Experimental Study on the Utilization of Coffee Husk as Particleboard Material for Sound Absorption (A Case Study in Bener Meriah and Central Aceh Regencies)

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Abstract

The growing demand for wood is not same by the availability of wood, so needed the other alternatives as a replacement, one of which is the use of particle board. The abundance of coffee skin in the regency Bener Meriah and Aceh Tengah is one of the potential that can be utilized to make particle board. This study aims to determines the physical properties, mechanical and absorption of particle board from coffee skin.

Making the particle board from coffee skin uses a synthetic adhesive urea formaldehyde (UF) with varying levels of adhesive at the 10% and 15% and the addition of wood particles variation of 0% and 30% with goal density of 0.4 g / cm ³ , 0.6 g / cm ³, 0.9 g / cm ³. Compression time of 10 minutes was using hot press machine at a temperature of 150 º C with a pressure of 200 bar. Testing of bonding internal and elasticity using a Universal Testing Machine Wood (UWTM) in Mechanics of Materials Laboratory of the University of Gadjah Mada. Data analysis of test results in the calculation of the MOE and MOR. For the absorption test using the impedance tube at the Laboratory of Acoustics and Vibration of Mechanical and Industrial Engineering Faculty of Engineering, Gadjah Mada University.

From the results showed that the density, the amount of adhesive and the addition of a wood particles affect the value of MOR, MOE and bonding internal . Where the higher value of density and greater number of adhesive will increase the value of MOE, MOR and bonding internal of the board. The lowest density of 0.31 g / cm ³ at the board adhesive 10% and 30% of wood particles with a density of 0.4 goals g / cm ³. While the highest density of 0.907 g / cm ³ at 15% adhesive and 30% wood particle density of 0.9 on the goal gr / cm ³. Value determination bonding internal lowest was 0.5 kgf / cm ² at 10% adhesive without wood particles with goals density of 0.4 g / cm ³. While the highest 3.8 kgf / cm ² on the board bonding internal the density objectives 0.9 g / cm ³ 15% adhesive and 30% of wood particles. MOE values that produced a board that no meets with SNI, and for all the MOR values of particle board with density 0.9 g / cm ³ goal of SNI. Lowest sound absorption coefficient is 0.07 at a frequency of 1200 Hz and 0.88 at the highest frequency of 1000 Hz.

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1. Introduction

A major problem currently faced by Indonesian society today is noise, especially in areas that are crowded with various kinds of community activities, industries, and the increasing number of motor vehicles. To reduce noise in room acoustics, the design of recording studios, office rooms, schools, and other rooms can use materials that can dampen and absorb sound. These are usually installed on partition walls and ceilings. Glasswool and rockwool materials are very expensive, so people look for alternative materials and make them from inexpensive and easily obtainable materials. Materials that contain lignocellulose include bagasse, coconut fiber, and coffee husk.

Bener Meriah Regency and Central Aceh Regency are regencies in the highlands of Nangroe Aceh Darussalam Province that have a cool climate, with an average temperature of 19°C–20°C. The average elevation in both regions—which have an area of 1,454 km² for Bener Meriah with 7 districts and 4,315.14 km² for Central Aceh with 14 districts—is between 1000–2600 meters above sea level. The area is well-known for producing organic coffee beans commonly called Gayo Mountain Coffee.

According to the Directorate for Regional Potential Development (2010), the availability of land for coffee commodities in Aceh is 155,598 ha. Data from the Department of Industry and Trade and the Department of Agriculture of Bener Meriah and Central Aceh Regencies show that the coffee plantation area in the Gayo highlands up to 2010 reached 90 thousand hectares, with productivity of 700–1,000 kg/ha/year. In 2009 and 2010, both regencies exported coffee beans totaling 2,646.4562 tons/year to the United States, dried parchment 121.2889 tons/year to Japan, and packaged coffee powder 45.401 tons/year to several European countries, and local consumption in the form of ground coffee 11.16 tons/year.

The coffee husk produced is scattered in several coffee milling facilities, one of which is the SILIH NARA coffee milling facility located in Angkup Village, Silih Nara District, in Central Aceh Regency. From the explanation of the coffee mill owner, it is stated that in one day the mill produces 3 tons of coffee beans, and in one week there are 6 working days. Usually the coffee mill operates during the coffee harvest season, which occurs twice a year for 8 months. From the obtained data, it can be seen that the amount of coffee husk produced by the SILIH NARA coffee mill reaches 460.8 tons/year. The increasing pile of coffee husk waste is usually burned to reduce the volume of accumulation or disposed of in waste dumping areas. By giving a touch of appropriate technology to the coffee husk waste, it will produce products that are truly useful and have economic value, such as making particleboard.

The study “Pengujian Serapan Akustik Blok Berbahan Dasar Ampas Tebu.” The results show the sound absorption coefficient produced is above 0.5 (Sita Agustina Anggraini, 2010

The study "Experimental Study on the Utilization of Coffee Husk as Particleboard Material for Sound Absorption." Sound absorption is influenced by density and air pores, with a coefficient value of 0.9 (Mevandita Widi Dharmantya, 2010).

The study "Pembuatan Papan Partikel Dari Limbah Batang Pohon Jagung dan Plastik Termoplast." The amount of adhesive and the type of adhesive affect the physical and mechanical properties of particleboard (Agus Rismanto, 2010).

The study "Pemanfaatan Kulit Kopi di Kabupaten Aceh Tengah Menjadi Papan Partikel Dengan Menggunakan Perekat Urea Formaldehyde, Phenol Formaldehyde dan Termoplastik." The results show that the physical and mechanical properties do not yet meet the standards (Odih Iskandar, 2009).

The study "Koefisien Penyerapan Bunyi Bahan Akustik Dari Pelepah Pisang Dengan Kerapatan Yang Berbeda." The results show that the denser the material, the greater the coefficient value (Evi Indrawati, 2009).

The study "Disain Peredam Suara Berbahan Dasar Sabut Kelapa Dan Pengukuran Koefesien Penyerapan Bunyi." The results show that coconut fiber meets the sound-absorbing requirements according to ISO 11654, with the highest alpha value of 0.51 (Ainie Khuriati, Eko Komaruddin, and Muhammad Nur, 2006).

The research to be carried out now is to utilize the potential of coffee husk, which is considered waste, into particleboard for sound-absorbing purposes that meet existing sound-absorber standards, and also have economic value.

Coffee Plant

Scientific Classification
Kingdom : Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Gentianales
Famili: Rubiaceae
Genus: *Coffea*

Figure 1. Coffee Plant

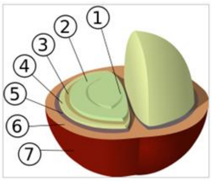
Coffee plants grow well in areas located between 20°N and 20°S. Indonesia, located between 5°N and 10°S, is very ideal and potential for the development of coffee plants. There are 40 varieties of coffee in the world; the most widely traded coffee is Arabica, almost 75% of the world's coffee production is of this type (Indonesia contributes 10%). Robusta coffee accounts for about 25% of world production (Indonesia contributes 90%).

Table 1. Differences between Arabica Coffee and Robusta Coffee

General Characteristics	Arabica	Robusta
Year discovered	1753	1895
Chromosome number (2n)	44	22
Time from flowering to fruiting	9 months	10–11 months
Flowering	After rainfall	Not fixed
Ripe fruit	Falls naturally	Harvested from the tree
Yield (kg/ha)	1500–3000	2300–4000
Root system	Deep	Shallow
Optimal temperature	15–24 °C	24–30 °C
Maximum growth altitude	1000–2000 m	0–700 m
Caffeine content	0.8–1.4%	1.7–4.0%
Bean shape	Flat	Oval
Brew characteristics	Acidic	Bitter

Source: ICO

Coffee husk is obtained from coffee fruit that is ripe/on the tree. The harvesting process of coffee fruit is carried out manually by picking red coffee cherries. Arabica coffee is pulped using a cylinder pulper to separate the coffee skin and the parchment coffee (coffee bean wrapped in hulls). Fermentation occurs during pulping and washing. Then the coffee is sun-dried until it reaches a certain moisture content and then milled again to separate the hulls from the coffee beans. Meanwhile, for Robusta coffee, after harvesting the cherries are pulped, dried to a certain moisture content, and then milled again to obtain the coffee beans.



Description:
1. Core cut
2. Coffee bean (*endosperm*)
3. Silver skin (*epidermis*)
4. Hull *(endoscarp*)
5. Pectin layer
6. Pulp (*Mesocarp*)
7. Outer Skin (*pericarp, exocarp*).

Figure 2. Structure of coffee fruit and seed

Table 2. Contents in Dry Coffee Husk

Component	Coffee Husk	Skin
Carbohydrates	50	57,8
Proteins	10	9,2
Fibres	18	
Fat	2,5	2
Caffeine	1,3	1,3
Tannins	1,8 - 8,56	4,5
Pectins	6,5	35,8
Reducing sugar	12,4	30
Non Reducing sugar	2	20
Cellulose	17,7	17
Lignin	24,4	

Source: Bressani et al. 1979

The yield of Arabica coffee processing ranges between 16–20%. To obtain 1 kg of green coffee beans, 5–6 kg of wet coffee cherries are needed. The yield of Robusta coffee can reach around 20–22%. To obtain 1 kg of green coffee beans, the amount of wet coffee cherries needed is the same or less than 5 kg (Tim Karya Tani Mandiri 2010). Every 100 kg of Robusta coffee produces 21.06 kg of coffee beans and 17.20 kg of coffee husk (Korikanthimath 2000).

Particleboard

Particleboard is one of the engineered board products that utilize wood waste. By definition, particleboard is an engineered board made from small pieces of wood (planer shavings, flakes, particles, chips) mixed with adhesive until evenly distributed, followed by preliminary pressing and hot pressing (Kasmudjo, 2010).

Particleboard is a type of composite/wood panel product made from wood particles or lignocellulosic materials, bonded with synthetic adhesives or other binders and then hot-pressed (Maloney 1997). Lignocellulosic waste is grouped into three categories: forest wood waste, wood waste from factories or the wood industry, and lignocellulosic waste such as agricultural and plantation waste, coconut, oil palm, and others (Prayitno 1994).

Particleboard based on durability level, pressing method, and number of layers:

a. Durability:
   Exterior particleboard: resistant to humidity and water. Interior particleboard: not resistant to humidity and water.
b. Pressing method: Flat pressed particleboard (pressed from top and bottom). Extruded pressed particleboard (pressed laterally).
c. Number of layers: Single particleboard: single layer (materials with single-dimensional size). Multiple particleboard: composed of several layers, made from materials of more than one size (Kasmudjo 2010).

Some advantages of particleboard: free from knots, free from checks and cracks, size and density can be adjusted according to requirements, uniform thickness and density, easy to work with, isotropic properties, and its characteristics and quality can be controlled (Maloney 1997).

The density of particleboard is influenced by several factors such as wood species, pressing pressure, the amount of wood particles, adhesive content, and other additives. Based on density, particleboard is divided into three categories:

1. Low density particleboard, less than 0,4 g/cm3.
2. Medium density particleboard, less than 0,4 – 0,8 g/cm3.
3. High density particleboard, more than 0,8 g/cm3. (Kelley 1997 in Sidabutar 2000).

Types of Engineered Board

1) Particleboard: panel products produced by compacting wood particles while simultaneously binding them with an adhesive (Haygreen and Bowyer 1996).
2) Mineral Board: particleboard with mineral binders such as cement, gypsum, magnesite, and magnesium oxysulfate.
3) Fiberboard: engineered board made from strands of fibers that interlock with one another.
4) Composite Board: board made by combining veneer with particleboard (Prayitno 1995).

Adhesives

Bonding, known in English as adhesion, is defined as a condition in which two surfaces become united due to interfacial forces. These forces may be valence forces or interlocking forces. The following is a side-sectional image of an adhesive system:

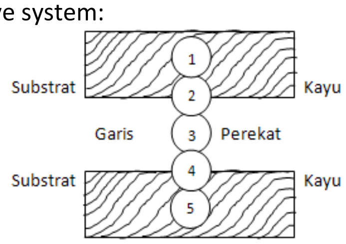


Figure 3. Five-chain force system in adhesion

Brown and colleagues analyzed adhesion by breaking it down into forces exerted by molecules when they are close to or far from each other. These forces are known as adhesive and cohesive forces, where an adhesive line can be described by five force circles or five glue line chains that are interconnected. In the first and fifth circles, cohesive forces between wood molecules play an important role in maintaining the physical integrity. In the second and fourth circles, adhesive forces between wood molecules and adhesive molecules dominate and are crucial in maintaining the bond between the two materials. In the third circle, cohesive forces among adhesive molecules play a dominant role and form the adhesive line.

Initially, wood adhesion was defined as the effort or condition of bonding one piece of wood to another piece of wood or to a non-wood material with the assistance of an adhesive (Kollmann et al., 1975).

Natural Adhesives

Most natural adhesives consist of plant-based and animal-based adhesives, with a small number of mineral adhesives. Plant-based adhesives include soy adhesive, starch, and natural gums. Animal-based adhesives include hide glue, bone glue, fish glue, blood glue, and casein. Mineral adhesives include lime and silicates (Prayitno, 1994).

Synthetic Adhesives

Synthetic adhesives include urea formaldehyde, phenol formaldehyde, resorcinol formaldehyde, and melamine formaldehyde, all of which are categorized as synthetic resin adhesives (Prayitno, 1987).

Sound

Sound has two definitions:

1) Physically, it is the movement of particles through an air medium, known as objective sound.
2) Physiologically, it is considered as the auditory sensation produced by a physical condition, known as subjective sound (Leslie L. Doelle 1990).

Sound Waves

Sound waves are longitudinal waves that occur due to compression and rarefaction within a liquid, gas, or solid medium. Longitudinal waves are waves whose propagation direction is parallel to the direction of particle motion, in which air molecules vibrate back and forth. The equation for sound waves is**:**

$$v = \frac{\lambda}{T} = f \text{ ë} \qquad (1)$$

Information:

v = wave propagation speed (m/s) T = period (T)
λ = wavelength (m) f = frequency (Hz)

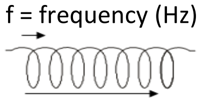


Figure 4. Longitudinal Wave

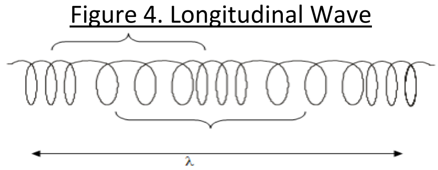


Figure 5. One Wave

Based on their frequency, sound waves are divided into three categories:

1) Infrasonic waves with frequencies < 20 Hz
2) Audiosonic waves with frequencies 20–20,000 Hz
3) Ultrasonic waves with frequencies > 20,000 Hz

Sound is a mechanical vibration wave in air or solid objects that can still be perceived by a normal human ear with a frequency range of 20–20,000 Hz.

Acoustic Impedance

The word *acoustic* comes from the Greek word *akoustikos*, meaning everything related to hearing within a room condition that can influence the quality of sound and noise (Suptandar, 2004). Acoustics is generally divided into room acoustics, which deals with desired sounds, and noise control, which deals with undesired sounds.

Reflection and Transmission

Sound is the transmission of energy through solids, liquids, and gases in the form of vibrations received by the ear and interpreted by the brain. Variations in sound occur due to air pressure changes in the form of compression and rarefaction of air molecules caused by disturbances propagating through an elastic medium in all directions (Suptandar, 2004).

The characteristics of sound include:

- It can be reflected
- It can undergo interference
- It can be refracted

When sound strikes a boundary of the medium it passes through, the energy in the sound wave may be transmitted, absorbed, or reflected by that boundary.

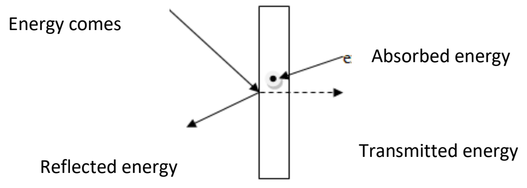


Figure 6. Reflection of Sound Energy on Material

Sound Absorption

Sound absorption is the conversion of sound energy into heat energy (Jailani et al., 2004). The sound absorption coefficient of a surface is the portion of the incident sound energy that is absorbed or not reflected by the surface. This coefficient is represented by the Greek letter α (Doelle, 1993).

The sound absorption coefficient (α) ranges from 0 to 1:

- α = 0 means no sound energy is absorbed
- α = 1 means perfect absorption

Acoustic materials are technical materials whose primary function is to absorb sound. Acoustic materials can be categorized into three basic types:

1. Absorbing materials
2. Barrier materials
3. Damping materials

It is possible that coffee husk can be used as a raw material for particleboard in accordance with SNI and ISO 11654:1997 for sound absorbers. Therefore, coffee-husk particleboard is expected to have economic value.

2. Methodology

Research Design

The manufacture of coffee-husk particleboard used three variables: board density, amount of adhesive, and amount of wood particles. The research was carried out from April to September 2011. The hot-pressing time was 10 minutes, with a pressure of 200 bar and a temperature of 150 °C. The particleboard to be produced was single-layer particleboard. Wood particles were added to determine whether they would affect the mechanical, physical, and sound-absorption properties of the coffee-husk particleboard. The boards were intended to be used as sound-absorbing material.

Density 0,4gr/cm^3=K04 Density 0,6gr/cm^3=K06
Density 0,9gr/cm^3=K09
Total UF 10% = P10 Total UF 15% = P15
Wood Particles 0% = C0 Wood Particles 30% = C30

Table 3. Completely Randomized Design with Factorial Experiment

Density	Adhesive Content	Wood Particle Content	Experimental Code
K04 = 0,4 gr/cm³	P10 = 10%	C0 = 0%	K04P10C0
			K04P10C30
			K04P15C0
			K04P15C30
K06 = 0,6 gr/cm³			K06P10C0
			K06P10C30
	P15 = 15%	C30 = 30%	K06P15C0
			K06P15C30
K09 = 0,9 gr/cm³			K09P10C0
			K09P10C30
			K09P15C0
			K09P15C30

Testing

The particleboard panels to be tested were cut into specimens measuring 30 cm × 30 cm.

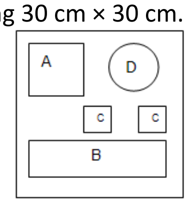


Figure 7. Cutting pattern of test specimens (30 cm × 30 cm)

Description of specimens:
A : Density, 10 cm x 10 cm.
B : Modulus of elasticity and modulus of rupture 20 cm x 5 cm.
C : Internal bond (tensile strength perpendicular to surface) 5 cm x 5 cm.
D : Sound Absorption ø 99 mm.

2. Testing of Physical Properties of Coffee-Husk Particleboard

Density

Density was determined by measuring the width, length, and thickness of the specimen using a caliper. The density value was calculated using the formula:

$$Density = \frac{B}{I} \qquad (2)$$

Where:

B = Weight (gr) I = Volume (cm^3) = length × width × thickness (cm).

2. Testing of Mechanical Properties of Coffee-Husk Particleboard

Modulus of elasticity

The modulus of elasticity was tested using a Universal Wood Testing Machine (UWTM). The specimen was simply supported with a span equal to 15 times its nominal thickness, as shown in Figure 8. A load was then applied at the center until the elastic limit of the board was reached. The modulus of elasticity was calculated using the following formula:

$$MOE\left(\frac{kgf}{cm^2}\right) = \frac{S^3}{4LT^3} X \frac{\Delta B}{\Delta D} \quad (3)$$

3. Modulud of ruptur

The modulus of rupture was tested together with the modulus of elasticity. For the MOR test, the load was continued until the specimen failed. The modulus of rupture was calculated using the formula:

$$MOR\left(\frac{kgf}{m^2}\right) = \frac{3BS}{2LT^2} \quad (4)$$

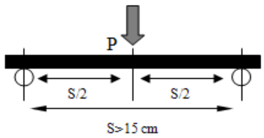


Figure 8. Schematic of modulus of elasticity and modulus of rupture testing

4. Internal bonding (tensile strength perpendicular to surface)

The specimen was bonded to two wooden loading blocks using epoxy adhesive and left to cure for approximately 24 hours. After curing, the two blocks were pulled in tension perpendicular to the board surface until maximum load was reached, as shown in Figure 9. The internal bond strength was calculated using the formula:

$$BI\left(\frac{\text{Kgf}}{\text{cm}^2}\right) = \frac{B}{PXL} \quad (5)$$

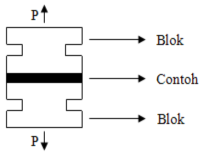


Figure 9. Schematic of internal bond testing

where:
SSS= span (cm)
LLL = width (cm)
TTT = thickness (cm)
ΔB = load difference (B_1 − B_2), taken from the load-deflection curve (kgf)
ΔD = deflection (cm) corresponding to the load difference (B_1 − B_2)
BBB = maximum load (kgf)
PPP = length (cm)

5. Sound Absorption Test (α)

For the sound absorption test, the particleboard specimens were circular with a diameter of 99 mm and a thickness of 10 mm. The test began by releasing the clamp on the impedance tube, then inserting the specimen into the holder at the end of the tube, and reclamping it. The next step was to set the sound-wave frequency to be used via the computer software. The test was carried out using a computer, and the sound absorption data were displayed as graphs on the monitor.

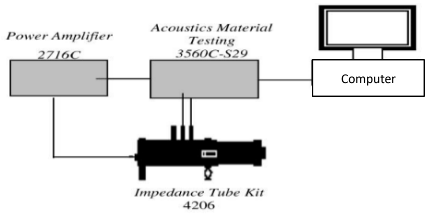


Figure 10. Schematic of sound absorption (α) testing

Table 4. Physical and mechanical properties of particleboard according to SNI 03-2105-2006

Physical and Mechanical Properties	Type	SNI	Unit
Density	-	0,40 – 0,90	(kg/cm³)
Water Content	-	< 14%	(%)
Thick Development		Max 20	(%)
MOR	8; 13; 18	82; 133; 184	(kgf/cm²)
MOE	8; 13; 18	2,04; 2,55; 3,06	(10⁴ kgf/cm²)
Internal bonding	8; 13; 18	1,5; 2,0; 3,1	(kgf/cm²)
Strong Screw Grip	8; 13; 18	31; 41; 51	(kgf)²

Table 5. Classification of sound absorption by class according to ISO 11654

Sound Absorption Class	αw
A	0,90; 0,95; 1,00
B	0,80; 0,85
C	0,60; 0,65; 0,70; 0,75
D	0,30; 0,35; 0,40; 0,45;0,50; 0,55
E	0,25; 0,20; 0,15
Not Clasified	0,10; 0,05; 0,00

The process of manufacturing coffee-husk particleboard can be seen in the following flow diagram:

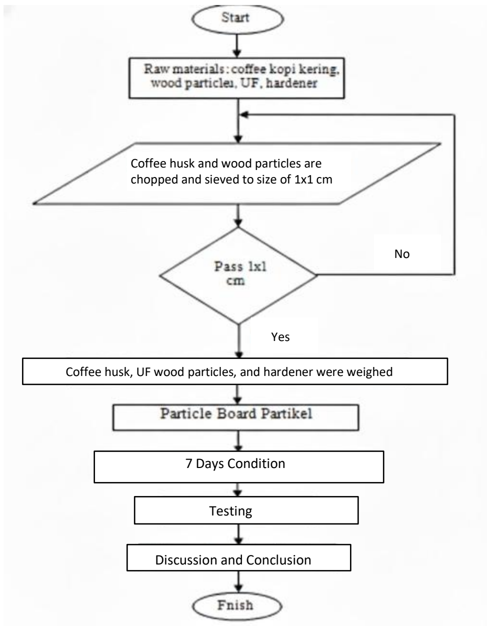


Figure 11. Flow chart of particleboard manufacturing process

Materials Used in the Study

Table 6. Materials used for manufacturing particleboard

No	Material Name	Satuan	Kescription
1	Arabica & Robusta coffee husks	kg	Dryt kopi kering
2	Urea formaldehyde	gr	Berbentuk cair dengan kadar perekat 6%
3	Partikel kayu	kg	Dari kayu jati
4	Hardener	gr	Untuk pengeras

Arabica and Robusta Coffee   Wood Particles

Figure 12. Coffee husks and wood particles

Raw Material Requirements for Each Density: 30 cm x 30 cm x 1 cm

The amount of raw material used to produce particleboard from coffee husk varies for each density.

The figure 66% in calculating the amount of adhesive represents an estimate of the water content in the solid fraction of the adhesive solution.

Density 0.4 gr/cm³

Particles = 30 cm x 30 cm x 1 cm x 0.4 gr/cm³ = 360 gr
Wood particles 30% x 360 gr = 108 gr
Adhesive 10% = 10% x 360 gr : 66% = 54.55 gr
Adhesive 15% = 15% x 360 gr : 66% = 81.82 gr

Density 0.6 gr/cm³

Particles = 30 cm x 30 cm x 1 cm x 0.6 gr/cm³ = 540 gr
Wood particles 30% x 540 gr = 162 gr
Adhesive 10% = 10% x 540 gr : 66% = 81.82 gr
Adhesive 15% = 15% x 540 gr : 66% = 122.73 gr

Density 0.9 gr/cm³

Particles = 30 cm x 30 cm x 1 cm x 0.9 gr/cm³ = 810 gr
Wood particles 30% x 810 gr = 243 gr
Adhesive 10% = 10% x 810 gr : 66% = 122.73 gr
Adhesive 15% = 15% x 810 gr : 66% = 184.1 gr

Equipment Used

Table 7. Equipment Used in the Manufacturing of Particleboard

No	Tool Name	Tool Quantity (unit)	Description
1	Manual chopper	1	Knife
2	Sieve	1	Size 1 cm x 1 cm
3	Plastic Tarpaulin	1	Size 200 cm x 80 cm
4	Ordinary Scale	1	To weigh particles
5	Analytical Balance	1	To weigh UF
6	Caliper	1	To measure boards
7	Sprayer	1	To mix adhesive
8	Mat 30 cm x 30 cm	1	To make a mattress/mat
9	Hot Press Machine	1	To press particle boards
10	Saw Machine	1	To cut test materials
11	Mechanical Test Equipment	1	For mechanical testing
12	Acoustic Test Equipment	1	For acoustic testing
13	Marker	1	To mark each board
14	Board support wood	-	To arrange boards during conditioning
15	Plastic Bucket	1	To mix particles

Process of Coffee Husk Particleboard Manufacturing

a) The coffee husk raw material is manually chopped, sieved, and the parts that do not pass the sieve are chopped again, then dried until the moisture content is <10%, after which it is weighed.
b) Coffee husk particles are mixed with urea formaldehyde adhesive at 10% and 15%, with variations of wood particle mixtures at 0% and 30%.
c) After all the materials are mixed homogeneously, they are formed into a mat and inserted into a mold for pre-pressing.
d) Hot pressing is conducted to cure the urea formaldehyde adhesive.
e) Conditioning is carried out for 1 week to equilibrate the moisture content of the particleboard with ambient conditions.
f) After reaching the desired moisture level, the resulting particleboard is cut for mechanical testing, physical testing, and sound absorption testing.

3. Result and Discussion

Test specimens were made using Arabica and Robusta coffee husks, sieved to 1 cm particle size, with UF adhesives at 10% and 15%, and combinations of wood particles at 0% and 30%.

Hot pressing was conducted at 200 bar and 150°C for 10 minutes, targeting densities of 0.4 gr/cm³, 0.6 gr/cm³, and 0.9 gr/cm³.

Particleboard manufacturing used a hot press machine at the Forestry Laboratory of Universitas Gadjah Mada. Mechanical testing was conducted at the Material Mechanics Laboratory, Center for Engineering Studies, Universitas Gadjah Mada. Sound absorption testing was conducted at the Acoustic and Mechanical Vibrations Laboratory, Faculty of Mechanical and Industrial Engineering, Universitas Gadjah Mada.

Figure 13. Resulting coffee husk particleboard

Physical and Mechanical Test Results of Coffee Husk Particleboard

Table 8. Mechanical Test Results of Coffee Husk Particleboard

No	Object Test	Density (gr/cm³)	Internal Bonding (Kgf/cm2)	Modulus Elastis /MOE (kgf/cm2)	Flexural Strength /MOR(kgf/cm2)
1	K04P10C0	0.35	0.52	907	15.33
2	K06P10C0	0.60	1.20	2.569.90	31.08
3	K09P10C0	0.90	1.56	7.002.14	94.50
4	K04P10C30	0.31	0.68	1.142.72	18.10
5	K06P10C30	0.60	1.40	2.143.94	34.71
6	K09P10C30	0.90	1.88	10.108.22	91.35
7	K04P15C0	0.40	1.08	2.390.45	30.45
8	K06P15C0	0.60	1.40	4.218.12	50.85
9	K09P15C0	0.90	2.16	10.008.81	102.60
10	K04P15C30	0.40	1.72	1.645.61	20.25
11	K06P15C30	0.60	2.20	4.785.79	64.80
12	K09P15C30	0.90	3.84	14.273.41	158.36

Physical and Mechanical Test Results of Coffee Husk Particleboard

Table 9. Sound Absorption Test Results of Coffee Husk Particleboardkopi

Frekuensi	alfa K04P10C0	alfa K04P10C30	alfa K04P15C0	alfa K04P15C30
250	0.43	0.75	0.23	0.09
500	0.33	0.27	0.59	0.48
750	0.64	0.43	0.55	0.39
1000	0.59	0.75	0.88	0.79
1200	0.55	0.33	0.16	0.64
Frekuensi	alfa K06P10C0	alfa K06P10C30	alfa K06P15C0	alfa K06P15C30
250	0.81	0.51	0.36	0.13
500	0.84	0.43	0.25	0.28
750	0.84	0.69	0.18	0.16
1000	0.84	0.88	0.75	0.81
1200	0.75	0.07	0.48	0.12
Frekuensi	alfa K09P10C0	alfa K09P10C30	alfa K09P15C0	alfa K09P15C30
250	0.13	0.33	0.20	0.16
500	0.64	0.64	0.75	0.43
750	0.64	0.68	0.68	0.22
1000	0.83	0.79	0.88	0.80
1200	0.71	0.43	0.33	0.41

Density

According to Indonesian National Standard (SNI) 03-2105-2006, the density of particleboard ranges between 0.40–0.90 gr/cm³.

The density results of the produced coffee husk particleboard are schematically shown in Figure 14:

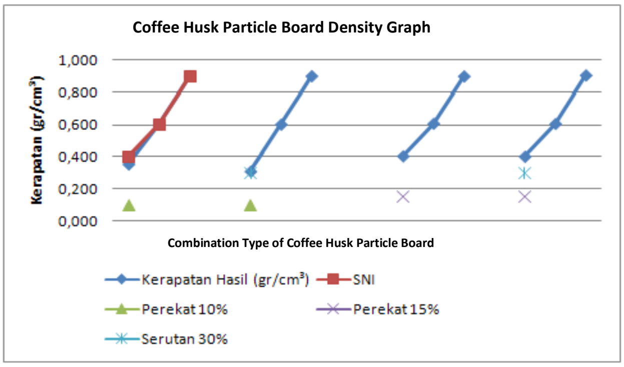


Figure 14. Density graph of coffee husk particleboard

Testing results show that particleboards with a target density of 0.4 gr/cm³ have the lowest measured value of 0.31 gr/cm³ for boards with 10% adhesive and 30% wood particles. Boards with 10% adhesive and no added wood particles have a density of 0.35 gr/cm³.Thus, both do not meet SNI requirements.Boards with a target density of 0.4 gr/cm³ using 15% adhesive meet SNI, and all boards with target densities of 0.6 gr/cm³ and 0.9 gr/cm³ also meet SNI requirements.Density indicates the mass of a material per unit volume.The higher the density, the stronger the material.Results show that adhesive amount influences density, the more adhesive used, the higher the density.Meanwhile, the addition of wood particles does not significantly affect the resulting density.

Internal Bonding (Tensile Strength Perpendicular to Surface)

According to SNI 03-2105-2006, the required internal bonding (IB) strength for particleboard is 1.5 kgf/cm². The IB test results are shown in Figure 15:

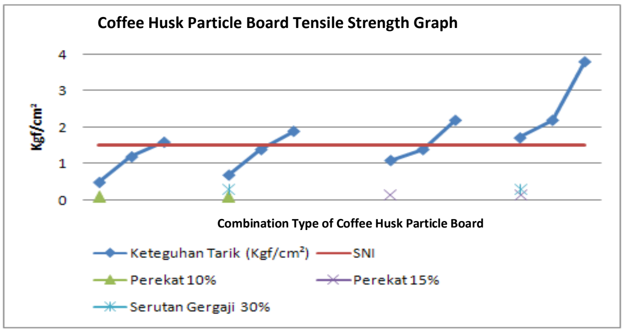


Figure 15. Internal Bonding (IB) graph of coffee husk particleboard

The lowest IB value is 0.5 kgf/cm² at density 0.4 gr/cm³ with 10% adhesive and no wood particles.

The highest IB value is 3.8 kgf/cm² at density 0.9 gr/cm³ using 15% adhesive with 30% wood particle addition. Particleboard combinations using 15% adhesive and 30% wood particles meet SNI requirements at all densities.

Other combinations only meet SNI at density 0.9 gr/cm³. Higher density results in higher IB values. Greater adhesive quantity also increases IB, as more adhesive strengthens inter-particle bonding.

Adding wood particles also improves tensile strength due to differing textures between coffee husk and wood particles, and combining them increases IB strength.

Modulus of Elasticity (MOE)

According to the Indonesian National Standard (SNI) No. 03-2105-2006, the modulus of elasticity (MOE) requirement for particleboard is 24,000 kgf/cm². The results of the MOE testing for the particleboard produced are schematically shown in Figure 16:

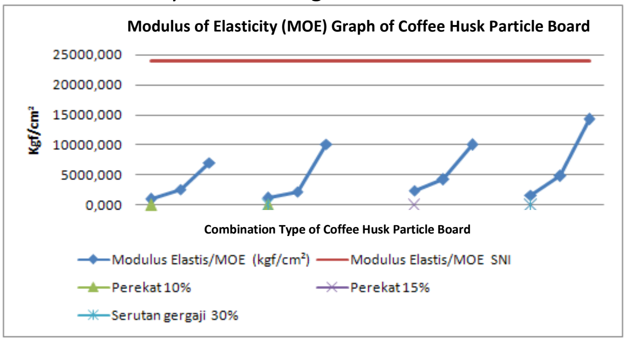


Figure 16. Modulus of Elasticity (MOE) of Coffee-Husk Particleboard

From the graph above, it is evident that all particleboard specimens with 10% and 15% adhesive content and target densities of 0.4 g/cm³, 0.6 g/cm³, and 0.9 g/cm³ do not meet the SNI requirement. The highest modulus of elasticity (MOE) value obtained was 14,273.411 kgf/cm² for particleboard with 15% adhesive, 0.9 g/cm³ density, and 30% wood-particle addition. The lowest MOE value was 907.009 kgf/cm² for particleboard with 10% adhesive, 0.4 g/cm³ density, without wood-particle addition.

From the graph, it can be observed that density, adhesive content, and wood-particle addition significantly influence the modulus of elasticity (MOE). Particleboard with higher density contains a greater number of particles packed more tightly, resulting in stronger inter-particle bonding and a higher resistance to applied loads than low-density boards. Similarly, higher adhesive content allows the resin to fill voids between particles more uniformly, leading to stronger bonds. The addition of 30% wood particles also contributes significantly to increasing the MOE value because coffee-husk particles and wood particles possess different physical characteristics.

Flexural Strength (Modulus of Rupture, MOR)

According to the Indonesian National Standard (SNI) No. 03-2105-2006, the flexural strength (MOR) of particleboard is 82 kgf/cm². The test results of the flexural strength (MOR) of the fabricated particleboard are schematically presented in Figure 17 below.

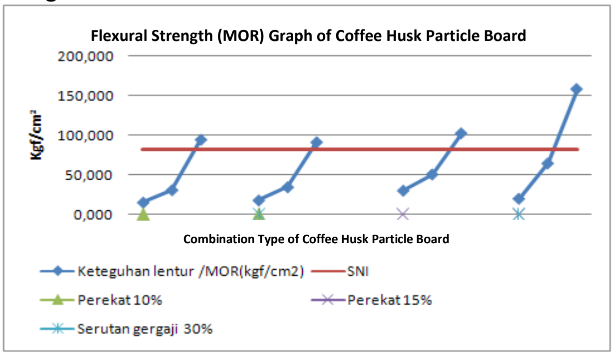


Figure 17. Modulus of Rupture (MOR) of Coffee-Husk Particleboard

The highest MOR value obtained was 158.867 kgf/cm² for particleboard with a combination of 15% adhesive, 30% wood particles, and a density of 0.9 g/cm³. The lowest MOR value was 15.331 kgf/cm² for particleboard with a density of 0.4 g/cm³, 10% adhesive, and no wood particle addition.

From the graph, it can be observed that particleboard with densities of 0.4 g/cm³ and 0.6 g/cm³ did not meet the SNI requirements for any combination. In contrast, all particleboard with a density of 0.9 g/cm³ met the SNI standard.

Density, adhesive content, and wood-particle mixture showed a significant effect on MOR values. Higher density leads to more compact boards due to a greater number of particles. A higher adhesive content results in more uniform resin distribution among particles, strengthening the inter-particle bonds. Consequently, the ability of the board to withstand maximum loads increases, resulting in higher MOR values. MOR is defined as the maximum load capacity the material including particleboard can withstand before failure.

Sound Absorption

The sound absorption coefficient (α) is expressed as a value between 0 and 1. A coefficient value of 0 indicates that no sound energy is absorbed, meaning that all incoming sound is reflected. Conversely, a coefficient value of 1 indicates perfect absorption, where all incoming sound is fully absorbed. Sound absorption testing was conducted using an impedance tube at frequencies ranging from 250 Hz to 1200 Hz. The results of the sound absorption tests for coffee-husk particleboard are schematically presented in Figures 18, 19, 20, and 21 below:

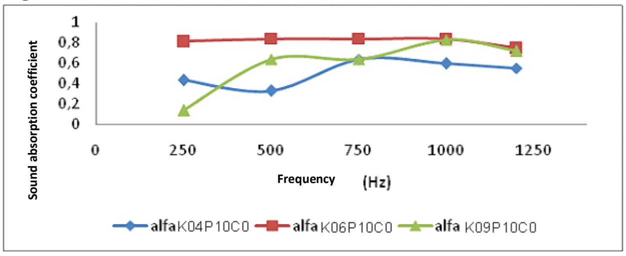


Figure 18. Graph of sound absorption test results for each density with 10% adhesive without wood particles

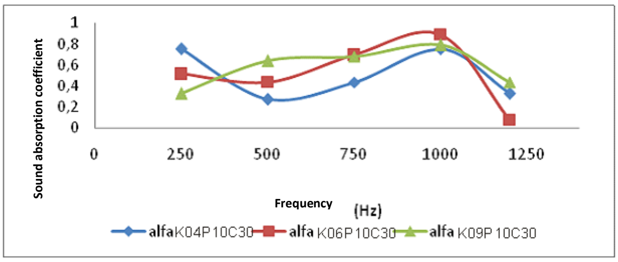


Figure 19. Graph of sound absorption test results for each density with 10% adhesive and 30% wood particles

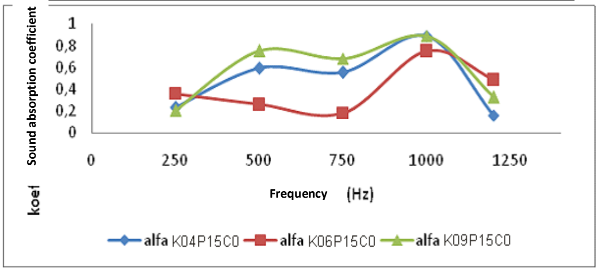


Figure 20. Graph of sound absorption test results for each density with 15% adhesive without wood particles.

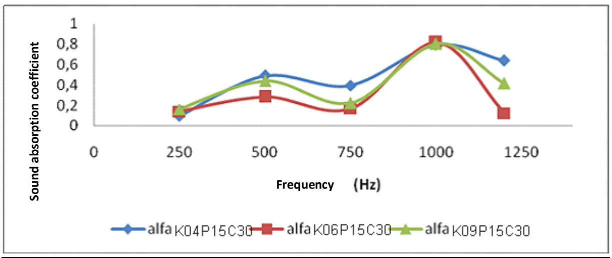


Figure 21. Graph of sound absorption test results for each density with 15% adhesive and 30% wood particles.

Based on the sound absorption test results shown in Figures 18, 19, 20, and 21, it is evident that coffee-husk particleboard is capable of absorbing sound, as the absorption coefficient values at all frequencies are greater than 0. This indicates that all boards are able to absorb sound energy. The lignocellulosic characteristics of coffee husk allow it to meet the requirements for sound-absorbing materials. The maximum absorption coefficient (peak absorption value) occurs at 1000 Hz, reaching nearly 0.88. All graphs show that each particleboard variation has different absorption coefficient values, which is due to the different particle compositions in each board.

Analysis of Figure 18 shows that density has a strong influence on the absorption coefficient values. Higher density results in a denser particleboard structure, with particles arranged more tightly. This causes sound waves passing through the board to travel at slower speeds. Low-density boards (K04P10C0) exhibit lower sound absorption coefficients at almost all frequencies compared to medium-density (K06P10C0) and high-density (K09P10C0) boards. This is because low-density boards have a more porous texture, allowing most of the incoming sound waves to pass through rather than be absorbed. Medium-density boards show that nearly all incoming sound is well absorbed across all frequencies due to their balanced particle arrangement—neither too loose nor too compact. Their resulting graph is nearly linear and very stable. For high-density boards, the absorption coefficient increases with increasing frequency. Sound waves traveling through denser material propagate more slowly than through less dense material, enabling higher sound absorption.

Analysis of Figure 19 indicates that the addition of wood particles significantly reduces sound absorption coefficient values at almost all frequencies, except at 1000 Hz. However, at 1200 Hz, the absorption coefficient decreases drastically for all densities. This is due to the reduced ability of the board to absorb sound above 1000 Hz, where incoming sound waves are no longer effectively absorbed and instead are partially transmitted or reflected. The added wood particles fill the empty spaces between coffee-husk particles with the help of adhesive, resulting in different material compositions. The inner and outer surfaces of coffee-husk particles differ, whereas wood particles have uniform surfaces.

Analysis of Figure 20 shows that using 15% adhesive in low-density boards results in higher absorption coefficient values than boards with 10% adhesive. However, this increase does not occur across all frequencies. For medium-density boards, the absorption coefficient tends to be unstable and decreases across frequencies. High-density boards exhibit increasing absorption coefficients as frequency increases, but at 1200 Hz the absorption coefficient becomes very low. This occurs because, at high frequencies, incoming sound waves are not effectively absorbed by the board.

Analysis of Figure 21 shows that adding 30% wood particles does not improve sound absorption performance; instead, it decreases absorption at nearly all frequencies. Low-density and high-density boards show increased absorption only at 1200 Hz, while medium-density boards show increased absorption at 500 Hz and 1000 Hz before dropping sharply at 1200 Hz. Figure 21 also shows that all density variations exhibit similar trends in rising and declining absorption values.

The factors influencing sound absorption coefficients include density—higher density enhances the board's ability to absorb sound. In contrast, the addition of wood particles and increased adhesive content reduce sound absorption performance. This occurs because adhesive fills the voids between particles, resulting in a denser structure that sound waves cannot easily penetrate, as adhesive is not a porous material. Consequently, only a portion of the sound waves are absorbed, while the rest are reflected or transmitted. From Figures 18, 19, 20, and 21, it can be concluded that the coffee-husk particleboard produced meets ISO 11654:1997 standards as a sound-absorbing material.

Economic Analysis

Initial Invesment Rp. 48.500.000
Fixed Costs Rp. 133.450.000
Annual Variable Costs (Particleboard with density 0.6 g/cm³) Rp. 794.796.000

$$\underline{Production\ Cost = Fixed\ Costs + Variable\ Costs}$$

Total Production Cost Rp. 928.246.000

The selling price of particleboard is assumed = RP. 200.000
Annual sales revenue = 11520 sheets x Rp.200.000 = Rp. 2.304.000.000

$$\underline{Annual\ Profit = Revenue - Production\ Cost}$$

The annual profit is 1375754000
Profit after tax and business capital loan repayment is Rp. 1.368.875.230

The Break Even Point (BEP) is the point at which the company neither gains profit nor incurs losses.

$$BEPproduksi = \frac{Total\ Cost}{Total\ Production}$$

BEP (Production Value) Rp. 80.576,9097
This indicates that the break-even point is achieved when particleboard is sold at Rp. 80576/sheet

$$BEP = \frac{Total\ Cost}{Selling\ Price}(Rp)$$

BEP 4.641,23
This means that the business reaches the break-even point when production reaches 4.641 sheets

The Revenue-to-Cost Ratio (R/C Ratio) represents the ratio between revenue and total cost. If the R/C ratio is greater than 1, the business is considered economically feasible.

$$\frac{R}{C}Ratio = \frac{Revenue}{Total\ Cost}$$

The obtained R/C value is 1.47, indicating that the establishment of a particleboard manufacturing plant with a density of 0.6 g/cm³ using coffee husk is economically feasible, as the value exceeds 1.

Return on Investment (ROI) represents the rate of return on the invested capital. The ROI value is calculated using the following equation:

$$ROI = \frac{Net\ Profit}{Total\ Cost} \times 100$$

The resulting ROI is 147.49% per year of production. This indicates that the coffee-husk-based particleboard manufacturing business is economically viable. With a profit exceeding 100%, the company is expected to market the particleboard products more easily. Even after deducting advertising costs, promotional expenses, and bulk-purchase discounts, the remaining profit exceeds 50%, indicating that the company achieves substantial profitability and that the particleboard manufacturing business is feasible.

The Payback Period (PBP) refers to the length of time required for the total investment cost to be fully recovered after the establishment of the business. The minimum payback period is defined as the time required to recover the invested capital. The PBP for the coffee-husk particleboard manufacturing business is calculated using the following equation:

$$PBP = \frac{Annual\ Cost}{Annual\ Profit}$$

All investment costs incurred for the production of particleboard with a density of 0.6 g/cm³ will be recovered within a period of 0.6 years. This indicates that the particleboard manufacturing business with a density of 0.6 g/cm³ is feasible, as the invested capital will be returned in less than one year.

Net Present Value (NPV) is defined as the difference between cash inflows and cash outflows while considering the time value of money. The time value of money formula using present value is applied to determine the current value of money to be received in the future. Therefore, since the funds will be received in the future, it is necessary to determine their equivalent value if received at the present time.

NPV in year 1 = Rp. 238.339.528
NPV in year 5 = Rp. 1.191.697.639
NPV in year 10 = Rp. 2.383.395.278

The calculated NPV values are greater than zero (NPV > 0) for all periods considered. Thus, the coffee-husk-based particleboard manufacturing business with a density of 0.6 g/cm³ is economically feasible.

4. Conclusions, Recommendations, and References

The produced particleboards satisfy the Indonesian National Standard (SNI) requirements for density, internal bonding strength (IB), and bending strength/failure strength (MOR, modulus of rupture). However, for the modulus of elasticity (MOE), none of the particleboards meet the SNI standard. The adhesive content, density, and the addition of wood particles significantly affect the physical and mechanical properties of the coffee husk particleboards.

The coffee husk particleboards produced for sound absorption applications comply with ISO 11654:1997 and are classified within Classes B, C, D, and E, with the highest sound absorption coefficient (α) reaching 0.88, indicating that nearly all incident sound waves are absorbed by the boards. The absorption coefficient is influenced by the density and chemical composition of the particleboards.

The coffee-husk particleboard manufacturing business is feasible for a density of 0.6 g/cm³, as all investment costs are recovered within a period of less than one year. The cost of production is more than 50% of the selling price, allowing all sales-related expenses (promotion, advertising, licensing, and price discounts) to be covered without increasing the selling price.

Future studies on coffee husk particleboards are expected to incorporate parameters such as higher pressing pressure and longer pressing time. Additionally, the production of multi-layer particleboards is expected to result in improved physical, mechanical, and sound absorption properties. The separation of arabica and robusta coffee husks, the addition of materials other than wood particles, and the use of adhesives other than urea formaldehyde are also expected to influence the physical, mechanical, and acoustic properties of the resulting particleboards.

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