy*et al.,* 1999). Among all the panel boards, bamboo made plywood, or plybamboo strength ranks as the highest and even as good as the solid wood of high density commercial timber (Chen and Qin, 1985). Plybamboo has already been accepted as an industrialized product that has the potential for building modern structures (Xiao *et al.,* 2009).

1.2 Application of plybamboo

Bamboo is considered to be the best alternatives for several end use panel applications such as doors, windows, frames, partitions, furniture and flooring (Gupta and Kumar, 2008). Current research of bamboo utilization covers a wide range of bamboo based panel products such as plybamboo, laminated bamboo, bamboo-zephyr board, bamboo particleboard and bamboo cement board (Chaowana, 2013). Bamboo-based panels have various advantages and conjunction with that; it also can be a suitable alternative for any material pruposes. It can be used in different ways for roof structure as trusses, roof skeletons, purlins, rafters and reapers (Anon, 2010), flooring, furniture, bamboo weaved product and bamboo cement framework (Wang and Guo, 2003).

Its use through industrial processing and have shown a high potential for production of composite materials and components which are cost effective and can be successfully utilized for structural and non-structural applications. The main characteristic features which make bamboo a potential building material are its high tensile strength and very good weight to strength ratio. It can withstand up to 3656 kg/cm^2 of pressure. It can be easily worked upon by simple tools and machines. The strength-weight ratio of bamboo

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also supports its use as a highly resilient material against forces created by high velocity winds and earthquakes (Tomas and Ganiron, 2014).

The quality, durability and wide range of applications of the bamboo based panel products particularly plybamboo become the major factors that contributed to the commercialization of these products in Asian countries before triggered the increasing demand in western markets (Barelli, 2009). These panels can be used from structure to roofs and wall panel cladding, or to replace most other building elements made of industrialized wood (Janssen, 2000). Also, it has been widely used in the vehicles compartments, moulding board of construction, scaffoldings and some of them have partly taken the place of wood, steel and plastic for furniture and decorating purposes. In fact, it has been applied in construction industry as structural materials for bridges, water-transportation facilities and skyscraper scaffoldings (Chaowana, 2013).

Glue laminated bamboo (GLB) panel is one of the many examples of structural bamboo used in construction (Xiao *et al.,* 2008). It is very versatile and can be applied for bearing parts in building such as I-beam and column and for non-bearing components such as wall, roofing and flooring boards depending on their strength. Laminated bamboo becomes an alternative for a proper prefabricated manufacturing and assembly construction process of structural elements and has an excellent mechanical properties and it is as good as wood (Vanages, 2003). Even nowadays, laminated bamboo has been gradually applied in furniture, interior decoration and its demand will gradually increase (Du, 2011*).* Table 1.1 summarises the several previous study on bamboo based panel product as a construction material.

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Table 1.1 : Recent work on various application of bamboo based panel products

Product	Purpose	Findings	Reference(s)
Plybamboo	Plywood	*G. scortechinii* has a potential in the production of plywood.	Zaidon *et al.* (2003)
	Flooring	In general, the mean hardness and dimensional stability of bamboo flooring was greater than red oak flooring and LBL.	Lee and Liu (2003)
	Structural bamboo plywood	The MOR, MOE and compression parallel to grain of the plywood were higher compared to commercial plywood.	Anwar *et al.* (2004)
	Wind turbines	Carbon-friendly Chinese Moso bamboo to make eco-friendly blades for generating wind energy.	Platts (2008)
	I-joists	Flexural strength of the bamboo (OSB) reached 36 MPa, shear strength was 14 MPa, while MOE was 14 000 MPa.	Aschheim*et al.* (2010)
	Concrete form	The mechanical properties of 3 layer bamboo curtain composite plybamboo were improved to meet the requirements of concrete form.	Du and Jin (2013)
Laminated bamboo panel	I-beam bearing girder and straddle	MOR and MOE value reached as high as 210 MPa and 89 GPa respectively.	Wang and Guo (2003)
	I-beam web/other complex components like wall board.	It showed good properties of aging resistance with almost no change happened on parallel laminated bamboo panel after 20 cycles, even under more severe conditions where boiled for 2 h and dried at high temperature for 17 h.	Hamdan (2004)
	Structural Construction material	The excellent properties of *G. scortechii*were suitable to structural application. Bending strength (126 MPa for MOR, 11700 for MOE) and compression strength (65.8 MPa) of parallel strand lumber (PSL) made from Calcutta bamboo was higher than all other structural composite lumber (SCL) products.	Mansur and Kamke (2005)
	Load-bearing applications	The MOR and MOE of laminated bamboo board (LBB) ranged from 38.61−95.07 MPa and 7266−100.31 MPa, respectively. No delamination occurred in all samples indicating high bonding quality.	Sulastiningsih and Nurwati (2009)
	Practical method for laminated bamboo timber production	A cylindrical bamboo culms were successfully been converted into flat and wide bamboo boards using the provided Grooving Table as a reference.	Bakar *et al.* (2013c)

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The improvement in processing technologies, product innovation with the application of scientific and engineering skills in a structural product application of the bamboo based panel products have led to an enhancement of laminated plybamboo. The application of plybamboo panels have been increasing. Currently, the main applications are flooring, veneer, decorative boards, sports equipment and other building materials. A number of agencies are already working towards promoting the usage of bamboo into value-added products to increase the potential of plybamboo into a various applications.

1.3 Phenolic resin treatment

As bamboo has less natural durability it requires chemical treatment for longer life. Bamboos have low natural durability (1 to 3 years) against attacks by fungi and insects. The treatment of bamboo is, therefore, the resin treatment using phenol formaldehyde resin into wood has been mainly developed for veneers to produce plywood of upgraded strength properties. Phenol formaldehyde (PF) resin has a softening effect, like steam or heat, which plasticizes the wood cell wall (Shams *et al.,* 2004). Phenolic resin impregnation and compression at considerably high hot pressing pressure is attractive for the improvement of strength properties, dimensional stability and durability of lignocellulosic materials against decay (Stamm and Seborg, 1955). Loh*et al.* (2011) and Furuno*et al.* (2004)used this treatment to improve oil palm plywood and poplar and cedar, respectively and concluded that PF resin treatment was able to enhance the mechanical strength, dimensional stability and resistance towards termites and fungi.

Shams and Yano (2009) also reported that that PF resin can improve the surface smoothness, density distribution, adhesive penetration and the physical and mechanical properties of the oil palm trunk (OPT) plywood. Anwar *et al.* (2009) treated bamboo strips with PF resin and concluded that PF resin impregnation offers a simple and effective method for improving the dimensional stability of bamboo, at the same time, greatly improved the strength properties of the bamboo.

Medium to low molecular weight phenolic resin has been normally used in wood modification purposes to ensure a complete penetration by the resin polymer into the wood cells. Loh*et al.* (2010) have successfully used LMwPF resin to improve the shear strength of pre-preg plywood compared with that commercial PF plywood due to the easy penetration of two classes of molecular weight PF resin (low and medium) into parenchyma cell of oil palm stem (OPS) veneer.

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1.4 Lay-up pattern in plybamboo

Bamboo has an interesting microstructure and macrostructure with hierarchical features which contributes to its structural integrity (Armada, 1995). Bamboo moreover exhibits significant anisotropy in strength: it is more than ten times stronger in tension in the longitudinal direction than in the transverse direction (Jain *et al.,* 1992).

Bamboo when converted into bamboo based panel products, the properties of the panels will behave differently depending on the geometry of the raw materials (fibre, particle, flake, strip, sliver, chip and more). Such differences would generate panels of different strength and dimensional stability. One of the methods to improve the strength of plybamboo panel is by arranging the bamboo slivers in a particular angle so that maximum strengths can be achieved at any direction. Several studies have been reported on the use of different lay-up patterns and angle configuration and their influence on the mechanical and physical properties of the laminated bamboo boards (Sulastiningsih and Nurwati, 1996; Nugroho and Ando, 2001; Lee *et al.,* 2012; Verma and Chariar, 2012) and the results were very encouraging.

1.5 Problem statement

Bamboo is naturally durable material that has been recognized throughout the world for its versatile and good structural properties. It provides an alternative to replace timber and other materials in construction and other works (Tjerk, 2014; Nayak*et al.,* 2013). In contrast to timber, the bamboo culm is thin and hollow and its strength comes from the way the grass evolved, adapting to natural forces. This allows it to move with the wind, unlike tree, which tries to simply withstand any natural forces it is exposed to. This adaptation for flexible movement required nature to come up with very light but tension-resistant fibre in the bamboo culm which is able to bend in extreme ways without breaking. Bamboo is harder to pull apart than timber or even reinforced steel thus offers great potential as raw material for commercial development. Numerous studies have been reported on the basic properties and processing of bamboo based panel products, and the findings indicated that there are great potentials for using bamboo as a commercial product (Mansur, 2000; Nugroho and Ando, 2001; Wan Tarmeze*et al*., 2005; Mahdavi*et al.,* 2012).

Nevertheless, bamboo has its own limitations such as change in dimension with time due to varying atmospheric moisture and degradation by biotic and abiotic agents (Yun *et al.,* 1991; Norimoto*et al.,* 1992; Narakhara and Fujii, 1993). Understanding dimensional stability by bamboo when exposed to water is practically important since it affects the mechanical properties of the product. Thus, a proper treatment is needed to treat the bamboo in order to prolong the service life of the product. Chemical modification ensures a longer service life for the bamboo products and maintains its quality (Satish and Dobriyal, 1992; Anon, 2006). The modification was able to overcome some of the problems, such as high hygroscopicity and instability dimension (Xiao *et al.,* 2008).

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The type of resin used and treatment will influence its effectiveness. In this study, bamboo as the substrate and MMwPF resin is the adhesive. It is anticipated that the treatment with medium molecular weight phenol formaldehyde (MMwPF) resin followed by a compression was chosen to produce almost flat and regular surfaces suitable for lamination. Formaldehyde-based resins have the advantages of superb bonding strength and are inexpensive (Kim, 2009). The bond strength of PF resin is considered high, and the strength degraded less at elevated temperatures in the presence of moisture compared with UF (Sulaiman*et al*., 2009). The PF resin usually starts as a low molecular weight pre-polymer and builds the degree of polymerization in the curing process. The resin will always be a resin but at some point it becomes an adhesive (once it cured). The treatment of bamboo sliver with MMwPF resin, using a soaking and impregnation process followed by compressing under hot press would yield a high performance of laminated plybamboo panel. At the same time, bamboo based panel products can retain the distinct physical, mechanical, chemical and aesthetic features of natural bamboo itself.

1.6 Objectives

The aim of this study was to develop laminated plybamboo panel with acceptable strength and dimensional stability. The main objectives of this study were to improve the laminated plybamboo dimensional stability via phenolic resin treatment and to increase the strength properties by using different sliver lay-up patterns.

The study consisted of three specific objectives:

1. To evaluate the effects of MMwPF resin treatment on the bonding properties and thermal behaviour of plybamboo.
2. To determine the mechanical and physical properties of 3-ply phenolic-treated plybamboo produced under different treatment conditions.
3. To evaluate the effects of lay-up pattern (angle configuration) on the mechanical and physical properties of 3- and 5-ply phenolic-treated plybamboo.

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