EFFECT OF UREA AND PHENOL FORMALDEHYDE RESIN IMPREGNATION ON PROPERTIES OF 7-YEAR-OLD KELEMPAYAN (*Neolamarckia cadamba*) WOOD

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by

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LIST OF SYMBOLS

%	Percentage
º	Degree
µ	Micro
mm	Millimeter
cm	Centimeter
m	Meter
g	Gram
kg	Kilogram
kN	Kilo Newton
N	Newton
C	Celsius
cP	Centipoise
ml	Millimeter
L	Liter
θ	Theta
@	At
sec	Second
min	Minute
h	Hour

LIST OF ABBREVIATIONS

ASE	Anti-swelling efficiency
ASEAN	Association of Southeast Asian Nations
ASTM	American Society for Testing and Materials
B	Bulking coefficient
BS	British Standards
CA	Contact angle
EN	European Standards
EU	European Union
FRIM	Forest Research Institute Malaysia
FT-IR	Fourier transform infrared
HTD	High temperature drying
ISO	International Organization for Standardization
KBr	Potassium bromide
L	Leaching efficiency
LHW	Light hardwood
lmw	Low molecular weight
MATRADE	Malaysia External Trade Development Corporation
MIFF	Malaysian International Furniture Fair
MITI	Ministry of International Trade and Industry
MOE	Modulus of elasticity
MOR	Modulus of rupture
MS	Malaysian Standards
MTCS	Malaysian Timber Certification Scheme
MTIB	Malaysian Timber Industry Board

NATIP	National Timber Industry Policy
OBM	Original Design Manufacturer
OEM	Original Equipment Manufacturer
OH	Hydroxyl
OPTL	Oil palm trunk lumber
PF	Phenol formaldehyde
ROI	Return on Investment
RWA	Resistance of water absorption
SEM	Scanning electron microscopy
SPSS	Statistical Package for the Social Sciences
TAPPI	Technical Association of the Pulp and Paper Industry
TGA	Thermogravimetric analysis
TH	Thermo-Hydral
THM	Thermo-Hydro-Mechanical
UF	Urea formaldehyde
US	United States
USA	United States of America
WA	Water absorption
WPG	Weight percent gain

KESAN PENGISITEPUAN RESIN UREA DAN PHENOL FORMALDEHID TERHADAP SIFAT-SIFAT KAYU KELEMPAYAN (*Neolamarckia cadamba*) BERUMUR 7 TAHUN

ABSTRAK

Kaedah pengisitepuan kayu dengan cecair resin adalah rawatan kayu di dalam tangki tekanan dengan merendam kayu dalam cecair yang mengandungi mampatan udara pada kelonggaran isipadu dan suhu pada atau di atas titik pelembutan kayu untuk membolehkan ruang-ruang kosong dalam kayu diisitepu dengan cecair resin. Kayu diisitepu-resin bertindak sebagai sokongan matrik polimer yang mempunyai kelebihan sifat-sifat kayu pada kestabilan dimensi, kekuatan dan pereputan apabila dibandingkan dengan keadaan sifat-sifat kayu yang asal. Dalam kajian ini, kayu kelempayan (*Neolamarckia cadamba*) berusia 7 tahun dipilih kerana ia adalah salah satu spesies yang berpotensi sebagai pengganti bahan mentah untuk komponen perabot dan papan komposit. Tujuan kajian ini adalah untuk menentukan ciri-ciri asas kayu kelempayan berusia 7 tahun mengikut peringkat ketinggian pokok iaitu bawah, tengah dan atas. Kajian ini juga menentukan pencirian kayu kelempayan berusia 7 tahun dan menganalisis sifat-sifat kayu diisitepu-resin. Masa tekanan maksima pengisitepuan resin berat molekul rendah (lmw) terdiri daripada urea formaldehid (UF) dan phenol formaldehid (PF) telah digunakan terhadap spesimen kayu bersaiz kecil untuk menentukan sifat-sifat mekanikal, kualiti permukaan, morfologi, fungsi kumpulan, rintangan haba dan ketahanan anai-anai. Pokok kelempayan berusia 7 tahun diperolehi dari Stesen Penyelidikan FRIM di Maran Pahang dan kemudian dibelah menjadi kayu gergaji menggunakan kemudahan Bengkel Pembelahan Balak FRIM di Kepong, Selangor. Kaedah ujian fizikal kayu mengikut piawaian MS 837, ISO 3131 (E) dan BS EN 13183. Sementara itu, kaedah ujian mekanikal kayu mengikut piawaian BS 373 dan komposisi kimia kayu mengikut piawaian TAPPI. Ujian tambahan dilakukan untuk mengkaji kualiti permukaan adalah kekasaran permukaan dan kebolehbasahan. Ujian-ujian pencirian telah dinilai menggunakan kaedah mikroskop pengimbas elektron (SEM), transformasi Fourier inframerah (FT-IR) dan analisis termogravimatrik (TGA). Kaedah ketahanan anai-anai adalah berdasarkan standard ASTM D 3345-08. Hasil kajian menunjukkan bahawa sifat-sifat fizikal dan mekanikal di bahagian bawah batang pokok mempunyai perbezaan yang ketara terhadap bahagian atas. Perbandingan komposisi kimia mengikut ketinggian pokok adalah tidak bererti. Analisa FT-IR menunjukkan getaran kumpulan hidroksil terhasil di dalam selulosa, hemiselulosa dan lignin yang ditunjukkan oleh rantau gelombang inframerah adalah sama pada ketinggian yang berbeza. Keputusan ujian kekasaran (Ra = 8.62 μm) dan kebolehbasahan (θ = 50.29 °) permukaan kayu mempunyai sifat yang baik. Keputusan mikrostruktur menggunakan SEM menunjukkan majoriti permukaan anatomi memiliki liang jenis sepasang dan mempunyai ira yang sempit kurang dari tiga seriat. Pencirian haba untuk lengkung-lengkung TGA di bahagian-bahagian yang berbeza menunjukkan nilai purata tahap penguraian pada degradasi haba awal ialah T_i = 305.86 °C, pada degradasi haba puncak ialah T_p = 339.82 °C dan pada degradasi haba akhir ialah T_e = 571.83 °C dengan nilai purata sisa kayu sebanyak 18.12 %. Keputusan analisis pengisitepuan resin didapati bahawa peratus pertambahan berat (WPG) yang maksimum di bahagian bawah batang iaitu 120 minit masa tekanan vakum untuk resin lmwUF dan 90 minit masa tekanan vakum untuk resin lmwPF. Nilai purata WPG maksima untuk kedua-dua resin ialah lebih kurang 166 %. Keputusan sifat mekanik menunjukkan bahawa kayu yang diisitepu dengan resin lmwPF adalah lebih kuat

daripada kayu yang diisitepu dengan resin lmwUF. Kualiti permukaan kayu diisitepu-resin menunjukkan peningkatan kestabilan dimensi berdasarkan keputusan purata kekasaran permukaan (Ra lmwUF = 6.33 µm, Ra lmwPF = 7.17 µm) dan kebolehbasahan (θ lmwUF = 69.40 °, θ lmwPF = 70.32 °). Pemerhatian SEM untuk kayu diisitepu-resin menunjukkan bahawa sebahagian resin lmwUF telah menetap di dalam liang, ira dan gentian sementara kebanyakan resin lmwPF telah menetap dalam sel-sel ira, parenkima dan gentian. Analisa FT-IR terhadap kayu diisitepu-resin memperlihatkan jalinan ikatan kimia telah berlaku antara kumpulan hidroksil dan atom resin di rantau getaran inframerah. Keputusan untuk lengkung-lengkung TGA membuktikan bahawa kayu diisitepu-resin telah menurunkan proses penguraian haba (lmwUF: T_e = 552.14 , lmwPF: T_e = 473.64 °C) berbanding dengan kayu yang tidak dirawat (T_e = 656.09 °C). Keputusan ketahanan anai-anai menunjukkan bahawa peratusan kehilangan berat kayu diisitepu-resin adalah lebih rendah (4 %) berbanding dengan kayu tidak dirawat (7 %). Secara umum, kayu kelempayan muda mempunyai ciri-ciri fizikal, mekanikal, haba dan ketahanan yang lebih baik selepas diisitepu oleh resin termoset di mana ia berkemungkinan boleh digunakan sebagai bahagian pemasangan perabot seperti tempat letak lengan, tempat sandar, tempat duduk, penahan rel dan rel.

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ABSTRACT

A method of impregnating wood with the resin liquid is a wood treatment in the pressure chamber by immersing the wood in the liquid with the air compression at the volume relaxation and the temperature at or above the softening point of the wood to allow the voids in the wood to be impregnated with the resin liquid. The resin-impregnated wood acts as a support for the polymer matrix that would exceed wood properties in terms of dimensional stabilities, strength and decay when it was differentiate with the ordinary state of wood properties. In this study, a 7-year-old kelempayan (*Neolamarckia cadamba*) was chosen because it is one of the potential species as a substitute raw material for furniture components and composite boards. The aim of this study was to determine the fundamental features of the 7-year-old kelempayan wood based on the different height level namely lower, center and upper. Besides that, the study determined the characterization of the 7-year-old kelempayan wood and analyzed the properties of a resin-impregnated wood. Maximum resin impregnation pressure time of low molecular weight (lmw) resin of urea formaldehyde (UF) and phenol formaldehyde (PF) were applied towards small clear specimen in order to determine the properties of mechanical, surface quality, morphological, functional group, thermal and termite resistance of resin-impregnated wood. The 7-year-old kelempayan trees were obtained from the Research Station FRIM at Maran, Pahang and then converted into sawn timber using the facilities of the Log Conversion Workshop FRIM at Kepong, Selangor. Physical test methods of wood were in accordance to MS 837, ISO 3131 (E) and BS EN 13183 standards. Meanwhile, the mechanical test method of wood was in accordance to BS 373 standard and wood chemical composition was in accordance to TAPPI standard. Additional test aims to study the surface quality which included surface roughness and wettability. Characterization tests were evaluated using scanning electron microscopy (SEM), Fourier transform infrared (FT-IR) and thermogravimetric analysis (TGA) methods. Termites resistance method is based on standard ASTM D 3345-08. The results revealed that the physical and mechanical properties of the lower portion of the trunk have significant difference to the upper portion. The chemical compositions was not significantly different along the trunk height. The FT-IR presents vibration bands of hydroxyl group in cellulose, hemicelluloses and lignin by the infrared wavenumber region along the trunk height was comparable. The results of surface roughness (Ra = 8.62 µm) and wettability (θ = 50.29 °) on the wood surface have indicated good properties. The results of microstructure using SEM showed the anatomical surfaces majority possessed pair-type vessels and the rays was narrow which have less than three seriate. Thermal characterization of the TGA curves at different parts of vertical variation indicated mean values of decomposition process at initial thermal degradation was ialah T_i = 305.86 °C, at derivative peak thermal degradation was T_p = 339.82 °C and at end thermal degradation was T_e = 571.83 °C with the wood residues of 18.12 %. The resin-impregnated analysis results found that the maximum weight percent gain (WPG) at the lower portion of the trunk were 120 minutes vacuum pressure time for lmwUF resin and 90 minutes vacuum pressure time for lmwPF resin. The mean values of maximum WPG for both resins were approximately 166%. The results of mechanical properties indicated that the resin-impregnated wood of lmwPF was stronger than the resin-impregnated wood of lmwUF. Surface quality of resin-impregnated wood showed an increase in dimensional stability based on the mean values of surface roughness (Ra lmwUF = 6.33 µm, Ra lmwPF = 7.17 µm) and wettability (θ lmwUF = 69.40 °, θ lmwPF = 70.32 °). SEM observation for resin-impregnated wood indicated several lmwUF resin was deposited in the vessels, rays and fibers while mostly lmwPF resin was deposited in the cells of rays, parenchymas and fibers. The FT-IR of the resin-impregnated wood presents the chemicals engagement between hydroxyl group and resin atom had occurred in the infrared vibration region. The result of TGA curves proven that the resin-impregnated wood (lmwUF: T_e = 552.14 , lmwPF: T_e = 473.64 °C) has reduced thermal degradation process than the untreated wood (T_e = 656.09 °C). The results of the termite resistance indicated that the percentage of weight loss for resin-impregnated wood (4%) was smaller than the untreated wood (7%). Generally, the 7-year-old kelempayan wood has better physical, mechanical, thermal and durability properties after being impregnated with the thermosetting resins which made it possible to be used as the furniture parts fabrication such as armrest, backrest, seat, stretcher and rail.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Kelempayan (*Neolamarckia cadamba*) was introduced by the Malaysian Timber Industry Board (MTIB) as a forest farmstead crop for Development of Forest Plantation Program (Malaysian Timber Industry Board, 2019). This is an effort of the Malaysian government to decrease the burden on natural forest as a basis for fresh resources and to guarantee its constant accessibility for the local wood industry. Kelempayan is a lesser-known commercial timber species with a density of 290 to 465 kg/m^3 (Lim et al., 2005) and it is included in the strength group D (weakest) and that means that the compression strength parallel to the grain was less than 27.6 N/mm^2 (Choo et al., 1999). It is evaluated as non-durable, and graveyard assessments in Indonesia display a normal lifespan in connection with the ground of fewer than 1.5 years (Agroforestree Database, 2013). This tree was successfully planted in Sarawak (Krisnapillay & Ong, 2003) and Indonesia (Rahayu, 2016) and it was utilized as raw material for making particleboard, plywood, laminated board and others.

In this context, light hardwoods with the density value of below 500 kg/m^3 are normally underutilized due to their poor strength and non-durability, which limit their final applications (Zaidon, 2017). Commonly, light hardwood is susceptible to biological agents and has low strength. Thus, this study is aimed to enhance the properties of low density wood species especially kelempayan, so that it can be made into alternative materials to commercial timbers. Nevertheless, once properly treated, these timbers can be converted into high value-added products. Several chemical modification techniques, such as bulking, internal coating and crosslinking, have shown satisfactory results in enhancing the quality of low density timbers (Hill, 2006).

Any treatment helps to improve dimensional stability. According to Rowell and Youngs (1981), the wood treatment reduced the tendency of wood to take on water will result in a reduction in the tendency to swell. On the other hand, heat treatment is a possible method to reduce the hygroscopicity of wood. Umar et al. (2016) found that the optimisation of heating parameters to enhance the resistance of rubberwood (*Hevea brasiliensis*) against white rot fungus at 228°C for 3 hours could maximize the resistance of the treated wood. Therefore, Rowell and Youngs (1981) revealed that at least three factors must be considered in selecting a treatment to achieve product stability to moisture: (i) the environment of the end product, (ii) the degree of dimensional stability and (iii) the cost effectiveness of a treatment.

Previously, the investigation on kelempayan wood covered only the physical, mechanical and anatomical properties of 20-year-old trees from plantation (Ismail, 1993; Ismail et al., 1995) and from natural growth (Lim & Chu, 2002; Lim et al., 2005; Nordahlia et al., 2014; Abd Latib et al. 2014). Recently, no information related to surface quality, SEM microstructure, FT-IR, TGA and resin-imprenated wood were found. Works on enhancement of the low density wood properties have been initiated by Zaidon (2009), who treated wood strips (5mm thick) of sesenduk, jelutong and mahang with low molecular weight phenol formaldehyde (LmwPF, MW = 600), followed by laminating and compressing them in a hot press to form three layered compreg laminates. The wood-based products industry in Malaysia is expected to face the problem of inadequate supply of raw materials to sustain the growth of the industry in the future. Therefore, this study contributes the 7-year-old kelempayan wood as an improvement of value-added substitute material through resin impregnation treatment especially for furniture part fabrication uses.

1.2 Problem statement and justification

The supply of prime tropical timber for furniture such as merbau, tembusu, chengal, mata ulat, kempas, keruing, nyatoh and others (Malaysian Timber Industry Board, 2019) today is very limited compared to the past 20 years. This is because many forests have been cleared for development, settlement, agriculture, and farming. Accordingly, various efforts have been made to explore the alternative sources so that sustainability of the raw materials for the wood-based industries can thrive. Generally, there are three main sources of wood processing products such as sawn timber, veneer and plywood and woodchip where they eventually contribute to one of the secondary products, furniture (National Timber Industry Policy, 2009). The furniture industry is the largest contributor to revenue-based commodity timber. The statistics from the export of the major products show that the total export of wooden furniture for January to December 2018 was higher (RM41.93 million) when compared to sawn timber and plywood (Malaysian Timber Industry Board, 2019). Indeed, the furniture industry is an important industry to the national economy and therefore efforts to find new materials in the furniture industry need to be implemented. Accordingly, the study on the 7-year-old kelempayan wood through resin impregnation technique is carried out.

Several studies have been carried out on kelempayan wood. It is found suitable to be used as furniture components because machining properties are simple for resaw, easy to transverse-cut and even to plane surface (Choo et al., 1999). However, it was reported that kelempayan wood is a light hardwood (LHW). Therefore, the physical and mechanical properties of the wood need to be enhanced to be at least comparable to the wood in strength group C (density above 500 kg/m^3) in which it will be suitable to be used as furniture components. However, very limited information has been reported on planted kelempayan wood converted into sawn timber for furniture components except that it has been produced as particles or chips for composite panel products (Noor Azrieda et al., 2012). As mentioned earlier, one of the methods that can be done is through impregnating liquid polymer or resin into the wood cellular. Related studies have been carried out related to LHW such as mahang (*Macaranga* spp.) by Ang et al. (2009), jelutong (*Dyera costulata*) by Nur Izreen et al. (2011) and sesenduk (*Endosoermum dedanium*) by Rabi'atol Adawiah et al. (2012). Meanwhile, the non-wood material such as oil palm trunk has been densified through resin impregnation in the form of lumber were carried out by Bhat et al. (2010), Abdullah et al. (2012), Dungani et al. (2013) and Aizat et al. (2017) whereas Sulaiman et al. (2012) introduced oil palm lumber through hot press densification.

Planted 7-year-old kelempayan wood has the possibility to be a substitute raw material for furniture production after it has gone through the modification treatment. Therefore, effect of vacuum pressure time for using techniques and tools will able to enhance properties of low density hardwood as well as kelempayan wood.

1.3 Significance of the study

Resin-treated wood is a technique of impregnating wood voids volume with liquid resin using a vacuum-pressure chamber then proven cured under high temperatures. The impregnated wood refers to the modification of porous material, particularly low-density wood becomes a stable and durable wood as compared to its original state. The application of the impregnated wood can be wider from general utility products to be a value-added product. Mechanical properties like flexural and compressive strength can be increased and the resistance to biological attacks and environment also appear to be improved. In this study, the 7-year-old kelempayan wood has been chosen because it is one of the fast-growing timbers from the forest plantation species which has been proposed by the government (Malaysian Timber Industry Board, 2019). It has great potential as a sustainable material for wood-based industries. It grows abound in the surrounding countries of ASEAN (Agroforestree Database, 2013). The resin-impregnated of low-density wood is important to reveal the ability of the 7-year-old kelempayan wood to be a treated wood with favorable use as a substitute material in the furniture industry. The significance of this study will be contributing new information in relevance to the properties of planted kelempayan wood from plantation grown and the method of resin impregnation of the 7-year-old kelempayan wood will be established. It is hoped that versatile products will be designed and innovated. Accordingly, the problems related to raw materials would declined especially for the furniture industry , and that it will be developed further, increasing the contribution of income to our country.

1.4 Objectives of the study

The versatility resin-impregnated of kelempayan wood can be manufactured in various dimensions and forms for the furniture industry. The present study evaluates the feasibility of resin-impregnated 7-year-old kelempayan wood as various part components in furniture fabrication. Hence the aims of this study are:

i) To determine the physico-mechanical and chemical properties as well as surface quality of 7-year-old kelempayan wood and its variation along the stem of the tree.

ii) To examine the microstructure, the functional group and the thermal characterization of the wood at different height levels.

iii) To assess the properties of the wood impregnated with low molecular weight urea formaldehyde and phenol formaldehyde resins.

CHAPTER 2

LITERATURE REVIEW

2.1 Alternative raw material for wood-based industry

The Government is very concerned about issues related to the deterioration of commercial tropical timber for wood-based industry. This issue has been specified by the researchers in their studies in recent years (Mohd Hamami et al., 2008; Abd Latib et al., 2014). Accordingly, various efforts have been searched for alternative materials for this industry, particularly promising from the plantation crops that offer tremendous resources. Alternative raw materials for wood-based industries can be classified into two different materials: timber and non-timber resources. The government does not just focus on rubberwood alone but has been promoting the fast-growing timber species. In accordance with this policy, the Cabinet, in March 2005, provided a significant mission to the Ministry of Plantation Industries and Commodities to track a hostile programme for the expansion of forest plantations in Malaysia (Malaysian Timber Industry Board, 2019). Thus, kelempayan is a promising alternative raw material based on several advantages such as rapid growing species, good machining properties, white in color and smooth surface. However, some drawbacks of kelempayan such as poor in density, strength and durability need to be overcome in order to increase its dimensional stability, mechanical properties and resistance to biological agents (Zaidon, 2017).

2.1.1 Lesser known timber species

Timber resources of our country contributed to the furniture manufacturing industry besides other materials such as plastic, metal, glass, fabric and leather. Wooden furniture is still showing the highest recorded revenue every year (Malaysian Timber Industry Board, 2019). Hence, the lesser-known timber species has been chosen as an alternative material by doing some modifications to its properties to render it suitable as a raw material for furniture. Usually it consists of less commercial timber species and the application is limited only as a frame, utility furniture parts and household goods. Several lesser-known timber species with densities below 500 kg/m³ have been suggested such as bangkal, bebusok, bekoi, kelempayan, melembu, membuloh and mempari (Lim et al., 2004; Lim et al., 2005).

2.1.2 Development of plantation species

Forest plantations detail for only a very minor proportion of the overall forest area in Malaysia. It is estimated that forest plantations covered about 0.31 million hectares, or approximately 16% of the total 1.7 million hectares forest area in Malaysia. The distribution of forest plantations was scattered in all the states of Malaysia; in Sabah around 174,000 hectares, in Sarawak it is around 60,000 hectares and in Peninsular Malaysia, 75, 000 hectares (Krisnapillay & Ong, 2003). The forest plantation established in Peninsular Malaysia contained a extensive series of species which can be separated into three different classes, namely wood for pulp and paper production such as *Acacia mangium*, *Pinus* spp. and *Eucalyptus* spp.; general utility timber such as *Hopea* spp., *Dryobalanops* spp., *Endorspermum malaccense* and *Hevea brasiliensis*; and high quality timber such as *Tectona grandis* and *Azadirachta excelsa* (Mohd Hamami et al., 2008).

The development of plantation species started with the exploitation of rubberwood (*H. brasiliensis*) as a material for furniture components and then for manufactured particleboard and fiberboard. Rubberwood now has been accepted as the panel materials for furniture, flooring and interior building construction in different parts of Asia, the Middle East, America and Europe. Thus, the Ministry of Plantation Industries and Commodities has outlined to grow 375,000 hectares of forest plantation at a yearly imbedding frequency of 25,000 hectares per year for the following 15 years (Malaysian Timber Industry Board, 2019). After positively realised, each 25,000 hectares of land planted is predictable to yield five million cubic meters of timber. Out of eight particular species, the programme is mostly concentrated on two species, namely rubberwood (Timber Latex Clone) and *Acacia* spp. (mangium/hybrid).

The government does not just focus on rubberwood and acacia alone but has been promoting the plantation of fast-growing timber species too. Supplementary rapid growing timber species suggested are *T. grandis* (teak), *A. excelsa* (sentang), *Khaya ivorensis*/*Khaya senegalensis* (khaya/mohagoni), *Neolamarckia cadamba* (kelempayan/laran), *Paraserianthes falcataria* (batai) and *Octomeles sumatrana* (binuang) (Malaysian Timber Industry Board, 2019). Meanwhile, non-timber resources that have been exploited were bamboo, rattan, kenaf and nibong, which grow naturally, and lately the list also included coconut and oil palm trees obtained from the government's plan land, private companies or private land. The newest data on non-timber species that were also preferred in this program are the five profitable bamboo species: *Bambusa heterostachya* (buluh galah), *Bambusa vulgaris* (buluh minyak), *Dendrocalamus asper* (buluh betong), *Gigantochloa levis* (buluh beting) and *Gigantochloa scortechini* (buluh semantan) (Malaysian Timber Industry Board, 2019).

After seeing the success of rubberwood, researchers are turning to study the most important crops species which is the oil palm tree. If it was also developed as a raw material for wood-based industry, no doubt Malaysia would be able to offer a complete source of raw materials from timber and non-timber sources. This study corresponded to Laurila (1995) and Moya and Muñoz (2010), who conducted studies to compare different wood properties of eight species under fast-growth conditions in Costa Rica due to the increasing demand for new species from fast-growth plantations as alternative timbers for tropical wood. Relatively fast-growing species had rotation periods of less than 30 years (Moya & Muñoz, 2010). The plantation species such as *A. mangium*, *Gmelina arborea*, *P. falcataria* and *Eucalyptus camaldulensis* were programmed to yield universal service timber of small saw log sizes for local retail in 15-year cycles (Mohd Hamami et al., 2008). Thus, it necessary to first identify the main characteristics that determine the quality of the wood products.

2.2 Kelempayan (*Neolamarckia cadamba*)

Kelempayan or *Neolamarckia cadamba* is a non-commercial light hardwood, and it has been studied as a potential alternative source for wood composite materials (Noor Azrieda et al., 2012). No studies has revealed that this substance has been studied as sawn timber for furniture components and interior products. This wood has the potential to be an alternative source because they are easily found in secondary forest, they can be planted in field crops and have a fast growth hectare (Krisnapillay & Ong, 2003).

Generally, kelempayan wood possesses physical and mechanical properties that are almost identical to alternative light hardwoods, including its suitable use as a general utility timber (Ismail, 1993). The usages are appropriate for veneering, chipboard, cement-bonded panel, hardboard, packing boxes, wooden sandals, throwaway chopsticks, basis of brief fiber pulp, and also appropriate for canoes and less luxurious furniture if correctly dried (Lim & Chu, 2002). These features offer a promising continued and sustainable source of raw materials in the future as compared to the commercial tropical timber species (Nordahlia et al., 2014).

Other common properties related to kelempayan such as wood working, drying, durability and treatability have been studied by Nordahlia et al., (2014). Kelempayan wood is easy to work on either using hand tools or machines such as ripping, cross-cut, and planing where the surface finish is smooth (Choo et al., 1999; Lim & Chu, 2002). The drying properties of the kelempayan wood show a rapid drying rate which its category as non-durable wood however it accessible to preserve with chemicals (Lim & Chu, 2002).

2.2.1 Availability and distribution

The availability and distribution of kelempayan as a raw material can be identified through its botanical and growing features. The botanical name for kelempayan is *Neolamarckia cadamba* (Roxb.) Bosser, syn. *Anthocephalus chinensis* (Lamk.) A. Rich. ex Walp., Rubiaceae. The features of the tree include having a broad crown and a straight cylindrical bole (Ismail et al., 1995 & Lim et al., 2005). It is a rapid growing species and it is very popular as plantation either in native or exotic countries. In Sumatra, this species has been successfully cultivated in plantations with crop rotation of four years (Agroforestree Database, 2013). The vernacular names of this tree in Malaysia varies, such as in Peninsular it is known as kelempayan, in Sabah as laran and in Sarawak as selimpoh/kalampayan. Meanwhile, in English, French and India the tree is called kadam or cadamba whereas in Thailand it is krathum and Indonesia recognizes it as jabon (Globinmed, 2011). This tree usually grows in moist areas and near water sources. Choo et al. (1999) and Lim et al. (2005) specified that it can be found in valleys to mountain forest at around 1000 m altitude, by the streams and in exposed places on broad humid sedimentary soil. It is also a dominating tropical secondary forest after logging activities.

2.2.2 Chemical properties

The chemical constituent of wood differs from species to species, it is approximately 50% carbon, 42% oxygen, 6% hydrogen, 1% nitrogen, and 1% other elements via mass. The principal essentials of wood are cellulose, hemicellulose, lignin and minor substances called extractives (Panshin & de Zeeuw, 1980). The major chemical component (contributing 40-50% of dry weight) of woody cell wall is cellulose, which is a crystalline polymer derived from glucose. Subsequent in plenty is hemicellulose, which is about 20% in deciduous trees but nearby 30% in conifers. It is largely five-carbon sugars that are related in an uneven way, in dissimilarity to the cellulose. Lignin confers the hydrophobic goods following the element that it is founded on aromatic rings. Lignin comprises 15% to 35% of polymeric substances that are interwoven, and through covalent connections happen among the lignin and the hemicellulose. Hardwood lignin is primarily consequent from sinapyl alcohol and coniferyl alcohol (see Figure 2.1). Softwood lignin is primarily a derivative from coniferyl alcohol **(**Boerjan et al., 2003). Apart from the lignocellulose, the wood contains a variation of low molecular weight organic compounds, named extractives.

The wood extractives are fatty acids, resin acids, waxes, terpenes and essential oils (Mimms et al., 1993). The composition of extractives in wood contrasts from fewer than 3 to over 30 percent of the wood oven dry weight (Shmulsky & Jones, 2011). The extractives of wood donate to the wood properties such as color, odor and decay resistance.

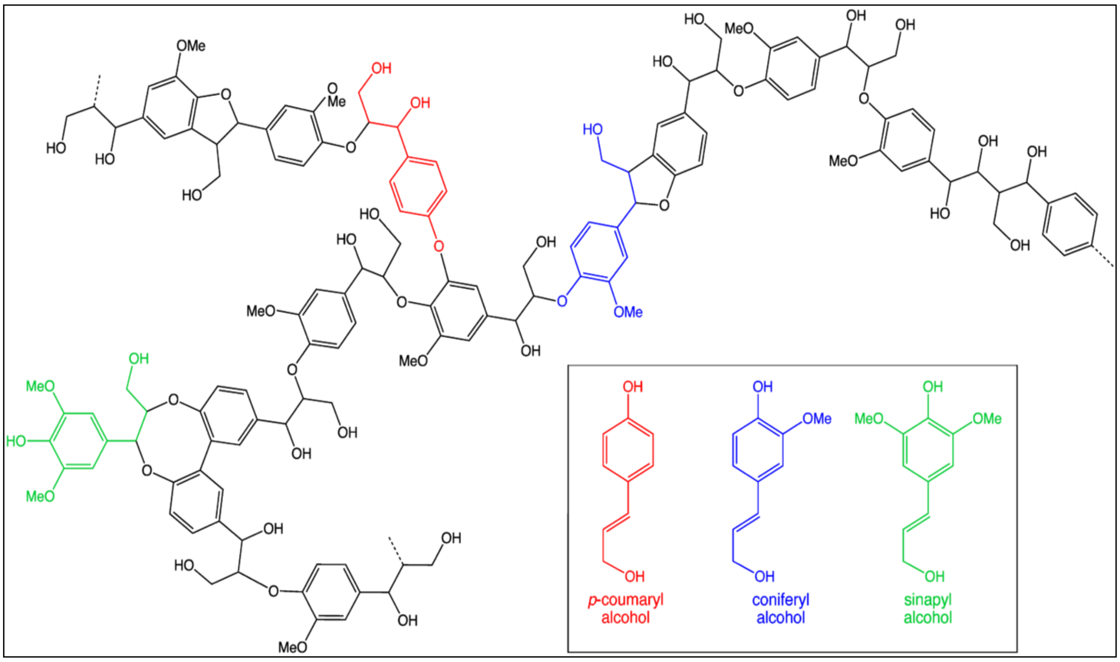

Figure 2.1 Chemical structure of lignin
Source: Smokefoot (2011)

The information on chemical compositions of kelempayan have been reported by Abd Latib et al. (2014) in order to use kelempayan effectively as a raw material especially in wood composite. Table 2.1 shows the chemical composition of kelempayan trees with diameters at breast height extending between 35 to 41 cm were collected from natural growth of the UiTM Pahang Forest Reserve. The results of holocellulose soluble represents the cellulose and hemicellulose contents were 83.87%, lignin content was 28.57%, extractive content was 4.28% and ash content was 0.62%. Chemical composition based on different portions indicate the inconsistency trend however it can be deduced that the middle portion almost possesses lower chemical contents as compared to the bottom and top portions. Both the bottom and top portions usually give an almost comparable value. Despite the hollocellulose content in the middle portion has significant difference with the bottom and top portions but the ash content at different portions has not significance. It can be proposed that the hollocellose content according to tree height was similar based on the insignificant value of the ash content obtained. In general, the wood when burned will produce ash; therefore the original wood particle weight will certainly affect the final weight with resulting ash.

Table 2.1 Chemical properties of kelempayan at different portions
Sources: Abd Latib et al. (2014)

Portion (%)	Cold Water Soluble	Hot Water Soluble	Alkali Soluble	Alcohol-Toluene Soluble	Ash	Lignin	Holocellu-lose Soluble
Top	5.54a	6.94a	18.33b	2.58a	0.55a	30.92a	84.84a
Middle	5.75a	6.03b	17.50c	2.24b	0.57a	24.58b	82.11b
Bottom	5.65a	6.70ab	18.83a	2.54a	0.74a	30.20a	84.65a
Average	**5.65**	**6.56**	**2.45**	**2.45**	**0.62**	**28.57**	**83.87**

Note: Mean with different letters indicate significant at $p<0.05$

2.2.3 Physical properties

The physical properties of wood consist of the appearance of wood, moisture and properties associated with its change, thermal properties, electrical properties, sound properties and electromagnetic radiation properties. The major physical properties of wood that are normally evaluated are the moisture content, density, specific gravity, shrinkage and swelling (Shmulsky & Jones, 2011).

Determination of the moisture content becomes very important before a study is conducted because the water content influences the properties of the wood where it could ultimately affect its mechanical, shrinkage, density and the aptitude to attack molds and pests. The average green moisture content of kelempayan was 175% while the dried moisture content ranges from 17% to 12% (Mohd Hamami & Ismail, 1992). The effect of moisture content towards the trunk diameter and trunk height showed a reverse trend where the moisture content decreased from the pith outwards near the bark and from the lower to the upper part of the stem, respectively **(**Mohd Hamami & Ismail, 1992). As is known, in the diameter of a tree there are two important parts known as the heartwood and the sapwood. The heartwood is close to the pith while the sapwood is close to the bark. The physical properties of the heartwood and the sapwood are different where the heartwood has inactive cells causing less water content but high content of extractive. The sapwood, instead, contains highly active wood cells for plant growth with water and less extractive. Similarly, the water content at the bottom of the tree is greater because of the volume of the wood fibers at the bottom portion is larger than at the top portion. In another study, the average initial moisture content of kelempayan was 100.05%. However, it was observed not to have significantly affect the tree portions (Abd Latib et al., 2014).

Wood basic density and specific gravity are very significant in defining the mechanical properties of wood, if a substrate is low density or specific gravity it is also low, and vice versa. Kelempayan wood is soft and a light hardwood (Nordahlia et al., 2014), and has uniform colour between the sapwood and the heartwood. The overall average specific gravity of kelempayan was 0.36 **(**Mohd Hamami & Ismail 1992; Ismail 1993). There were significant differences between the specific gravities of the three radial positions and height levels where specific gravities tend to increase from the pith outwards and with height. This is because the construction of the heartwood which is usually fairly weightier than the sapwood due to the accretion of air in the locked cell organization, thus leading to the formation of extraneous substances and causing the death of the parenchyma cells which are denser than the life cells (Panshin & de Zeeuw, 1980). In another study, the mean specific gravity of kelempayan was 0.37. However, it was not significantly influenced by the tree portions (Abd Latib et al. 2014). On average, the density of kelempayan ranges from 370 to 465 kg/m^3 (Nordahlia et al., 2014).

The timber will shrink when moisture is lost under fiber saturation points (FSP) which is known as the loss of bound water. On the contrary, when water enters the structure of the cell fence, the wood will swell. Shrinking and swelling is a reversal development on stress-free small parts of wood (Shmulsky & Jones, 2011). Shrinkage and swelling properties have been reported by Mohd Hamami and Ismail (1992) and Ismail (1993). The average means of shrinkage of a 20-year-old kelempayan at tangential, radial, longitudinal and volumetric were 6.46%, 3.28%, 0.47% and 9.90% respectively. Generally, wood near the pith has a higher volumetric shrinkage whilst wood near the bark has the least volumetric shrinkage. No general vertical pattern was observed for all types of shrinkages, although tangential shrinkage appears to decline with height. Tangential movement was found to be about twice of that of the radial movement, i.e. 1.7 and 0.9, respectively, and showed no significant difference within and between trees. Another study reported that the shrinkage from green to air dry at tangential direction was 2.1% and at radial direction was 0.8% (Nordahlia et al., 2014). The drying properties of the kelempayan wood of 13 mm panels take about 2.5 months to air dry, while the 38 mm panels take 3.5 months with slight end checks and splitting (Choo et al., 1999; Lim & Chu, 2002). Meanwhile, Mohd Hamami and Ismail (1992) earned a faster drying rate (in the forced-air dryer) of 25 days for the 25 mm thick boards with minimal traces of drying defects such as surface cheeks, bow, spring and twist.

2.2.4 Mechanical properties

The strength and resistance to shape change are known as the mechanical properties. The phrase strength is frequently used universally for all mechanical properties. Mechanical properties are regularly the most vital features of wood products to be utilized as architectural building materials. Some of the basic strengths that need to be known of a wood product include flexural, compression and shear. To appreciate the meaning of the various types of wood strength, the basic purpose of engineering mechanics should be understood first. The flexural strength (modulus of rupture) is aimed at determining the load to be carried by a beam. The flexural strength (modulus of elasticity) is to analyze the endurance of the bending straight associated to the strength of a beam which is also an aspect in the strength of a long pole (Shmulsky & Jones, 2011). Compression parallel to wood grain is important in determining the load to be carried by a short pole. Whereas the compression perpendicular to wood grain is important in the design of the connection between the interior part of the building and the support of a beam (Shmulsky & Jones, 2011). Finally, the shear parallel to wood grain is often used to determine the ability of the load beam to carry the load (Shmulsky & Jones, 2011). General mechanical properties of kelempayan wood for modulus of rupture (MOR) was 50 N/mm^2, modulus of elasticity (MOE) was 7700 N/mm^2 (Trairat & Nikhom, 2010; Nordahlia et al., 2014), compression was 37 N/mm^2 and shear was 15 N/mm^2 (Soerianegara & Lemmens, 1994; Nordahlia et al., 2014). Meanwhile, Ismail (1993) has reported that the overall means of a 20-year-old kelempayan for MOE and MOR were 7667 and 71 N/mm^2.

2.2.5 Wood structure characteristics

Wood structure is the architectural organization of wood of the nature and arrangement of its physical and chemical building components (Tsoumis, 1991). The general characteristics of kelempayan have been reported by Nordahlia et al. (2014) for sapwood color was not definitely from the heartwood, from white revolving to yellow on revelation. It had diffuse-porosity, the growth rings were absent, the texture was an evenly fine and medium, the grain was generally straight, and the vessels lines were present on cross section surface (Nordahlia et al., 2014; Agroforestree Database, 2013). Meanwhile, Choo et al., (1999) and Lim et al. (2005) described the sapwood color as white with a bright-yellow tone which develop into soft yellow while the heartwood was darken to creamy yellow (Choo et al., 1999; Lim et al., 2005).

The anatomical properties indicated the macrostructure characteristics that were observable with the naked eye, or with hand lens proficient of magnifying 2-3 times while the microstructure characteristics were those that were observable using electronic light microscope or Scanning Electron Microscopy (SEM) to provide high resolution, high magnification images, allowing for the imaging of features on the sub-micron scale. Figure 2.2 shows the macroscopic of kelempayan wood with the vessel grouping mainly solitary or in radial multiples of 2 to 6, the vessel arrangement in radial series, the vessel shape in round to oval shaped, the vessel contents had no deposit and tyloses, the wood parenchyma was axial parenchyma diffuse to diffuse in aggregates and the rays were heterocellular of multiseriate with 2 to 4 cells. Ismail (1993) stated that the microstructure components of kelempayan wood for vessel comprised 16.69%, ray with 11.96% and fiber with 71.41%. The measurements of fiber length averaged at 1.38 mm, fiber diameter was 35.01 microns, fiber lumen diameter was 24.82 microns and fiber wall depth about 5.11 microns.

Neolamarckia cadamba (kelempayan/laran) (10 ×)

Figure 2.2 Macrostructure of kelempayan wood
Source: Nordahlia et al. (2014)

2.3 Wood densification and its history

The modification of wood via densification can be introduced to improve the ability of light hardwood to have density and strength equivalent to the medium hardwood in order to be suitable material for furniture components and interior products. Some of the methods of timber densification have been carried out such as the pressing method, chemical modification and polymer resin infusion. Indeed, the study on resin impregnation of 7-year-old kelempayan wood can be an alternative raw material to produce furniture components and interior products. In addition, the diversity of its unique and attractive design will be realized with the production of lightweight compressed hardwood components infused low molecular weight resins.

The history of timber densification has started since 1930 in Germany to introduce the compressed wood products named Lignostone (Sulaiman et al., 2012). In the United States, Stamm and Seborg have introduced a product called Compreg in 1941 meanwhile Seborg and his partners have introduced a product called Staypack in 1962 with the specific gravity both was 1.3 to 1.4 (Kultikova, 1999; Furuno et al., 2004). Compreg is resin-treated compressed wood by impregnating its void volume with resins, dried and then compressed under temperatures. Meanwhile Staypak is not impregnated with resin but it is pressed under hot temperatures that cause adequate flow of the lignin which played as natural binder in the wood cells (Kultikova, 1999). The mechanical features of Staypak were commonly similar with those of Compreg, excluding the impact strength that was much advanced. Staypak was less dimensionally constant than Compreg (Kultikova, 1999).

2.3.1 The process of wood densification

Wood is the eventual renewable substance. It owns potentials that have made it a substantial of choice for periods. This ordinary material might necessitate changes to be made in order to obtain the wanted functionality. By using somewhat high-tech expansion regarding wood, it would be better to regulate, to homogenize, to decline anisotropy, to solve the problems of dimensional unsteadiness and to recover its toughness and resistance to micro-organism and fire (Sandberg & Navi, 2007). Densification is the process where the wood compactness is improved by dropping the void size of the cavities in the wood material. This is normally attained by pressing the wood in the cross-section order. The primary purpose of the densification is to expand the mechanical and moisture sorption performance of the wood (Sandberg & Navi, 2007). Compressing is a well-studied method of wood densification. This approach concerns surface densification and bulk densification. The greatest difference between surface densification and bulk densification is that in the bulk densification process, the wood material is usually water saturated, and, therefore, the process time is quite long. The surface densification process starts with relatively dry wood; in most of the studies the moisture content of the wood has been approximately 12%. Therefore, the densification process is comparatively quick; only some minutes or even seconds (Rautkari et al. 2010). The results of the study showed that a product's mechanical properties were correlated with the degree of compression. Meanwhile, Sims et al. (1988) discovered different process where wood densification was the process of pleasing wood by-products (industrial remains) such as slabs, chips, or sawdust and altering them into even sized particles so they can be crushed into a firewood product namely logs (long cylindrical shape), pallets (short cylindrical shape) and briquettes (disc shape).

Wood densification refers to the modification of wood through chemical and thermo-mechanical treatments. Figure 2.3 shows a basic synoptic illustration of chemical and thermo-mechanical treatments, which are applied at the current time. Chemical alteration of wood is defined as somewhat chemical response among approximately responsive portion of a wood cell constituent and a chemical mixture, with or without catalyst that arrangements a covalent bond between the two components (Hon & Shirashi, 1991; Hill, 2006). Two groups of chemical treatments can be eminent: subversive and soft (Hill, 2006). The subversive treatments were able to arrive at the central of the cellulose fibrils. They were able to collapse the crystalline construction of cellulose and remove the multilevel and hierarchical building of wood. These treatments drastically adjust the chemical mechanisms of wood. Therefore, the material formed misses virtually all the inherent features of untreated normal wood. Otherwise, the soft chemical treatments permissions the crystalline construction of wood completely and trace only the amorphous fragment and the side groups (purposeful groups) of the wood components at the molecular proportion (Hill, 2006). These treatments leave the microstructure of altered wood unaffected. In this type, several distinctive treatments are formaldehydation, acetylation, etherification, liquid impregnation by carbinol/ maleic acid/resins, filling by metal alloys at short melting point, etc (Sandberg & Navi, 2007). These treatments principal to upgrade in certain physical and mechanical properties of wood like hygroscopicity, resistance to microorganisms, fire resistance and its mechanical behavior with esteem to the moisture differences (Sandberg & Navi, 2007). Thermo-mechanical processing can advance the essential properties of wood, to yield novel resources and to obtain a form and functionality wanted by engineers without varying its eco-friendly features. Thermo-mechanical processing can be divided into two major categories; Thermo-Hydral (TH) and Thermo-Hydro-Mechanical (THM) treatments (Sandberg & Navi, 2007). TH is typically utilised to improve wood characteristics and is of significance in growing stress relaxation during seasoning below high temperature, in the creation of wood-based compounds or veneer goods and in the synthetic ageing of wood. Otherwise, THM is working in the manufacturing of novel materials by densification, shaping by molding, fusing of wood by friction, embossment, bending of wood, wood fusion, and chip-less production.

Therefore, low density wood can be value-added to increase the dimension stability and to reduce the hygroscopicity by means of resin infusion (soft chemical modification) via vacuum pressure. By this method, the resin-impregnated sawn timber will increase the density and the strength properties. The application of low molecular weight resins as the medium of liquid infusion into the wood cell cavities is the latest method to get results more effective penetration.

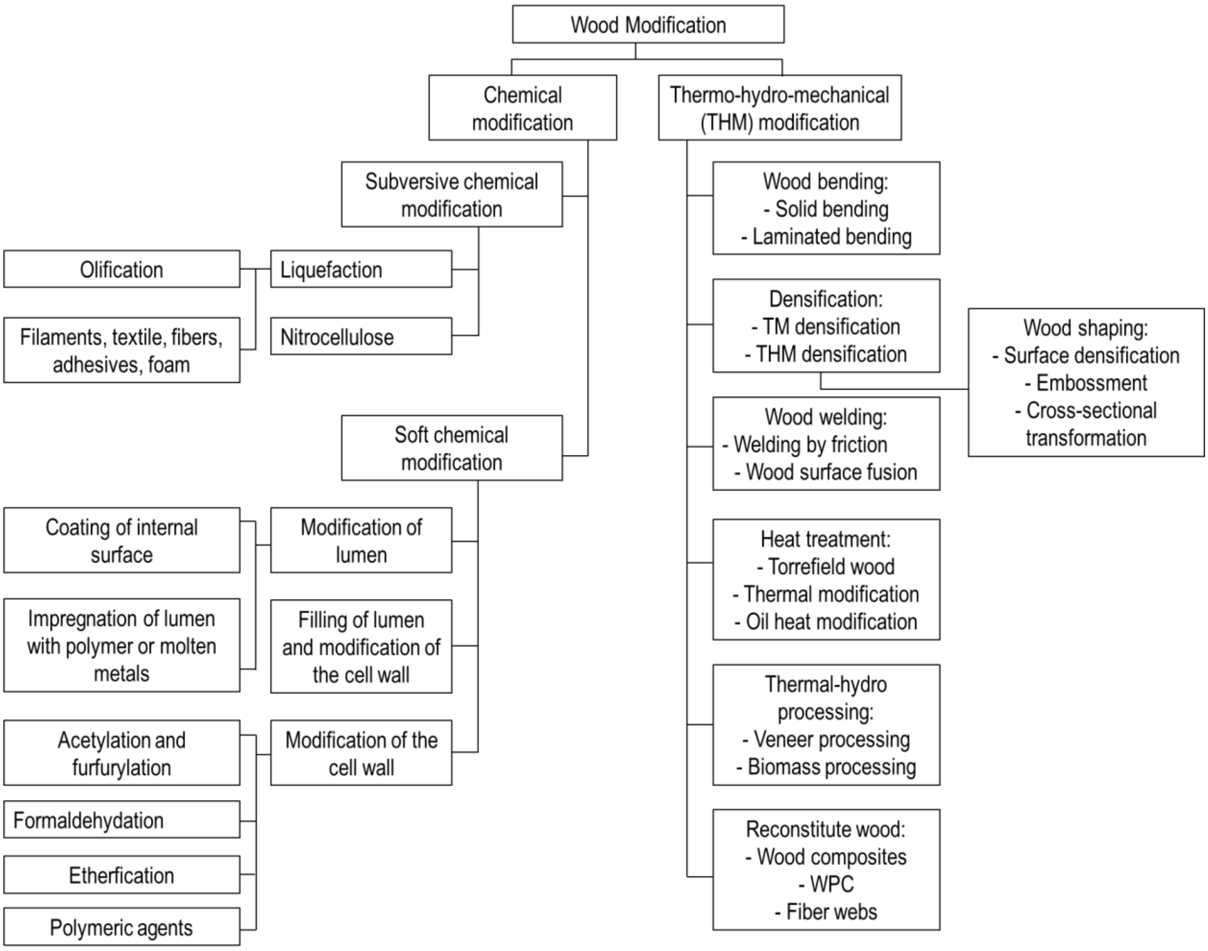

Figure 2.3 The various processes for the modification of wood
Source: Sandberg and Navi (2007)

2.3.2 The properties of wood densification

Light density wood and juvenile wood can be applied in new high-performance wood-based compound materials instead of the mature-growth timber. Previous studies on the densification properties of wood have been revealed by the researchers using various techniques of densification toward timber and non-timber materials. Compreg was adapted by impregnating 30% resin loading of low molecular weight phenolic resins into Japanese cedar wood (*Cryptomeria japonica D. Don*) and achieved a great dimensional steadiness of 60% anti-swelling effectiveness (Furuno et al., 2004). On the other hand, without impregnating resin into the correspondingly mature and juvenile southern pine *(Pinus taeda)* and yellow poplar *(Liriodendron tulipifera)* that were flattened radially at three dissimilar temperatures and moisture content settings pertinent to the glass evolution of wood, have resulted in an increase in the ultimate ductile stress and modulus of elasticity subsequently entirely densification treatments during the tensile tests (Kultikova, 1999). A local plantation species that has been densified by both methods was oil palm trunk where it improved the dimensional stability along with increases of density, mechanical characteristics and higher resistance against termites (Bhat et al., 2010; Abdullah et al., 2012; Sulaiman et al., 2012; Dungani et al., 2013). A local low-density tropical timber was mahang (*Macaranga* spp.) has been modified with methyl methacrylate (MMA) in a mixture with a crosslinker trimethylolpropane trimethacrylate (TMPTMA) and the density improved meaningfully by around 200% from 288 kg/m³ (untreated) to around 829–910 kg/m³ (Ang et al., 2009). Other low-density hardwoods were jelutong (*Dyera costulata*) and sesenduk (*E. diadenum*) were infused with low molecular weight phenol formaldehyde (lmwPF) by introducing 30% urea in the treating solution in order to decrease formaldehyde release. (Nur Izreen et al., 2011; Rabi'atol Adawiah et al.,