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Effect of Pressing Temperature and Time on the Physico-mechanical Properties of Citric Acid Bonded Buluh Minyak (*Bambusa vulgaris*) Particleboard

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DECLARATION

I declare that this thesis entitled "Effect of Pressing Temperature and Time on the Physico-mechanical Properties of Citric Acid Bonded Buluh Minyak (*Bambusa vulgaris*) Particleboard" is the results of my own research except the cited in the references.

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Effect of Pressing Temperature and Time on the Physico-mechanical Properties of Citric Acid Bonded Buluh Minyak (*Bambusa vulgaris*) Particleboard.

ABSTRACT

This study investigated the effect of pressing temperature and pressuring time on the physico-mechanical properties of citric acid bound buluh Minyak (*Bambusa vulgaris*). Particleboard was produced using a laboratory hot press machine with different pressing temperatures (170°C, 180°C, 190°C) and time (5, 10 minutes). The physical properties evaluated were thickness swelling (TS), as well as water absorption (WA), with constant density and moisture content (MC), while the mechanical properties tested are modulus of rupture (MOR), modulus of elasticity (MOE). The determination of physical and mechanical properties of the samples were conducted in accordance with JIS A 5908:2003 standard. The results showed that increasing the temperature and pressing time significantly increased the strength and reduced the swelling thickness and water absorption. The highest MOR value was achieved at the highest pressing temperature and highest pressing time which are 190°C and 10 minutes, respectively, while MOE value was achieved at the highest temperature (180°C) and short pressing time (5 minutes), which is related to the superior bond in the boards pressed under these conditions. Overall, the optimal parameter for the manufacturing of citric acid (CA) bonded bamboo particleboard with sufficient physico-mechanical properties was a pressure temperature of 180°C for 10 minutes. This study showed the potential of using a non-toxic citric acid adhesive to produce buluh Minyak particleboard for environmentally friendly structural applications.

Keywords: Buluh Minyak, Pressing temperature, Pressing time, Physical properties, Mechanical properties.

Kesan Suhu dan Masa Menekan ke atas Sifat Fiziko-mekanikal Papan Partikel Asid Sitrik Berikat Buluh Minyak (*Bambusa vulgaris*).

ABSTRAK

Kajian ini telah menyiasat kesan suhu tekanan dan masa tekanan ke atas sifat fiziko-mekanikal buluh Minyak terikat asid sitrik (*Bambusa vulgaris*). Papan partikel telah dihasilkan menggunakan mesin penekan panas makmal dengan suhu menekan yang berbeza (170°C, 180°C, 190°C) dan masa (5, 10 minit). Sifat fizikal yang telah dinilai ialah pembengkakan ketebalan (TS), serta penyerapan air (WA), dengan ketumpatan dan kandungan lembapan (MC) adalah malar manakala sifat mekanikal yang diuji ialah modulus pecah (MOR), modulus keanjalan (MOE). Penentuan sifat fizikal dan mekanikal sampel telah dijalankan mengikut piawaian JIS A 5908:2003. Keputusan menunjukkan bahawa peningkatan suhu dan masa menekan dengan ketara meningkatkan kekuatan dan mengurangkan ketebalan bengkak dan penyerapan air. Nilai MOR tertinggi telah dicapai pada suhu menekan tertinggi dan menekan masa tertinggi iaitu masing-masing 190°C dan 10 minit, manakala nilai MOE telah dicapai pada suhu tertinggi (180°C) dan masa menekan pendek (5 minit), yang berkaitan dengan ikatan unggul dalam papan yang ditekan di bawah keadaan ini. Secara keseluruhannya, parameter optimum untuk pembuatan papan partikel buluh terikat asid sitrik (CA) dengan sifat fiziko-mekanikal yang mencukupi ialah suhu tekanan 180°C selama 10 minit. Kajian ini telah menunjukkan potensi penggunaan pelekat asid sitrik bukan toksik untuk menghasilkan papan zarah buluh Minyak untuk aplikasi struktur mesra alam.

Kata kunci: Buluh Minyak, Suhu menekan, Masa menekan, Sifat fizikal, Sifat mekanikal.

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LIST OF ABBREVIATON

CA	Citric Acid
UF	Urea formaldehyde
PH	Phenol formaldehyde
MC	Moisture content
TS	Thickness swelling
WA	Water absorption
MOR	Modulus of rupture
MOE	Modulus of elasticity
JIS	Japanese Industrial Standard

LIST OF SYMBOLS

%	Percentage
°C	Degree Celsius
Wt%	Percentage by weight
±	Plus-minus
Δ	Change
mm	Milimetre
mm^3	Milimetre per cubic metre
g/cm^3	Gram per centimetre cubic
N/mm^3	Newton per cubic metre
Kgf/cm^{-2}	Kilogram-force per square centimetre

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Particleboard is a commonly used wood composite material for the manufacturing of furniture and cabinets in the interior of buildings. According to Zaia et al. (2015), the manufacturing of particleboard can be produced by the utilisation of industrial waste materials such as sawdust, peeling, and trimming, as well as non-wood lignocellulosic biomass materials like bamboo, kenaf, rice husk, and other similar resources. Due to its comparable mechanical properties to wood and its status as a sustainable and renewable resource, bamboo provides an attractive alternative material for the production of particleboard. Bamboo, which is part of the Poaceae family, is a rapidly growing plant that is common in developing nations (Sharma et al., 2015). According to Suwan et al. (2020), bamboo contains 73.83% cellulose, 12.49% hemicellulose, 10.15% lignin, 3.16% aqueous extract, and 0.37% pectin.

Gauss et al. (2019) report that the global bamboo industry is currently experiencing significant growth, resulting in the generation of waste during the production of bamboo products. The production of particleboard utilising bamboo and eco-friendly resin is undertaken to ensure sustainable management of waste generated from this sector. The cause of the occurrence is attributed to the production of laminated bamboo, which incurs a waste rate exceeding 30%. In accordance with the article, Vietnam, China, Costa Rica, and Malaysia have successfully introduced bamboo-based particleboard into the commercial market. Nevertheless, numerous nations continue to employ traditional synthetic resins, including formaldehyde, as binders for particleboards.

Formaldehyde is a conventional resin used as a binder in particleboard. As an adhesive, phenol formaldehyde (PF) resin is used to attach exterior quality plywood panels, particleboard, and even oriented strand board panels. This PF can increase mechanical and physical qualities like as strength and moisture resistance. Because of the flexible qualities of phenolic resin, this can give good temperature stability and avoid delamination. Furthermore, urea formaldehyde (UF) resin is commonly utilized as a particleboard adhesive. Because UF is less expensive than PF, it can be used in alternative to PF. Despite this, the use of UF as a binding agent is limited due to the high formaldehyde release and subsequent exploitation of the board until it creates significant swelling of the thickness to water (Pędzik et al., 2022).

In order to overcome environmental concerns, our civilization, according to Ando and Umemura (2020), has changed from fossil fuels to sustainable new energy. As a result, individuals began to turn their focus to bio-based wood adhesives to replace hazardous formaldehyde adhesives. Citric acid has recently been proposed as a green binding agent for lignocellulosic materials, with the objective of replacing current treatment procedures. Esterification between citric acid and other wood components is expected to occur during the citric acid-based wood treatment process, boosting particleboard's dimensional stability. According to Lee et al., (2020), 180°C is the optimum temperature for developing high bond strength in particleboard, and with the addition of 20% citric acid, wood waste and non-wood materials may generate highly effective particleboard.

1.2 Problem Statement

Renewable biomass, such as bamboo, has emerged as an attractive replacement for raw material for composite production. This is due to the growing demand for wood composites derived from waste wood, which has been contributing to a decline in forest wood resources. The utilisation of bamboo as a primary resource has the potential to provide environmental advantages. This is due to the fact that a significant portion of biomass waste is either left unattended, incinerated, or incorporated into the soil. The issue at hand is addressed through the utilisation of this biomass waste to produce particleboard.

The wood composite industry in most countries, including Malaysia, use urea formaldehyde (UF) resin as the primary particleboard binder. Because of its quick drying time period, chemical resistance, high bonding strength, and inexpensive cost, UF is widely utilized as a binding material. However, the binder has a flaw in that it releases formaldehyde. Long-term exposure to high-concentration UF resin can induce hand eczema and dermatitis due to the production of formaldehyde. Furthermore, it pollutes the environment regardless of the relative durability of chemical structures, which are difficult to remove even after chemical, hydrothermal, or mechanical treatment. When set down in soil, this UF resin is likewise difficult to biodegrade and takes a long time for it to decompose.

To fix the problem, UF is substituted by a non-formaldehyde based adhesive or a green binder such as citric acid. This binding agent has been utilized as the primary binding component in particleboard, fiber board, plywood, and veneer-based panels, many other applications. Citric acid is an ecologically friendly binding agent used as an adhesive for wood and wood composites that does not emit formaldehyde. This is because citric acid is a biodegradable organic acid. This substance decomposes fast into water and carbon dioxide. Moreover, the toxicity of citric acid is minimal, making it safe to use and not classified as a persistent organic pollution. Citric acid is also reported to act as an agent that may stabilize wood dimensions and provide biological resistance to wood composites, as well as protect wood composites against termites, insects, and other insects as well.

However, limited research exists regarding the impact of citric acid as a binder on the physico-mechanical properties of particleboard, specifically when using bamboo culm as the raw material. Therefore, this study aims to assess the physical and mechanical properties of citric acid-bonded particleboard, with a specific focus on the effects of different pressing temperatures and times. The selected bamboo species for this investigation is Buluh Minyak (*Bambusa vulgaris*).

1.3 Expected Outcome

The expected result that will be obtained in this study is an improvement in bamboo particleboard (*Bambusa vulgaris*) whose main binder is modified from formaldehyde-based resin to citric acid (CA). The implementation of this modification occurs because citric acid can increase the strength of particleboard's physical and mechanical properties by adding 20% citric acid and this CA can also be a good adhesive to particleboard.

Through this project, it is also hoped that the waste from the industry, especially from the bamboo industry, can be optimized because bamboo is a resource that can be renewed quickly, a good carbon absorber, has a low cost and so on.

1.4 Objectives

The objectives of this study are as following:

i) To investigate the effects of pressing temperature and time on the physical properties of citric acid bonded Buluh Minyak (*Bambusa vulgaris*) particleboard.

ii) To investigate the effects of pressing temperature and time on the mechanical properties of citric acid bonded Buluh Minyak (*Bambusa vulgaris*) particleboard.

iii) To determine the optimum pressing temperature and time for Buluh Minyak (*Bambusa vulgaris*) particleboard bonded with citric acid (CA).

1.5 Scope of Study

This research focuses on the effectiveness of using citric acid as a binder for *Bambusa vulgaris* particleboard. It includes tests on the physical and mechanical properties of *Bambusa vulgaris* at different temperatures (170°C, 180°C, and 190°C) and pressure times (5 minutes and 10 minutes) in order to explain the effect of the main application of citric acid against panels made from 100% bamboo. Citric acid, used as a resin material to bond buluh Minyak particles, is the environmentally friendly green binding agent that identifies this study. Samples of particleboard were evaluated using the Japanese Industrial Standard (JIS) method for density, moisture content (MC), modulus of elasticity (MOE), modulus of rupture (MOR) in dry bending, thickness swelling (TS), and water absorption (WA).\

The sample dimensions for this particleboard are 200mm x 200mm x 10mm, and according to the temperature and pressure conditions, as many as 6 particleboard samples will be prepared and this test will be done three replicates to ensure this test is successful.

Data from each level of pressure, temperature and time will be presented in tables and graphs for better understanding.

1.6 Significant of Study

The objective of this current study was to determine the optimal temperature and duration required for the bonding of buluh Minyak particleboard with citric acid. The findings of this research are expected to result in significant advances in the bamboo sector, which are currently constrained by concerns such as insufficient waste disposal options, as previously discussed. Furthermore, this research has the potential to yield advantages for the industry as it can facilitate the creation of bamboo-derived commodities for the production of furniture and the interior design of edifices. This is due to the fact that bamboo, being a readily available and cost-effective raw material, provides high efficiency during the processing stage.

The significance of the study involves the potential for enhancing the physical and mechanical characteristics of bamboo-based particleboard, which will allow researchers and manufacturers in the bamboo sector to improve the quality of their products.

CHAPTER 2

LITERATURE REVIEW

2.1 *Bambusa vulgaris* (Buluh Minyak) as a Raw Material

According to the National Parks Singapore website, *Bambusa vulgaris*, also known to as golden bamboo or common bamboo, is a member of the Poaceae family. The cultivation of this particular species is relatively quick, and it is commonly distributed throughout regions characterized by tropical and sub-tropical climates. According to Darwis and Iswanto (2018), this particular species has the ability for growth in watery environments and can reach maturity within a span of 2-3 months. The height of the bamboo culm can grow up to 20 meters, while its thickness and diameter are determined based on its intended purpose.

2.2 Characteristics of Buluh Minyak

According to Srichan and Raongjant (2020) research, buluh Minyak (*Bambusa vulgaris*) may be utilized as a raw material for particleboard according to its high cellulose, lignin, and fibre content. This bamboo has a cellulose content of 49.3%, a lignin content of 22.4%, an extractive content of 16.8%, and an ash content of 1.5%-3%. Because of its low mortality rate, buluh Minyak is a popular plant for cultivation. This bamboo has a strong stem wall with nodes and segments that are of the same size (Wahab et al., 2010). The general characteristics of bamboo culm are shown as in Figure 2.1.1.

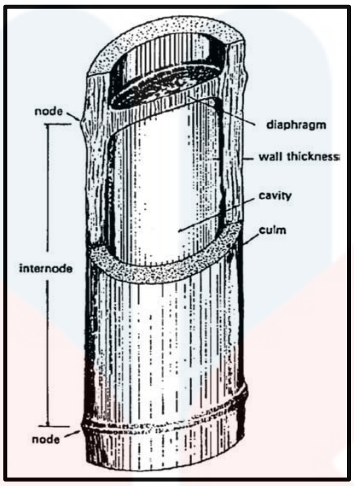


Figure 2.2: General Characteristics of a Bamboo Culm.

(Source: Bui et al., 2017)

2.3 The Benefits of Buluh Minyak

Bamboo plants have the ability to absorb a greater amount of carbon compared to other plants in a similar environment, even when grown on soils with different types of grading. This is due to their fast growth rate. Bamboo has the potential for multiple harvests within its quick growth cycle, allowing farmers to obtain their income at a faster rate, comparable to other crops. According to Binfield et al. (2022), bamboo cultivation is a viable method for minimising deforestation in regions with limited wood resources, as it does not harm other plants during the harvesting process.

Atanda (2015) proves that *Bambusa vulgaris* is a readily available and rapidly renewable resource due to its ability to be harvested within 3-5 years of planting, in compares to woody species which require a longer period of 10-20 years for harvesting.

Bamboo species possess a biomass ranging from 2% to 5%, rendering them significant in the construction and engineering sectors. They are utilized as fiberboard (medium density), chipboard, floor tiles, briquettes (fuel), and composite thermoplastic reinforcement (roof) and among other uses.

2.4 Particleboard

Ramah (2012) states that particleboard is a composite material that is produced by combining wood products such as wood chips, sawdust, or sawmill wood chippings with synthetic resin or appropriate binders. The density and consistency of this particleboard exceeds that of traditional wood, while also being more cost-effective. Particleboards exhibit varying grades based on their respective density.

According to a studies article titled "Wood as Bio-Based Building Material" (2017), the production of particleboard is designed to improve the utilisation of sawdust waste, recycled wood, and residual materials from manufacturing operations. In addition to timber resources, lignocellulosic materials, including but not limited to bagasse, rice husk, and residual by-products from the bamboo sector, have the potential to serve as viable alternatives. Particleboard is manufactured using a layered approach, in which the core section of the particleboard is composed of larger particles in contrast to the outer layer, which consists of finer particles. The purpose of this is to enhance surface cleanliness.

In the present day, bamboo-based particleboard serves as a viable substitute for particleboard derived from wood. Furthermore, it has the potential to enhance the utilisation of bamboo waste generated by the growing demand of the bamboo sector in the global marketplace. According to Gauss et al. (2019), the manufacturing process of bamboo particleboard is comparable to that of other particleboards derived from wood waste. Additionally, it has the potential to be utilised when mixed with eco-friendly resin.

2.4.1 The Uses of Particleboard

The application of renewable raw materials in the global economy has led to a demand in the acceptance of natural resources like wood and bamboo for construction purposes. Karlinasari et al. (2021) discovered that particleboard is utilised as an element of furniture, wall sections, and automotive components, serving the purpose of sound absorption. Regarding bamboo particleboard, it has a lowered density and the capacity to serve as an acoustic attenuator throughout a broad range of frequencies. Particleboard is a commonly utilised material in the production of furniture, flooring, wall panels, and other similar applications. According to the research, particleboard is commonly exposed to a coating process to enhance its visual appeal and needs treatment with preservative chemicals ("Wood as Bio-Based Building Material," 2017).

2.5 Citric Acid (CA) as a Bonding Agent

According to Widyorini et al. (2016), citric acid (CA) is a binding agent with green properties that contains three carboxyl groups linked to the ester, in addition to the hydroxyl group found in wood. This causes it an attractive option for use in composite product development. Lee et al. (2020) carried out a study which revealed that citric acid, with a chemical formula of $C6H8O7$, is classified as an organic acid that have a higher level of acidity compared to typical carboxylic acids. The stabilisation of intramolecular hydrogen bonds generated by the citric acid group can be supported by anions. CA is also known as 5-dioic acid, β-hydroxytricarbalic acid, 3-carboxy-3-hydroxypentane-1 acid, and many more. The molecular structure of CA is shown as in Figure 2.3.

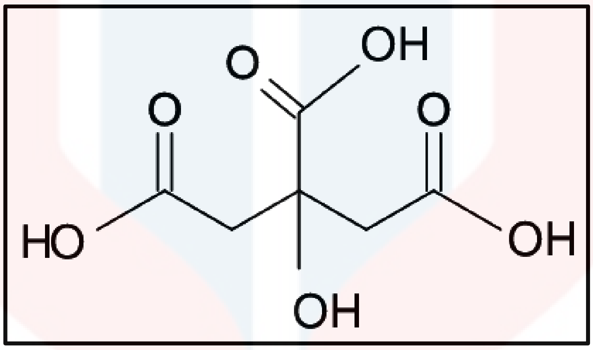


Figure 2.3: Molecular Structure of Citric Acid.

(Source: Olsson & Erik, 2013)

Zhou Huaxu et al. (2020) did a study on the physical and mechanical properties of particleboard bonded with CA in comparison to particleboard strained with UF. The results indicated that the former demonstrated lower physical and mechanical properties. However, the addition of citric acid content was found to improve these properties. Particleboard bonded with CA exhibits more effective resistance to termites and fungi in comparison to particleboard bonded with UF, because of to the acidic properties of CA.

2.5.1 Properties of Citric Acid

Citric acid, according to the World of Chemicals website, is a weak organic acid that is odourless and appears like a colourless crystalline white solid. It has a density that is denser than water, which is 1.665 g/cm^3, and it has a boiling temperature (175°C-310°C) and a melting point (153°C). It dissolves easily in water, acetone, alcohol, and ether. This solubility is useful for particle bonding since it may diffuse consistently throughout the surface of the substrate, making this CA an excellent binder because it is simple to combine with other components.

According to PubChem (2019), CA is a basic metabolite since it is a route for all aerobic organisms. CA also functions as an antibacterial agent and a food acidity regulator. CA is citrate anion and citrate conjugate acid (1-).

2.6 Physical Properties of the Particleboard

Water absorption in composites is classified into two types: bound water and free water. The free volume content of water molecules in the composite allows them to move freely through micro holes and gaps, which is referred to as free water. Bound water refers to water molecules that are connected to the polar groups of composites. Water may permeate straight into the cellulose fibre network and into the gap between the fibrils and places where the fibrils are less linked due to chemical bonding in the cellulose molecules. This softens the cellulose mass and allows the fibre diameters to be readily altered (Tay et al., 2014).

Halligan (1970) discovered that thickness swelling is an essential aspect to consider when analysing the effect of moisture on particleboard. Wood species, board density, particle shape, blending efficiency, pressure conditions, and resin levels are all factors that influence swelling thickness. Particleboard has quantifiable components such as sample swelling and the release of compressive force during the pressing process. When the moisture content is high and the section that cannot be recovered after the sample is dry, compressive stress is released. The term "springback" refers to the irreversible expanding of thickness.

2.7 Mechanical Properties of the Particleboard

The mechanical characteristics of particleboard can be used as measures of its quality and the suitability for employment in the industry of construction. The mechanical properties of particleboard are influenced by various factors including temperature, pressure, pressing duration, and the type of resin used. According to Tiryaki et al. (2017), an increase in pressing time can enhance the modulus of elasticity (MOE) and modulus of rupture (MOR) of particleboard.

Vladimir Mihailović et al. (2022) agree that the mechanical properties of particleboard need to be evaluated in accordance with its intended application, such as its use in the construction industry. The loading rate, as per the conventional destructive test method, has an impact on the mechanical characteristics of particleboard. Typically, high loading rates result in significant enhancements in both MOE and MOR.

Saad and Kamal (2013) did a study on MOR particleboard, which demonstrated that its high density and resin content enabled it to withstand transverse forces and resist perpendicular along its longitudinal axis. Additionally, the slope of the tangent line at the point of proportional limit was identified as MOE. An increase in the modulus of elasticity (MOE) will result in a corresponding increase in stiffness, as MOE is strongly correlated with the stiffness of particleboard.

2.8 Gap of Research

Previous research studied and proposed numerous studies on particleboard, but only a few tests have been conducted on bamboo particleboard bonded with citric acid. Christian Gauss, Victor De Araujo, Maristela Gava, Juliana Cortez-Barbosa, and Holmer Savastano

Junior did research in 2019 that explained the use of bamboo as a raw material in the production of particleboard. In addition, Lina Karlinasari, Ulfa Adzkia, Anugrah Sabdono Sudarsono, Pipiet Larasatie, Yusup Amin and Nareswaro Nugroho carried a study on the properties of bamboo particleboard coated with Polyurethane Varnish, while Ragil Widyorini, Pradana Nugraha, Muhammad Zakky, Arief Rahman and Tibertius Prayitno (2016) argued that citric acid (CA) is an environmentally friendly binder when compared to conventional resins. In this investigation, the Japanese Industrial Standard (JIS) A 5908:2003 will also be utilised. With this standard, the future testing and improvement of particleboard's moisture content, physical properties (thickness swelling (TS) and water absorption (WA)), and mechanical properties (MOE and MOR) will be achievable.

CHAPTER 3

MATERIALS AND METHODS

3.1 Raw Materials

3.1.1 Buluh Minyak (*Bambusa vulgaris*)

This research had focused on buluh Minyak (*Bambusa vulgaris*) as a raw material for particleboard. Buluh Minyak had been found at Agropark UMK in Jeli. Then, this bamboo was prepared for air-drying for about two weeks. The bamboo was then cut using table saw into smaller pieces about two meter long, and all parts of the bamboo were ground into chips using a grain machine. Figure 3.1.1 below displayed an image of buluh Minyak taken at UMK Jeli's Agropark.

Figure 3.1.1: Buluh Minyak Taken at UMK Jeli's Agropark.

3.1.2 Citric Acid

The citric acid (CA) particleboard binder used in this study was obtained from a supplier in Selangor and the purchase was made through the Shopee application. After that, the CA powder was dissolved in distilled water and 60wt% of the resulting solid content was used as a binding agent during the particleboard manufacturing process.

3.2 Methodology

3.2.1 Manufacturing of Particleboard

Particleboard production with one layer and dimensions of 260 x 260 x 10 mm^3 has been produced with a target density of 0.7 g/cm^3. In the production of particleboard, citric acid has been used as a binding agent, which consists 20% of the resin content and 60% of the solid content. The process of mixing particles and adhesives was achieved through the utilization of a rotary blender. Subsequently, the particles were put into the hot-pressing process, followed by the placement of the particleboard within a room characterised by a temperature range of 23±3°C and a humidity level of 65±5%. Table 3.2.1 shows the process involved in the manufacturing of particleboard.

Table 3.2.1: The Manufacturing of Particleboard.

Information	**Condition**
Size of sample	260 mm x 260 mm x 10 mm

Adhesive	Citric acid Resin content: 20% Solid content: 60%
Targeted density	0.7g/cm^3
Hot pressing	Temperature: 170°C, 180°C, 190°C Time: 5 minutes, 10 minutes Pressure: 2.44N/mm^3

3.2.1.1 Blending Process

The Buluh Minyak Particles were oven dried at 80°C to achieve a moisture content (MC) of 12%. Buluh Minyak particles and citric acid (CA) were weighed using an automatic weighing balance according to particleboard production calculations. The particles were then placed in a grinder, and the adhesive mixture was sprayed into the grinder using an air pressure spray gun. After spraying the adhesive mixture, the particles were mixed in a blender for 5 minutes to ensure that the mixture was homogeneous and uniform.

3.2.1.2 Mat Forming

After 5 minutes, the resinated particles were taken from the grinder and weighed using an electronic scale. The bamboo particles were then placed uniformly on a 260 x 260 mm wooden mould using a sealant plate as a base to make a loose mat. The mat was pressed to unify the thickness. Mat formation was considered a significant process because mechanical parameters such as modulus of elasticity (MOE), modulus of rupture (MOR) were closely related to the uniformity of particle distribution.

3.2.1.3 Hot Pressing

The mats were hot pressed in a thermal oil heated hydraulic hot press with set temperatures of 170°C, 180°C and 190°C and a specific pressure of 18kgf/cm^{-2} to achieve the required board thickness of 10mm. The mats were pressed for 300 seconds (5 minutes) and 600 seconds (10 minutes). Table 3.2.1.3 is a table of parameters that have been used during the hot press particleboard manufacturing procedure.

Table 3.2.1.3: Parameters in the particleboard manufacturing hot pressing procedure.

Time	**Temperature (°C)**		
5 minutes	170	180	190
10 minutes	170	180	190

3.2.1.4 Conditioning

The test pieces were stored in a well-ventilated environment with a relative humidity of 65±5% and a temperature of 23±3°C until obtained a constant weight, according to JIS A 5908:2003 standards. Constant weight refers to the mass value measured every 24 hours, or when the constant rate of change is 0.1% or less.

3.3 Statistical Analysis

To verify the significance of the studied variables, the data have been statistically analysed. All the data were analysed using statistical package for the social science procedure (SPSS) for the analysis of variance (ANOVA) at a confidence level of 95% significance level ($P \leq 0.05$). Tukey's Honest Significant Difference was then used to further determine the significant level of average values of each testing. Because ANOVA may increase statistical power (the ability for identifying significant changes in means), it had been applied in this study.

3.4 Properties Evaluation

The following parameters must be measured for particleboard: density, moisture content (MC), water absorption (WA), thickness swelling (TS), modulus of rupture (MOR), and modulus of elasticity (MOE) in dry bending. This test had been done three (3) replicates to ensure this test is successful. The dimensions and number of specimens required for this study are shown in table 3.4 below.

Table 3.4: Summary of types of the testing, specimen dimension and number of replicates.

Testing	**Dimension (mm^3)**	**Number of specimens**
Moisture Content (MC) & Density	50 x 50 x 10	3 replicates
Water Absorption (WA) & Thickness Swelling (TS)	50 x 50 x 10	3 replicates
Dry Bending (MOR, MOE)	200 x 50 x 10	3 replicates

3.4.1 Moisture Content (MC) Measurement

The sample mass before and after drying with an oven and were measured with an analytical balance and Advance Moisture Analyzer. Moisture content was calculated using the following formula:

$$MC\ (\%) = \frac{AD - OD}{OD} \times 100\% \qquad \text{Equation 3.3.1}$$

Where:

MC = moisture content (%)

OD = oven dry weight of wood particles

AD = air drying weight

3.4.2 Density

To determine the volume of the sample, a digital calliper was used to measure the length, width, and thickness. This step was followed by measuring the mass of the sample and calculated the density using the equation below. Length, width, thickness, and mass were measured to the nearest 0.1mm, 0.1mm, 0.5mm and 0.1g and density also was measured to the nearest 0.1g/cm^3.

$$\rho = \frac{M^1}{V} \qquad \text{Equation 3.3.2}$$

Where:

ρ = density

M^1 = mass (g)

V = volume (cm^3)

3.5 Physical Properties

The physical properties of particleboard, such as thickness swelling (TS) and water absorption (WA) were evaluated according to the guidelines provided by JIS A 5908:2003.

3.5.1 Thickness Swelling

The thickness swelling of the specimen test was calculated after the absorption of the sample submersion in distilled water for 2 hours and 24 hours by using six particleboard samples (50mm × 50mm × 10mm). This test was to observe the thickness of the particleboard before and after submersing where two intersections of two diagonal points were measured using a vernier calliper. Thickness swelling was then determined using the formula:

$$TS\ (\%) = \frac{T^1 - T^0}{T^0} \times 100$$ Equation 3.3.3.1

Where:

TS = thickness swelling

T^0 = initial thickness before immersion (mm)

T^1 = thickness after immersion (mm)

3.5.2 Water Absorption

The water absorption was tested by weighing the samples before and after submersing in distilled water for 2 hours and 24 hours. After 2 hours, all six samples were removed from the distilled water and weighed and followed by a 24-hour submersing the next day. The difference between the initial weight and the weight after the sample was expressed in percentage according to the volume of the water absorption percentage of the sample (length x width x height). Three replicates have been acquired for the determination of each of the physical and mechanical properties, respectively. The sample of water absorption was measured using the formula:

$$WA\ (\%) = \frac{W^1 - W^0}{W^0} \times 100 \qquad \text{Equation 3.3.3.2}$$

Where:

WA = water absorption (%)

W^0 = initial weight (g)

W^1 = weight of the sample after immersion (g)

3.6 Mechanical Properties

3.6.1 Bending Test

Mechanical properties such as modulus of elasticity (MOE) and modulus of rupture (MOR) were evaluated according to the JIS A 5908:2003 standard. The bending properties, specifically the MOE and MOR, were evaluated using three points bending test. The load was applied continuously at midspan at an approximately uniform rate of motion of the movable crosshead at a speed of 5mm/min^{-1}.

According to the following equation, the sample's modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated based on the formula below:

$$MOR = \frac{3PL}{2bt^2}$$ Equation 3.3.4.1

Where:

P = maximum load (N)

L = span (mm)

b = width of the test piece (mm)

t = thickness of test piece (mm)

While, MOE were calculate using the following formula:

$$MOE = \frac{\Delta PL^3}{\Delta ybd^3}$$ Equation 3.3.4.2

Where:

Δy = flexibility in load (cm)

P = load (kgf)

L = distance of buffer (cm)

b = width (cm)

d = thickness (cm)

An illustration of the bending strength test is shown in figure 3.6 below.

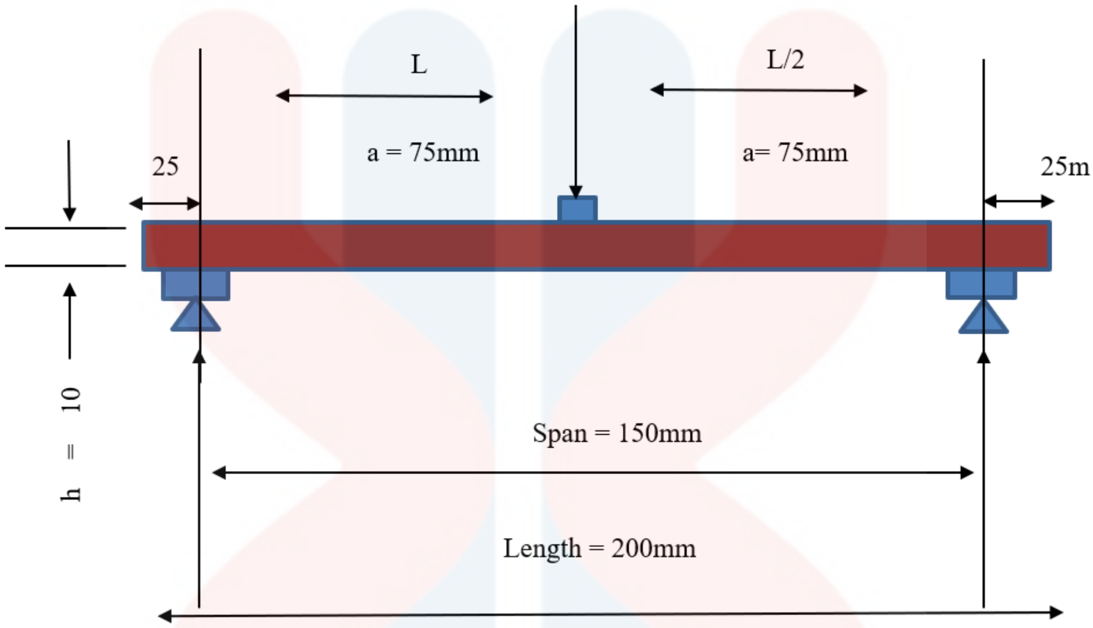
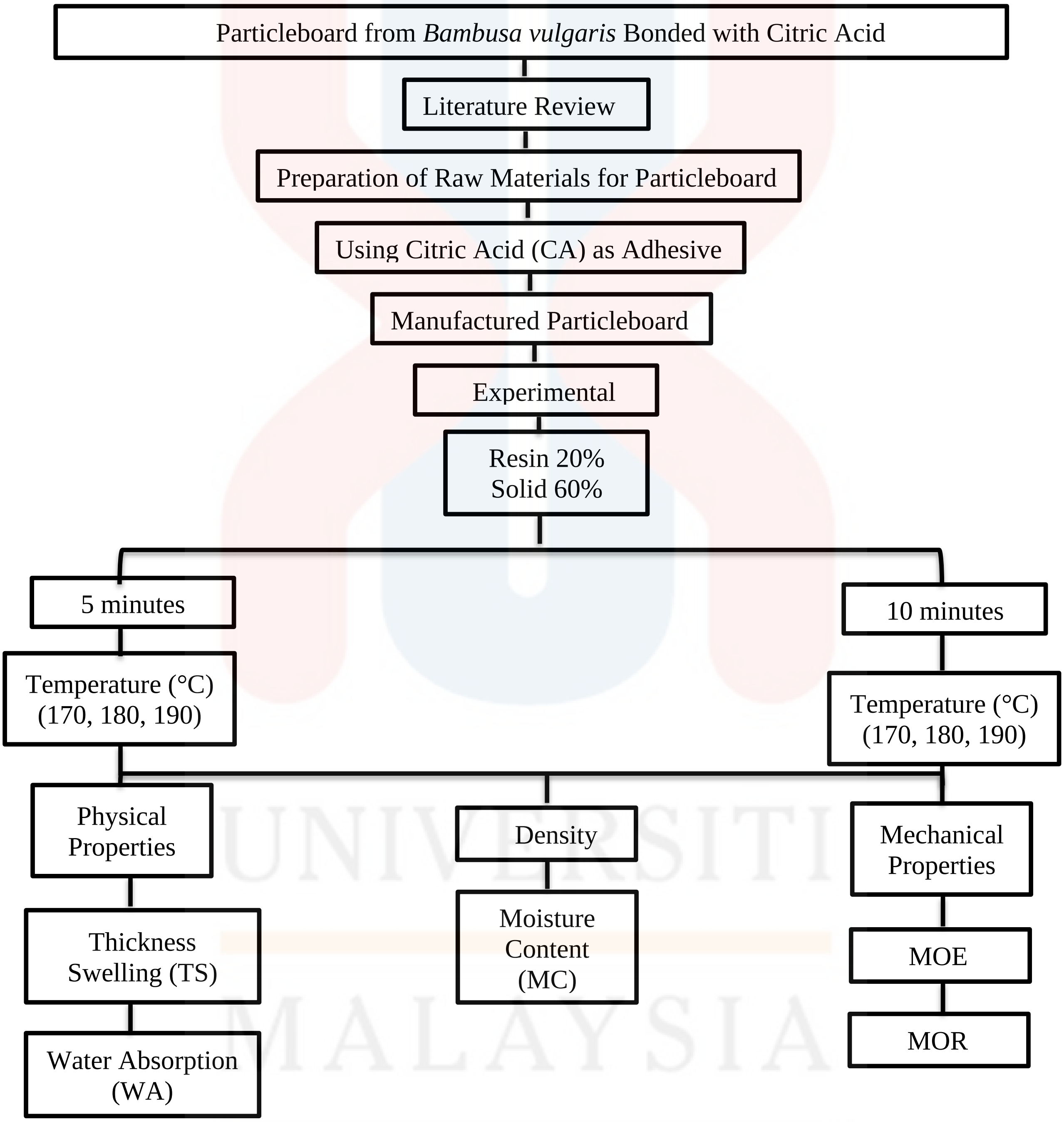


Figure 3.6: Test Setup for Determining the MOR and MOE.

(Source: JIS A 5908:2003)

3.7 Experimental Design

The experimental design of this research was displayed as shown in Figure 3.7:



CHAPTER 4

RESULTS AND DISCUSSION

4.1 Properties of Particleboard

For each parameter, six particleboards have been produced to demonstrate the effectiveness of the manufacturing process between *Bambusa vulgaris* and the citric acid resin used in this study. Multiple tests were carried out in this study, such as measuring dimensional stability and strength, to ensure that the particleboard meets the JIS A 5908:2003 standard in terms of its physical and mechanical condition. Particleboard, known for its low moisture content, is highly valued in industry as a replacement material for wood products. Applying the right resin to particleboard products intended for use in exposed areas reduces the risk of product damage. Thus, the aim of this study is to investigate how differing pressing temperatures impact the physical and mechanical characteristics of buluh Minyak (*Bambusa vulgaris*) particleboard with citric acid, as well as the effect of different pressing times on the physico-mechanical properties of *Bambusa vulgaris* combined with citric acid to create a unique binding agent for particleboard.

4.2 Physical Properties

The average value for thickness swelling (TS) and water absorption (WA) after immersing in water for 2 hours and 24 hours for all types of particleboards were recorded.

Table 1 shows the physical properties for all types of particleboards produced from this study.

Table 1: Physical properties of particleboard from buluh Minyak with different pressing temperature and time.

Temperature (°C)	Time (minutes)	*n*	TS 2h	TS 24h	WA 2h	WA 24h
170	5	3	30.78 ± 20.70	39.76 ± 16.89	65.15 ± 16.87	70.64 ± 18.73
	10	3	3.31 ± 0.76	7.33 ± 1.01	15.27 ± 0.71	30.65 ± 1.08
180	5	3	17.65 ± 5.29	22.10 ± 2.58	54.29 ± 0.54	58.63 ± 0.18
	10	3	3.83 ± 0.70	7.11 ± 0.09	21.38 ± 4.90	32.91 ± 1.08
190	5	3	12.04 ± 1.88	18.32 ± 1.28	47.94 ± 2.04	52.77 ± 1.30
	10	3	3.23 ± 0.28	6.25 ± 0.93	10.90 ± 0.46	22.85 ± 0.43

Note: TS: Thickness swelling; WA: Water absorption; 2h: 2 hours; 24h: 24 hours; n: number of replicates.

Analysis of variance (ANOVA) was conducted for physical properties and all research variables, and the results are summarised in Table 2.

Table 2: Summary of analysis variance (ANOVA) at $P \leq 0.05$ for interaction between pressing temperature, pressing time and physical properties of *Bambusa vulgaris* particleboard samples.

Study Variable	TS 2h		TS 24h		WA 2h		WA 24h	
	F-Value	Pr > F	F-Value	Pr > F	F-Value	Pr > F	F-Value	Pr > F
Temperature	1.198	0.335^{ns}	2.870	0.095^{ns}	2.458	0.127^{ns}	2.837	0.098^{ns}
Time	10.980	0.006^{**}	23.953	0.000^{**}	91.508	0.000^{**}	52.526	0.000^{**}
Temperature * Time	1.214	0.331^{ns}	2.462	0.127^{ns}	1.497	0.263	0.910	0.429

Note: TS: Thickness swelling; WA: Water absorption; 2h: 2 hours; 24h: 24 hours; ** indicates significance level at $P \leq 0.01$; ns indicates no significance level at $P \leq 0.05$.

Based on ANOVA results in Table 2, highly significance ($P \leq 0.01$) is observed for main effects (time) on TS 2h, TS 24h, WA 2h, WA 24h. However, the pressing temperature, and the interaction between pressing temperature and time have no significant effect ($P \leq 0.05$) on all the physical properties. It can be concluded that dimensional stability (thickness swelling and water absorption) in this study was strongly influenced by the pressing time.

Since the main effect (time) is significant, Tukey's HSD was performed to evaluate whether there are significant differences between each group. Table 3 show the summary of the Tukey's HSD analysis of TS and WA values for all particleboards manufactured with different pressing time of 5 minutes and 10 minutes. Observation from Table 3 reveals that the particleboards produced with higher pressing time had better TS and WA compared to the particleboards produced with lower pressing time.

Table 3: Means comparison of TS and WA using Tukey's HSD for all particleboards manufactured with different pressing time.

Time (minutes)	***n***	**TS 2h**	**TS 24h**	**WA 2h**	**WA 24h**
5	3	20.16 ± 14.66^{a}	26.73 ± 13.61^{a}	55.79 ± 12.12^{a}	60.68 ± 13.14^{a}
10	3	3.46 ± 0.67^{b}	6.90 ± 0.92^{b}	15.85 ± 5.17^{b}	28.80 ± 4.41^{b}

*Means followed by the different superscript letters in the same column are significantly different according to Tukey's Honest Significant Difference test at $P \leq 0.01$.

4.2.1 Thickness Swelling

The distribution of TS values for all types of particleboards after 2 hours and 24 hours of immersion in water are plotted in Figure 1 and Figure 2 respectively.

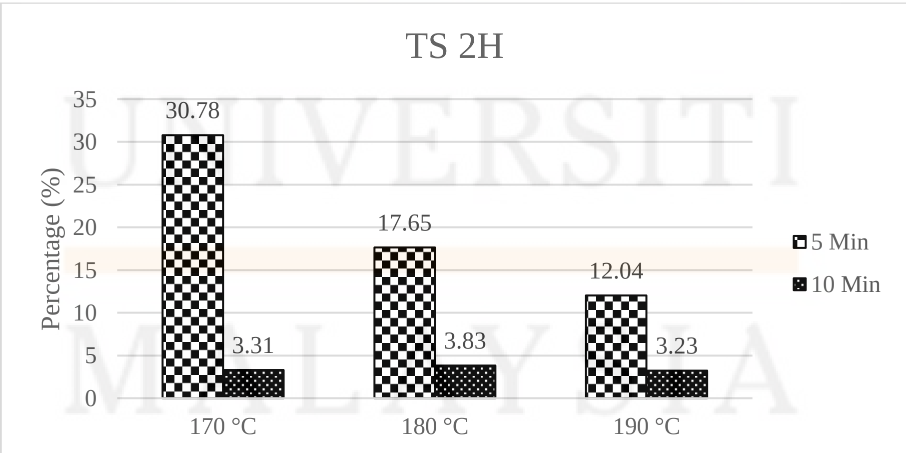


Figure 1: Result of Thickness Swelling for 2 Hours.

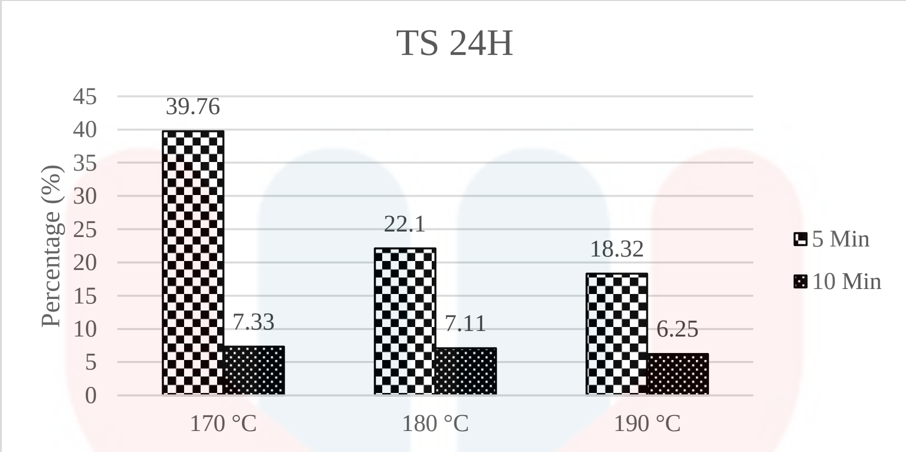


Figure 2: Result of Thickness Swelling for 24 Hours.

Based on Figure 1 and Figure 2, the hot press TS at different pressing temperature (170°C, 180°C, and 190°C) and pressing time (5 minutes and 10 minutes) were measured after 2 hours and 24 hours. TS within 2 hours at a pressing temperature of 170°C swelled by 30.78% and then increased to 39.76% within 24 hours at a pressuring time of 5 minutes. The increase in TS percentage that occurred was 8.98%. At 10 minutes of pressure, there was an increase in swelling percentage of 4.02%, which was 3.31% at 2 hours and 7.33% at 24 hours.

At a pressing temperature of 180°C, the percentage increased from 17.65% (TS 2h) to 22.10% (TS 24h) for a time pressure of 5 minutes. The increase in swelling was 4.45% within 24 hours. While for pressure for 10 minutes, the swelling percentage was 3.83% and 7.11%, respectively at 2 hours and 24 hours. At a pressing temperature of 190°C for a time pressure of 5 minutes, it was 12.04% in 2 hours and 18.32% in 24 hours. This shows that the TS percentage is as high as 6.28%. For the 10-minute time pressure, it was found that there was an increase of 3.02%, which is 3.23% to 6.25% within 2 hours and 24 hours.

In general, the highest percentage increase in TS occurs at a temperature of 170°C at a pressure of 5 minutes, which is an increase of 8.98%. This happens because the resin will not dry completely at low temperatures with short pressure times. This causes the cross-linking between particles to decrease. As a result, the bond will be weaker, allowing water to easily enter and bulk (Wan Abdul Rahman et al., 2019). The percentage of swelling for the temperature pressure of 190°C at the pressure of 10 minutes is the least, which is only 3.02%. According to Umemura et al. (2012), cross-linking between citric acid and particles may occur at a higher rate and at a higher temperature, resulting in good water resistance.

Overall, the TS at three different temperature pressures (170°C, 180°C and 190°C) and at a 10-minute pressure meet the JIS A 5908 (2003) standard, which is no more than 12%, which indicates that the acid-bonded particleboard citric has good dimensional stability.

4.2.2 Water Absorption

The distribution of WA values for all types of particleboards after 2 hours and 24 hours of immersion in water are plotted in Figure 3 and Figure 4 respectively.

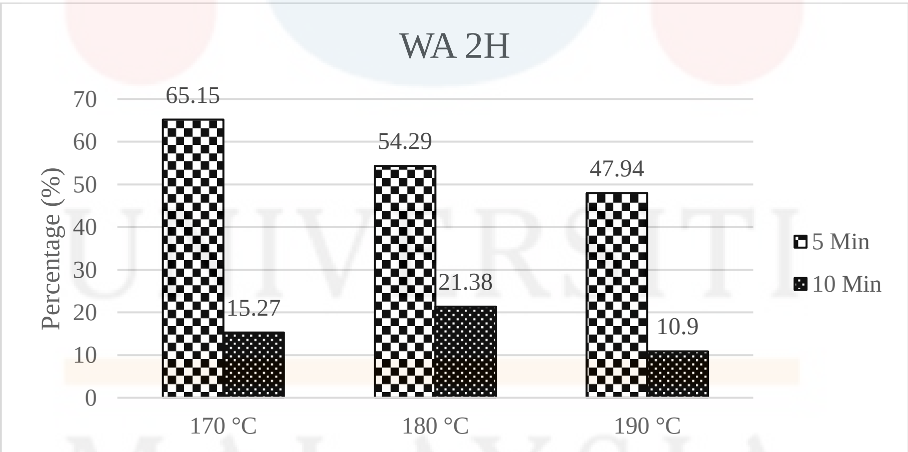


Figure 3: Result of Water Absorption after 2 Hours.

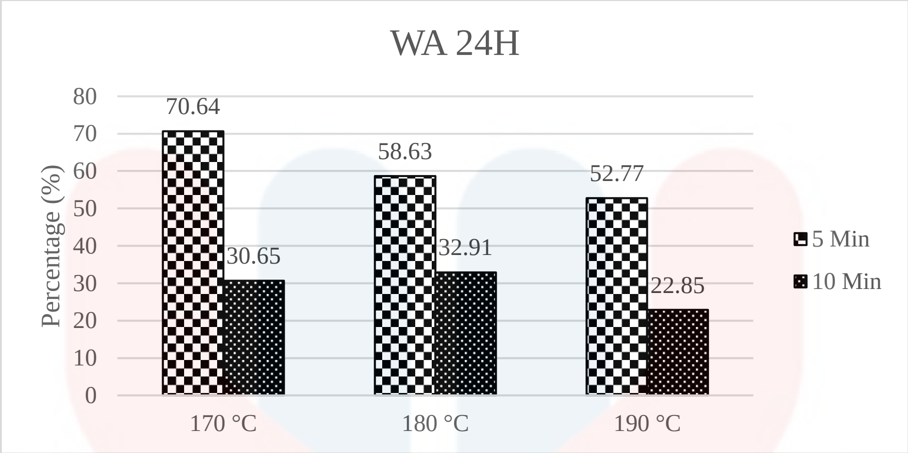


Figure 4: Result of Water Absorption after 24 Hours.

According to Figure 3 and Figure 4, the highest value of WA is obtained with a pressing temperature of 170°C and a pressing time of 5 minutes, where the percentage increase in WA at a pressing temperature of 170°C and a pressuring time of 5 minutes is as much as 65.15% in a period of 2 hours and increases to 70.64% in 24 hours. At a pressing time of 10 minutes, WA increased from 15.27% to 30.65%, which is an increase of 15.38% for both hour periods (WA 2h and WA 24h). At a pressing temperature of 180°C and a pressing of 5 minutes, it was found that WA increased from 54.29% in a period of 2 hours to 58.63% in a period of 24 hours, which is an increase of 4.34%. For the 10-minute time pressure, the WA percentage for the 2-hour period is 21.38%, while the 24-hour period is 32.91%.

At a temperature of 190°C and a time pressure of 5 minutes, WA is 47.94% for a period of 2 hours, while for a period of 24 hours, it is 52.77%. The WA percentage increase rate is 4.83%. The time pressure of 10 minutes in the 2-hour period is 10.9%, and the 24-hour period is 22.85%. It was found that the percentage increase of WA at 190°C pressing temperature and pressing for 10 minutes was 11.95%. The percentage trend of the WA increase can be seen in Figure 4, which is the result after 24 hours.

The graph above also shows the percentage of WA at a temperature of 170°C, and the pressure for 5 minutes is the highest. Khazaeian et al. (2015) stated in their study that this happened due to the hydrophilic lignocellulosic fibre because it has many hydroxyl groups, causing a high percentage of WA. Furthermore, the large number of porous structures in the fibre also accelerates air penetration by capillary action. During the manufacturing process, the low temperature pressure and short pressure time cause the particles not to bond with the CA well. This phenomenon leads to the accumulation of moisture between the fibre cell wall and the fibre adhesive surface, thus affecting particleboard dimensional changes, especially in thickness and swelling (Widyorini et al., 2015). A good percentage of WA can also be seen at pressure for 10 minutes at a pressuring temperature of 190°C, as shown in Figure 4. According to Widyorini et al. (2018), increasing the pressuring temperature causes the WA value to decrease.

4.3 Mechanical Properties

The average value for modulus of rupture (MOR), modulus of elasticity (MOE) for all types of particleboards were recorded, Table 4 shows the mechanical properties for all types of particleboards produced from this study.

Table 4: Mechanical properties of particleboard manufactured from buluh Minyak with different pressing temperatures and time.

Temperature (°C)	Time (minutes)	*n*	MOR	MOE
170	5	3	9.68 ± 2.22	3056.52 ± 926.46
	10	3	12.07 ± 0.75	3252.12 ± 66.68
180	5	3	11.57 ± 1.21	3680.14 ± 318.74

	10	3	12.13 ± 1.05	3341.52 ± 82.03
190	5	3	11.21 ± 0.50	3502.53 ± 149.01
	10	3	10.22 ± 1.09	2951.26 ± 115.87

Note: MOR: Modulus of Rupture; MOE: Modulus of Elasticity; n: number of replicates.

Analysis of variance (ANOVA) was conducted for mechanical properties and all research variables, and the results are summarised in Table 5.

Table 5: Summary of analysis of variance (ANOVA) at $P \leq 0.05$ for interaction between pressing temperature, pressing time and mechanical properties of *Bambusa vulgaris* particleboard samples.

Study Variable	**Modulus of Rupture**		**Modulus of Elasticity**	
	F-Value	Pr > F	F-Value	Pr > F
Temperature	0.954	0.422^{ns}	0.846	0.453^{ns}
Time	0.814	0.385^{ns}	0.958	0.347^{ns}
Temperature* Time	1.800	0.207^{ns}	0.882	0.439^{ns}

Note: ns indicates no significance level at $P \leq 0.05$.

Based on the ANOVA result in Table 5, all the main effects (temperature and time) and the interaction between pressing temperature and time have no significant effect ($P \leq 0.05$) on the mechanical properties of all particleboards produced. It can be concluded that bending properties (MOR and MOE) in this study were not influenced by the pressing temperature, pressing time, and the interaction between pressing temperature and time.

4.3.1 Modulus of Rupture

Figure 5 illustrate the distribution of mean MOR values for all types of particleboards produced with varying pressing temperature and times.

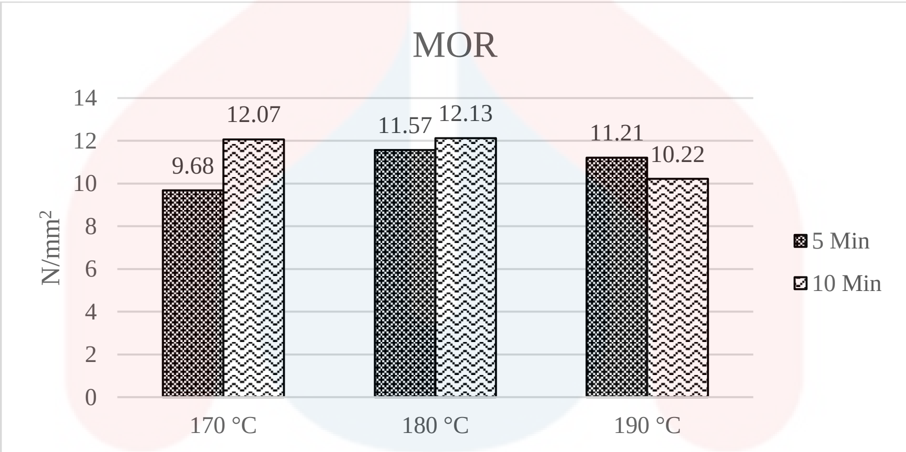


Figure 5: Average Modulus of Elasticity (MOR) of Particleboard Samples.

Based on Figure 5, generally, MOR was obtained by measuring the strength of particleboard in resisting load. The results showed that the MOR value with increasing pressing temperature from 170°C to 180°C and pressing time from 5 minutes to 10 minutes. However, there was a slight decrease at the pressing temperature of 190°C for both pressing duration of 5 minutes and 10 minutes.

The lowest average MOR value of 9.68 N/mm^2 occurred at a manufacturing pressing temperature of 170°C for a 5-minute pressing time. This happens because the particles cannot bond well at low temperatures and in a short time. Based on the study of Umemura et al. (2015) on the bending properties of particleboard produced at temperatures below 180°C, the average value of MOR was found to be less than 10 N/mm^2. However, at a time pressure of 10 minutes, the average value of MOR increased, which was 12.07 N/mm^2.

The average result of the MOR value at 5 minutes of time pressure is 11.57 N/mm^2, and at 10 minutes, it is 12.13 N/mm^2, which occurs at 180°C temperature pressure. Overall, samples pressed for 10 minutes had the highest average MOR. A temperature pressure of 180°C is the optimum temperature for producing good bond strength for 20% citric acid (CA) as a binding agent for lignocellulosic materials (Cahyono & Syahidah, 2019).

Particleboard hot pressed for 5 minutes at 190°C temperature pressure has an average MOR of 11.21 N/mm^2, while the particleboard sample hot pressed for 10 minutes at 190°C temperature pressure is found to be only 10.22 N/mm^2. According to Tiryaki et al. (2017), increasing temperature and time stress are positively proportional. In other words, the average value of MOR generally increases in the event of an increase in temperature and time pressure. However, according to Umemura et al. (2012), pressing temperature that exceeds 180°C causes the MOR value to decrease which inline with the findings from this study.

Overall, all average MOR values are above 8.0 N/mm^2. This shows that the particleboard produced complies with the JIS A 5908:2003 standard, which is type 8 particleboard, as a minimum benchmark for the use of particleboard.

4.3.2 Modulus of Elasticity

Figure 6 illustrates the distribution of means MOE values for all types of particleboards produced with varying pressing temperature and times.

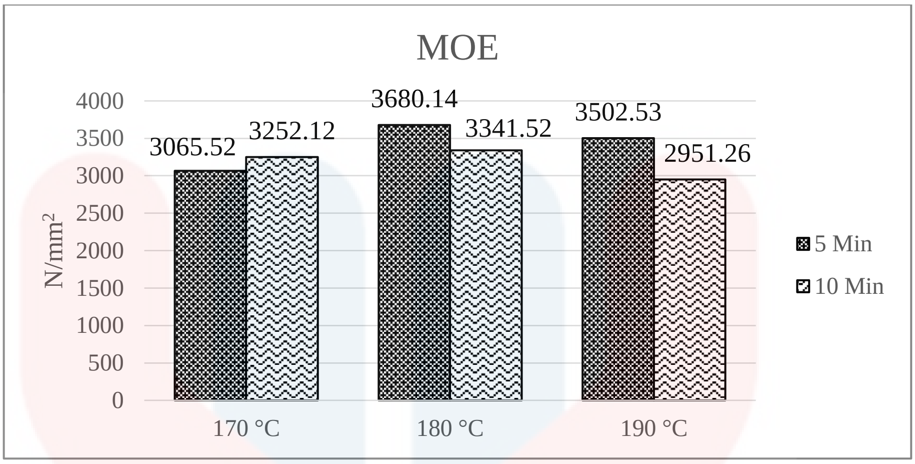


Figure 6: Average Modulus of Elasticity (MOE) of Particleboard Samples.

The average value of elasticity (MOE) of particleboard samples is shown in Figure 6. The average value of MOE is in the range of 2951.26 N/mm^2 to 3680.14 N/mm^2. The test on a temperature pressure of 170°C shows the average MOE value at 5 minutes of time pressure is 3065.52 N/mm^2. At a pressing time of 10 minutes, it is as much as 3252.12 N/mm^2.

At a temperature pressure of 180°C and a time pressure of 5 minutes, it showed the highest average MOE value of 3680.14 N/mm^2. The results can be compared with previous studies where the researcher found that good mechanical properties can be obtained with at least a temperature pressure of 160°C and a short pressure time (Esteves et al., 2023). At the 10-minute time pressure, the average value of MOE is 3341.52 N/mm^2.

At a pressing temperature and time of 190°C and 5 minutes, respectively, the average value of MOE is 3502.53 N/mm^2. This average value shows a slight decrease from the pressing time of 5 minutes at a temperature pressure of 180°C. According to a study by Milawarni et al. (2019), MOE values have a positive relationship with pressing temperature and rise as pressing temperature rises. However, when the temperature pressure exceeds 180°C, the MOE value tends to decrease. At a pressuring time of 10 minutes, the average MOE value was 2951.26 N/mm^2. This average value shows the lowest value among all test conditions. A previous study by Nitu et al. (2022) found that the adhesion of particles is disturbed, causing the mechanical properties to be low due to the formation of volatile components at high temperatures.

According to JIS A 5908:2003, all particleboard design MOE values meet the standard, which is above 2000 N/mm^2.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, this study investigated the effect of pressing temperatures (170°C, 180°C, 190°C) and time (5 and 10 minutes) on the physico-mechanical properties of particleboard made from buluh Minyak particleboard with citric acid resin.

The results of thickness swelling, water absorption, modulus of rupture and modulus of elasticity can be optimized at a temperature pressure of 180°C for 10 minutes. Pressing temperature (170°C) or lower pressing time of 5 minutes resulted in the bond between the particles and the adhesive not being able to bond well. However, higher temperature (190°C) also caused deterioration of the particleboard.

The optimum pressing temperature condition of 180°C with a pressing time of 10 minutes, enables the manufacture of durable particleboard that complies with the JIS A 5908:2003 standard which is type 8 particleboard. This shows the possibility that bamboo waste and citric acid binding can be used for sustainable composite production thus being viable as an available by-product which is environmentally friendly, formaldehyde-free particleboard.

5.2 Recommendation

According to this study, it is important to take into consideration the optimum pressing temperature, and time, while producing particleboard from buluh Minyak using citric acid as an adhesive in the manufacturing process. These characteristics have the capacity to enhance strength, dimensional stability, and overall material performance.

Although this study shows an understanding of the impact of pressing temperature and pressing time, there are other parameters requiring further study to further explore more variables that could potentially influence the properties of citric acid-bonded particleboard. Comprehensive research into the concentration of citric acid, particle size, and additions may lead to an enhanced understanding of material function.

In order to evaluate the environmental impact of using citric acid as an adhesive and the sustainability of buluh Minyak, it is necessary to do a detailed environmental assessment. An evaluation of the life cycle of particleboard can be conducted to substantiate its claim as an environmentally friendly material.

This research has the potential to achieve type 13 of particleboard by making improvements to properties such as, changing pressing temperature or pressing time, improving resin or solid content. In addition, additives such as starch can also be added to further increase the strength of particleboard.

To enhance the visual appeal and functionality of buluh Minyak particleboard with citric acid, it is suggested to explore the application of coating, finishing, or other relevant treatments. The purpose of this is to provide more protection against environmental elements in order to expand a variety of materials and their uses, including interior design, furniture production, and architectural applications.

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APPENDIX A

Figure A.1: Buluh Minyak that has been cut before chipping.

Figure A.2: Citric acid as a binding agent.

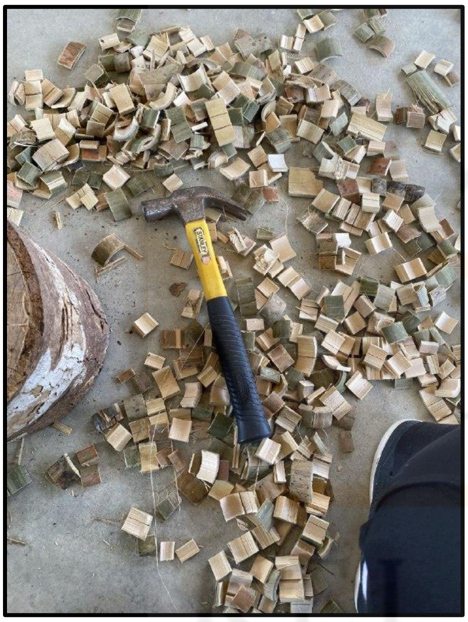

Figure A.3: Crushed bamboo before the chipping process.

Figure A.4: Chipping process.

Figure A.5: Buluh Minyak particles.

Figure A.6: Sieving process.

Figure A.7: Mat forming process.

Figure A.8: After the mat forming process.

Figure A.9: The particles were put into a hot press machine.

Figure A.10: Process of hot pressing.

Figure A.11: Results of particleboard.

Figure A.12: Thickness swelling and water absorption process.

Figure A.13: Process of bending test.