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Characteristics of Particle Cement Board and Wood Plastic Composite from Oil Palm (Elaeis guineensis Jacq.) Fronds

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A B S T R A C T

The yield of oil palm fronds is 8.4 tons/ha/year [1], a huge potential that has not been used optimally. Particle Cement Board (PCB) is a biocomposite that uses inorganic adhesive, namely cement, to bind biomass particles into a board. Wood Plastic Composite (WPC) is a biocomposite that combines plastic and biomass particles molded into boards. This study used the same biomass particles—oil palm fronds—to analyze the properties of PCBs and WPCs. Characteristics assessment by measuring and testing physical and mechanical properties were density, moisture content, water absorption, thickness swelling, elasticity (MOE and MOR), and internal bond strength (IBS) of oil palm fronds PCB (refers and compared to JIS A 5417-1992 and SNI 8299-2017 standards) and WPC (refers and compared to JIS A 5908-2003 and SNI 03-2105-2006 standards). The test results on the PCB are density 1.143 g/cm^3, moisture content 8.429%, water absorption 26.414%, thickness swelling 1.368%, MoE 188.899 N/mm^2, MoR 5.765 N/mm^2, and IBS 0.054 N/mm^2. The test results on the WPC are density 0.84 g/cm^3, moisture content 2.36%, water absorption 16.21%, thickness swelling 7.11%, MoE 590.87 N/mm^2, MoR 13.40 N/mm^2, and IBS 0.31 N/mm^2. Oil palm fronds is quite well used as a raw material for making particle cement board (PCB) and Wood Plastic Composite (WPC)

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INTRODUCTION

Particle Cement Board (PCB) is a biocomposite that uses inorganic adhesive, namely cement, to bind biomass particles into a board. Wood Plastic Composite (WPC) is a biocomposite that combines plastic and biomass particles molded into boards. Both have different characteristics, based on the binding material.

So far, oil palm fronds have not been utilized optimally, they are limited to waste in plantations. Meanwhile, its potential is very large, namely 8.4 tons/ha/year [1], providing a great opportunity to be used as a raw material for making PCB and WPC. Several studies have been conducted on PCB and WPC, but few have used oil palm fronds.

LITERATURE REVIEW

The production of PCB and WPC is influenced by the chemicals found in oil palm fronds.

Table 1. Content of Chemical Compounds in Oil Palm Fronds[2].

Chemical compounds	(%)
Cellulose	33,7
Hemicellulose	35,9
Lignin	17,4
Silica	2,6
Ash	3,3
Nitrogen	2,38
Potassium	1,316
Calcium	2,568

Catalyst ratio and other parameters are among the many that influence the quality of the particle cement boards produced. Magnesium chloride ($MgCl_2$) is a catalyst that is quite good for use in hardening cement boards using wood particles. $MgCl_2$ may also be able to catalyze glycosidic bonds in lignocellulose [3]. Standards that applies to the physical and mechanical properties (characteristics) of PCB are the JIS A 5417-1992 standard and SNI 8299-2017, shown in Table 2 and Table 3 below.

Table 2. Characteristics of PCB Based on JIS A 5417-1992[4].

Characteristics of PCB		
Density	≥ 0.8	g/cm^3
Moisture content	≤ 16	%
Water absorption	-	%
Thickness swelling	≤ 8.3	%
Modulus of Elasticity (MoE)	> 2,353.596 (> 24,000	N/mm^2 kg/cm^2)
Modulus of Rupture (MoR)	> 6.178 (> 63	N/mm^2 kg/cm^2)
Internal Bond Strength (IBS)	-	-

1 kg/cm^2 = 0,0980665 N/mm^2

Table 3. Characteristics of PCB Based on SNI 8299-2017[5].

Characteristics of PCB		
Density	≥1.15	g/cm^3
Moisture content	≤ 15	%
Modulus of Rupture (MoR)	≥ 9.807 (≥ 100	N/mm^2 kg/cm^2)

1 kg/cm^2 = 0,0980665 N/mm^2

One of the key factors that influences the quality of wood plastic composites is the type, content and distribution of the matrix (plastic) [6].

Standards that applies to the physical and mechanical properties (characteristics) of WPC are the JIS A 5908-2003 standard and SNI 03-2105-2006, shown in Table 4 and Table 5 below.

Table 4. Characteristics of WPC Based on JIS A 5908-2003[7].

Characteristics of WPC		
Density	0.4-0.9	g/cm^3
Moisture content	5-13	%
Water absorption	-	%
Thickness swelling	≤12	%
Modulus of Elasticity (MoE)	> 2,000.557 (> 20.400	N/mm^2 kg/cm^2)
Modulus of Rupture (MoR)	≥ 8.042 (≥ 82	N/mm^2 kg/cm^2)
Internal Bond Strength (IBS)	≥ 0,147 (≥1,5	N/mm^2 kg/cm^2)

1 kg/cm^2 = 0,0980665 N/mm^2

Table 5. Characteristics of WPC Based on SNI 03-2105-2006[7].

Characteristics of WPC		
Density	0.4-0.9	g/cm^3
Moisture content	≤14	%
Water absorption	-	-
Thickness swelling	≤12	%
Modulus of Elasticity (MoE)	> 2,000.557 (> 20.400	N/mm^2 kg/cm^2)
Modulus of Rupture (MoR)	≥ 8.042 (≥82	N/mm^2 kg/cm^2)
Internal Bond Strength (IBS)	≥ 0,147 (≥1,5	N/mm^2 kg/cm^2)

$1\ kg/cm^2 = 0{,}0980665\ N/mm^2$

IBS is one of the mechanical properties of plastic boards which shows the amount of adhesion and bonding between the constituent materials which can be combined to form plastic boards [7].

METHODOLOGY

Oil Palm Fronds Particle Cement Board (PCB) Making Process

The materials were oil palm fronds particles, portland cement (PCC) type II, $MgC1_2$ (Magnesium Chloride) catalyst 7% by weight of cement, and water to dissolve the catalyst.

The tools were a grinder (Hammer-mill Machine), mold with a size of 30 x 30 x 1.2 cm, limiting sticks, wooden racks, press machines, flasks, thermometers, plastic cups, measuring cups, ovens, water baths, petri dishes, desiccators, calipers, scales, tools for mixing particles with cement (mixer), Universal Testing Machine (UTM), soaking tub, and milimeter paper.

Particle cement board making process as show below:

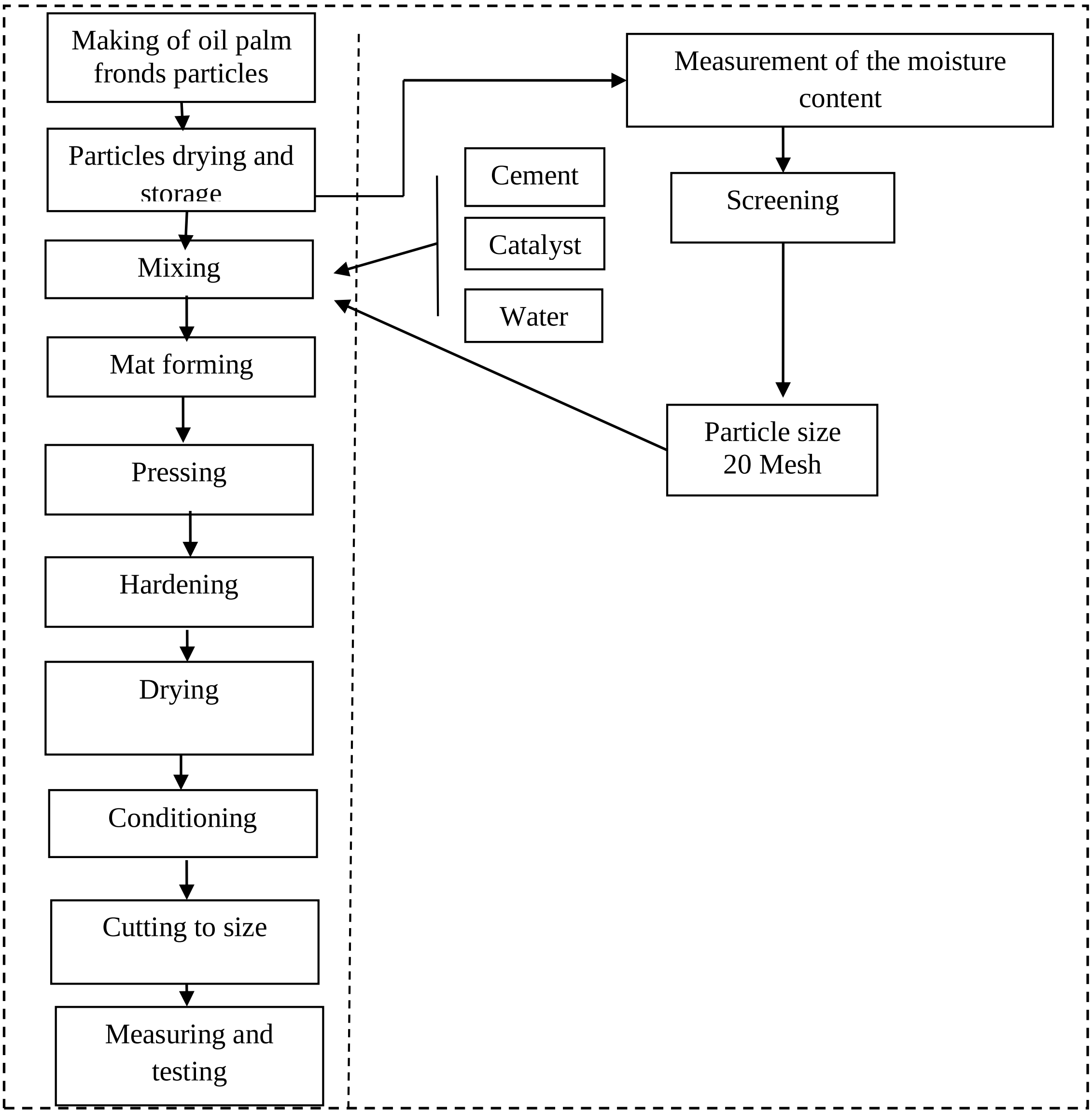

Figure 1. Oil Palm Fronds Particle Cement Board (PCB) Making Process

A 3:1 cement to oil palm fronds particle ratio, 20 minutes and 40 bar press machine pressure, and 7% $MgCl_2$ catalyst are used to create PCB

Oil Palm Fronds Wood Plastic Composite (WPC) Making Process

The materials were oil palm fronds particles and Polyethylene (PE) plastic.

The tools were a grinder (Cross beater mill), mold with a size of 32 x 32 x 0.6 cm, limiting sticks, wooden racks, press machines, plastic cups, measuring cups, ovens, water baths, petri dishes, desiccators, caliper, scales, tools for mixing particles with cement (mixer), Universal Testing Machine (UTM), soaking tub, and milimeter paper.

Wood plastic composite making process as show below:

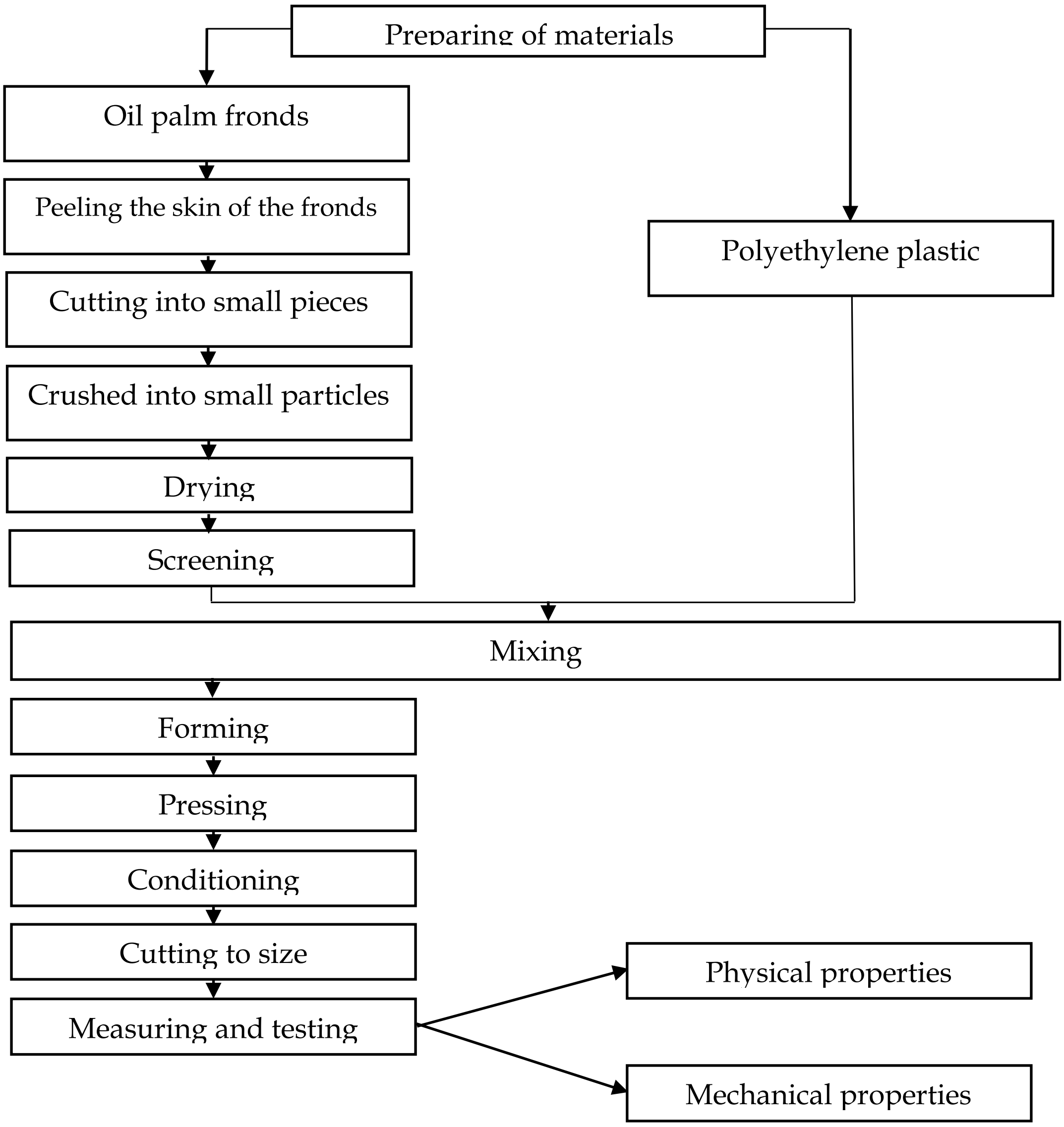

Figure 2. Oil Palm Fronds Wood Plastic Composite (WPC) Making Process

Thirty percent particles and seventy percent plastic (polyethylene) are used to make WPC. The press machine is heated to 180°C and runs for twenty minutes at 30 bar of pressure.

Oil palm fronds PCB and WPC's testing were carried out based on JIS A 5417-1992 and JIS A 5908 (2003).

1. Testing the physical properties of oil palm fronds particle cement board

a. **Density**

$$\rho_o = \frac{m_o}{v_o} (g/cm^3)$$

po = dry cement board cement particle density (g/cm^3)
mo = dry mass of test sample (g)

vo = dry volume of test sample (cm^3)

b. Moisture Content

$$\mu = \frac{m_n - m_0}{m_0} \times 100\%$$

μ = normal moisture content (%)
mn = normal mass of the test sample (g)
mo = dry mass of test sample (g)

c. Water Absorption

$$\tau = \frac{m_1 - m_0}{m_0} \times 100\%$$

τ = Water absorption (%)
m1 = Mass of the test sample after soaking (g)
mo = Mass of test sample before soaking (g)

d. Thickness Swelling

$$\alpha = \frac{t_1 - t_o}{t_o} \times 100\%$$

α = Thickness swelling (%)
t1 = Thickness of the test sample after soaking (mm)
to = Thickness of the test sample before soaking (mm)

2. Testing the mechanical properties of oil palm fronds particle cement board

a. Modulus of Elastisity (MoE)

$$\epsilon b = \frac{\Delta F . l^3}{\Delta f . a^3 . b . 4} \ (N/mm^2)$$

ϵb = Modulus of elasticity (MoE) (N/mm^2)
ΔF = Change at the limit of proportion (N)
a = Thickness of test sample (mm)
b = Width of test sample (mm)
Δf = Deflection at the limit of proportion (mm)
l = Support distance (mm)

b. Modulus of Rupture (MoR)

$$\beta b = \frac{Fmax . l . 3}{a^2 . b . 2} \ (N/mm^2)$$

βb = Modulus of Rupture (MoR) (N/mm^2)
Fmax = maximum load/amount of force (N)
a = Thickness of test sample (mm)
b = Width of test sample (mm)
l = Support distance (mm)

c. Internal Bonding Strength (IBS)

$$Qibs = \frac{Fmax}{A} \ (N/mm^2)$$

Qibs = Internal Bonding Strength (IBS) (N/mm^2)
Fmax = maximum load/amount of force (N)
A = Test cross-sectional area (mm^2)

RESULTS

Table 6. Physical and Mechanical Properties (Characteristics) of Oil Palm Fronds Particle Cement Board (PCB)

Characteristics of oil palm fronds PCB		
Density	1.143	g/cm^3
Moisture content	8.429	%
Water absorption	26.414	%
Thickness swelling	1.368	%
Modulus of Elasticity (MoE)	188.899 (1,926.234	N/mm^2 kg/cm^2)
Modulus of Rupture (MoR)	5.765 (58.787	N/mm^2 kg/cm^2)
Internal Bond Strength (IBS)	0.054 (0.551	N/mm^2 kg/cm^2)

1 kg/cm^2 = 0,0980665 N/mm^2

Table 7. Physical and Mechanical Properties (Characteristics) of Oil Palm Fronds Wood Plastic Composite (WPC)

Characteristics of oil palm fronds WPC		
Density	0.84	g/cm^3
Moisture content	2.36	%
Water absorption	16.21	%
Thickness swelling	7.11	%
Modulus of Elasticity (MoE)	590.89 (6,025.401	N/mm^2 kg/cm^2)
Modulus of Rupture (MoR)	13.40 (136.642	N/mm^2 kg/cm^2)
Internal Bond Strength (IBS)	0.31 (3.161	N/mm^2 kg/cm^2)

DISCUSSION

Oil Palm Fronds Particle Cement Board (PCB)

Based on data from the research results, each test value is compared with the standard used to assess the quality of oil palm fronds PCB, as shown in the following table.

Table 8. Comparison of the Result of Oil Palm Fronds PCB Testing Against JIS A 5417-1992 and SNI 8299-2017 Standards

	Oil palm fronds PCB	JIS A 5417-1992	SNI 8299-2017	Remark
Density (gr/cm³)	1.143	≥ 0.8	≥1.15	Has fulfilled
Moisture content (%)	8.429	≤ 16	≤ 15	Has fulfilled
Water absorption (%)	26.414	-	-	No remark
Thickness swelling (%)	1.368	≤ 8.3	-	Has fulfilled
Modulus elasticity (MoE) (N/mm²)	188.899 (1,926.234)	> 2,353.596 (> 24,000)	-	Not fulfilled
Modulus of Rupture (MoR) (N/mm²)	5.765 (58.787)	> 6.178 (> 63)	≥ 9,807 (≥ 100)	Not fulfilled
Internal Bonding Strength (IBS) (N/mm²)	0.054 (0.551)	-	-	No remark

(*) = in kg/cm²
1 kg/cm² = 0,0980665 N/mm²

Based on the data in Table 7, all mechanical properties of oil palm fronds PCB do not meet standard requirements, but all physical properties meet the requirements. This indicates that although oil palm fronds PCB are in acceptable physical condition, their mechanical capacity to support loads is still inadequate, especially in structural applications.

The weight of the board is mostly determined by the amount of cement, as opposed to the weight of the particles, due to the relatively high ratio of cement to particles (70:30).

The added $MgCl_2$ catalyst (7%) can produce better oil palm fronds PCB density because the faster the cement hardening process is able to bind palm fronds particles and resist the increase in volume due to spring back which has a direct impact on the density value, this can occur when the load or pressure is released from the pressing machine. The higher the percentage of catalyst used will produce a higher density of particle cement board [8].

The high density of oil palm fronds PCB means that there are fewer cavities in the board which results in the board's ability to absorb water from the outside being reduced. This also has an impact on lower water absorption and thick swelling of oil palm fronds PCB.

The $MgCl_2$ (7%) catalyst provided produces better elasticity strength (MoE and MoR) of palm fronds PCB because the cement hardens more quickly so that the bond between particles and cement becomes better. The greater the catalyst composition added will result in a better value of the elasticity of the palm fronds PCB [8].

The addition of a catalyst causes an increase in density and then results in an increase in the compactness of the bond between cement and oil palm fronds particles, so that the internal bond strength of the particle cement board also increases. There is a relationship between increasing the density of cement board and improving the connection between the matrix and wood particles [9].

Oil palm fronds particles are classified as good enough to be used as raw material for particle cement board, as stated by achieving a hydration temperature measurement of 30°C. Quite good when compared to oil palm trunks which reach 52°C [10].

Oil Palm Fronds Wood Plastic Composite (WPC)

Table 9. Comparison of the Result of oil Palm Fronds Wood Plastic Composite (WPC) Testing Against JIS A 5908-2003 and SNI 03-2105-2006 Standards

	Oil palm fronds WPC	JIS A 5908-2003	SNI 03-2105-2006	Remark
Density (gr/cm^3)	0.84	0.4-0.9	0.4-0.9	Has fulfilled
Moisture content (%)	2.36	5-13	≤14	Has fulfilled
Water absorption (%)	16.21	-	-	No remark
Thickness swelling (%)	7.11	≤12	≤12	Has fulfilled
Modulus elasticity (MoE) (N/mm^2)	590.89 (6,025.401)	> 2,000.557 (> 20.400)	> 2,000.557 (> 20.400)	Not fulfilled
Modulus of Rupture (MoR) (N/mm^2)	13.40 (136.642)	≥ 8.042 (≥ 82)	≥ 8.042 (≥82)	Not fulfilled
Internal Bonding Strength (IBS) (N/mm^2)	0.31 (3.161)	≥ 0.147 (≥1.5)	≥ 0.147 (≥1.5)	Has fulfilled

(*) = in kg/cm^2

1 kg/cm^2 = 0,0980665 N/mm^2

Based on the information in Table 8, the mechanical internal bond strength (IBS) of oil palm fronds WPC satisfies standards; nevertheless, its elasticity does not, even though all of its physical attributes comply. This demonstrates that oil palm fronds WPC is used in lightweight constructions because it has respectable physical qualities and a sufficient mechanical capacity to withstand loads, despite its poor flexibility.

Polyethylene plastic is thought to influence the density value of the oil palm fronds WPC, because the size and weight of the plastic pellets are relatively larger than particles so that their distribution can cause a difference in weight which increases the oil palm fronds WPC density.

The structure of the oil palm fronds particles has few cavities so that when the plastic melts during compression it can completely cover the particles thereby reducing the cavities in the board which causes a small amount of water vapor to be absorbed.

In general, the water content of plastic boards is lower than particles, furthermore because of the heat press and plastic as a matrix used it can reduce the absorption of water vapor [11].

The oil palm fronds WPC's high density causes the board to have fewer voids, which lowers their capacity to absorb water vapor from the outside. This affects oil palm fronds WPC's thickening and reduced water absorption as well.

The MoE and MoR of WPC oil palm fronds do not meet standards because the mixing process between the particles and plastic is uneven so that the bond between the two is less compact. Despite this, the internal bonding is quite good and meets standards.

CONCLUSIONS AND RECOMMENDATIONS

Palm fronds are quite good for making particle cement board (PCB) and wood plastic composite (WPC), proven to have good physical properties even though their mechanical properties are not so good so they are suitable for light structural or non-structural uses.

FURTHER STUDY

It would be interesting to carry out further research using other biomass which is available in abundance but has not been utilized optimally.

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