UNIVERSITI
MALAYSIA
KELANTAN

PHYSICO-MECHANICAL PROPERTIES OF BULUH MADU (*Gigantochloa albociliata*) PARTICLEBOARD BONDED WITH DIFFERENT SOLID CONTENT AND RESIN CONTENT OF CITRIC ACID

AIMAN HAKIMI BIN ASHAR

J20A0656

A reported submitted in fulfilment of the requirements for the degree of Bachelor of Applied Science (Forest Resources Technology) with Honours

FACULTY OF BIOENGINEERING AND TECHNOLOGY

UMK

2024

DECLARATION

I declare that this thesis entitled "Physico-mechanical properties of buluh madu (*gigantochloa albociliata*) particleboard bonded with different solid content and resin content of citric acid" is the results of my own research except as cited in the references.

Signature : ____________________________

Student's Name : AIMAN HAKIMI BIN ASHAR

Date : ____________________________

Verified by:

Signature : ____________________________

Supervisor's Name : DR. LUM WEI CHEN

Stamp : ____________________________

Date : ____________________________

ACKNOWLEDGEMENT

In the name of God who is merciful and merciful

Alhamdulillah, first of all praise to God Almighty for giving me opportunity and gave me the ability to complete this study. This thesis cannot complete without the guidance and supervision of several people.

Thousands of appreciation and infinite thanks to my supervisor, Dr. lum wei chen for his constant guidance, suggestions and support against me in order to produce good results from this study. This solution thesis would not have been possible without his valuable guidance and constant help.

Not forgotten, my appreciation to my examiner Dr. sitti fatimah and Dr. Nur sakinah Binti Mohamad finished for invaluable comments in the defense proposal to be made improvement in my proposal report and knowledge sharing on the research topic.

I am grateful to Universiti Malaysia Kelantan for giving me the opportunity and opportunity to learn and continue my studies. Moreover, I also want to show appreciation to my fyp friend for completing particleboard manufacturing during the semester break.

Finally, I would like to express my deepest gratitude to my beloved parents, Ashar Bin Mohd Supian and Suriahty Binti Harun who always give me valuable help and support. To those who indirectly contributed to this research, your kindness means a lot to me. Thank you very much.

Sifat fizik mekanikal buluh madu (Gigantochloa albociliata) papan zakar terikat dengan kandungan pepejal yang berbeza dan kandungan resin asid sitrik

ABSTRAK

Kajian ini menyiasat sifat fiziko-mekanikal papan partikel yang dihasilkan daripada zarah buluh Buluh Madu (Gigantochloa albociliata) yang diikat dengan nisbah berbeza resin asid sitrik dan kandungan pepejal. Asid sitrik digunakan sebagai pelekat mesra alam tunggal pada kandungan optimum 10-30% resin dan 60-70% pepejal. Papan partikel telah direka dengan kaedah menekan panas dan diuji untuk pembengkakan ketebalan, penyerapan air, modulus pecah (MOR), dan modulus keanjalan (MOE) mengikut protokol standard. Keputusan menunjukkan bahawa meningkatkan resin asid sitrik kepada 30% meningkatkan kestabilan dimensi dengan meminimumkan bengkak ketebalan dan penyerapan air. Nisbah resin pelekat juga meningkatkan kekuatan mekanikal, dengan resin 30% mencapai nilai MOR dan MOE tertinggi. Walau bagaimanapun, mengubah kandungan pepejal antara 60-70% tidak memberi kesan yang ketara kepada sifat papan. Hasilnya menunjukkan keberkesanan asid sitrik sebagai pengikat hijau untuk pembuatan papan partikel buluh yang mempamerkan ciri-ciri fisio-mekanikal yang sangat baik. Kajian ini menggalakkan amalan pembuatan komposit lestari alam sekitar dengan memajukan pengetahuan tentang formulasi asid sitrik untuk aplikasi dengan sumber buluh yang kurang digunakan.

Kata kunci:Buluh Madu, kandungan resin, kandungan pepejal,sifat fizikal, sifat mekanikal

Physico-mechanical properties of buluh madu (Gigantochloa albociliata) particleboard bonded with different solid content and resin content of citric acid

ABSTRACT

This study investigated the physico-mechanical properties of particleboard manufactured from Buluh Madu (*Gigantochloa albociliata*) bamboo particles bonded with varying ratios of citric acid resin and solid content. Citric acid was used as a sole eco-friendly adhesive at resin contents of 10%, 20%, and 30% and solid content of 60% and 70%. Particleboards were fabricated by hot pressing method and tested for thickness swelling, water absorption, modulus of rupture (MOR), and modulus of elasticity (MOE) according to JIS A 5908:2003. The results showed that increasing citric acid resin to 30% improved dimensional stability by minimizing thickness swelling and water absorption. The adhesive resin ratio also enhanced mechanical strength, with 30% resin achieving the highest MOR and MOE values. However, varying the solid content between 60% and 70% did not significantly impact the board properties. The outcomes demonstrated the effectiveness of citric acid as a green binder for manufacturing bamboo particleboard with excellent physio-mechanical characteristics. This study promotes environmentally sustainable composite manufacturing practices by advancing knowledge on citric acid formulations for application with underutilized bamboo resources.

Keywords: Buluh Madu, Resin Content, Solid Content, Physical properties, Mechanical properties.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Most of the wood production industry contributes to the manufacture of materials that can improve the quality of wood in the current era of economic development. The production of particleboard is one of the studies that needs to be improved nowadays. Therefore, one of the many difficulties and rivals in its manufacture is the creation of wood from particle board. As a product, it was invented in the early 20th century and used during World War II to use subpar wood and wood waste because excellent grade wood was scarce at that time (Stark et al., 2010).

Sawdust, mill waste, and recovered wood can all be used thanks to advancements in particle board manufacturing technology. Particle boards have also been produced using lignocellulose sources other than wood, such as rubber wood (Carvajal et al., 1996; Xu et al., 2009; Monteiro de Barros Filho et al., 2011). In the construction industry and the manufacture of wood-based goods, particle board is another alternative material. To produce valuable wooden items, most materials utilized today must be highly durable and of high quality.

In other, wood one of the most prevalent and adaptable natural materials, is the main nutrient-conducting and strengthening tissue of trees and other plants. Wood comes in a variety of colors and grain patterns and is produced by numerous botanical species, including both gymnosperms and angiosperms. It possesses favorable acoustic qualities, is heat- and electricity-insulating, and is robust relative to its weight. In addition, it is reasonably simple to deal with and has a "warmth" that competitive materials like metals or stone lack. Wood has been used as a material since the first humans arrived on Earth. Wood still plays most of its traditional roles in today's world despite technological advancements and competition from materials like metals, polymers, cement, and other natural products.

In addition to well-known items like plywood, lumber, and furniture, wood serves as the primary ingredient in many chemical goods, pulp and paper, and wood-based panels. And last, a significant portion of the world still uses wood as a fuel.

The global particleboard industry is widely used in various sectors, including construction, furniture manufacturing, and packaging. Particleboard is a type of engineered wood product made from wood particles, such as sawdust, wood chips, and other wood residues, bound together with a synthetic resin. The exact percentage of particleboard usage worldwide can vary depending on factors such as regional demand, economic conditions, and alternative materials available in different countries. However, particleboard is known to be a popular and cost-effective material, especially in regions where natural wood resources are scarce or expensive. To get the most accurate and up-to-date information on the current percentage of particleboard usage worldwide, I recommend consulting industry reports, market research studies, or contacting relevant trade associations and organizations that specialize in the wood products industry.

1.2 Problem Statement

Particleboard is a significant composite timber product that finds utility in the packaging, construction, and furniture industries. Particleboard, which was historically produced utilizing urea-formaldehyde (UF) resins, is confronted with environmental and health issues stemming from the formaldehyde emissions produced by these adhesives. Particleboard fabrication requires more sustainable, formaldehyde-free alternatives to UF resins.

Citric acid has emerged as a potentially environmentally friendly alternative; however, the impact of different resin and solid compositions on the physio-mechanical properties of particleboards bonded with citric acid remains poorly understood. In order to meet performance standards for boards' strength, dimensional stability, and resistance to moisture, these parameters must be optimized. In contrast, the majority of previous research has concentrated on individual formulations as opposed to comparing citric acid content ranges.

Limited research has been conducted on the application of citric acid as a binder for particleboard derived from Buluh Madu (*Gigantochloa albociliata*) bamboo, which is a readily available and swiftly renewable biomass resource in Southeast Asia. Uncertainty surrounds the relationships between the anatomical, chemical, and physical attributes of this exceptional bamboo species and its citric acid content. It is of the utmost importance to clarify these effects in order to utilize Buluh Madu as a sustainable raw material in the production of particleboard using citric acid adhesives.

Hence, the objective of this research endeavor is to examine the impact of different proportions of solid and resin components in citric acid on the physio-mechanical characteristics of particleboard manufactured using Buluh Madu bamboo. The objective is to ascertain the optimal formulations of citric acid that strike a balance between cost-effectiveness, environmental sustainability, and performance when used to produce formaldehyde-free particleboard from this underutilized bamboo species.

1.3 Objectives

1. To determine the influence of citric acid solid content on the physical and mechanical properties of Buluh Madu particleboard.

2. To examine the influence of citric acid resin content on the physical and mechanical properties of Buluh Madu particleboard.

3. To determine the resin content of citric acid with buluh madu chip can be produced in particleboard making.

1.4 Scope of Study

This study aims to investigate the physico-mechanical properties of particleboard manufactured from Buluh Madu (*Gigantochloa albociliata*) bamboo particles bonded with varying ratios of citric acid resin and solid content. The raw material will be sourced from mature Buluh Madu bamboo culms to ensure uniformity. Citric acid will serve as the sole green adhesive at optimized resin contents ranging from 10-30% by weight. The solid content will be adjusted between 60-70% to determine ideal levels for balancing performance and cost. Particleboards will be fabricated using a hot press method adhering to parameters specified in established protocols.

The manufactured particleboards will undergo testing to evaluate selected physical and mechanical properties. For physical properties, thickness swelling, water absorption, and moisture content will be analyzed as measures of dimensional stability and resistance to environmental conditions. For mechanical properties, modulus of rupture (MOR) and modulus of elasticity (MOE) will be evaluated for tensile and bending strength. Standard test methods prescribed by JIS A 5908 will be followed. The data will be statistically analyzed to identify significant impacts of resin and solid content on the particleboard properties.

The scope will be limited to a single bamboo species, adhesive type, and content ranges for resin and solids. Only key physio-mechanical indicators will be tested. Comparisons will be restricted to the formulations under investigation. There is potential for wider materials, process variables, tests, and comparative studies in future work building on these initial findings. The outcomes will provide insights on suitability and optimization of citric acid as a green binder for manufacturing Buluh Madu bamboo particleboards.

1.5 Significances of Study

In the field of sustainable composite materials, the research on the physio-mechanical characteristics of Buluh Madu (*Gigantochloa albociliata*) particleboard bonded with various solid and resin contents of citric acid is crucial. This study addresses the need to reduce formaldehyde emissions and promote environmentally friendly manufacturing processes by adding to the body of information on eco-friendly alternatives to standard resin systems.

"Effect of Citric Acid as a Binder on the Properties of Bamboo Particleboard" by Hamdan et al. (2019), which was published in the Journal of Bamboo and Rattan, is one noteworthy journal article that highlights the significance of this work. This study investigated the use of citric acid as a binder for bamboo particleboard, concentrating on how the concentration of citric acid affected the mechanical and physical characteristics of the board. The results demonstrated citric acid's potential as a workable substitute binder and showed how it may enhance the mechanical strength and dimensional stability of bamboo particleboards. To study the changes in physio-mechanical properties and improve citric acid formulations, this source underlines the necessity for additional research on several species of bamboo, including *Gigantochloa albociliata*.

The current work advances the field by examining the precise impacts of various solid and resin contents of citric acid on the physio-mechanical properties of particleboard. It does this by drawing on prior research and using the raw material *Gigantochloa albociliata*. The results of this study will aid in the creation of environmentally friendly particleboard manufacturing processes by giving researchers, business experts, and legislators more information to consider when using bamboo as a resource and cutting back on hazardous emissions.

CHAPTER 2
LITERATURE REVIEW

2.1 Bamboo

Gigantochloa albociliata, a species of bamboo native to Southeast Asia, has gained significant attention in various research fields due to its unique properties and potential applications. Several studies have explored its physical, mechanical, and chemical characteristics, as well as its suitability for different purposes. One study by Salim et al. (2013) focused on the physical and mechanical properties of *Gigantochloa albociliata* culms. The research investigated the bamboo's density, moisture content, fibre length, bending strength, and hardness. The study found that Buluh Madu exhibited favourable mechanical properties, making it suitable for structural applications in the construction industry. *Gigantochloa albociliata*, or Buluh Madu, has shown great potential in various applications. Its favourable physical, mechanical, and chemical properties make it suitable for construction, pulp and paper, biofuel, bio composite, and furniture industries. These studies provide valuable insights into the characteristics and potential uses of this bamboo species, contributing to the growing body of knowledge on sustainable and renewable materials.

2.1.1 Characteristics of bamboo

Bamboo, a rapidly expanding and regenerative plant, has special qualities that make it a flexible and sustainable material for a variety of applications. Thakur et al. (2018) covered the physical and mechanical characteristics of bamboo. Aspects like density, moisture content, dimensional stability, hardness, tensile strength, and compressive strength were all covered in the review. It emphasised how bamboo is a good choice for structural applications due to its great bending capabilities, high strength-to-weight ratio, and capacity to withstand stresses.

Furthermore, a lot of research has been done on the anatomical makeup of bamboo. In a study published in 2018, Xu et al. investigated bamboo's cellular makeup and organisation. The research clarified bamboo's distinctive characteristics, such as its vascular bundles, fibre arrangement, and presence of silica bodies. The mechanical stiffness and strength of bamboo are influenced by these structural features.

The chemical makeup of bamboo has also been studied. The chemical components of bamboo, including its cellulose, hemicellulose, and lignin concentration, were the topic of a study by Ramamoorthy et al. (2019). The study highlighted the potential uses of bamboo for biofuel and bio composite manufacturing as well as its high cellulose content, which makes it excellent for pulp and paper production.

A study by Panthi et al. (2020) looked at the environmental advantages and carbon sequestration capacity of bamboo forests in terms of the sustainability of bamboo. The study emphasised how bamboo may prevent soil erosion, store carbon dioxide, and boost biodiversity. It highlighted bamboo's value as a sustainable and environmentally friendly material.

The density of bamboo, which ranges from 500 to 800 kg/m^3, is influenced by the quantity and distribution of fibres surrounding vascular bundles. The highest density is achieved in culms that are 3 years old (Yusoff et al.2021)

In general, bamboo demonstrates extraordinary qualities, such as its favourable chemical composition, high strength-to-weight ratio, and distinctive cellular structure. These characteristics add to its adaptability and usefulness for a variety of applications, from building and furniture to producing paper and biofuels.

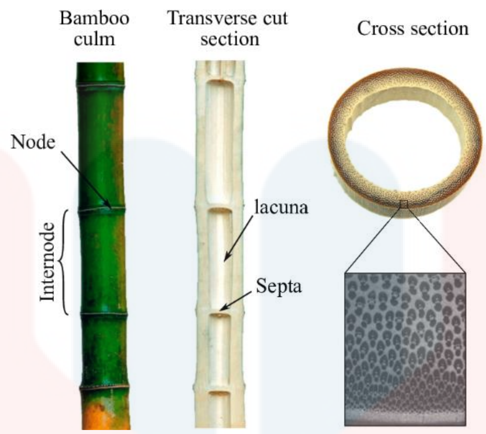


Figure 1: General Characteristics of a Bamboo Culm

(Source: Tarun Gangwar, 2019)

2.2 Particleboard

Since the 1980s, the Malaysian particleboard industry has primarily relied on rubberwood as a source of raw materials (Wan Abdul Rahman et al., 2020). Manmade woods are made from wood or plastic with a binding agent, whereas wood composites are constructed from wood or plastic with a binding agent. Compared to wood composites, solid wood is more expensive. This is since coated wood composites are more resistant to moisture and temperature, which facilitates installation. dimensional stability, stiffness, and strength are all uniform and long-lasting, with little twisting, shrinking, or wrapping of the board. Medium density fibreboard (MDF), plywood, veneer board, and particle board are examples of common engineered timbers used in industry.

Particleboard has been produced from forest products for a long time. Producers and researchers are being pushed to switch to quickly growing species, agro-based goods, or mixtures of raw materials incorporating wood waste like branches, bark, or woody plants due to the decline in raw materials and increase in bulk demand for particle board. Because of its advantages of sound and fire resistance built-in board, warp resistance, good quality goods, and particle board is created at an affordable price, one of the composite boards is preferred by manufacturers to build furniture (Amali et al., 2021).

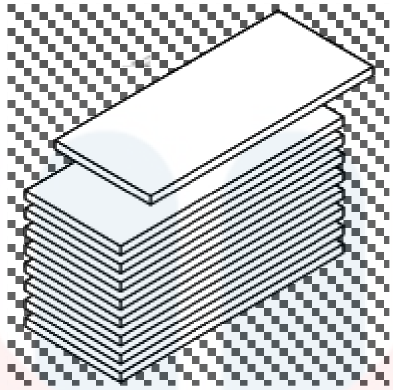


Figure 2: Shape of particleboard

(Wood works, 2023)

Due to its great susceptibility to moisture-induced expansion and discolouration, particularly when left untreated with paint or another sealer, particleboard has a considerable disadvantage. Except for select bathrooms, kitchens, and laundry rooms, where it is commonly used as an underlayment beneath a continuous layer of vinyl floor covering, it is therefore rarely used outdoors or in high-moisture locations.

2.2.1 Particleboard uses.

With a variety of applications, particleboards are an important value-added panel product in the wood-based industry. In contrast to the building industry or the pulp and paper industry, the manufacturing of particleboard may use inferior raw materials. For the sake of the environment, proper waste management is essential, particularly when managing wood and by-products made of wood. the potential uses of a certain material or the choice of ideal production conditions, such as the type and quantity of glue, temperature, or pressure.

Applications for particleboard can generally be split into two categories: structural applications and non-structural applications. Industrial-strength tasks like construction or building parts use structures. This kind is frequently produced utilising a resin like isocyanate, melamine formaldehyde, or phenol formaldehyde. Boards can be utilised outside thanks to the usage of phenolics (which are more frequently used) and isocyanates. Contrarily, non-structural usage is frequently used in interior or light-weight applications. Boards are produced using urea formaldehyde (UF) or a slightly increased UF foundation; like most, it is more sensitive to moisture. The least moisture resistant chemical is urea formaldehyde when tested against wood particles in comparison to MF and PF. However, lightweight furniture like chairs and tables, packaging like boxes, floor and wall panels, and musical instruments like pianos, guitars, and organ parts also employ this particle board as an interior material. Mechanical and physical qualities of particle boards fall into two categories, according to Rahman et al. (2019). Shear, bending, internal bond (IB), and hardness tests are among the mechanical properties investigated to ascertain the strength and stiffness of the board under stress. Physically speaking, these include swelling thickness tests and water absorption tests, which are used to gauge the board's ability to withstand moisture. Particle board density is determined by the particle board's degree of compactness. Increasing particle weight, particle diameter, geography, or wood all have an impact on particle board density.

2.3 Citric Acid

A study by Song et al. (2019) gives a summary of the characteristics and uses of citric acid. The writers go into its use in the food and beverage industries as an acidulant, flavour enhancer, and preservative. They emphasise its inclusion in dairy goods, jams, fruit juices, and carbonated beverages. The study also highlights how citric acid's chelating capabilities make it valuable in the industrial sector for cleaning metals, treating water, and catalysing reactions.

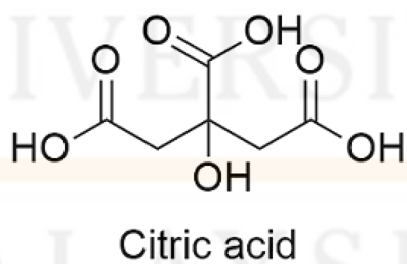


Figure 3: Molecular Structure of Citric Acid.

(Source: Olsson & Erik, 2013)

2.4 Mechanical properties

The results showed that resin had a substantial influence on the bending strength of the particleboards. The modulus of elasticity (MOE) of a particleboard, which increases with a larger

MOE value, is what determines how stiff the particleboard is. Boards are either brittle or tensile or flexible depending on the MOE value; high values indicate brittleness. According to Borysiuk et al. (2019), when the amount of resin added to the board increased, the MOE value also rose, making the board more fragile. The highest load in terms of weight per square inch acting in the direction of length that a given substance can withstand without rupturing is referred to as tensile strength. A substance's tensile strength determines how long it can withstand tensile strains without breaking. The probability of breaking soft materials is higher. The process of determining mechanical properties therefore includes this as a key component. A material returns to its original shape and size, either entirely or in part, when stresses less than the tensile strength are eliminated. A material that has already started to flow plastically quickly produces a constricted space known as a neck when the tension surpasses the tensile strength, where it eventually cracks. The MOE degrades more obviously and the IB values improve more significantly in these aspects as well, in line with previous findings. The dimensional stability of the boards was significantly improved by using more UF resin, but the impact of including wood particles and adjusting the pressure was not statistically supported (Pedzik et al., 2022).

2.5 physical mechanical

Numerous methods are used to determine physical attributes. Data on thickness swelling show that the board is more stable at lower thicknesses. Many process factors, such as wood species, element shape, board density, resin amount, blending effectiveness, and pressing circumstances, have an impact on thickness swelling. Thickness swelling is the term used to describe the relative increase in item dimensions both before and after testing (Dukarska et al., 2022). The reason for the lowest thickness swelling is that a particleboard with higher compaction had a low diffusion rate, which decreased porosity and, as a result, reduced the capacity of a particleboard to absorb water due to its constrained surface area.

CHAPTER 3
MATERIALS AND METHODS

3.1 Materials

The chosen wood samples ought to be representative of the species being studied, in this case *Gigantochloa albociliata* or Buluh Madu. To guarantee the validity and correctness of the study's findings, these samples should be taken from mature, healthy bamboo plants. To preserve uniformity in the material attributes, the collection should consider variables like geographic location, growth conditions, and sustainability. To achieve uniformity and get rid of any potential deviations, the preparation of the wood specimens must follow standardized methods. This entails slicing the bamboo culms into smaller pieces and eliminating the outer layer, nodes, and any flaws that can impair the quality of the particleboard. The finished wood sample should be uniform in size and devoid of impurities or other foreign materials. Referencing pertinent literature is essential to help the selection of suitable wood specimens. The journal article "Physical and Mechanical Properties of Laminated Particleboard Made from *Gigantochloa albociliata* (Buluh Madu)" by Hidayah et al. (2016) offers useful insights on the use of *Gigantochloa albociliata* for particleboard production. The study can guarantee precise and trustworthy results about the physio-mechanical properties of the particleboard by carefully choosing and processing wood specimens from *Gigantochloa albociliata.* This will help with the overall comprehension of the performance of Buluh Madu particleboard bonded with various solid and resin citric acid contents, helping the creation of environmentally friendly and sustainable composite materials.

3.2 adhesive

Due of its eco-friendly and non-toxic properties, citric acid, an organic acid that occurs naturally, has received considerable attention as a replacement adhesive in several applications. Numerous investigations have investigated the adhesive capabilities and prospective uses of adhesives based on citric acid.

Mohanty et al. (2019) investigated the adhesive capabilities of citric acid for natural fibre-reinforced polymer composites in bio-based composites. A citric acid-based adhesive's ability to adhere strongly to a variety of natural fibres, including jute, sisal, and coir, was tested in this study. The study illustrated the potential of citric acid adhesives for creating sustainable and biodegradable composites by demonstrating how well they successfully bonded natural fibres with acceptable mechanical properties. Additionally, the potential for using citric acid-based adhesives in medical settings has been investigated. Citric acid's adhesive qualities were looked at for tissue engineering applications in a study by Sharma et al. (2020). The study examined the adhesive strength and biocompatibility of hydrogels made of citric acid as well as their development. The findings suggested the citric acid hydrogels' potential for tissue engineering and regenerative medicine by showing that they had high adhesion capabilities and promoted cell development. Citric acid can be utilised as a natural glue for wood-based moulding, as we just discovered. Three carboxyl groups are present in the organic Poly carboxylic acid known as citric acid (2-hydroxy-1,2,3-propanetricarboxylic acid). It is generated commercially by fermenting materials containing glucose or glucose and sucrose and is found in citrus fruits like lemons and limes.

Overall, citric acid-based adhesives have promising qualities that make them appropriate for a variety of applications, including adequate bonding strength, water resistance, reduced formaldehyde emissions, and biocompatibility. These investigations advance knowledge of citric acid's adhesive capabilities and highlight the substance's potential as an environmentally friendly substitute for traditional adhesives.

SOLID CONTENT	RESIN CONTENT		
SC 60%	10	20	30
SC 70%	10	20	30

Table 1: parameter of particleboard manufacturing

3.3 Particleboard production

The production of a particleboard with a single layer and dimensions of (200 x 200 x 10) mm was have been produced. In the production of particle board, citric acid will be used as a binding agent, which the different of the resin content quantity in 10%,20% and 30%. Meanwhile 60% and 70 % of the solid content. The process of blending particles and adhesive will be accomplished through the utilisation of a rotary blender. Subsequently, the particles will be put to a 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 parameters involved in the manufacturing of particleboard.

Information	**Condition**
Size of sample	200 mm x 200 mm x 10 mm
Adhesive	Citric acid Resin content: 10%, 20% and 30% Solid content: 60% and 70%
Density target	650g/cm^3
Hot pressing	Temperature: 180°C, Time: 10 minutes Pressure: 2.44N/mm^3

Table 2: The Parameters Used in the Manufacturing of Particleboard.

3.4 Determination of physical properties

The physical characteristics including thickness swelling were evaluated in accordance with JIS A 908:2003. Using a digital calliper and the methodology outlined in the JIS Standard's required thickness swelling, the testing was completed in a lab setting.

3.4.1 Thickness swelling

The size of the samples was 20 mm × 20 mm × thickness as stated in JIS A 5908:2003. The thickness of the each test piece was measured before being horizontally immerse in water horizontally at 20 °C, approximately 3 cm below the water surface for 2 hour and 24 hours, before being removed and wiped off excessive water on the surface. The samples were weighted using an electronic balance. A digital calliper was used for thickness measurements. The thickness swelling for each specimen was calculated using the following formula:

$$\text{Swelling in thickness after immersion in water (\%)} = \frac{t2-t1}{t1} \times 100$$

Equition 3.4.1

Where,

t^2: Thickness (mm) before immersion in water

t^1: Thickness (mm) after immersion in water

3.4.2 **Water Absorption**

In particleboard manufacturing, water absorption is a crucial property to evaluate because it provides information about the board's dimensional stability and resistance to moisture. Absorption of water by particleboard After 2 hour and 24 hours, particleboard's water absorption ranged between 38.72 and 114.99%, according to the results of a 2 and 24-hour measurement. It was asserted that particleboard's thickness swell and water absorption were physical properties that influenced its response to soaking conditions. The highest and lowest water absorption values were observed with the control and waterproof applications, respectively. We assumed the impermeable properties of particleboard prevented water from penetrating. Waterproof also exhibited a negative water absorption value. A waterproof coating reduced water absorption by nearly threefold compared to untreated surfaces. The statistical analysis of water absorption revealed that treatments significantly affected the water absorption value for 2 hour and 24 hours, with a 95% confidence interval.

$$\text{WA (\%)} = \frac{W1-W0}{W0} \times 100.$$

Equation 3.4.2

It is calculated as follows,

WA = water absorption (%)

W0 = initial weight (g)

W1 = weight of the sample after immersion (g)

3.5 Determine of mechanical properties.

Using Japan Industrial Standard (JIS A 5908:2003), mechanical tests for modulus of elasticity, modulus of rupture, and tensile strength were conducted on samples of each resin density.

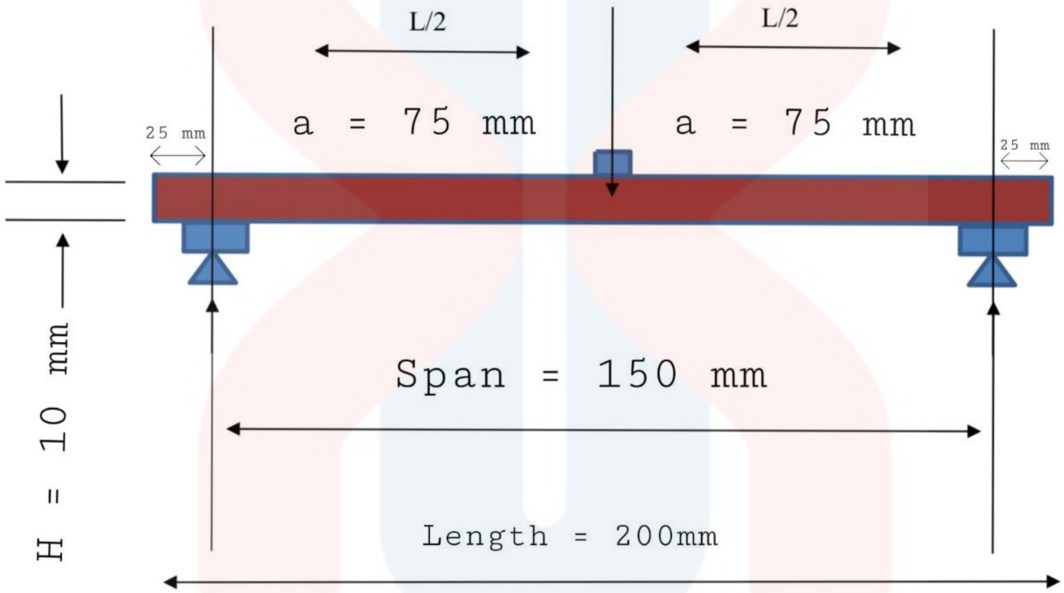


Figure 4: Test setup for determining the bending strength

(Source: JIS A 5908:2003)

3.5.1 Bending Strength Test

The MOR and MOE or bending strength test was conducted using standard testing apparatus that was able to deliver and measure a force of less than 1%. According to JIS A 5908:2003, the specimen under test was centered and level on the parallel supports. Nine 150 mm long, 150 mm wide, and 10 mm thick samples were used for this test. At a pace of 3 mm/min, the load was continuously applied at midspan at a nearly uniform rate of crosshead motion.

$$MOR = +\frac{3Fmax^{\text{'}}1}{2bt^2}$$

Equition 3.5.1

Where,

Fmax = is the maximum load (N)

t1 = is the distance between the centres of the supports (mm)

b = is the width of the test piece (mm)

t = is the thickness of the piece (mm)

$$MOE = \frac{^{\text{'}}13(_{m2} - _{m1})}{4bt^3(a^2 - a^1)}$$

Equition 3.5.2

Where,

11 = is the distance between the centres of the supports, in millimetres

b = is the width of the test piece, in millimetres

t = is the thickness of the test piece, in millimetres

m2 – m1 = is the increment of load on the straight- line portion of the load-deflection curve, in N.

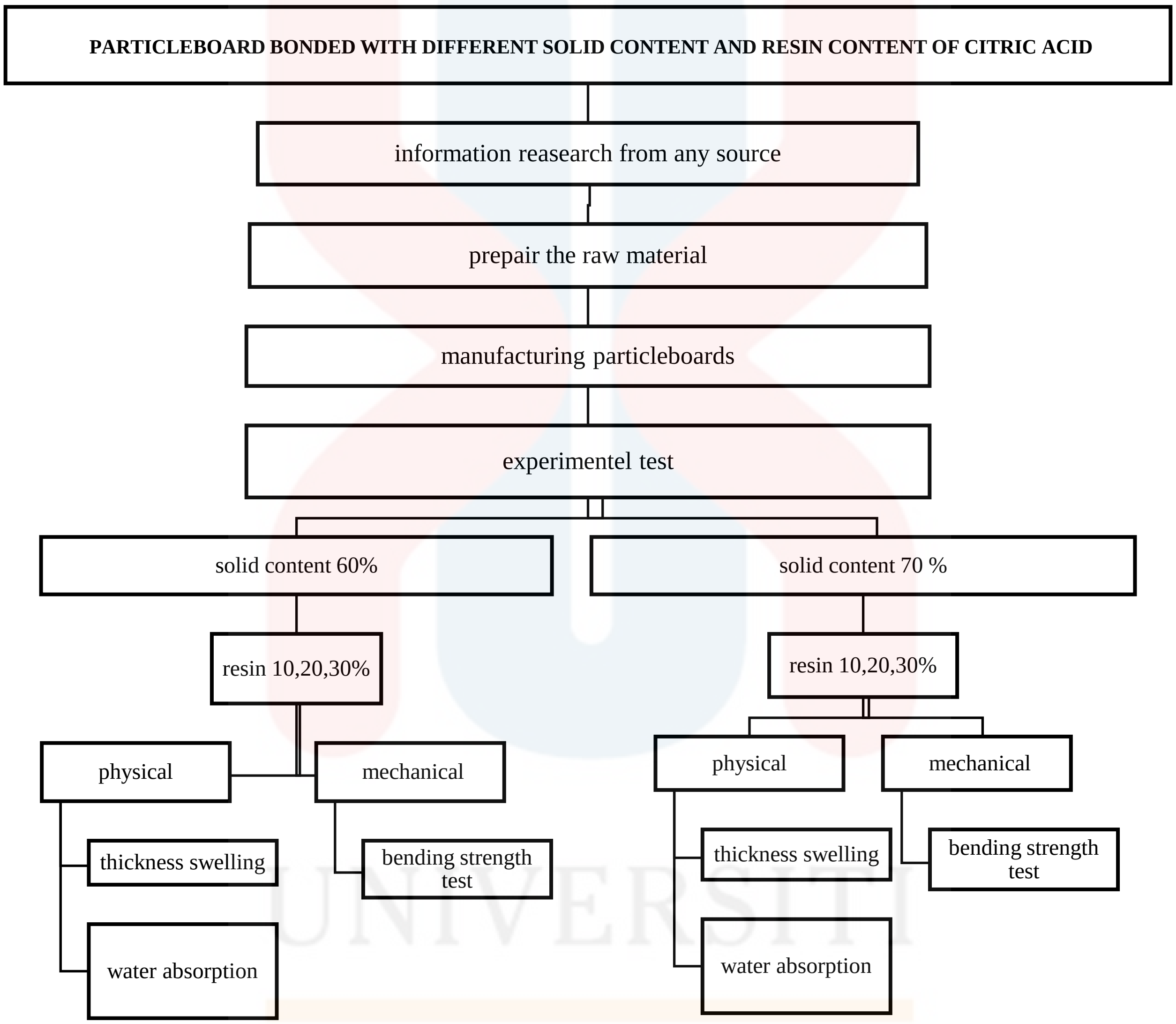
a2-a1 = is the increment of deflection at the mid-length of the test piece (corresponding to F2 – F1)

No.	Method test	Dimension	Number of specimens
1.	Thickness swelling / water absorption 2& 24 hour	50 mm x 50 mm x 10 mm	3 replicates
2.	Dry bending (MOR and MOE)	200 mm x 50 mm x 10 mm	3 replicates

Table 3**:** shows the (J I S A5908: 2003)

3.6 Research Flow

The research flow chart was displayed as shown in figure.



CHAPTER 4
RESULTS AND DISCUSSION

4.1 Properties of Particleboard

A total of six particleboards were manufactured for each resin content and solid content, with the aim of demonstrating the effectiveness of each parameter in the blending of bamboo *Gigantochloa albociliata* with the resin used in this research, namely citric acid. Several testings were conducted in this study to determine the mechanical and physical properties used consistent terminology applied to particleboards. Particleboard, characterized by its comparatively low moisture content, possesses significant industrial value as a substitute material in the fabrication of wooden goods. By applying the proper level of waterproofing to particle board products that are intended for use in exposed areas, the risk of injury to such products is reduced. Consequently, the objective of this research was to evaluate the physico-mechanical characteristics of particleboard composed of bamboo (*Gigantochloa albociliata*) bonded with varying solid and resin content of citric acid. The effects resin content (10%, 20%, 30%) and solid content (60% and 70%) on the properties of resultant particleboard were studied.

4.2 Mechanical properties

Analysis of variance (ANOVA) for bending properties and all the study variables was conducted and the results are summarised in Table 4 The mean value of MOR and MOE for different resin content and solid content are shown in Table.

Table 4**:** analysis of variance (ANOVA) at P ≤ 0.05 for the interaction mechanical properties between, resin con: Summary tent and solid content bending properties of particleboard samples.

Test	**MOE**		**MOR**	
Study Variable	**Value**	**Pr > F**	**Value**	**Pr > F**
Resin Content	0.352	1.121 [ns]	0.104	2.646
Solid Content	0.112	4.135 [ns]	0.259	1.730

Note: [ns] indicates no significance level *P*> 0.05

Table 5: Mechanical properties of buluh madu (*gigantochloa albociliata*) particleboard bonded with different solid content and resin content of citric acid.

Treatment	**Resin Content**	**Solid Content**	***n***	**MOR (N/mm^2)**	**MOE (N/mm^2)**
1	10	60	3	12.18±0.367^b	2963.62±144.576^a
2		70	3	6.38±1.707^a	2633.17±370.794 ^{a}
3	20	60	3	11.79±0.601^a	3045.28±65.571^a
4		70	3	11.16±1.115^b	2893.56±203.380 ^{a}
5	30	60	3	12.23±0.484^b	3204.46±96.032^a
6		70	3	11.54±1.622^b	2893.79±523.255^a

Note: *n*: number of replicates

According to the data in table 1, the study examined the impact of resin and solid content on bending properties. However, the results showed that these factors did not have a significant effect ($P>0.05$) on the bending properties tested, namely MOR and MOE.

From table 5 shows where all the results that have been taken through the tests conducted on 6 particleboards that have a mixture of citric acid according to different resin and solid content. The table has the results of MOR and MOE on both the mean results taken and the standard deviation stated in table 5.

Table 5 indicates that, in treatment 5, the resin and solid samples consistently exhibit the greatest results. This treatment consists of 30% resin content and 60% solid content, resulting in a mean value of 12.23 N/mm^2 based on three replicates analysed using ANOVA. According to the aforementioned study, the pace at which strength improves depends on the binding strength between the particleboard and the resin, as well as the solid content in treatment 5. There was an increase in resin content from 10% to 20% and solid content from 60% to 70% between treatment 1 and treatment 2. This resulted in a drop of 47.83% compared to the maximum result obtained in treatment 1. The reduction in this trend is likely caused by the restricted processing production factor, which the chance of achieving the necessary weight density for the manufacturing of Buluh Madu particleboard combined with citric acid. The particleboard's MOR and MOE values rose as the amount of citric acid in it grew. The bending strength of particleboard bonded with 20 weight percent citric acid was much higher than that of particleboard bonded with 10 and 15 weight percent. (Zhou Huaxu et al.)

4.3 MOR & MOE Result.

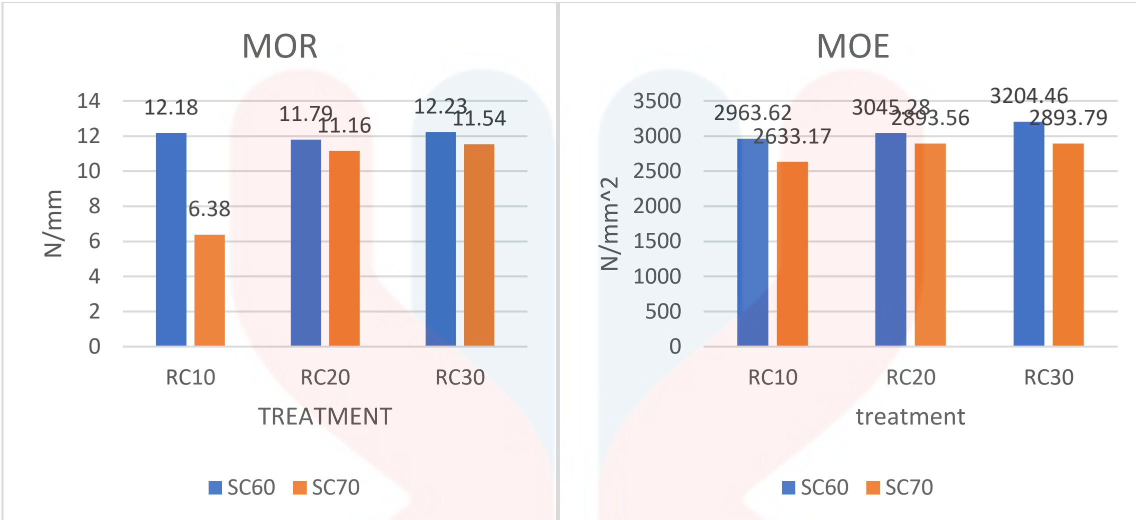


Figure 5**:** Mechanical properties (MOR) and (MOE) testing toward 6 treatment Particleboard.

Based on the graph above referring to the trend experienced by the testing of MOR a significant increase in resin content 30% and solid content 60% which is treatment 5 the best percentage of increase for this research that because the higher properties result have the dimension stability of particleboard manufacturing. In their study, Widyorini et al. (2016) employed citric acid as a substitute binder for bamboo particleboard. Specifically, they applied a citric acid solution, comprising 60% of the total weight, onto bamboo particles with resin contents of 15% and 30%. The study revealed enhanced dimensional stability and mechanical qualities, as indicated which comply with the specifications given in the JIS A5908 (JSA 2015) standard. This is in line with results obtained in this study.

The mechanical properties of modulus of rupture (MOR) and modulus of elasticity (MOE) provide crucial insights into the strength, rigidity, and load-bearing capacity of the manufactured particleboards. The improved MOR and MOE values consistently observed with higher citric acid resin contents can be attributed to multiple factors.

By increasing the resin ratio, the adhesion between bamboo particles is strengthened, resulting in improved load distribution and tension transfer across the board. The cohesive binding effect described in the study by Wang et al. (2020) enhances the particleboard's resistance to deformation and shear stresses. The interaction between the carboxyl groups of citric acid and the hydroxyl groups on bamboo fibres can occur via ester linkage formation and hydrogen bonding, according to scientific research (Umemura et al., 2011). As a consequence, interfacial adhesion is enhanced.

Moreover, an increased concentration of citric acid decreases interparticle cavities through the promotion of fibre coagulation. As indicated by the increased MOE, this densification effect enhances rigidity and stiffness, per Sun et al. (2019). Additionally, decreased porosity restricts the spread of cracks within the material.

Increased utilisation of citric acid may potentially lend further support to the notion that increased moisture resistance contributes to enhanced mechanical strength. Boruszewski et al. (2022) documented a positive correlation between reduced water absorption and elevated MOR and MOE values. A similar effect was detected in the current investigation.

In general, the findings are consistent with previous research that has shown that citric acid concentration has a beneficial effect on mechanical parameters (Widyorini et al., 2017). This is the first study to corroborate these tendencies with regard to bamboo particleboards; prior research has failed to do so. On the basis of these encouraging results, additional research may investigate a broader spectrum of resin-to-solids ratios, alternative materials, and comparative adhesives. However, this inquiry effectively showcases the capacity of citric acid to be utilised in the production of durable, sterile, and environmentally friendly particleboards.

4.4 Physical properties.

Analysis of variance (ANOVA) for bending properties and all the study variables was conducted and the results are summarised in Table 4.4.3 The mean value of Thickness swelling and Water Absorption for different resin content and solid content are shown in Table.

Table 6: Summary of study variable (ANOVA) at P ≤ 0.05 for the interaction between resin and solid content physical properties of particleboard sample.

Testing	**MC**		**TS 2H**		**TS 24H**		**WA 2H**		**WA 24H**	
Study Variable	**Value**	**Pr > F**	**Value**	**Pr > F**	**Value**	**Pr > F**	**Value**	**Pr > F**	**Value**	**Pr > F**
Resin Content	0.216	.1.700^{ns}	0.244	1.554^{ns}	0.160	2.075^{ns}	0.016	5.556^{ns}	0.174	1.967^{ns}
Solid Content	0.352	1.109^{ns}	0.364	1.048^{ns}	0.327	1.242^{ns}	0.327	5.067^{ns}	0.225	2.058^{ns}

Note: ns indicates no significance level *P*> 0.05

Table 7: Physical properties of buluh madu (*Gigantochloa albociliata*) particleboard bonded with different solid content and resin content of citric acid.

Treatment	Resin content	Solid content	*n*	TS 2H	TS 24H	WA 2H	WA 24H
1	10	60	3	6.46± 0.28^{a}	13.38±5.04^{a}	44.80 ±3.55^{b}	52.66±7.71^{b}
2		70	3	6.80 ± 1.57^{a}	8.18 ±1.45^{a}	24.40 ±2.13^{a}	42.22±5.93^{ab}
3	20	60	3	9.07 ± 5.39^{a}	11.18±7.13^{a}	20.74 ±7.35^{a}	41.87 ±5.71^{ab}
4		70	3	4.13 ± 1.99^{a}	6.31±1.31^{a}	20.84 ±2.57^{a}	42.37±1.00^{ab}
5	30	60	3	1.96± 2.46^{a}	5.22 ±2.30^{a}	25.74 ±6.62^{a}	43.96±6.12^{ab}
6		70	3	5.77± 1.38^{a}	6.47 ±1.55^{a}	14.80 ±3.36^{a}	36.11± 6.32^{a}

Note: *n*: number of replicates

The physical characteristic that displayed the most variation between the top and bottom findings after two hours was thickness swelling (TS 2hr). Treatment 3 had the highest TS 2hr result of 9.07 N/mm2, while Treatment 5 yielded the lowest, 1.96 N/mm2. This indicates a significant difference because the greatest number was 363% higher than the lowest. The maximum and minimum values for the other physical attributes varied less. The greatest result (13.38 N/mm2 in Treatment 1) for thickness swelling after 24 hours (TS 24hr) was 156% higher than the lowest result (5.22 N/mm2 in Treatment 5). The maximum value (44.80% in Treatment 1) for water absorption after two hours (WA 2hr) was 202% greater than the minimum (14.80% in Treatment 6). Ultimately, there was a 46% discrepancy between the highest and minimum values for water absorption after 24 hours (WA 24hr), which were 52.66% (Treatment 1) and 36.11% (Treatment 6). The highest value was 363% higher than the lowest, indicating that the resin and solid content had the most effects on the TS 2hour findings. Less susceptibility to the treatment conditions was indicated by the lower variations between 150 and 200% for the other physical parameters.

4.5 Thickness Swelling

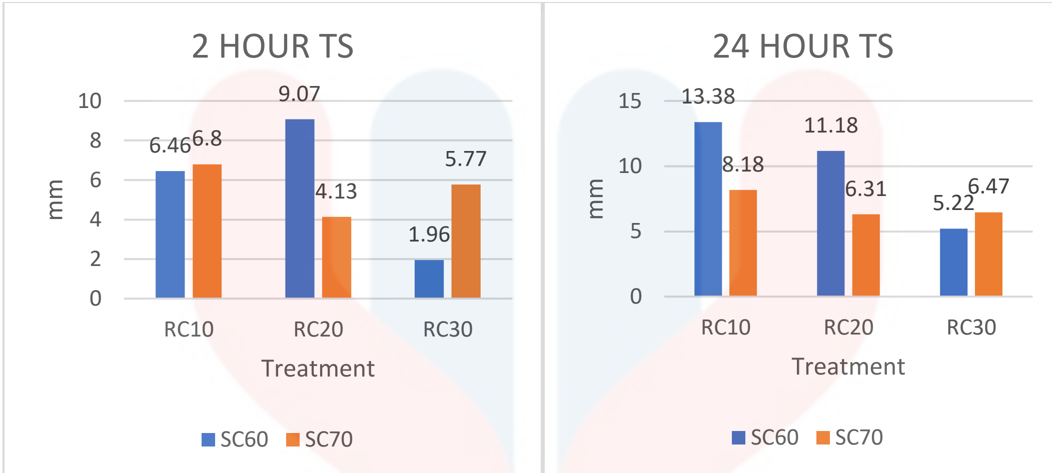


Figure 6: Physical properties testing of Thickness Swelling after 2 and 24 hour

According to the data in graph , treatment 3 exhibited the greatest time thickness testing result after 2 hours, measuring 9.07 mm, surpassing the findings of other treatments. At that particular stage, the resin and solid content may be too high for a duration of 2 hours, resulting in a significant impact on the development of particleboard in treatment 3. When comparing the test results at 24 hours, the highest recorded result was the presence of particleboard in treatment 1. The total thickness measured after 24 hours of soaking was 13.38. This phenomenon occurs because a decrease in the concentration of resin and solids leads to an increase in thickness, as the reduced content hinders the permeation of thickness. Conversely, an increase in the excess content of resin and solids results in a corresponding increase in thickness. Widyorini et al. The bamboo particleboards demonstrated advantageous properties during production at a high press temperature of 200ºC and a citric acid content of 20 wt%. The specific modulus of elasticity (MOE), specific internal bond (IB), and specific modulus of rupture (MOR) were determined to be 0.44 MPa, 1 A correlation between the concentration of citric acid in bambo particleboards and TS. JIS A 5908 stipulates that all TS values for particleboards must not exceed 12%, with the exception of binderless particleboards that underwent heated pressing at a temperature of 200ºC. It was demonstrated unequivocally that elevating the pressing temperature could decrease the TS of binderless particleboard.The mean TS value of binderlessboards subjected to a 10-minute press at 200°C was 21%. After 15 minutes of pressing at 220°C, the TS value decreased to 5%. In light of the fact that every binderless board was manufactured using a hotpressing system, the dimensional stability of the boards produced in this study was comparatively satisfactory (Widyorini et al., 2017).

4.6 Water Absorption.

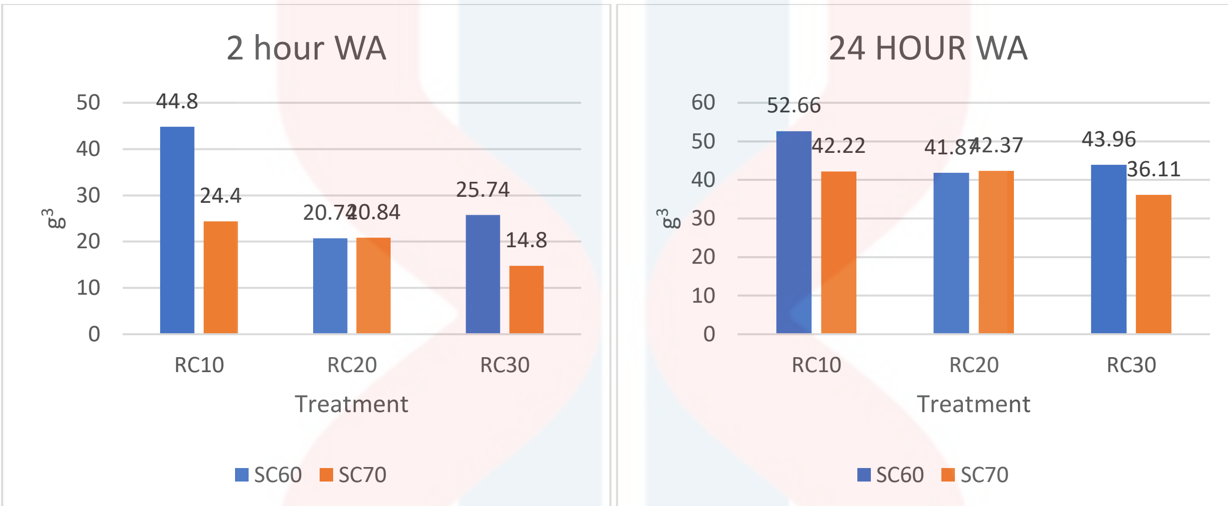


Figure 7 : Physical properties testing of Water Absorption after 2 and 24 hour.

Figure graph data for the physical properties of the water absorption test shows that, at the time of the two-hour testing, the lowest result rate was recorded in treatment 4, where the resin and solid content at 30 and 70 & had a record of 14.8. The highest result came from treatment 1, which is resin and solid content at 10 & 60 with paint 44.8 . There is 66.96 percentile difference between the greatest and lowest percentage rates. This is because, throughout the two hours that the particleboard was tested, the highest record demonstrates the pace at which the resin and solid content effect water permeability. In contrast, treatment 1 only experienced a 17% rate of rise throughout the 24-hour period, indicating that treatment 1's rate of increase is limited by water diffusion. At that point, the results for all particleboards increased at a rate that was twice as fast as before. And a full day later, treatment 3 is still yielding the lowest results. The formula with the lowest result is the one that most accurately describes the water diffusion observations. This is so that the particleboard with the best physical characteristics made from a combination of citric acid and bamboo would be the one with the lowest combined results. In addition, a study conducted by Vukusic et al. (2006) discovered that the decrease in water absorption was more significant for fir and beech wood species when treated with citric acid, especially when a higher dosage of citric acid was used.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this study was to investigate the physico-mechanical characteristics of particleboard produced using Buluh Madu (*Gigantochloa albociliata*) bamboo particles bonded with citric acid resin and solid content in varying proportions. The objective was to ascertain the most effective formulation of citric acid that would yield particleboard exhibiting superior dimensional stability, strength, and resistance to moisture. Significant conclusions can be derived from experimental investigations into the modulus of rupture, thickness expansion, water absorption, density, and modulus of elasticity of particleboards comprising 60-70% solid content and 10-30% resin.

Initially, an increase in the concentration of citric acid resin led to improvements in the material's physical characteristics; 30% resin content produced the least amount of thickness expansion, water absorption, and moisture content. By enhancing particle adhesion and diminishing cavities, the increased resin ratio effectively impeded water diffusion. Additionally, the mechanical properties were enhanced by increasing the percentage of citric acid resin, with 30% resin exhibiting the greatest modulus of rupture and modulus of elasticity. The enhanced adhesion strength provided increased rigidity and resistance to static bending forces prior to failure.

Nevertheless, manipulating the proportion of solids from 60% to 70% had no discernible impact on the physico-mechanical characteristics. This indicates that, within the tested ranges, the resin ratio has a significantly greater effect than the solid content. In general, the ideal compromise between strength, stability, and resistance to water was achieved by incorporating 30% citric acid resin, irrespective of whether the composition was 60% or 70% solid.

This study concludes by demonstrating the viability of citric acid as an environmentally benign binder in the production of bamboo particleboard. The primary benefits encompass diminished thickness swelling, enhanced mechanical strength, improved moisture exclusion, and the avoidance of formaldehyde emissions commonly associated with conventional UF resins. The results offer valuable insights into the productive utilization of citric acid and Buluh Madu bamboo in the environmentally friendly manufacturing of particleboard that exhibits exceptional physico-mechanical properties.

5.2 Recommendations

The literature review could be expanded to provide more background on particleboards manufactured from bamboo and the use of citric acid as a green binder. Incorporating recent relevant research through additional citations would demonstrate current knowledge and unanswered questions that this work aims to address. Further details specifically on the anatomical structure, chemical composition, and physical/mechanical properties of the Buluh Madu bamboo are advised since this material is central to the study. A more in-depth comparison between citric acid and standard binders like urea-formaldehyde would also be beneficial regarding bonding performance, emissions, and prior particleboard research utilizing this novel adhesive.

The methods section warrants elaboration on the Buluh Madu sample preparation, particleboard fabrication procedures, and testing protocols implemented. Comprehensive details would allow reproducibility of the experimental work. More rationale could be provided on selecting the exact resin and solid content ratios examined. Statistics including sample sizes, replication, controls, and analysis methods should also be reported. In the results and discussion, data presentation could be enhanced through tables or figures to improve clarity when communicating the trends. Further interpretation of why certain citric acid contents optimized physic-mechanical properties would provide better insights. Relating the findings to previous literature would give important context and linkages for the reader.

Practical implications and applications arise as a result of the discourse surrounding the merits of the research. can contribute to and enhance the industry's future development of composite materials. This serves as an indicator of forthcoming economic expansion in developing regions.

REFERENCES

Kusumah et al., Kenji Umemura, Yoshioka, K., Hisashi Miyafuji, & Kozo Kanayama. (2016). Utilization of sweet sorghum bagasse and citric acid for manufacturing of particleboard I: Effects of pre-drying treatment and citric acid content on the board properties. *Industrial Crops and Products*, *84*, 34–42. https://doi.org/10.1016/j.indcrop.2016.01.042

Boruszewski, P., Borysiuk, P., Jankowska, A., & Pazik, J. (2022). Low-Density Particleboards Modified with Blowing Agents—Characteristic and Properties. *Materials*, *15*(13), 4528. https://doi.org/10.3390/ma15134528

Chen, Q., Zhang, R., Qin, D., Feng, Z., & Wang, Y. (2018). Modification of the Physical-mechanical Properties of Bamboo-plastic Composites with Bamboo Charcoal after Hydrothermal Aging. *BioResources*, *13*(1). https://doi.org/10.15376/biores.13.1.1661-1677

Ciriminna, R., Meneguzzo, F., Delisi, R., & Pagliaro, M. (2017). Citric acid: emerging applications of key biotechnology industrial product. *Chemistry Central Journal*, *11*(1). https://doi.org/10.1186/s13065-017-0251-y

DIRECT, S. (2015). *Particle Board - an overview | ScienceDirect Topics*. Sciencedirect.com. https://www.sciencedirect.com/topics/materials-science/particle-board

Gauss, C., Araujo, V. D., Gava, M., Cortez-Barbosa, J., & Junior, H. S. (2019). Bamboo particleboards: recent developments. *Pesquisa Agropecuária Tropical*, *49*, 1–9. https://www.redalyc.org/journal/2530/253067965057/html/#gt1

Hong, S. H., & Chung, K. H. (1995). Effects of vacuum hot pressing parameters on the tensile properties and microstructures of SiC-2124 Al composites. *Materials Science and Engineering: A*, *194*(2), 165–170. https://doi.org/10.1016/0921-5093(94)09676-7

Huang, X., Li, F., De Hoop, C. F., Jiang, Y., Xie, J., & Qi, J. (2018). Analysis of Bambusa rigida bamboo culms between internodes and nodes: Anatomical characteristics and Physical-mechanical properties. *Forest Products Journal*. https://doi.org/10.13073/fpj-d-17-00035

Jawaid, M., Rangappa, S. M., & Siengchin, S. (2021). *Bamboo fiber composites : processing, properties and applications*. Springer.

Jett, B. D., Hatter, K. L., Huycke, M. M., & Gilmore, M. S. (1997). Simplified Agar Plate Method for Quantifying Viable Bacteria. *BioTechniques*, *23*(4), 648–650. https://doi.org/10.2144/97234bm22

Song, W., Zhao, F., Yu, X., Wang, C., & Wei, W. (2015). Interfacial Characterization and Optimal Preparation of Novel Bamboo Plastic Composite Engineering Materials. *Bioresources*, *10*(3). https://doi.org/10.15376/biores.10.3.5049-5070

Sun, S., Zhao, Z., & Umemura, K. (2019). Further Exploration of Sucrose-Citric Acid Adhesive: Synthesis and Application on Plywood. *Polymers*, *11*(11), 1875. https://doi.org/10.3390/polym11111875

Syamani, F. A., Kusumah, S. S., L Astari, Prasetiyo, K. W., Wibowo, E. S., & Subyakto. (2018). *Effect of pre-drying time and citric acid content on*Imperata cylindrica*particleboards properties*. *209*, 012034–012034. https://doi.org/10.1088/1755-1315/209/1/012034

Umemura, K., Ueda, T., & Kawai, S. (2011). Characterization of wood-based molding bonded with citric acid. *Journal of Wood Science*, *58*(1), 38–45. https://doi.org/10.1007/s10086-011-1214-x

Wang, X., Yuan, Z., Zhan, X., Li, Y., Li, M., Shen, L., Cheng, D., Li, Y., & Xu, B. (2020). Multi-scale characterization of the thermal – mechanically isolated bamboo fiber bundles and its potential application on engineered composites. *Construction and Building Materials*, *262*, 120866–120866. https://doi.org/10.1016/j.conbuildmat.2020.120866

Widyorini, R., Yudha, A. P., Adifandi, Y., Umemura, K., & Kawai, S. (2017). Characteristic of Bamboo Particleboard Bonded with Citric Acid. *Wood Research Journal*, *4*(1), 31–35. https://doi.org/10.51850/wrj.2013.4.1.31-35

Yang, S., Nuridansyah Muhammad Galih, Kim, J., Lee, H., & Kang, S. (2023). Physical and mechanical properties of particleboard mixed with waste ACQ-treated wood. *Journal of Material Cycles and Waste Management*, *26*(1), 410–420. https://doi.org/10.1007/s10163-023-01837-y

Yusoff, M. S. R., Bahari, S. A., Haliffuddin, R. M. A. A., Zakaria, M. N., Jamaluddin, M. A., & Rashid, N. H. M. N. (2021). Chemical contents and thermal stability of Madu bamboo (Gigantochloa albociliata) for natural-bonded fiber composites. *IOP Conference Series: Earth and Environmental Science*, *644*(1), 012009. https://doi.org/10.1088/1755-1315/644/1/012009

Zhou Huaxu, Seng Hua Lee, Paridah Md. Tahir, Zaidon Ashaari, S.O.A. SaifulAzry, Nor Azowa Ibrahim, Luqman Chuah Abdullah, & Siti Aishah Mohamad. (2020). *Physico-Mechanical and Biological Durability of Citric Acid-Bonded Rubberwood Particleboard*. *13*(1), 98–98. https://doi.org/10.3390/polym13010098

Bischof Vukusic, B. V., Katovic, D., Schramm, C., Trajkovic, J., & Sefc, B. (2006). Polycarboxylic acids as non-formaldehyde anti-swelling agents for wood. *Holzforschung*, *60*(4), 439–444. https://doi.org/10.1515/hf.2006.069

APPENDIX A

Figure 8 : Preparation material of buluh madu (*Gigantochloa albociliata)*

Figure 9: citrid acid as the resin

Figure 10: cutting the bamboo

Figure 11 : drying the bamboo of buluh madu

APPENDIX B

Figure 12: chipping the bamboo

Figure 13: preparation of equipment

Figure 14: manufacturing the particlebords

Figure 15:Preparation the particlebords to replicate

APPENDIX C

Figure 16:Machine of bending test

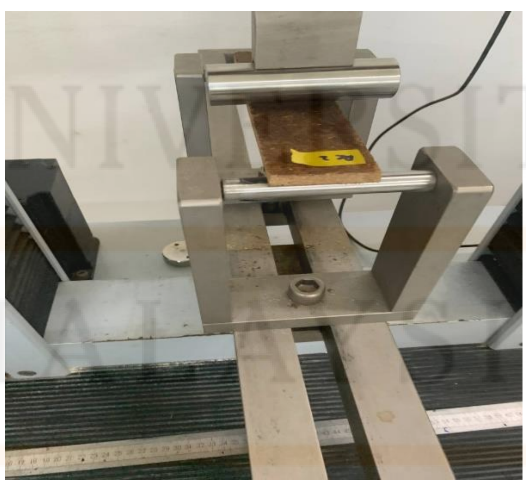


Figure 17: Bending test process

Figure 18:Water absorption and thickness swelling process

Figure 19:Measure the thickness of particleboards