PERFORMANCE OF SESENDUK WOOD [*Endospermum diadenum* (Miq.) Airy Shaw], SEMANTAN BAMBOO (*Gigantochloa scortechinii* Gamble) AND LAMINATED COMPRESSED PRODUCTS TREATED WITH LOW VISCOSITY MELAMINE UREA FORMALDEHYDE RESIN

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

July 2019

FPAS 2019 16

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

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Low density wood is one of potential raw material to be used in reducing dependency on commercial timber species. However, these woods are relatively poor in properties and require special treatment to enhance their properties before they can be further utilized into high value-added products. There have been many attempts to enhance the properties of low density wood through bulking treatment with low molecular weight phenol formaldehyde (LmwPF) and the results showed that the physic-mechanical properties and durability of the treated materials were improved significantly. However, due to the oligomer state of the resin, high free formaldehyde is emitted. Therefore, a study was undertaken to formulate low viscosity melamine urea formaldehyde (MUF) that can be served as a bulking agent as well as to maintain its adhesion properties. The MUF resin was synthesized at different amount of melamine (20 to 30%), urea (10 to 25%) and formaldehyde (50 to 60%) and the solution was diluted to gain concentrations of 20% and 30%.

It was found that MUF formulation (F4) which consist of 30% melamine, 50% formaldehyde and 20% urea had a viscosity of 9 cP, 118 min pre-curing time, 24 min curing time and 32% solid content which is believed to have excellent bulking and adhesion properties. Thus, this formulation was used to treat sesenduk (*Endospermum diadenum*) wood and bamboo (*Gigantochloa scrtechinii*). Air-dry samples were treated separately with the synthesized MUF solutions using empty cell process. The impregnated materials were pre-cured at 70ºC and followed by curing at 140ºC. The other set of treated samples, they were undergone hot compressing at 140ºC immediately after pre-curing and the resultant product is known as compressed material. Commercial MUF was also used as treating solution for comparison purposes. The results show that the impregnant had successfully penetrated and bulked the cell wall of the

material as indicated by the positive values of density (44 to 55%), polymer loading (27 to 55%) and bulking coefficient (3.8 to 7.8%). Lower PDI value for the synthesized resin (1.12) as compared to commercial MUF (1.19) was due to smaller particles and dispersion of the formulated resin which is essential for the impregnant to penetrate the wood cell wall. Excellent penetration of the MUF resin was also proven by micrograph from scanning electron microscope (SEM) which show lumen cells and voids were occupied with the MUF resin.

It was also found that the treatment had successfully imparted dimensional stability where the water absorption was reduced to 32% and anti-swelling coefficient was improved for 48%. The bulked resin managed to increase mechanical strength of the wood strips as the MOR increased up to 17% and MOE increased up to 59% when compared to the untreated wood. The MUF-compressed strips treated with higher melamine content resin likes 30% F4 yield the lowest formaldehyde emission (FE) of 0.94 ppm and was categorized in E2 class. The formaldehyde emission was very low due to formation of methylene bridge (melamine formaldehyde) which were spotted in few peaks in spectroscopic analysis of FTIR-UATR.

In the second phase of the study, several products were produced, viz. laminated wood, laminated bamboo, laminated wood/bamboo hybrid and laminated untreated wood. In terms of dimensional stability, WA and ASE of formulated MUF-compressed products were excellent than treatment using commercial MUF. For the mechanical properties, MOR and MOE significantly increased parallel to increasing of density. The commercial MUF-compressed products had greater MOR and MOE than formulated MUF-compressed products. The high solid content of the commercial resin cause greater bulking of the resin into wood cells that make the wood stronger and more stiff. Generally, it was found that formulated MUF-compressed sesenduk produced the highest shear strength compared to another treatments. However, the hardness and tensile strength of the compressed products treated with commercial MUF was greater due to high bonding strength between wood and resin. Durability of the laminated compressed products against white rot fungus was determined where the treatments has included the products into durable category with weight loss values less than 4%. The durability of the treated products was improved for 66 to 83% as compared to the untreated wood which explain that the formulated MUF resin has bulked the lumen cell resulting in prevention of water bonding and the resin itself became toxic to the fungus.

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

PRESTASI KAYU SESENDUK [*Endospermum diadenum* (Miq.) Airy Shaw], BULUH SEMANTAN(*Gigantochloa scortechinii* Gamble) DAN PRODUK BERLAMINA TERMAMPAT DIRAWAT MENGGUNAKAN MELAMIN UREA FORMALDEHID RESIN BERKELIKATAN RENDAH

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Kayu yang berketumpatan rendah adalah salah satu sumber yang berpotensi untuk mengurangkan kebergantungan kepada spesies kayu komersil. Walau bagaimanapun, kayu ini mempunyai kelemahan sifat dan memerlukan rawatan khusus untuk meningkatkan sifatnya sebelum dapat digunakan untuk menjadi produk yang mempunyai nilai tambah tinggi. Terdapat banyak percubaan untuk meningkatkan sifat-sifat kayu berketumpatan rendah melalui rawatan pemadatan dengan phenol formaldehid yang berat bermolekul rendah (LmwPF) dan hasilnya menunjukkan bahawa sifat fizik-mekanik dan ketahanan bahan-bahan yang dirawat meningkat dengan ketara. Walau bagaimanapun, oleh kerana keadaan oligomer resin, formaldehid bebas yang tinggi dikeluarkan. Oleh itu, satu kajian telah dijalankan untuk membuat formula melamin urea formaldehid berkelikatan rendah (MUF) yang boleh digunakan sebagai ejen pemadatan serta mengekalkan sifat pelekatan. MUF disintesis pada jumlah melamin yang berbeza (20 hingga 30%), urea (10 hingga 25%) dan formaldehid (50 hingga 60%) dan kepekatan resin telah dicairkan kepada 20% atau 30%.

Telah dijumpai bahawa formulasi MUF (F4) yang terdiri daripada 30% melamin, 50% formaldehid dan urea 20% mempunyai kelikatan sebanyak 9 cP, 118 minit sebelum pengawetan, 24 jam pengawetan dan kandungan pepejal 32% yang dipercayai mempunyai ciri pemendapan dan lekatan yang sangat baik. Oleh itu, formula ini digunakan untuk merawat sesenduk (*Endospermum diadenum*) dan buluh (*Gigantochloa scortechinii*). Sampel udara kering dirawat secara berasingan dengan penyelesaian MUF yang disintesis menggunakan proses sel kosong. Sampel yang telah diimpregnasi di pra-awet pada suhu 70ºC dan diikuti dengan pengawetan pada 140ºC. Satu set sampel lain yang dirawat, dikenakan mampatan panas pada suhu 140ºC sejurus selepas pra-

pengawetan dan produk yang dihasilkan dikenali sebagai bahan termampat. MUF komersil juga digunakan sebagai cecair perawat untuk tujuan perbandingan. Hasil kajian menunjukkan bahawa pengimpregnasi telah berjaya menembusi dan memenuhi dinding sel bahan seperti yang ditunjukkan oleh nilai positif kepadatan (44 hingga 55%), kemasukan polimer (27 hingga 55%) dan keberkesanan penempelan (3.8 hingga 7.8%). Nilai PDI yang lebih rendah untuk resin yang disintesis (1.12) berbanding dengan MUF komersil (1.19) disebabkan oleh zarah-zarah yang lebih kecil dan penyebaran resin yang diformula adalah penting untuk pengimpregnasi menembusi dinding sel kayu. Penembusan resin MUF yang cemerlang juga dibuktikan oleh mikrograf dari mikroskop elektron imbasan (SEM) yang menunjukkan sel lumen dan rongga ditempel oleh resin MUF.

Juga telah didapati bahawa rawatan itu telah berjaya memberikan kestabilan dimensi di mana penyerapan air telah dikurangkan kepada 32% dan anti pengembangan telah meningkat sebanyak 48%. Resin yang telah menempel berjaya meningkatkan kekuatan mekanikal kepingan kayu apabila MOR meningkat sehingga 17% dan MOE meningkat sehingga 59% berbanding kayu yang tidak dirawat. Kepingan yang telah dimampatkan dan dirawat dengan MUF dengan kandungan melamin yang lebih tinggi seperti 30% F4 menghasilkan pembebasan formaldehid terendah (FE) sebanyak 0.94 ppm dan dikategorikan dalam kelas E2. Pembebasan formaldehid yang sangat rendah akibat pembentukan jambatan methylene (formaldehid melamin) yang telah didapati di beberapa puncak dalam analisis spektroskopi FTIR-UATR.

Dalam fasa kedua kajian ini, beberapa produk telah dihasilkan, iaitu kayu berlamina, buluh berlamina, kayu /buluh hibrid berlamina dan kayu berlamina yang tidak dirawat. Dari segi kestabilan dimensi, WA dan ASE produk MUF yang dimampatkan adalah sangat baik berbanding rawatan menggunakan MUF komersil. Untuk sifat mekanik, MOR dan MOE meningkat secara ketara selari dengan peningkatan ketumpatan. Produk yang dimampatkan menggunakan MUF komersil mempunyai MOR dan MOE yang lebih besar daripada produk yang menggunakan MUF yang telah diformulasi. Kandungan pepejal tinggi resin komersil menyebabkan lbih banyak penempelan resin ke dalam sel kayu yang membuatkan kayu menjadi lebih kuat dan lebih kaku. Secara amnya, didapati bahawa sesenduk yang dimampatkan menggunakan MUF yang telah dirumus menghasilkan kekuatan ricih tertinggi berbanding dengan rawatan lain. Walau bagaimanapun, kekerasan dan kekuatan tegangan produk termampat yang dirawat dengan MUF komersil adalah lebih besar disebabkan kekuatan ikatan tinggi antara kayu dan resin. Ketahanan produk berlapis termampat menentang kulat reput putih telah ditentukan di mana rawatan telah memasukkan produk ke dalam kategori berketahan tinggi dengan nilai penurunan berat kurang daripada 4%. Ketahanan produk yang dirawat meningkat sebanyak 66 hingga 83% berbanding dengan kayu yang tidak dirawat yang menjelaskan bahawa resin MUF yang dirumus telah menempel di dalam sel lumen yang mengakibatkan pencegahan gabungan dengan air dan resin itu sendiri menjadi toksik kepada kulat.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude to my honourable supervisor Prof. Dr. Zaidon Bin Ashaari. Without his professional and guidance, this research project would not have been completed successfully.

Special thanks to my co-supervisor Prof. Madya Dr. Edi Suhaimi Bakar and Dr. Mohd Khairun Anwar Uyup for giving so much help and guidance. Also, I am grateful to my supportive friends, for helping me in many aspects during conducting my research. I would like to extend my heartfelt appreciation and recognition to their valuable contribution in this research.

I would also like to thank Aica Chemicals Sdn. Bhd. for supplying the commercial MUF resin needed in this research. Also thanks to Evergreen Chemicals whom supply raw materials and laboratory equipment during laboratory testing process. With the supplied resin, this research can be finished without major problem.

My warmest thanks dedicated to my beloved husband, children, mother, brothers, sisters and family in laws for their understanding throughout my study journey. Their endless love, spirit and financial support gave me the strength to finish up my study through thick and thin.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
MOR	Modulus of rupture
MOE	Modulus of elasticity
MUF	Melamine urea formaldehyde
PF	Phenol formaldehyde
UF	Urea formaldehyde
WA	Water absorption
TS	Thickness swelling
DSC	Differential Scanning Calorimetry
FTIR	Fourier Transform Infrared Spectrometer

CHAPTER 1

INTRODUCTION

1.1 General introduction

Human population and economic values are growing faster especially in developing countries demanding for higher timber products to be used in daily usage such as furniture, buildings and transportation. Continuous development in return does not only cater human needs, but also threatened natural forest resources including timber supply and animal population. Malaysia itself consists of tropical forest which is a primary importance to biodiversity and climate change (Gibbs *et al*., 2007; Pimm *et al*., 2014). Nevertheless, poor forest management caused great loss and degradation to the forest resources (Wright, 2010). Ecosystem of tropical regions including in Malaysia and Indonesia experience significant threats (Sodhi, 2004). Wood timber resources around the world especially in Malaysia decreased over the years caused by higher wood demand. According to FAOSTAT (2015), rubberwood plantation in Malaysia has depleted for 40% until 2014. Selective logging is one of the major reason in degrading forests with low species richness (Slik *et al*., 2002).

In Malaysia, researchers and technologist are struggling to find alternative ways to reduce dependency on commercialized timber species before they extinct. Invention of wood polymer composites such as medium density board, fibre board, particle board, hardboard and laminated veneer lumber has become an alternative to fully utilise the wood resources. At the same time, researchers are now paying interest in utilizing under utilized timber species of low density hardwoods such as Mempening (*Lithocarpus spp*), Nyatoh or Nangka Kuning (*Pouteria malaccensis*), Pauh Kijang (*Irvingia malayana*) and Petai (*Parkia speciosa*) (Hamami *et al.*, 1993). Low density hardwoods are not preferable due to their poor strength, poor dimensional stability and low resistant against fungal decay and termite attacks. Treatment by depositing non leachable bulking agents such as low molecular weight phenol formaldehyde (LmwPF) into the cell structure of wood through impregnation may provide permanent stabilization to the wood products.

Sesenduk (*Endospermum diadenum*) and Jelutong (*Dyera Costulata*) wood which had been treated using low molecular weight phenol formaldehyde (LmwPF) through impregnation and followed by hot pressing managed to improve dimensional stability, strength properties, and durability against fungi decay (Nur Izreen *et al.,* 2011, Rabiatol Adawiah *et al*., 2012; Nabil *et al*., 2015; Zaidon, 2017). Rabiatol Adawiah *et al*., (2012) shows that anti-swelling efficiency (ASE) of *compreg* Sesenduk wood was enhanced for 20% to 30% greater than untreated wood. The impregnation and compression of Mahang wood (*Macaranga sp.*) using 15% (w/v) of LmwPF managed to increase the polymer retention for 30% which was sufficient to increase dimensional stability, mechanical properties and 100% resistancy against fungal decay (Ang *et al.,* 2014). Shams *et al.*, (2004) has impregnated Japanese cedar (*Cryptomeria japonica*) with LmwPF and found that the treatment has successfully increased the bending strength and in line with increasing of the density. However, there are few drawbacks of using LmwPF. Even though, dimensional stability was improved, the ASE values were lower than treatment using MUF resin. A study conducted by Cai *et al.*, (2007) shows that ASE of the impregnated aspen wood with MUF alone yield 63% of ASE, while wood treated with MUF with addition of nano fillers has gained for 100% ASE values. It shows that MUF resin significantly affected dimensional stability greater than LmwPF resin. Besides, the release of formaldehyde from LmwF-treated products is higher than other resins. A study by Rabiatol Adawiah *et al.*, (2012) has found that formaldehyde emission (FE) values for LmwPF-*compreg* sesenduk wood was in the range of 64 to 110 ppm. Nur Izreen *et al.*, (2011) also proof that LmwPF-treated wood has higher FE values in the range of 81 to 172 ppm . The high concentration of formaldehyde in the air may cause harmful effect such as nasopharyngeal cancer and probably leukimia (Tang *et al.*, 2009).

Nowadays, formaldehyde based resin such as urea formaldehyde (UF), melamine formaldehyde (MF), phenol formaldehyde (PF) and melamine urea formaldehyde (MUF) are widely used as binders and coaters in manufacturing of wood products. UF resin is used as adhesives in board making, MF is used in laminating and surface coatings, PF is used in building construction and MUF is used in coating technology and kitchenware production (Anisuzzaman *et al.,* 2014). In some cases, melamine was used together with UF to increase water resistant and to reduce formaldehyde emission (Hse, 2009). However, melamine is an expensive chemical, thus, melamine content should be reduced, but the consequence may be diminished of external grade performance. Therefore, there is a need to formulate a new resin with enhanced properties and at the same time do not endanger the environment and human population.

1.2 Problem statements

Malaysia like other countries is having crisis in managing forest resources. Poor forest management has lead to depleting of natural timber resources especially commercial timber species like Balau, Chengal, Merbau and Jati. One way to reduce the extinction of commercial species is by utilizing tree species likes low density hardwoods. The low density hardwoods are classified as non-durable 1due to susceptible to fungal decay and insect attacks. However, low density hardwoods are easy to treat and has good machining properties (Engku, 1988b).

To make the low density wood accepted by the industries, the low density wood needs to be treated to enhance its poor properties. There are few treatment types that can be implemented including cross-lamination products, water resistant coating, hygroscopicity reduction, cross linking of treatment chemicals and bulking treatment (Rowell and Youngs, 1981). Bulking treatment with aqueous solutions of PF, UF and MUF resin in impregnation or compression treatment produced bulked products where the insoluble polymers do not bound with the wood cell wall and do not leach out when exposed to water. With the right resin formulation, the efficient bulking treatment may increase dimensional stability, mechanical properties and highly resistance towards fungal decay and insect attacks.

Melamine urea formaldehyde is a synthetic resin belongs to amino resin family by combining with aldehyde and amino groups (Amit and Subrata, 1996). It has been widely used in particle board, medium density board, fibre board and other wood products since a long time ago (Tohmura *et al*., 2001). The main characteristic of MUF is its higher water resistance which differentiate it from UF resin. Pizzi (1994) stated that MUF resin had properties intermediate between UF and MF but its durability equal to MF content. Nevertheless, the MF resin is too expensive, so urea has been added to produce the MUF resin that has equivalent properties to the MF but at a lower manufacturing cost (Bono, 2001). Melamine content is also essential to improve the MUF properties, yet, due to highly cost, its content may be reduced during synthesis process. Parker and Crews (1999) asserted that MUF resin with low melamine content has been widely used in Europe and Asia-Pacific region. Unfortunately, Anisuzzaman *et al*., (2015) reported that reduction of melamine content may reduce its exterior grade performance. In addition, faulty MUF formulation may lead to minimal resin consumption and resulting in weak bonding with the wood substrates.

In Malaysia, researchers are actively involved in introducing latest treatment for full use of wood especially consumption of under utilized hardwood. The preferable resin to treat wood is low molecular weight phenol formaldehyde (LmwPF) which is very known in enhancing properties of wood products. Anwar *et al*., (2008) managed to gain 13% to 14% weight percent gain (WPG) by impregnating bamboo strips (*Gigantochloa scortechinii*) with LmwPF. Pre-curing the bamboo samples at 60°C for 9 hr significantly reduce the moisture content (MC) to 7% , but after 9 hr, the strips begin to warp. Masseat *et al*., (2018) also used 30% LmwPF to treat oil palm veneer which has the lowest water absorption (WA) of 17% . Purba *et al*., (2014) has produced *compreg* sesenduk wood and found that the dimensional stability and mechanical properties of the resin were improved.

Another major concern in wood industries is formaldehyde emission emitted from the wood products. Even though MUF had excellent bonding properties compared to UF resin, formaldehyde emission from the product had become indoor air pollution just like the UF resin. The formaldehyde emission above 0.1 parts per million of air can cause watery and burning sensation of eyes, nose and throats, coughing, nausea, chest tightness, skin rashes and allergic reactions (H'ng *et al*., 2011). International Agency for Research on Cancer (IARC) has classified formaldehyde as carcinogen. Many regulations has been made by authorities including the government of Japan, Australia and United

Kingdom by limiting indoor formaldehyde exposure to 0.1 mg/m^3, 0.12 mg/m^3 and 0.1 mg/m^3 respectively (Tang *et al*., 2009).

1.3 Justification

The effectiveness of MUF resin as a bulking agent in compressed wood remains unknown with little information on impregnation treatment. The understanding on behaviour of low density wood products treated with MUF resin is scarce. In this study, compressed treatment of low density wood using low viscosity MUF resin was selected. The sesenduk wood from light hardwood category was chosen in order to utilize the less density timber species as an effort to reduce dependency on medium or heavy hardwood in manufacturing wood products. Even though, low density hardwood had poor dimensional properties and less susceptible to fungal and insects attack, treatment using formaldehyde based resin may improve its poor properties. Non-bonded and non-leachable resin through compression treatment was chosen due to excellent properties mentioned by other researchers. For example, compression of wood after impregnation process resulting in the highest ASE for more than 90% (Rowell, 1981).

Another types of resin that frequently used in wood industry is UF, PF and MF resin. The UF resin had few advantages and disadvantages like high reactivity, fast curing, water solubility and low price but at the same time had poor water resistance and high formaldehyde emission (Myers *et al.,* 1990 and Dunky, 1998). Reformulate the UF resin by reducing molar ratio of formaldehyde to urea managed to reduce FE but also had reduce water resistance and bonding strength of panels the (Meyer *et al.,* 1980; Pizzi *et al.* 1994; Ebewele *et al.* 1994; Bono *et al.* 2003; Fan *et al.* 2006). Melamine itself has the properties of higher resistancy against water, high functionality in reducing formaldehyde emission and stable structure compared to urea (No and Kim, 2004; Hse *et al.,* 2008; Hse, 2009). Nevertheless, due to expensive cost of melamine, adjustment in concentration of urea, melamine and formaldehyde must be made to produce resin with low FE and high resistance against water. The PF resin is widely used resin in wood composites and wood products fabrication. The low molecular weight PF (LmwPF) is preferable due to higher degree of penetration into both lumen and cell wall. Nabil *et al*., (2016) has found that the durability of sesenduk against fungal attack was 98% when treated with LmwPF with addition of nanoclay. The dimensional stability of the sesenduk *compreg* was enhanced as the anti swelling efficiency (ASE) values recorded were 20% to 30% indicates that the LmwPF has bulked the cell wall to some extends. The impregnation using the LmwPF is also a promisible treatment in improving MOR and MOE properties of low density wood , i.e, jelutong and sesenduk (Nur Izreen *et al*., 2011).

The excellent properties of MUF resin may be achieved by the right formulation of the MUF resin (Luo *et al*., 2015). A few parameters that need to be considered including molar ratio, melamine content, pH value, reaction stages and catalysts. Shiau and Smith (1985) exhibit that melamine content determine methylolation steps, where 2% melamine incorporated in two stages managed to reduce FE of particle boards. Paiva *et al.* (2012) found that resin synthesized with acidic pH between 4.5 to 4.7 produced resin with good internal bond strength and low FE. A study by Xu *et al.* (2009) found that addition of melamine to the urea and formaldehyde resulting in lowest thermal stability and addition of formaldehyde and melamine in two stages showed the highest wet shear strength. Even though, many researchers investigated different synthesis parameters in producing resin with excellent properties as an adhesive in wood composites manufacturing, study on impregnation and compression treatment of low density wood using the low viscosity MUF has not been reported. Hence, in this study, a brand new MUF resin formula was formulated with the capability to bulk the cell wall and thus, enhance the dimensional stability, mechanical properties and resistancy against fungi of the treated wood.

1.4 Objectives of study

The main objective of this research was to determine the effect of low viscosity MUF resin treatment on properties of sesenduk and bamboo laminated products. The specific objectives are as follows:

1) To characterize the properties of formulated MUF resin that can be used as bulking treatment of wood and bamboo

2) To assess the effectiveness of these formulated MUF resin in improving physico-mechanical of sesenduk wood and bamboo

3) To compare the performance of laminated product made from sesenduk wood, bamboo or sesenduk-bamboo hybrid which were treated with low viscosity formulated MUF and commercial MUF resins

1.5 Research hypothesis

1) Bulking treatment using the new formulated MUF resin would give different degree of penetration into the wood cells

2) Application of the low viscosity MUF through impregnation process should enhance dimensional stability, mechanical properties, durability against fungus attack and reduce formaldehyde emission of the treated wood

3) The properties of laminated compressed sesenduk and bamboo was improved especially in bonding strength even though no adhesives being used to assemble the laminated products

1.6 Scope of study

Chapter 1 discusses the scenario in Malaysian timber industry including shortage of raw materials and ways to conserve the natural forest resources. Development of new wood products should benefit the timber industry and must be non hazardous to human and environmental. Chapter 2 explains types of treatment and resin that can be used to enhance properties of wood. The mechanisms involved during curing of the resin and its effect on properties of the treated wood.

The experimental design was divided into three phases consist of synthesis of resin, compression of wood strips and fabrication of laminated wood products. Chapter 3 is about synthesis process of ten different MUF formulations. The effect of resin concentration and amount of each components (melamine, urea and formaldehyde) on resin properties were determined. The formulated resins were further tested for viscosity, pH value, solid content, pre-curing period, curing period, curing behaviour and molecular weight of the resin.

Chapter 4 introduces the treatment process that was applied to the low density (sesenduk) wood in improving its poor dimensional stability. The treatment was impregnation using low viscosity MUF and followed by hot pressing. Efficiency of the bulking treatment was determined through changes of density and weight percent gained. Dimensional stability of compressed strips were tested using soaking test to obtain anti swelling efficiency values (ASE). Meanwhile, strength properties of the compressed strips were evaluated from static bending and hardness test. Degree of penetration of the MUF resin into wood cell was investigated using scanning electron microscopic (SEM), FTIR and formaldehyde emission.

Chapter 5 focus more on properties of laminated compressed products. The laminated compressed products were fabricated from assembling of sesenduk wood layers, hybrid of sesenduk and bamboo layers and also layers of bamboo itself. Mechanical strength was analyzed using static bending test, shear block and tensile test. Lastly, the compressed laminated products were exposed to *Pycnoporus sanguineus* to measure weight loss caused by the fungal.

1.7 Limitation of study

There were few limitations in conducting this study. The raw material used to fabricate the compressed laminated products were only sesenduk and bamboo. The wood sample was cut into the dimension of 200 mm x 150 mm x 4 mm. The used of specified dimension was to allow full penetration of the resin into wood cell structures. Lower degree of penetration may be occur if larger and thicker size of samples being used. For resin formulations, the content of each component was set to 20% to 30% for melamine, 50% to 60% for formaldehyde and 10% to 25% for urea content. Those formulations were adapted from previous research on synthesis of MUF resin. A laboratory scale cylindrical impregnation chamber and vacuum pressure were used to impregnate the MUF resin into the treated samples. Later, the samples were subjected to compression at temperature of 140 °C with 80 % compression ratio (CR).

1.8 Significance of study

This study is significantly important in exploring new method to help wood sectors to fully utilize the low density wood in order to reduce dependency on commercial species hardwood. In current study, results obtained from series of testings would provide sources of information on latest technology that can be applied in improving the properties of wood. The successful treatment may be very useful in helping Malaysian wood industry to find alternative ways to preserve local timber species from extinction. The formulated MUF resin managed to upgrade the poor properties of low density sesenduk wood and bamboo in term of physical and mechanical properties, dimensional stability and durability against fungal attack. In developing a greener wood product, the MUF-compressed sesenduk succeed to reduce the indoor formaldehyde emission to a low level. However, further research may be done on formulating a new MUF resin to incur super low or zero formaldehyde emission as regulated by authorities.

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