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Physico-mechanical Properties of Buluh Minyak (*Bambusa vulgaris*) Particle board Bonded with Different Solid Content and Resin Content of Citric Acid

Jermaine Allen Anak Emparie

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DECRALATION

I declare that this thesis entitled of Physico-mechanical Properties of Buluh Minyak (*Bambusa vulgaris*) 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 : JERMAINE ALLEN ANAK EMPARIE

Date : ____________________________

Verified by:

Signature : ____________________________

Supervisor's Name : DR. LUM WEI CHEN

Stamp : ____________________________

Date : ____________________________

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Table of Contents

Physico-mechanical Properties of Buluh Minyak (*Bambusa vulgaris*) Particle board Bonded with Different Solid Content and Resin Content of Citric Acid

ABSTRACT

Oil Bamboo (*Bambusa vulgaris*) is versatile bamboo that is often used because of its potential in various applications. However, the data on the properties of citric acid bonded particleboard fabricated from oil bamboo is lacking. Therefore, this study aims to investigate the physical and mechanical properties of bamboo particleboard, bonded with different solid content, and resin content of citric acid. Solid content (60% and 70%); and ii) resin content (10%, 20%, and 30%). The boards were pressed using a hydraulic press with pressing temperature and time of 180ºC and 10 minutes respectively. The determination of physical and mechanical properties of the samples was conducted in accordance with JIS A 5908:2003. Physical properties, including density, moisture content, thickness swelling (TS), and water absorption (WA), were examined. Additionally, mechanical properties such as Modulus of Elasticity (MOE), and Modulus of Rupture (MOR) were assessed. The results show that the solid content and resin content affect the physical and mechanical properties of the particleboard which changes the particleboard for the better. Similarly, the resin content increase of particle board more water resistant.

Sifat Fiziko-mekanikal Buluh Minyak (Bambusa vulgaris) Papan zarah Terikat dengan Kandungan Pepejal yang Berbeza dan Kandungan Resin Asid Sitrik

ABSTRAK

Buluh minyak (*Bambusa vulgaris*) adalah buluh serbaguna yang sering digunakan kerana potensinya dalam pelbagai aplikasi. Walau bagaimanapun, data tentang sifat papan partikel terikat asid sitrik yang dibuat daripada buluh minyak adalah kurang. Oleh itu, kajian ini bertujuan untuk menyiasat sifat fizikal dan mekanikal papan partikel buluh, terikat dengan kandungan pepejal yang berbeza dan kandungan resin asid sitrik. Kandungan pepejal (60% dan 70%); dan ii) kandungan resin (10%, 20%, dan 30%). Papan ditekan menggunakan penekan hidraulik dengan suhu menekan dan masa iaitu 180^{O}C dan 10 minit. Penentuan sifat fizikal dan mekanikal sampel telah dijalankan mengikut JIS A 5908:2003. Sifat fizikal , termasuk ketumpatan, kandungan kelembapan, pembengkakan ketebalan (TS), dan penyerapan air (WA), telah diperiksa. Selain itu, sifat mekanikal seperti Modulus of Elasticity (MOE), dan Modulus of Rupture (MOR) telah dinilai. Keputusan menunjukkan bahawa kandungan pepejal dan kandungan resin mempengaruhi sifat fizikal dan mekanikal papan partikel yang mengubah papan partikel menjadi lebih baik. Begitu juga, papan partikel lebih tahan air dengan peningkatan kandungan resin.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Bamboo is made up of the *Bambusoideae* family, a subfamily of grasses that grow tall like trees and have species consisting of 115 genera and 1400 species. Bamboo can be found in tropical and subtropical regions as well as in areas with moderately cold climates. Bamboo is a plant that grows rapidly, compared to trees, which means that bamboo is suitable for use as a sustainable resource in the timber industry, especially in construction work, (Dinie Awalludin, 2017). (Camelbalk, 1999) bamboo is a type of wood that is easy to obtain and renewable, which is widely used in the manufacture of furniture that replaces wood.

Bamboo resources in Malaysia are limited. However, demand in local and international markets is potentially high. The parameters used on bamboo are the number of stems, stem height, number of bamboo shoots, bamboo height, and bamboo weight (Johar, 2012). *Phyllostachys bambusoides* is from China but extensively cultivated in Japan since 1866 and it is the largest and the most commercially after *Phyllostachys pubescens*. (IFAR/INBAR, 1991) *Dendrocalamus asper* thought from Thailand. Thailand suggests breeding this plant because most production of edible bamboo is from natural forests. Bamboo was neglected in the past because wood was preferred because of the strength and the durability found in wood.

Wood rubber particleboard has many advantages such as higher density and strength than plywood. In addition, bamboo particle board is stronger than plywood, among flexible plants, and often used as a daily use material such as furniture, buildings, and interiors because it is easy to find and create.

One of the ways to improve the mechanical properties of bamboo particleboard is by adding citric acid resin. (Nadeem, 2010) citric acid is a tricarboxylic acid that is a universal intermediate product in metabolism. Citric acid is a chemical commonly used in the manufacture of composite materials, such as particle board. Citric acid has also been shown to have strong binding properties. Therefore, this resin can improve the mechanical properties of bamboo particleboard by increasing dimensional stability.

Among the advantages of resin for use on bamboo particleboard is better strength and durability. Bamboo particleboard will be more resistant to pressure and moisture after being mixed with resin. Particleboard will be more durable than that which does not use resin. The resin also works to improve the particle board surface that feels rougher to be smoother. The possibility of citric acid resin is also more affordable because bamboo is easily available and grows faster.

1.2 Problem statement

Bamboo is a resource that can be found in large quantities and plays a role in socio-economic development (Panda, 2011). Since its growth is very fast, bamboo emerges as a suitable alternative and availability that other wood. Bamboo is also used as an environmentally friendly material used in civil engineering and construction (Tan et al., 2011).

Bamboo is used intensively in Malaysia traditionally and structurally. In the past, the shape was used in a round shape, but it was expanded to splits and strips (Hamdan et al., 2009). Mixing fast-growing wood species to produce bamboo particleboard, the problem of the declining supply of raw wood such as bamboo in Malaysia can increasingly be overcome. Examples of bamboo species available are Thorn bamboo (*Bambusa blumeana*), Betung bamboo (*Dendrocalamus*), Semantan bamboo (*Gigantochloa scortechinii*), Honey bamboo (*Gigantochloa atroviolacea*), and Oil bamboo (*Bambusa vulgris*).

Although there is growing interest in utilizing bamboo particleboard production, limited research has been conducted on the effects of different solid content and resin content of citric acid on the physical and mechanical properties of particleboard, particularly when fabricated from oil bamboo (*Bambusa vulgaris*) bamboo culm. Therefore, this research aims to address this research gap by investigating the influence of varying solid content and resin content of citric acid on the physical and mechanical properties of particleboard manufactured from the culm of oil bamboo. The findings of this study will contribute to optimizing the formulation of citric acid bonded particleboard, improving its performance, and expanding its potential applications in sustainable construction and furniture industries.

1.3 Objectives

1.3.1 To investigate the effect of different solid content of citric acid on the physical and mechanical properties of oil bamboo particleboard.

1.3.2 To investigate the effect of different resin content of citric acid on the physical and mechanical characteristics of oil bamboo particleboard.

1.4 Scope of study

This research refers to the study of the effects of different solid content in citric acid resin to bamboo particleboard and the effect of different content of citric acid resin. This study aims to test the effectiveness of using citric acid as a binder for bamboo particleboard. This study includes testing the physical and mechanical properties of bamboo with different amounts of resin which is 10%, 20%, and 30%, and solid content which is 60%, 70% at a pressure temperature of 180°C for 10 minutes. Citric acid is an environmentally friendly resin and was used as a binder for bamboo particles to become particleboard. The particleboard sample was assessed based on the Japan Industrial Standard (JIS A 5908:2003) for moisture content, Modulus of Elasticity (MOE), and Modulus of Rupture (MOR). The dimension of the board produced was 300mm×300mm×10mm.

1.5 Significance of study

The focus of this study is to study the effect of different solid content of citric acid resin and the effect of different resin content. This study will provide a lot of information to manufacturers to identify problems that should be solved in the future. This study is also useful to the furniture industry to make a big change for the industry by mixing resin into bamboo particleboard because of the big potential in furniture manufacturing. Not only that, it is a benefit to the environment for the benefit of slow tree growth, and a benefit to the furniture industry in taking advantage of the use of fast-growing wood.

The aim of this research is not only to make use of wood species, but to provide some improvement ideas to the manufacturers about the mixture of bamboo with citric acid resin in the manufacture of particleboard and to test the strength and durability of particle board. Manufacturers should find other ways to make furniture by using raw materials that are cheaper but have the potential to make strong and durable furniture because the cost of other wood is increasing and for tree growth it takes years. Therefore, citric acid is the priority of the manufacturer to grow rapidly in the production of bamboo particleboard with reduced formaldehyde emissions.

CHAPTER 2

LITERATURE REVIEW

2.1 *Bambusoideae* (bamboo) as a raw material

Bamboo or its scientific name, *Bambusoideae* can reach a height of 10 to 20 meters from the ground. Bamboo is the fastest growing plant that takes 3 to 4 years to mature before being harvested as a daily need for people. Although bamboo has been used as a substitute for wood for a long time, before it finally became difficult to obtain wood because it disturbed the earth's ecosystem, bamboo is the best alternative that can replace wood today. However, studies on oil bamboo are mostly limited to the use of silviculture and fertilizers for growth (Azmy et al., 2004).

Figure 2.1: Oil bamboo tree.

(Source: Anim Hosnan, 2014)

This oil bamboo has been found to have strength and durability. In Malaysia, bamboo grows in abundance and covers 5% of the total forest reserve (Mohmod. A, 1992).

2.1.1 Bamboo characteristic

There are several characteristics of bamboo that bamboo grows very quickly that other wood that only needs 3 to 5 years to mature and be harvested before use. Bamboo does not need fertilizers or pesticides to protect bamboo from insect attacks. Bamboo produces more oxygen than other trees and plays an important role in the balance of oxygen and carbon dioxide in the atmosphere. The impact on the environment of bamboo fiber production is lower than other fibers, especially synthetic fibers.

There are approximately 1200 species of bamboo, and the growth conditions will affect the characteristics of each bamboo stalk. Bamboo is among the most durable plants, the outer layer of the stem is dense and strong, and bamboo is flexible. Items or products made from bamboo tend to be durable and resistant to breakage even under heavy pressure (Dasso, 2014). (Bhonde, 2015) bamboo is important because it is widely used for a product. It is a versatile raw material as a substitute for wood. Bamboo is light, cheap, flexible, and strong.

2.1.2 The uses of bamboo

Bamboo is used as food. Bamboo is the newly grown part of the bamboo that is still soft and protected by several skin sheaths. This bamboo shoot is taken after several layers of the sheath are removed and the soft part is washed clean and then cut into pieces before being used as a vegetable in cooking. In China and Japan, monopodial bamboo species such as *Phyllostachys edulis p.,* are the most eaten and most delicious (Hossain et al., 2015).

Bamboo is also used in the construction sector. Bamboo has strong characteristics and is suitable as substitute for wood and steel because of its microfiber structure that contains lignin and hemicellulose. Bamboo can withstand twice the weight and replace materials in road construction, drainage pipes, housing show in figure 2.1.2, and wind turbine construction (Borowski et al., 2022).

Figure 2.1.2: Bamboo as a replacement for steel reinforcement.

Bamboo is used as furniture, but before use, manufacturers will boil, dry, and perhaps grind the bamboo to create many other shapes. The furniture industry uses bamboo as a substitute for wood to make furniture as shown in figure 2.1.3.

Figure 2.1.3: Bamboo dining table set.

2.2 Particleboard

A particle board is a wooden panel made from wood residues created during product manufacturing. There are many products made from particle board into furniture and other items for outdoor and indoor use. Particle board is known as low-density fiberboard (McCoymart, 2023). To produce particle board, standards are listed according to standard values, and this is useful for manufacturers to produce products according to standards. There are several standards in the production of particle board that must comply with international standards such as the British Standard (BS), the Japanese Industrial Standard (JIS), and the European Standard. Particle board is widely used in the manufacture of furniture, where it is usually used for decorative purposes. Particle boards are usually mixed or bonded using citric acid resin. (Stark, N. M, & Cai, Z. (2015) according to Malaysia Standard (MS) 2006, each particle board has thickness with the requirements and specifications of the board.

2.2.1 Properties of particle board

According to Kinjal Mistry 2017, particle board is created with its own advantages because it is taken from the remains of pieces of wood that can be used as furniture such as shelves, tables, chairs, and cabinets because of the cheap purchase cost and the stock that is always available. Since this particle board is made up of pieces cut from wood, this means that the weight of this particle board is very less or lighter than that of medium density fiberboard or plywood. Due to its light nature, it is easy to transport and handle. In terms of strength, particle board has low strength because it is made from wood scraps. Therefore, particle board cannot withstand heavy loads and is only used for light loads. Particle board easily swells and expands in the presence of moisture. In addition, when exposed to moisture, particle board will change color. To prevent that from happening, particle boards should be sanded or painted as it can help prevent moisture and increase strength. Particle board is also a good insulator such as sound insulation. Therefore, most particle boards are used in studios and ceilings of recording studios and even concert halls. Not only does it work as insulation, but particle board is also environmentally friendly because it is produced from recycled materials such as wood scraps. Thus, it helps in environments conservation.

2.3 Citric acid

According to (Ciriminna, R. et al.; (2017), citric acid was first discovered in 1784 in Sweden made from lemons. Citric acid is a preservative, flavoring, emulsifier, and buffering agent commonly used in the food, beverage, pharmaceutical, nutraceutical, and cosmetic industries. Citric acid as an energy metabolism because of its high concentration will increase the metabolic imbalance. The resin content affects the strength of particle board, it will produce physical and mechanical properties (Wan Abdul Rahman et al., 2020).

To produce particleboard should be suitable for the type and amount of resin to be used. Citric acid resin will be used as a binder. The use of appropriate resin will produce quality particle board and the price will be more affordable. The use of resin will also reduce water absorption on particle board (Widyorini, 2016).

2.4 Physical properties

There are different types of physical properties that are determined by various tests. thickness is a physical property indicating the distance between the top surface and the bottom surface of the particle board. thickness affects strength, density, and resistance to stress which also affects curing. For example, the thicker the particle board, the more particle board can support heavy loads. However, the thickness of particle board will make it difficult to form particle board because it is less flexible and difficult to cut. The thickness of particle board affects the safety and comfort of particle board users. If it is too thin, the particleboard will easily break and be dangerous to users, but thick particle board also makes the product heavy and difficult to lift.

2.5 Mechanical properties

The mechanical properties of particleboard are important because they include bending strength, and stiffness. The bending strength of the particle board is tested so that it can withstand pressure before being permanently tested for cracking. This property is very important for particle board as an advantage or disadvantage of this particle board as a support. In addition, stiffness or resistance to weight is the ability of particle board to withstand the weight it receives. This property examines structural stability.

CHAPTER 3

MATERIAL AND METHOD

3.1 Bamboo specimens

Oil bamboo or its scientific name *Bambusa vulgaris* was selected as the raw material in this experiment. The species was chosen because of its various benefits such as rapid growth, strength durability, and lightness. The bamboo selected was more than 5 years old and was taken from UMK Jeli agro park. The bamboo culm was then dried for about 2 weeks until the moisture content reached 12% before being processed into bamboo particles. The bamboo particle were then dried in an oven at 60°C for 7 days to achieve a 3% moisture content before particleboard fabrication. Then, the bamboo particles are stored in plastic to prevent moisture entry.

3.2 Adhesives

Natural adhesives obtained from non-fossil sources such as citric acid are very important in the future (Umemura et al., 2011). Therefore, citric acid in powder form was used as a green adhesive in this study. The citric acid powder was added to distilled water to produced solution with solid content of 60% and 70%. The adhesive solution and bamboo particles were then mixed in a container to ensure even spread-out of the adhesive on the bamboo particles surface. The resin contents used were 10%, 20%, and 30%. The resin and solid content employed in this study were determined following the recommendations provided by previous researches conducted by Widyorini et al., (2016), and Zakaria et al., (2021).

Figure 3.1: Citric acid solution

Material required per board.

*= Length (mm) * Width (mm) * Thickness (mm) * Density (g/cm^3)*

*Amount of liquid resin required (g) = [RS/SC * weight per board (g)] + 5%*

RS = Resin Content

SC = Solid Content

	Dimension	**Specimen Number**
Dry Bending	10mm*50mm*200mm	3 replicates
Thickness Swelling & Water Absorption	10mm*50mm*50mm	3 replicates
Moisture Content	10mm*50mm*50mm	3 replicates

3.3 Particleboard making

Particle board is made from a mixture of wood particles and wood adhesives such as citric acid resin and medium density particle board is often used in the manufacture of furniture, kitchen tables, and many other products (Prasittisopin, 2010).

The wood powder that has been mixed with the binder will be heated and pressed with pressure. The resulting particle board will be cut to the desired size before being used to make products based on particle board. The manufacture of this particle board is very good because it utilizes wood waste, and the binding material is also cheap.

3.4 Particle board manufacture

The production of a particle board with single layer and dimensions of 200*200*10 (mm). Citric acid was used as binding agent, with resin content of 10%, 20%, and 30%, based on the oven-dried weight of the bamboo particles used, meanwhile solid content used was is 60% and 70%. The process of blending particle board and adhesive will be accomplished through the utilization of rotary blender. the particle board will be put in a hot pressure, within a room temperature 23+-*C.

Information	Condition
Sample size	200mm*200mm*10mm
Adhesive	Citric acid Resin content: 10%, 20%, 30% Solid content: 60%, 70%
Density target	0.7g/cm^3

Hot pressing	Temperature: 180°C Time: 10 minutes Pressure: 2.44N/mm^3

3.5 Determination of physical properties

These physical properties refer to properties of a material that are observed regarding the behavior, performance, and suitability of the material. Understanding the physical characteristics of particle board is very important because the priority of particle board production is based on the quality, durability, and performance of particle board in various conditions. Physical properties in this test include density, moisture content, thickness swelling, and water absorption.

3.5.1 Density

Density refers to the mass of a substance. It provides information about the density found in the material. Density plays an important role in producing particle board with strength, durability, and quality. Density in kilograms per cubic meter (kg/m^3). The mass of the sample is weighed using a balance, while the content is calculated by measuring the dimensions of the sample. Density is affected by various factors, especially the particle size of the wood used, the resin content, and the production process. Particle boards with a dense content tend to be stronger and more resistant, but if the density is too high, the work of the board will be more difficult. Density also affects sound, as particle board with a high density can offer better insulating properties due to the presence of less air in the material. An understanding of the density of particle board is very important in the furniture manufacturing industry as it aids in the production of quality boards, and compliance with industry standards and regulations. The density was calculated using the

Following formula:

$$p = \frac{M1}{V}$$

Where,

p = density

M1 = mass (g)

V = volume (cm^3)

3.5.2 Moisture content

Moisture content refers to the amount of water contained in a material. Moisture content measurement is knowing the moisture level of particle board because it can affect the strength, dimensional stability, and physical properties of the entire material. Moisture content that is too high will cause swelling, loss of strength, and bad smell. Particleboard samples are taken and weighed with notes before and after drying to measure the moisture content of the material. The sample is usually dried in a kiln at a set temperature and time. The weight between the wet and dry samples is one way to calculate the moisture content of the sample. The determination of particle board moisture content is important in the production and storage process of particleboard, it can ensure that particleboard meets the requirements of standards.

Following formula:

$$MC\ (\%) = \frac{AD - OD}{OD} \times 100\%$$

Where,

MC = moisture content (%)

OD = oven dry weight of wood particle

AD = air drying weight

3.5.3 Thickness Swelling

Swelling is a phenomenon that occurs on particle boards that experience an increase in thickness because they are exposed to water, or the surrounding conditions are humid. These physical properties should be practiced in evaluating the particle board's ability to maintain its structure and dimensions. Particleboard absorbs moisture causing wood particles and binders to dissolve in water. As a result, the particle board swells. The swelling test is done by immersing the particle board sample in water. The thickness is measured before and after soaking for a specified period. The change in the sample is not only in the distribution, but also occurs in the increased mass of the material. In addition, the swelling test determines the particle board's resistance to moisture and dimensional changes. The information obtained from this test is the initial planning in using particle board as furniture production, and so on.

Following formula:

$$TS\ (\%) = \frac{T1 - T0}{T0} \times 100$$

Where,

TS = thickness swelling

T0 = initial thickness before immersion (mm)

T1 = thickness after immersion (mm)

3.5.4 Water absorption

Water absorption is where particleboard directly absorbs water or moisture from the environment. It is important to study and consider because it maintains the stability of the particle board. The occurrence of water absorption on particle board depends on the density of the board, the quality of the binding material, and the particleboard is exposed to the remains of pieces of wood that have a more open structure and tend to absorb water. To measure the water absorption of particleboard in water and record whether the particleboard can withstand water and how susceptible it is to swell or strength due to water absorption. These characteristics are important in the production of strong and water-resistant particleboard and the use of adhesives to protect the surface of the board.

Following formula:

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

Where,

WA = water absorption (%)

W0 = initial weight (g)

W1 = weight of the sample after immersion (g)

3.6 Determination of mechanical properties

Determining the mechanical properties of particle board is important in knowing its behavior under various loads. These properties include tensile strength, compressive strength, flexural strength, and impact strength. The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) is an additional mechanical property that is important in evaluation board stiffness.

The formula MOR

$$Bending\ strength\ \left(\frac{N}{mm2}\right) = \frac{3PL}{2bt^2}$$

Where,

P = maximum load (N)

L = span (mm)

b = width of the test piece (mm)

t = thickness of test piece (mm)

While MOE

$$MOE = \frac{3(F2 - F1)l1\ 2l2}{4bt3(U2 - U1)}$$

It is calculated as follows,

(F2-F1) = increment of load on the straight-line portion of the load deflection curve.

F1 = approximately 10%

F2 = approximately 40% of maximum load

Fmax, (U2-U1) = increment of deflection corresponding to (F2-F1) in load deflection curve.

An illustration of the bending strength test is shown in figure 3.3.4 below.

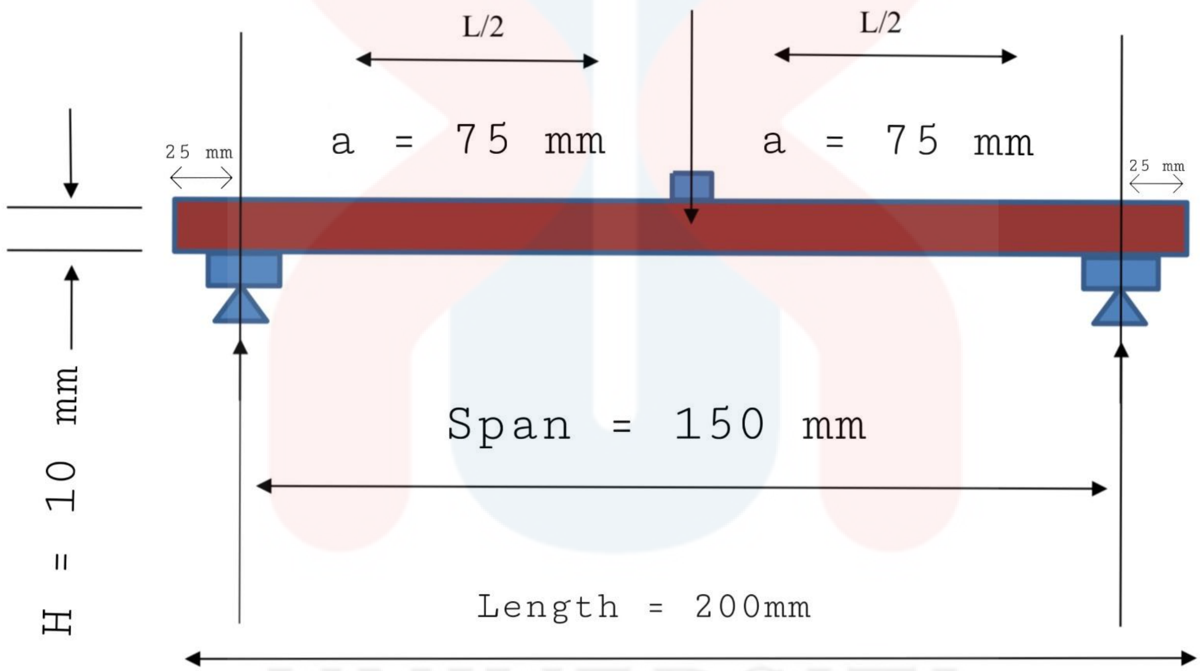


Figure 3.6.1 Test Setup for Determining the Bending Strength

(Source: JIS A 5908:2003)

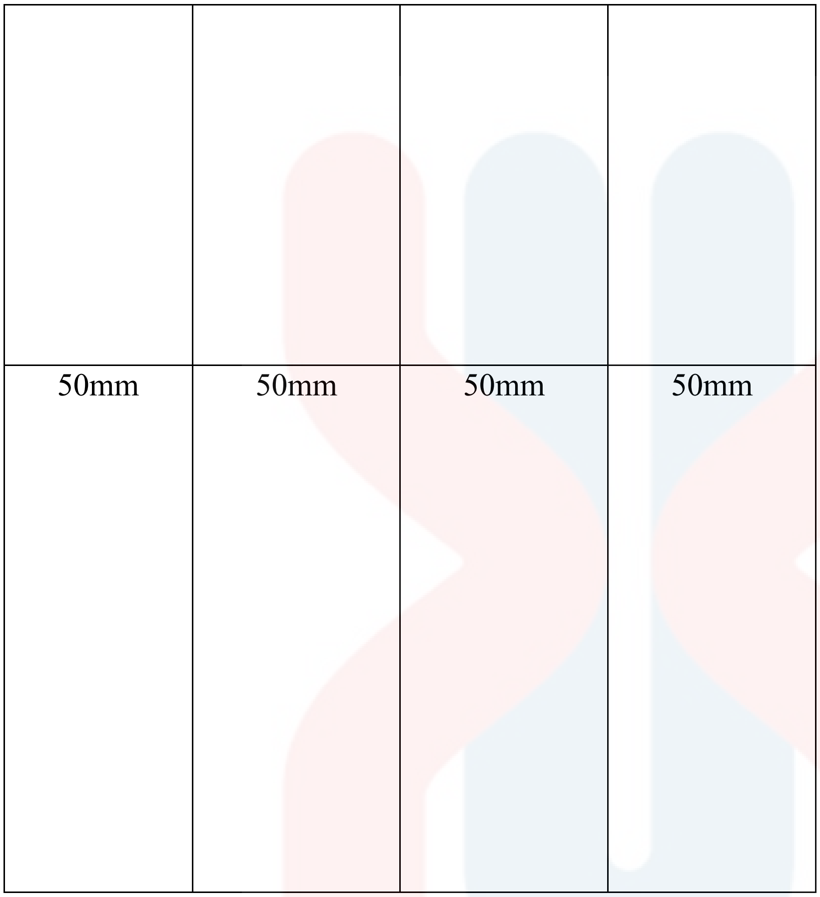
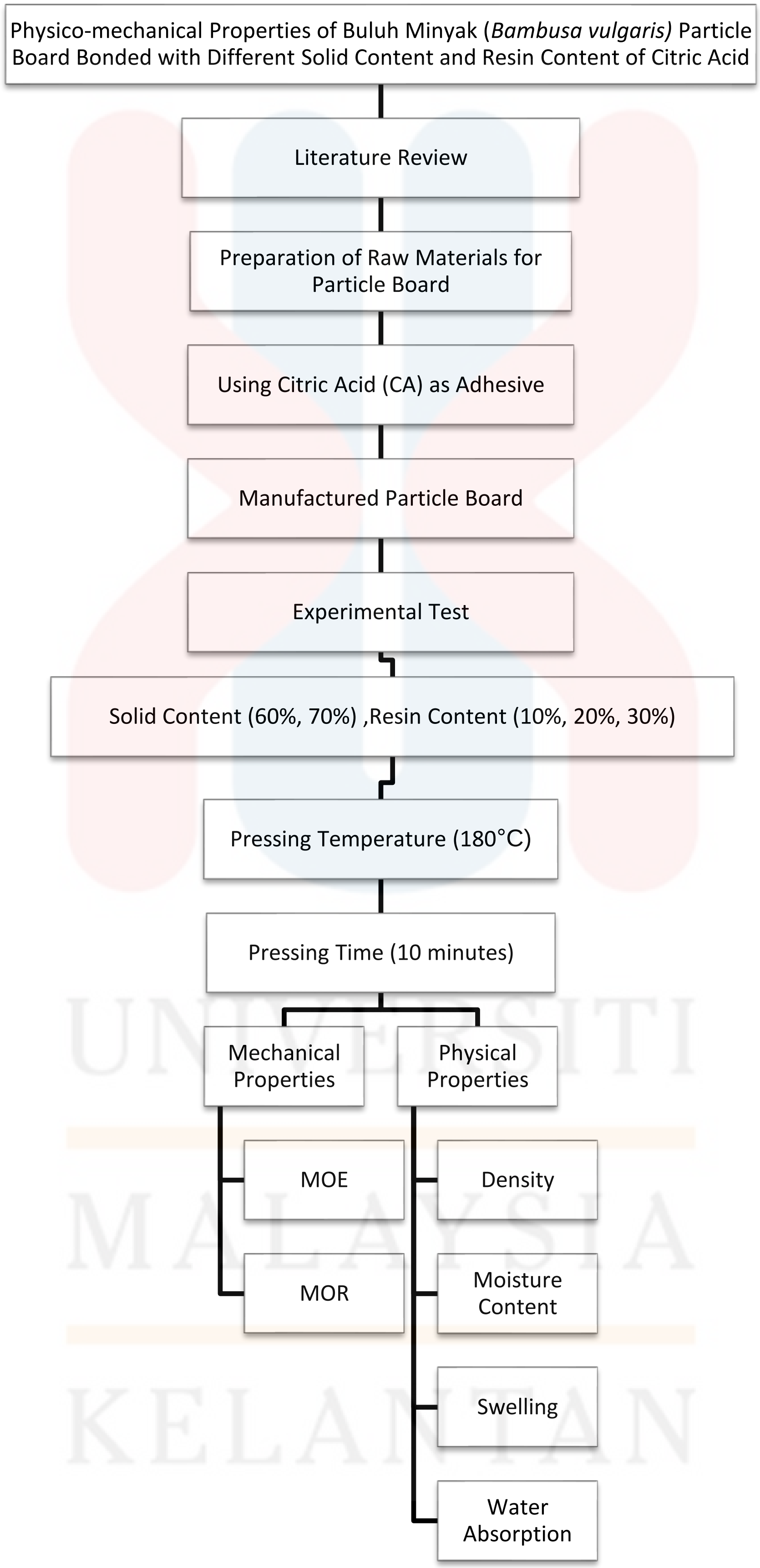


Figure 3.6.2: The cutting pattern of one particle board replicate.

3.7 Research flow chart

A research flow chart is a graphical presentation that illustrates the order or sequence of steps in the research process. It involves several important steps including sample preparation, evaluation, and synthesis of experimental results. Illustrated in the diagram about solid content and citric acid content.


Physico-mechanical Properties of Buluh Minyak (*Bambusa vulgaris)* Particle Board Bonded with Different Solid Content and Resin Content of Citric Acid
Literature Review
Preparation of Raw Materials for Particle Board
Using Citric Acid (CA) as Adhesive
Manufactured Particle Board
Experimental Test
Solid Content (60%, 70%) ,Resin Content (10%, 20%, 30%)
Pressing Temperature (180°C)
Pressing Time (10 minutes)
Mechanical Properties
Physical Properties
MOE
MOR
Density
Moisture Content
Swelling
Water Absorption

CHAPTER 4

RESULT AND DISCUSSION

4.1 Properties of particleboard

In this investigation, six board were obtained using citric acid as the adhesive. This particleboard was created by using the culm of *Bambusa vulgaris* and binding it with citric acid as a glue raw material. The particleboard was produced using a press test equipment with a temperature of 180°C and a duration of 10 minutes. This experiment aims to investigate the mechanical and physical properties of particleboards under specified conditions. The benefits of the wood or furniture industry may be seen in the way it combines and reduces human labour requirements in a particular product that is produced based on verified data.

4.1.1 MECHANICAL PROPERTIES

HOMOGENEOUS SUBSET, SPSS (Tukey LSD)

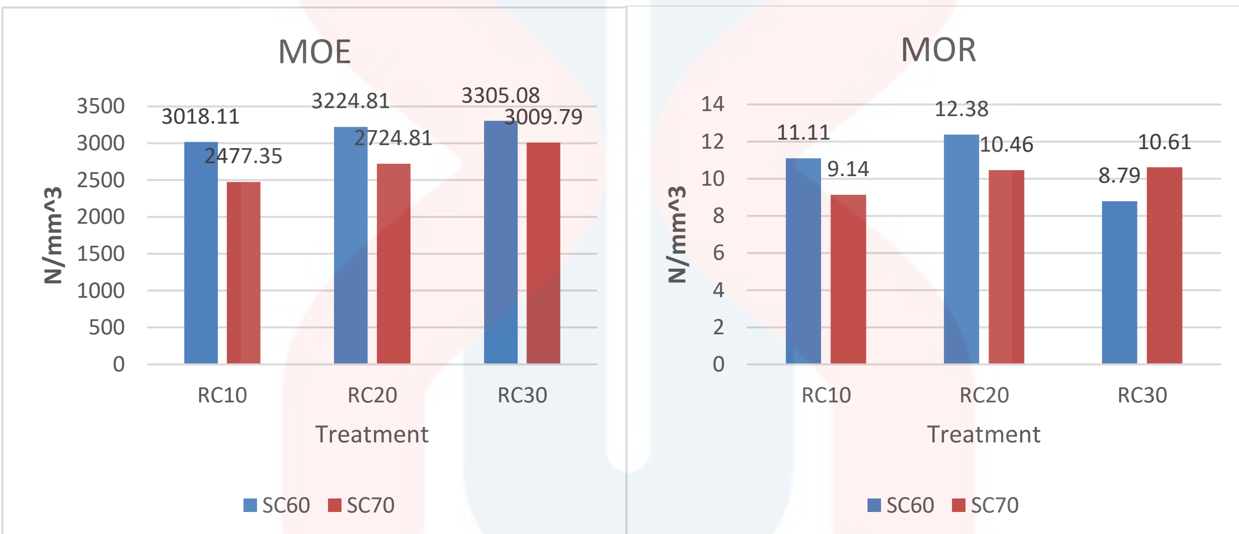
The resin content, solid content, MOE, and MOR of all particleboard samples was summarized in Table 1.

Table 1: Bending properties of MOE and MOR particleboard from oil bamboo.

Treatment	Resin Content	Solid Content	MOE (N/mm^3)	MOR (N/mm^3)
1	10	60	3018.11±3018.11^{a}	11.11±11.11^{b}
2		70	2477.35±2477.35^{a}	9.14±9.14^{b}
3	20	60	3224.81±3224.81^{a}	12.38±12.38^{b}

4		70	2724.66±2724.66[a]	10.46±10.46 [b]
5	30	60	3305.08±3305.08[a]	8.79±8.79 [b]
6		70	3009.79±3009.79[a]	10.61±10.61 [b]

Note: Means followed by the different superscript letters in the same column are significantly different according to Tukey's Honest Significant Difference test at P≤0.05.



The modulus of rupture (MOR) and modulus of elasticity (MOE) can be utilized to quantify the particleboard's mechanical characteristics. The MOE of the samples produced with 10% resin content and 60% solid content, was 3018.11 N/mm^^{3}. This figure shows a 17.92% decrease to 2477.35 N/mm^^{3} alongside a solid content of 70%. For MOR, its value was 11.11 N/mm^^{3} at a solid content of 60%; when there is a solid content of 70%, it goes down to 9.14 N/mm^^{3}, referring to a 17.73% decrease.

Mechanical strength at 20% further resin content, and similar results for MOE and MOR, i.e., approximately 15.51%. In solid content 60%, MOE is 3224.81 N/mm^^{3}, while in solid content

70%, it is 2724.66 N/mm^3. Generally, MOR with solid content of 60% is 12.38 N/mm^3 and decreases to 10.46 N/mm^3.

Resin 30%, solid content 60%, and MOE of 3305.08 N/mm^3 are reduced by approximately 8.93%, i.e., solid content 70%, 3009.79 N/mm^3. However, there is a 20.71% increase in solid material from 60% to 70% on the MOR. Solid content MOR pada 60% is 8.79 N/mm^3 and solid content on 70% is 10.61 N/mm^3.

Each of the resin contents—10%, 20%, and 30%—has a different effect that results in a decrease in both MOE and MOR; yet MOR at 30% resin content experiences a drop in MOR compared to other resin contents.

PHYSICAL PROPERTIES

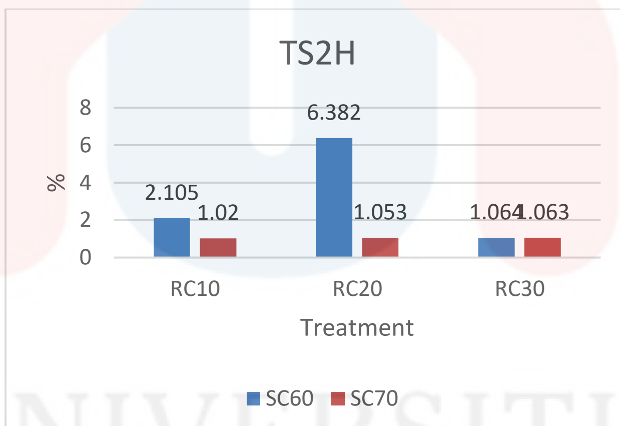
HOMOGENEOUS SUBSET, SPSS (Tukey LSD)

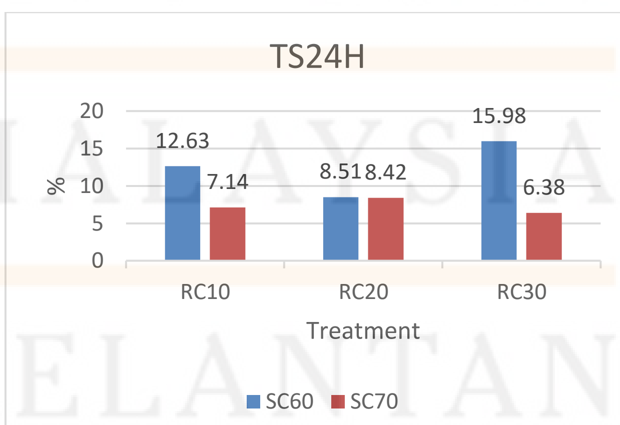
Treatment	**RC**	**SC**	**TS2H**	**TS24H**	**WA2H**	**WA24H**	**MC**
1	10	60	2.105±2.105	12.632±12.632	33.449±-33.449^{a}	82.669±82.669^{b}	42.227±42.227^{a}
2		70	1.02±1.02	7.143±7.143	9.619±-9.619^{a}	95.55±95.55^{b}	33.039±-33.039^{a}
3	20	60	6.382±6.382	8.511±8.511	0.124±-0.124^{a}	66.705±66.705^{b}	19.577±19.577^{a}
4		70	1.053±1.053	8.421±8.421	20.331±20.331^{a}	98.363±98.363^{b}	44.18±44.18^{a}

5	30	60	1.064±1.064	15.975±15.975	32.237±32.237[a]	72.254±72.254[b]	48.51±48.51[a]
6		70	1.063±1.063	6.383±6.383	9.707±9.707[a]	50.309±50.309[b]	33.379±33.379[a]

Table 2: Bending properties of thickness swelling (TS), water absorption (WA), and moisture content (MC) of particleboard from oil bamboo.

The physical properties explain moisture content (MC), water absorption (WA), and thickness swelling (TS). Research is conducted on the particle size distribution of resin content with solid content. Particles undergo changes that affect their quality and stability.





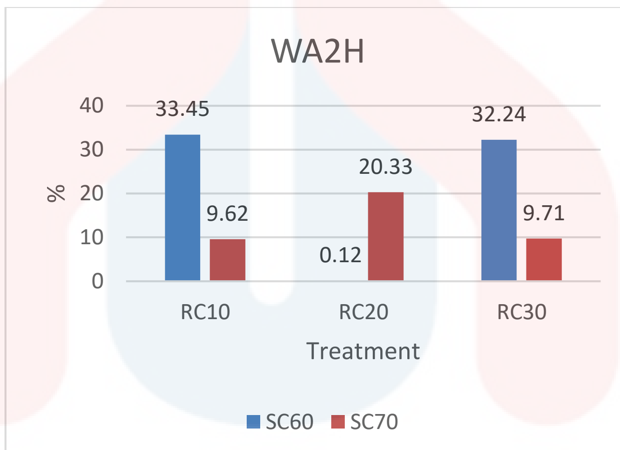
The swelling thickness is related to the increase in thickness of particle particles and is measured every two and twenty-four hours. In the case of 10% resin content and 60% solid content, thickness swelling is 2.105% and decreases to 1.02% in the case of 70% solid content. This is around 51.54% decreased. Along with a 20% resin component, the solid content at 60% is 6.382%, and at 70% it is 1.053%. Data shows reports a decrease of about 83.5%. In general, at 30% resin content, it experiences a slight deformation of about 0.09% compared to 1.064% for solid content 60% and 1.063% for solid content 70%.

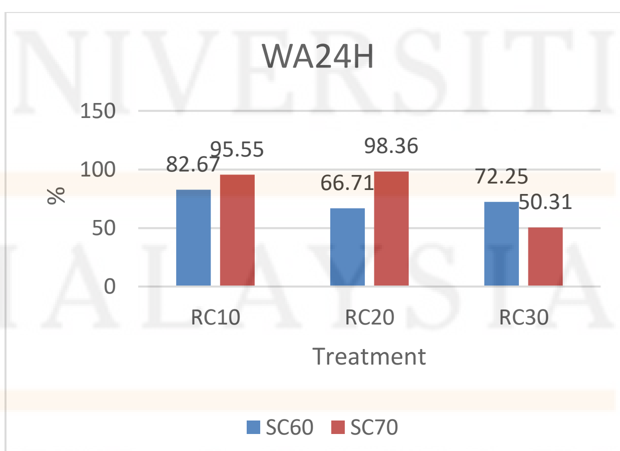
Additionally, thickness swelling is noted after 24 hours of particle direct delivery. With 10% resin content, solid content 60% experiences a decrease of 12.632% and solid content 70% experiences a decrease of 7.143%. Decreasing is about 43.45%. 20% further resin content, approximately 8.511% in solid content 60% and approximately 8.421% in solid content 70%. It has a slight decrease of approximately 1.06%. The 30% resin content is noted, whereas the solid content 60% and 70% correspond to 15.975% and 6.383%, respectively, and 60.04%, respectively.

Based on the percentages of specified in the table, by increasing the amount of solid content from 60% to 70% and the same amount of resin content can add strength and reduce moisture or reduce occurrence of swelling on the particleboard.

Water absorption is related to a substance's ability to hold onto water or its ability to hold onto particles in suspension. Water absorption is measured every two and twenty-four hours. In resin, 10%, water absorption after two hours at 60% solid content is 33.449%, while at 70% solid content, it is 9.619%. It indicates a decrease of approximately 71.24% when compared to a 20% resin content; it also experiences an increase from 60% to 70% solid content, or approximately 99.39%. 60% of the solid content is 0.124%, and 70% of the solid content is 20.331%. 30% resin content is 32.237% for 60% solid content and 9.707% for 70% solid content. It experiences changes of about 69.89%.

Water absorption happens as well for 24 hours. In resin 10%, it sees an increase of approximately 15.58% with solid content 60% and 70% corresponding to 82.669% and 95.55%, respectively. Assuming a 20% resin content as well, the percentage increases to 47.46% with noted 60% and 70% solid content, or 66.705% and 98.363%, respectively. Generally, resin 30% after 24 hours yields 72.254% for 60% solid content and 50.309% for 70% solid content.





Moisture content is the amount of water or vapor that is present in bamboo to create furniture. One of the factors affecting product quality is this. Table 2 indicates that the moisture content for 10% resin is 42.227% for 60% solid content and 33.039% for 70% solid content. It decreased about 21.76%. Generally, for 20% resin, the solid content is 60%, or 19.577%, and 70%, or 44.18%, experiences an increase of around 55.69%. In addition, at 30% resin content, 60% solid content is 48.51%, and at 70% solid content, 33.379% is approximately 31.19%.

Based on the data, at 10% of solid content resin at 60% water absorption done for 2 hours is higher than 70% solid content and water absorption done for 24 hours, solid content at 70% is more higher than 60% of solid content, which mean 60% of solid content required better and stable in water absorption. At 20% resin content, 60% of solid content water absorption for 2 hours and 20 hours is lower than 70%. That means, 60% solid content with resin is 20% better than 70% in water absorption. Seen also at 30% resin content, 70% of solid content is better than 60% of solid content because of less water absorption due to effectiveness or the appropriate amount of resin content.

This proof shows that the physical and mechanical properties of particle particles are significantly affected by the resin's use and the different containing solid that contributes to the particle's strength. Overall, research indicates that the differences in particle size between the solid content and acid used in citric acid assays affect particle shape and size. A study like this one helps the wood industry or furniture business in using particle averaging instead of bulk material, mostly from the strength and resilience of particle averaging concerning humid environments.

TABLE RESULT ANOVA

Table 2: Summary of analysis of variance (ANOVA) at $P \leq 0.05$ for the interaction between Resin Content and Solid Content.

Study Variable	R-Value	Pr > F
Resin Content	0.001	11.821
Solid Content	0.001	8.242

CHAPTER 5

CONCLUSION

5.1 Conclusion

In conclusion, this study has revealed the crucial impact of mechanical and physical properties on particle board, particularly in regard to oil bamboo, or *Bambusa vulgaris,* mixed with citric acid resin. The examination of these factors has yielded valuable insights, as the varying percentage of resin and solid content have been found to significantly affect the quality of particle board. Specifically, a solid content of 60-70%, in combination with 10%, 20%, or 30% citric acid resin, has demonstrated optimal results for this type of particle board. With this newfound understanding, we can confidently incorporate scientific evidence into the production of superior particle board.

After conducting a thorough Analysis of Variance (ANOVA), the data was carefully examined. The results revealed a significant difference in the average performance among the various tests, indicating a high value for the best level of resin. Furthermore, the quality of the board can be precisely predicted based on both its mechanical and physical properties. This insight not only helps in reducing production costs but also promotes the widespread use of solid wood in various applications.

As indicated in the panel's table with resin content, an increase in this factor results in higher levels of thickness swelling, water absorption, and moisture content. Furthermore, the inclusion of citric acid has a direct impact on the physical and mechanical characteristics of the particle board. This not only ensures higher quality for furniture use, but also emphasizes the role of resin and citric acid in shaping these essential properties.

APPENDIXES

Figure 1: Particle bonded with citric acid into a particleboard measure size.

Figure 2: Mold was used to hold the particle.

Figure 3: Using hydraulic press at temperature 180^{o}C within 10 minutes.

Figure 4: Particleboard made from bonded with oil bamboo particle and resin citric acid.

REFERENCES

Awalluddin, D., Ariffin, M. A. M., Osman, M. H., Hussin, M. W., Ismail, M. A., Lee, H. S., & Lim, N. H. A. S. (2017). Mechanical properties of different bamboo species. https://doi.org/10.1051/matecconf/201713801024

Camelback Displays. (n.d.). What is Bamboo? Retrieved from 2023 https://www.camelbackdisplays.com/what-is-bamboo/

Johar bin Mohamed. (November 2012). Effect of silvicultural treatments on buluh madu (gigantochloa albociliata (munri) Kurz) for shoot production. Retrieved from https://core.ac.uk/download/pdf/153818304.pdf.

Chao, C.S. (1989) A Guide to Bamboos Grown in Britain. Royal Botanic Gardens, Kew, U.K. 47 pp.

IFAR/INBAR (1991) Research Needs for Bamboo and Rattan to the Year 2000. Tropical Tree Crops Program, International Fund for Agricultural Research/ International Network for Bamboo and Rattan, Singapore.

Nadeem, A., et al. "Enhanced Production of Citric Acid by Aspergillus niger M-101 Using Lower Alcohols." Turkish Journal of Biochemistry–Turk J Biochem 35, no. 1 (2010): 7-13.

Tan, T. et al. (2011). Mechanical properties of functionally graded hierarchical bamboo structures. *Acta Biomaterialia*, 1,1-8.

Hamdan, H., U.M.K. Anwar, A. Zaidon and M. Mohd. Tamizi. (2009). Mechanical Properties and Failure Behaviour of Gigantochloa scortechinii. J. Trop. For. Sci. 21(4): 336-334.

Nordahlia, A.S. et al (2011). “Anatomical, physical, and strength properties of Shizostachyum brachycladum (Buluh lemang).” Anatomical properties, physical properties, strength properties, density, vascular bundle.

Hosnan, A. (2014, August 1). Tanam Buloh-Buloh Minyak (Part 2) [Blog post]. Anim Hosnan. http://animhosnan.blogspot.com/2014/08/tanam-buloh-buloh-minyak-part-2.html

Azmy, M., Razak, W., Hashim, W.S. & Othman, S. 2004. Application of organic fertilizers on natural stand bamboos for sustainable management in Peninsular Malaysia. Journal of Bamboo and Rattan 5(4): 301-309.

Mohmod, A. L., & Mustafa, M. T. (1992). VARIATION IN ANATOMICAL PROPERTIES OF THREE MALAYSIAN BAMBOOS FROM NATURAL STANDS. Journal of Tropical Forest Science, 5(1), 90-96. https://doi.org/10.2307/43581673

Dasso, B. (2014, May 9). Characteristics of Bamboo – A Highly Sustainable Material [Blog post]. Dasso Blog. Retrieved from Characteristics of Bamboo - A Highly Sustainable Material - dasso Blog (dassousa.com)

Bhonde, D., et al. (2015). Mechanical and physical properties of bamboo reinforced polymer matrix composites: A review. Journal of Minerals and Materials Characterization and Engineering, 3(6), 420-425. doi: 10.4236/jmmce.2015.36047

Hossain, M. F., Islam, M. A., & Numan, S. M. (2015). Diversity, classification, and ethnobotanical use of bamboo in northeastern Bangladesh. International Research Journal of Biological Sciences, 4(12), 64-73. Retrieved from http://www.isca.me/IJBS/Archive/v4/i12/10.ISCA-IRJBS-2015-140.pdf

Borowski, P. F., Patuk, I., & Bandala, E. R. (2022). Innovative Industrial Use of Bamboo as Key “Green” Material. Sustainability, 14(4), 1955. https://doi.org/10.3390/su14041955

Okokpujie, I., Akinlabi, E., & Fayomi, O. (2020). Assessing the policy issues relating to the use of bamboo in the construction industry in Nigeria. Heliyon, 6(5), e04042. https://doi.org/10.1016/j.heliyon.2020.e04042

McCoymart. (n.d.). What is a Particle Board and its Types? Retrieved March 14, 2023, from https://mccoymart.com/post/what-is-a-particle-board-and-its-types/

Stark, N. M., & Cai, Z. (2015). Wood-Based Composite Materials-Panel Products, Glued-Laminated Timber, Structural Composite Lumber, and Wood-Nonwood Composite Materials. In Handbook of Wood Chemistry and Wood Composites (2nd ed., pp. 277-334). CRC Press.

Mistry, K. (2017). Particle Board Properties: You Need to Know! Gharpedia. Retrieved from https://gharpedia.com/blog/particle-board-properties/

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

Wan Abdul Rahman, W., Nabilah Johari, N., Sarmin, S., Mohd Yunus, N., Japaruni, Y., Mahmud, J., and Khairuddin, M. (2020). "Leucaena leucocephala: A fast-growing tree for the Malaysian particleboard industry," BioResources, 15(4), 7433-7442.

Widyorini, R., Umemura, K., Isnan, R., Putra, D. R., Awaludin, A., & Prayitno, T. A. (2016). Manufacture and properties of citric acid-bonded particleboard made from bamboo materials. European Journal of Wood and Wood Products, 74, 57-65. https://doi.org/10.1007/s00107-015-0967-0

Jia Dong, C. (2019). Properties of green particleboard made with citric acid, furfuryl alcohol, and palm oil. Jurnal of UPM. Retrieved from http://psasir.upm.edu.my/id/eprint/84768/1/FH%202019%2049%20IR.pdf

Umemura, K., Ueda, T., Munawar, S. S., & Kawai, S. (2011). Application of citric acid as natural adhesive for wood. Journal of Applied Polymer Science, 123(4), 1991-1996. https://doi.org/10.1002/app.34708

Prasittisopin, L., & Li, K. (2010). A new method of making particleboard with a formaldehyde-free soy-based adhesive. Composites Part A: Applied Science and Manufacturing, 41(10), 1447-1453. https://doi.org/10.1016/j.compositesa.2010.06.006

Panda, H. (2011). Bamboo plantation and utilization handbook. Delhi: Asia Pacific Business Press Inc. ISBN 9788178331508.