



**CHARACTERISTICS OF LAMINATED *COMPREG* HYBRID FROM OIL
PALM TRUNK INNER WITH SESENDUK WOOD**

By

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**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
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SPECIAL DEDICATED TO:

MY BELOVED PARENTS

Hj. Ahamad bin Hj. Wan Ismail
Hjh. Rokiah binti Hj. Mamat

MY LOVELY SIBLINGS

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Their love, prayers, concerns, and strength
have motivated me to complete my journey.

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

CHARACTERISTICS OF LAMINATED *COMPREG* HYBRID FROM OIL PALM TRUNK INNER WITH SESENDUK WOOD

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July 2022

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Faculty : Forestry and Environment

The oil palm inner wood is dimensionally unstable, has poor machining characteristics, as well as low in strength and durability. The compression method is one of the potential methods for improving the physical and strength properties of wood. The study was conducted to determine effect of compression ratio (CR) and resin concentration (RC) on polymer loading. The primary study was to optimise the treatment variables for *compregnation* of oil palm inner wood based on its treatability and dimensional stability. The samples with nominal dimension of 200mm x 100mm x 20mm with 50-60% MC placed in impregnation apparatus were the initial vacuum was applied for 15 minutes, then filled with the LMW-PF solution and soaked under pressure of 689 kPa for 30 minutes followed by pre-curing in an oven at 70°C for 7 hours. The pre-cure samples being pressed at 150 °C for 45 minutes with 70%, 80% and 90% CR. The polymer loading and dimensional stability of the *compreg* oil palm inner wood for each treatment were determined. The effectiveness of the treatment was indicated by PR, WPG, and density. The samples treated with 20% RC and 70% CR had the highest PR, which was reported at 92.12%. 80% and 90% CR samples treated with 15% RC had 64.56 and 61.56% PR, respectively. For the first phase, the most optimum *compregnation* treatment variables was determined based on the performance of laminated *compreg* hybrid products. The oil palm inner wood (pre-cure) was laminated parallel with untreated or treated wood with the dimension of 200mm x 100mm x 5mm (sesenduk) to form three layer laminae. They were then hot pressed at 150°C for 60 minutes with 80% and 90% CR, and then conditioned at 25±2°C temperature and 65%±2 relative humidity until constant weight prior to determination of physical and mechanical properties. The deposition of resin polymer in *compreg* oil palm inner wood reduces the ability of the wood to absorb water because the cross-linking of PF polymers can prevent water molecules from penetrating the cell walls. As a results, laminated *compreg* hybrid products treated with 80% CR had WPG value of 63.21 to 99.53% (P1 and P2) and 63.09 to 105.52% (P3 and P4). Meanwhile, the highest MOR value of 40.67 N/mm² is recorded in laminated *compreg* hybrid products treated with 80% CR and 20% RC, while the lowest MOR value is found in products made with 90% CR with 15% RC.

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

**CIRI-CIRI PRODUK LAMINASI KAYU SAWIT TERAWAT (*COMPREG*) HIBRID
DIPERBUAT DARIPADA LAPISAN DALAM, BATANG KELAPA SAWIT DAN
KAYU SESENDUK**

Oleh

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Kayu dalaman kelapa sawit mempunyai dimensi yang tidak stabil, ciri pemesanan lemah, daya kekuatan dan ketahanan yang rendah. Kaedah mampatan merupakan satu potensi baru untuk meningkatkan sifat fizikal dan kekuatan kayu tersebut. Kajian ini dijalankan untuk melihat nisbah mampatan (CR) dan kadar kepekatan damar dalam penembusan polimer. Kajian utama adalah untuk mengoptimumkan rawatan kayu *compreg* berdasarkan kestabilan dimensi. Sampel dengan ukuran 200mm x 100mm x 20mm dengan 50 – 60% MC dimasukkan ke dalam kebuk impregnasi dan dikenakan vakum selama 15 minit, kemudian larutan LMW-PF dimasukkan dan diredam dengan tekanan 689 kPa selama 30 minit. Diikuti pra-pematangan dalam ketuhar selama 7 jam pada suhu 70°C. Sampel yg telah siap pra-pematangan akan ditekan dengan tekanan berbeza iaitu 70, 80 dan 90% dengan tekanan panas pada suhu 150°C selama 45 minit. Setiap data muatan polimer dan kestabilan dimensi akan diambil dan dikira. Untuk fasa pertama kajian ini, produk laminasi kayu sawit terawat (*compreg*) hibrid dihasilkan bertujuan untuk menentukan pemboleh ubah rawatan paling optimum. Sampel pre-pematangan dilapiskan selari dengan kayu yang dirawat dan tidak dirawat dengan ukuran 200mm x 100mm x 5mm (sesenduk) untuk membentuk tiga lapisan lamina kayu. Tekanan panas pada tahap 80% hingga 90% nisbah mampatan, bersamaan suhu 150°C selama 60 minit digunakan. Sampel kemudiannya dimasukkan ke dalam bilik sejuk dengan suhu 25±2°C dengan kelembapan 60%±2 sehingga mencapai berat tetap dan tidak berubah. Sifat fizikal dan mekanikal akan dinilai. Muatan polimer dalam kayu kelapa sawit dipengaruhi oleh mampatan fiber dan kepekatan damar. Produk laminasi kayu sawit terawat (*compreg*) hibrid menunjukkan hasil prestasi yang lebih baik di mana produk yang dirawat dengan 80% nisbah tekanan mempunyai nilai WPG 63.21 – 99.53% (P1 dan P2) dan 63 – 105.52% (P3 dan P4). Sementara itu, hasil kajian bagi MOR, peratusan tertinggi yang diperolehi adalah 40.6 N/mm² bagi produk laminasi kayu sawit terawat (*compreg*) hibrid yang diperbuat daripada hasil rawatan 80% nisbah tekanan bersamaan 20% kepekatan damar. Manakala, nilai terendah diperolehi daripada produk yang dirawat dengan 90% nisbah tekanan bersamaan 15% kepekatan damar.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASE	Anti-swelling Efficiency
BS	British Standard
CPO	Crude Palm Oil
CR	Compression Ratio
EFB	Empty Fruit Bunch
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
iOPW	inner Oil Palm Wood
LMW-PF	Low Molecular Weight Phenol Formaldehyde
MC	Moisture Content
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPOB	Malaysian Palm Oil Board
MSPO	Malaysian Sustainable Palm Oil
MTIB	Malaysian Timber Industry Board
OPF	Oil Palm Frond
OPT	Oil Palm Trunk
OPW	Oil Palm Wood
PF	Phenol Formaldehyde
PKS	Palm Kernel Shell
POME	Palm Oil Mill Effluents
RC	Resin Concentration
RSPO	Roundtable Sustainable Palm Oil

SALCRA	Sarawak Land Consolidation and Rehabilitation Authority
SLDB	Sabah Land Development Board
SPSS	Statistical Package for Social Science
TS	Thickness Swelling
UPM	Universiti Putra Malaysia
WA	Water Absorption
WPG	Weight Percent Gain



CHAPTER 1

INTRODUCTION

1.1 Background of Study

Agricultural waste has recently been considered as a potential alternative for wood composites. Today, oil palm is regarded as one of the most promising *lignocellulosic* non-wood raw materials for various kinds of wood-based panels. Numerous studies have shown that due to the higher moisture content of the oil palm trunk, it must be dried and treated properly before to use. The trunk, on the other hand, is often utilised as a raw material in the manufacture of composite materials like as plywood, flooring, and furniture (For and Smes, 2017).

In the wood-based industry, oil palm wood (OPW) from the trunk has a high raw material potential. Nonetheless, the oil palm trunk (OPT) is not widely used commercially due to its anatomical properties. Bakar and co-workers (2005), reported that OPW has four weaknesses, i.e., low strength, low dimensional stability, low durability, and poor machining characteristics. However, treating OPW with phenolic resin significantly improves OPW performance shortages (Loh *et al.*, 2011; Amarullah *et al.*, 2010 and Bakar *et al.*, 2007), makes them more usable and beneficial in curbing wood supply.

A recent study on wood modification discovered that chemical treatments can improve OPW from the outer and inner parts. Using bulking treatment, Hill (2006) found that low-density wood may be improved in terms of quality. A number of research studies have been completed to improve the properties of tropical hardwoods like sesenduk (*Endospermum diadenum*), jelutong (*Dyera costulata*), mahang (*Macaranga sp.*), Kedondong (*Spondias cytherea*), and OPW including the outer part of wood through bulking treatment with low molecular weight phenol formaldehyde (LMW-PF) resin (Rabi'atol *et al.*, 2012; Lee and Zaidon, 2015; Izreen *et al.*, 2011; Ang *et al.*, 2014; Boneka *et al.*, 2021 and Ghani *et al.*, 2017). According to Ashaari *et al.*, (1990a, 1990b), wood modifications have been discovered to improve low-quality wood either by bulking, internal coating, or crosslinking for possible applications from the early 1990s till now (Islam *et al.*, (2012); Boneka *et al.*, 2021).

Bulking materials like resin and wax are forced into wood cells via vacuum impregnation, *compregnation*, or a vacuum-pressure combination method. Vacuum and pressure are used in wood treatment to push chemicals into cell lumen, according to Zabel and Morrel (1992). Rowell (2005) found that compression following resin impregnation is a significant element in defining the treated material's characteristics for low-density wood.

It has been reported that impregnation of sesenduk and mahang with LMW-PF followed by compression under heat (*compreg*) enhanced the physical and mechanical properties

of these woods as well as their durability against fungal decay and termites (Izreen *et al.*, 2011 and Ang *et al.*, 2014). Researchers from Rabi'atol *et al.*, (2012) and Nabil *et al.*, (2016) conducted a similar research and found that impregnating wood with 30% concentration LMW-PF resin and then compressing it at high temperatures enhanced the dimensional stability and bending strength of the wood. Following the findings of Rabi'atol *et al.*, (2012), the laminated *compreg* oil palm wood (outer part) demonstrated significant improvements in terms of density, dimensional stability, strength, stiffness, and bonding quality when compared to that of the laminated untreated oil palm wood bonded with the same type of resin in a previous study conducted by Aizat *et al.* (2014).

In the production of wood composites, the material must be assembled with resin and then hot-pressed (*compregnated*) until the resin is partially cured. To develop *compregnation* products, thin pieces of wood are soaked in PF resin solution and compressed in a hot press to penetrate the PF resin deeply (Aizat *et al.*, 2014). Previous research by Lee and Zaidon (2015) identified that *compregnation* is an effective method for increasing the strength and dimensional stability of wood. The *compregnation* technique used in the production of laminated composites may improve some of the characteristics of low-quality raw materials.

The secondary forests' primary raw material, sesenduk (*Endospermum diadenum*), is capable of providing a new supply of resources for wood-based industries. Because of its poor properties, almost all Malaysian wood-based industries are unwilling to use it. However, the disadvantages of this wood, such as inherent properties, can be mitigated by wood treatment. The use formaldehyde-based resins, as a bulking agent in impregnation treatment, for instance PF, urea formaldehyde (UF) and melamine formaldehyde (MF) in manufacturing wood composites are vastly being studied (Ali *et al.*, 2020). Treatability, physical, mechanical strength, dimensional stability as well as durability of the tropical hardwoods due to treatment at different levels of viscosity and at different formulations were reported (Ashaari, 2018).

1.2 Problem Statement

As evidenced by recent trends in various industry sectors, oil palm trunk (OPT) wood is only used for renewable products when its outer part is strong enough to be used as lumber or timber. When the inner part of the wood is not strong enough to be used as lumber or timber, the wood is disposed. Moreover, due to the high quantities of sugar and starch found in the inner wood, it is very vulnerable to fungus and insect attack. Within the inner wood, parenchyma tissues dominate (70%), and these tissues have very low dimension stability, high shrinkage rates, poor strength and durability, and are subject to rapid decomposition (Bakar, 2008).

It is difficult to machine the inner wood of the oil palm trunk because of its low dimensional stability, strength, and durability (Nuryawan *et al.*, 2017). Using OPT inner wood as an example, Bakar *et al.*, (1998) found that the green moisture content (MC) of this wood may reach 575% due to the presence of abundant parenchyma tissue. Although OPT inner wood is slightly easier to cut than outer wood, processing it is a little more

complex because of the presence of silica in the cells. In addition, because of its high moisture content, it is very vulnerable to degradation agents (Rafidah, 2012). In accordance with Febrianto and Bakar (2004), the outer part of the OPT may produce high-quality sawntimber, while the inner part is a waste product.

However, OPT, whether outer or inner wood, has great potential when treated using suitable techniques so that it can be used efficiently and transformed into high-value products. Before OPW can be used to make high-value products, it must be properly treated. Bulking treatment and crosslinking are two of a few chemical modification techniques that have shown promising results in improving low-quality wood (Hill, 2006 and Ashaari *et al.*, 1990a). It was discovered that using a particular percent of molecular weight (MW) phenol formaldehyde (PF) resin during bulking treatment was one of the most efficient methods to enhance the dimensional stability, machining characteristics, strength properties, and decay resistance of OPT (Wahab *et al.*, 2012).

Bulking treatment of wood with PF resin followed by curing under heat pressure has been shown to significantly improve dimensional stability and mechanical strength. This technique is known as *compreg*. Several factors, such as compression ratio (CR), must be considered for an efficient bulking treatment (Zaidon *et al.*, 2014). When compression is applied to the samples in a hot press, the softening effect of the PF resin plasticizes the cell wall and the heat deforms the cell walls without rupturing the resin (Yano *et al.*, 1997). The complete penetration of resin into the inner wood is a key factor in the effective treatment.

Abdul Khalil *et al.*, (2011a) and Abdul Khalil *et al.*, (2011b) has found that OPT biomass and other agricultural waste can be used with proper treatment in the manufacture of value-added products, such as medium-density panels, chipboards, thermoset composite and thermoplastic composites, nano bio composites, pulp and paper. Particleboards, wood cement boards, medium density fibreboards (MDF), and laminated products are all examples of composite panel products made from OPW. According to Anis *et al.*, (2007), the outer and inner parts of OPT have potential uses in lumber, pulp and paper, reconstituted boards, bio-composite, animal feed, and fuel.

Laminated *compreg* hybrid products are made by assembling parallel pre-cured strips to form three-layer laminated *compreg* hybrid products, then compressing under a hot press with a different CR. Laminated *compreg* hybrid systems are ones in which the reinforcing material is integrated into a combination of various materials utilising a compression technique, resulting in a stronger composite system. It is the presence of two or more reinforcing and filling components in a single matrix, or the combination of both methods, that is referred to as "hybrid" (Karger-Kocsis, 2000 and Fu *et al.*, 2002). Bulking treatment of wood with phenol formaldehyde (PF) resin followed by hot pressing curing has been shown to improve dimensional stability, mechanical strength, and resistance to decay and termite attack.

Although the anatomy of OPW differs from that of wood, it may be suitable for use as compressed wood with some modifications, such as laminated *compreg* hybrid products with wood. The use of non-wood resources (oil palm inner wood) in conjunction with wood (sesenduk) may be able to overcome the problem of limited wood supply. Previous

study proved that impregnation of low-density wood such as sesenduk and jelutong wood resulted in stronger and more dimensionally stable product (Lee and Zaidon, 2015). Ashaari and co-workers (2015) later discovered that by producing laminated bamboo/wood hybrid with sesenduk as core layer could compensate the inferior properties of sesenduk, being softer and weaker than bamboo. Sesenduk, being softer and more compressible might result in better compression and consolidation.

1.3 Objectives

The purpose of this research is to examine the performance of laminated *compreg* hybrid products made from *compreg* oil palm inner and sesenduk wood. The following are the specific objectives:-

1. To optimise the treatment variables for *compregnation* of inner oil palm trunk i.e., concentration ratio of low molecular weight phenol formaldehyde (LMW-PF) resin and compression ratio based on its treatability (weight percent gain) and dimensional stability (WA, TS and ASE).
2. To determine the physico-mechanical properties of laminated *compreg* hybrid products that includes density, weight percent gain (WPG), dimensional stability, i.e., TS, WA, ASE and bending strength, i.e., MOR and MOE.
3. To determine the most optimum LMW-PF resin concentration and compression ratio for producing laminated *compreg* oil palm inner and sesenduk wood

1.4 Research Questions

1. Does the compression ratios (CR) and LMW-PF resin concentration ratios affected the enhancement of physical properties and dimensional stability of *compreg* oil palm inner wood?
2. What is the optimum compression ratio and the concentration of LMW-PF resin to produce laminated *compreg* hybrid oil palm inner wood with good mechanical properties and acceptable dimensional stability?

1.5 Significance of Study

This research is necessary to contribute to the nation's economy by converting biomass from oil palm plantations into value-added products. It is important in developing a novel treatment to improve the performance of laminated *compreg* hybrid products made from waste. Nonetheless, this will benefit users especially the wood industry, as well as community or individual. The use of OPT in laminated *compreg* hybrid products as an alternative source for future wood-based industries may help to alleviate the problem of solid wood scarcity. Furthermore, laminated *compreg* hybrid products may be regarded as the most viable alternative source for construction and building materials.



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