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Environmentally Friendly Particle Board from Sawdust with the Addition of PP and PET Plastic Waste without Using UF Adhesive

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Abstract Particle board is generally made from sawdust and urea formaldehyde (UF) adhesive. UF is actually a material that is dangerous to health and the environment, and the price is relatively expensive. Likewise, PP and PET waste is very dangerous for health and the environment. It is interesting to know whether polypropylene (PP) and polyethylene terephthalate (PET) plastic waste can be used as a substitute for UF. In this research, PP plastic waste and PET plastic waste were used as adhesive substitutes for urea formaldehyde in the manufacture of particle board. Particleboard will be made into four combinations, namely sawdust + UF + PP measuring 1 cm x 5 cm; sawdust + UF size + PP pass No.4 sieve; sawdust + PP size passing No.4 sieve; and sawdust + PET in size that passes filter number 4. The mixture proportion for each combination is 70% sawdust: 30% plastic waste; 60% sawdust: 40% plastic waste; and 50% sawdust: 50% plastic waste, each heated for 20 minutes with a temperature set at 180 ℃ for PP waste and 200 ℃ for PET waste, with a pressure amount of 25 kg/cm^2. It is interesting that PP that passes filter No. 4 sieve can be used in making particle board, but further research is needed to determine the optimal mixture proportions and temperature, as well as meeting all standards required by SNI and JIS. This research is useful for particle board manufacturing companies to determine alternative materials to replace UF, so that production costs can be cheaper.

Keywords Particleboard, Plastic Waste, Polypropylene, Polyethylene Terephthalate

1. Introduction

As a raw material for construction, wood should be a sustainable raw material and will not run out compared to stone or iron; as long as it is appropriately managed, every tree cut down must be of sufficient age. There must be a replacement tree for the tree that was cut down. There is quite a lot of wood processing waste in West Kalimantan because there are many sawmills and doors, windows, ventilation, frames, and furniture manufacture. Saw dust waste is mainly used as a landfill material [1], [2]. In contemporary times, the practice of burning has been subject to restrictions as a result of growing environmental apprehensions. Moreover, it is worth noting that burning

serves as a catalyst for environmental pollution [3]. This wood processing waste can be used to make particle boards. Sawdust and Urea-formaldehyde (UF) are commonly used as adhesives to manufacture particle boards [4], [5].

Plastic waste is increasing yearly due to its practical manufacture and use; it consists of various types [6]–[8], including polypropylene (PP) and polyethylene terephthalate (PET). PP and PET are highly non-biodegradable in soil and water environments; these plastics demonstrate significant resistance to decomposition in the natural ecosystem [9], [10]. Plastic waste, particularly from materials like polypropylene (PP) and polyethylene terephthalate (PET), is a growing environmental concern. These plastics are non-biodegradable, leading to long-term persistence in natural environments. Consequently, there is a strong interest in finding ways to recycle and reuse plastic waste in various industries, including construction [11]–[13].

Traditionally, Urea-Formaldehyde (UF) adhesives have been used in the production of particle boards. While effective, UF is known for its environmental hazards, including the release of formaldehyde, a known carcinogen. As such, there is a significant push towards finding alternatives to UF adhesives in particle board manufacturing [14]–[16]. In this research, the test object will be made in the form of particle board with sawdust base material added with PP and PET plastic waste using UF adhesive and without using UF adhesive, only PP plastic waste, besides being able to reduce the cost of making particle board. Research has increasingly focused on incorporating plastic waste into construction materials to enhance their properties and provide a recycling pathway for plastics. Studies have shown that adding plastics such as PP and PET to construction materials can improve their durability, resistance to water and weather, and even resistance to biological degradation by pests like termites. The reference standards for testing particle board are [17]–[19] regarding particle board.

2. Materials and Methods

The material used to manufacture particle board test samples consists of sawdust mixed with PP or PET plastic waste, UF adhesive, catalyst, and paraffin [20], [21] as follow:

Particleboard dimension = 30cm x 30cm x 1cm
Density target = 0,8 gr/cm^3
Adhesive needs: - UF 11% (solid content 52%)
- Catalyst 0.1% (solid content 25%)
- Paraffin 1% (solid content 40%)

Sawdust dry oven = length x width x thick x density = 30 cm x 30 cm x 1 cm x 0,8 g/cm^3= 720 g

2.1. Materials Requirement for Making the Samples: sawdust + PET or PP + adhesive

(a) Proportion 1 (70:30)

$$S=\frac{70}{100}x642.28\ g=449.60\ g\ (sawdust)$$

$$P=\frac{30}{100}x642.28\ g=192.69\ g\ (PP\ or\ PET)$$

$$UF\ with\ sc\ 52\%=\left(\frac{11}{112.1}x720\ g\right)x\frac{100}{52}=135{,}87\ g$$

$$Catalyst\ with\ sc\ 25\%=\left(\frac{0.1}{112.1}x720\ g\right)x\frac{100}{25}=2.57\ g$$

$$Paraffin\ with\ sc\ 40\%=\left(\frac{1}{112.1}x720\ g\right)x\frac{100}{40}=16.06\ g$$

(b) Proportion 2 (60:40)

$$S=\frac{60}{100}x642.28\ g=385.37\ g\ (sawdust)$$

$$P=\frac{40}{100}x642.28\ g=256.91\ g\ (PP\ or\ PET)$$

$$UF\ with\ sc\ 52\%=\left(\frac{11}{112.1}x720\ g\right)x\frac{100}{52}=135{,}87\ g$$

$$Catalyst\ with\ sc\ 25\%=\left(\frac{0.1}{112.1}x720\ g\right)x\frac{100}{25}=2.57\ g$$

$$Paraffin\ with\ sc\ 40\%=\left(\frac{1}{112.1}x720\ g\right)x\frac{100}{40}=16.06\ g$$

(c) Proportion 3 (50:50)

$$S=\frac{50}{100}x642.28\ g=321.14\ g\ (sawdust)$$

$$P=\frac{50}{100}x642.28\ g=321.14\ g\ (PP\ or\ PET)$$

$$UF\ with\ sc\ 52\%=\left(\frac{11}{112.1}x720\ g\right)x\frac{100}{52}=135{,}87\ g$$

$$Catalyst\ with\ sc\ 25\%=\left(\frac{0.1}{112.1}x720\ g\right)x\frac{100}{25}=2.57\ g$$

$$Paraffin\ with\ sc\ 40\%=\left(\frac{1}{112.1}x720\ g\right)x\frac{100}{40}=16.06\ g$$

2.2. Materials Requirement for Making the Samples: sawdust + PP size passes sieve No. 4 (without UF)

(a) Proportion 1 (70:30)

$$S=\frac{70}{100}x642.28\ g=449.60\ g\ (sawdust)$$

$$P=\frac{30}{100}x642.28\ g=192.69\ g\ (PP\ or\ PET)$$

(b) Proportion 2 (60:40)

$$S=\frac{60}{100}x642.28\ g=385.37\ g\ (sawdust)$$

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(c) Proportion 3 (50:50)

$$S=\frac{50}{100}x642.28\ g=321.14\ g\ (sawdust)$$

$$P=\frac{50}{100}x642.28\ g=321.14\ g\ (PP\ or\ PET)$$

The materials used to make particle board can be seen in the following table:

Table 1. Particleboard proportion

No	Proportion (%)	S (g)	PP (g)	PET (g)	UF (g)	C (g)	F (g)
	PP & PET 1 x 5 mm						
1	70:30:00	449.6	192.69	0.00	135.87	2.57	16.06
2	60:40:00	385.37	256.91	0.00	135.87	2.57	16.06
3	50:50:00	321.14	321.14	0.00	135.87	2.57	16.06
	PP & PET passing sieve no. 4						
4	70:30:00	449.6	192.69	0.00	135.87	2.57	16.06
		449.6	0.00	192.69	135.87	2.57	16.06
5	60:40:00	385.37	256.91	0.00	135.87	2.57	16.06
		385.37	0.00	256.91	135.87	2.57	16.06
6	50:50:00	321.14	321.14	0.00	135.87	2.57	16.06
		321.14	0.00	321.14	135.87	2.57	16.06
	PP passing sieve no. 4 without UF						
7	70:30:00	449.6	192.69	0.00	0.00	0.00	0.00
8	60:40:00	385.37	256.91	0.00	0.00	0.00	0.00
9	50:50:00	321.14	321.14	0.00	0.00	0.00	0.00

The physical and mechanical characteristics of particleboard are outlined in SNI 03-2105-2006 and JIS A 5908:2003 [20]:

Table 2. Particleboard properties standardions

No	Properties	JIS	SNI
1	Tolerance on thickness, mm	± 1.0	± 1.0
2	Density, g/cm^3	0.40 – 0.90	0.40 – 0.90
3	Moisture content, %	5 – 13	< 14
4	Swelling in thickness, %	Max. 12	Max. 12
5	Internal bonding, kgf/cm^2	Min. 1.5	Min. 1.5
6	MOR, kgf/cm^2	Min. 80	Min. 82
7	MOE, kgf/cm^2	Min. 20,000	Min. 20,400
8	Screw holding power, kg	Min. 30	Min. 31

The sawdust is allowed to air dry for approximately 7 (seven) days. After the sawdust is air dried, it is put in the oven at ±105 ℃; it is checked whether the moisture content has reached 5%; if it has not reached 5%, the sawdust is put back in the oven. Waste plastic bottles (PET) and PP plastic waste are collected, washed, and dried in the sun; after drying, they are crushed until they pass sieve No 4. This park is also equipped with various public facilities provided with seating, which can relax after facing life's fatigue [22].

Particle board is produced by combining sawdust and PET or PP in a plastic container, followed by stirring to ensure uniform distribution based on the specified proportions of the mixture. This process is carried out in three different variants, namely 70:30, 60:40, and 50:50, each with a specific adhesive composition. The adhesive composition consists of 11% UF adhesive (SC 52), 1% paraffin (SC 40), and 0.1% catalyst (SC 25). The amount of adhesive used remains consistent across all variants, with the exception of the variant without adhesive (UF) [4]. The homogeneously mixed sample is thereafter put into the mold. The mixture's surface was leveled using a steel ruler, followed by pressing it with a hot packing press at a weight of 25 kg/cm^2. The press was then heated to a temperature of ±180 ℃ (PP) for 15 minutes and ±200 ℃ (PET) for 20 minutes. Subsequently, the test samples were left to dry naturally for a duration of 24 hours. Tests to compare the two scaffolding formwork systems were carried out in one-story buildings to four-story buildings with a typical floor area of one to a specific four-floor floor area with the same place to compare and measure the two scaffold formwork systems [23].

3. Results and Discussion

3.1. Physical Properties

3.1.1. Density

PP passed sieve No. 4 shows a better density than PP with a 1 cm x 5 cm size. This shows that the finer the PP, the more evenly the PP spreads in the mixture; for PET, the density is lower than PP because PET requires a higher

temperature to melt. The density of PP mixes without adhesive tends to stay the same with different mix proportions, as shown in figure 1.

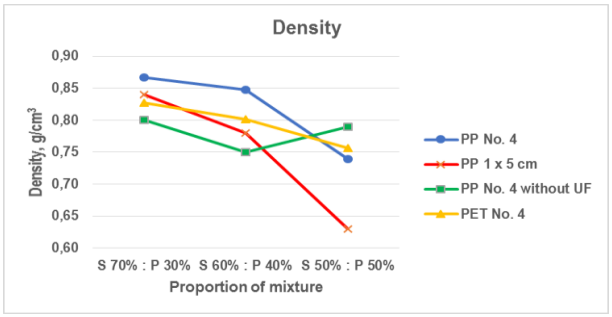

Figure 1. Density average values

3.1.2. Moisture Content

From the results of testing the water content samples, it was obtained that all the proportions of the mixture of the four variations met SNI and JIS standards, and the average values of moisture content range from 1.23% - to 5.32%, as shown in figure 2.

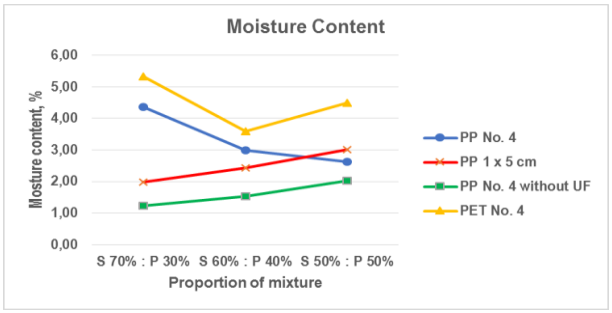

Figure 2. Moisture content average value

The water content of polyethylene terephthalate (PET) is found to be the highest, suggesting that there is an uneven mixing of PET with sawdust in the mixture. Conversely, polypropylene (PP) without adhesive exhibits an increase in water content as the amount of sawdust in the mixture decreases. This observation implies that an increase in PP in the adhesive-free mixture leads to increased cohesion, resulting in reduced binding to sawdust when subjected to heat. Additionally, the dimensions of the PP material are measured to be 1 cm x 5 cm. This has resulted in settlements that do not meet the basic housing requirements, including providing open spaces or communal areas for residents [24].

3.1.3. Water Absorption

The results of the water absorption test range from 0.13% - 0.35%; the entire test results can be seen in figure 3.

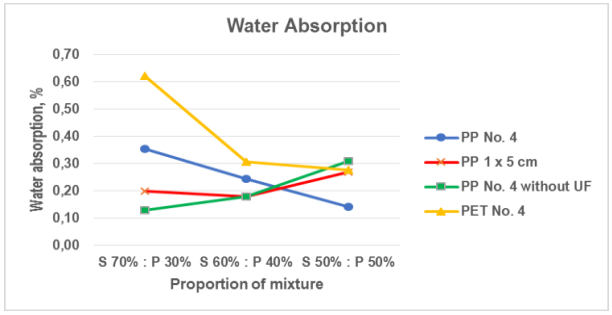

Figure 3. Water absorption average value

The water absorption capacity of sawdust, when combined with PP, passed through the No. Sieve Four, whereas the water absorption capacity of sawdust, when combined with PET, passed through the No. Sieve Four. The water absorption capacity decreased as the quantity of PP and PET plastic waste in the combination increased. Conversely, the water absorption capacity of sawdust increased as the amount of PP plastic waste in the mixture increased, with the addition of 1 x 5 cm PP and PP passing filter No. 4 without adhesive. Although not mandatory in SNI and JIS, conducting this water absorption test is crucial to understand how the environment can impact the durability of particle board [21].

3.1.4. Swelling in Thickness

The results of the swelling in thickness test for particle board ranged from 0.42% - 14.92%, as shown in figure 4 below:

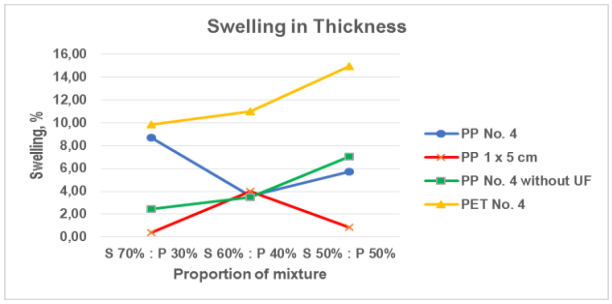

Figure 4. Swelling in thickness average value

All three particle boards, made from sawdust and a mixture of PP plastic waste, meet the SNI and JIS criteria. This indicates that PP plastic waste effectively binds to sawdust. However, the particle board made from sawdust and a mixture of PET plastic waste in a ratio of 50%:50% did not meet the SNI and JIS criteria. This suggests that the particle board expands more easily when exposed to water when more PET plastic waste is added, as plastic waste tends to bind with other plastic wastes compared to sawdust. In the contemporary e-commerce landscape, personalized recommendation systems play a vital role in enhancing the shopping experience [25].

3.2. Mechanical Properties

3.2.1. Modulus of Rupture (MOR)

The test samples yielded test findings indicating that the mean MOR value varied between 21.68 kgf/cm^2 and 266.65 kgf/cm^2, as seen in figure 5:

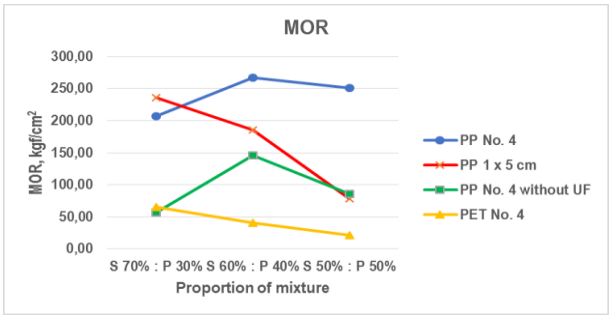

Figure 5. Modulus of Rupture average value

The MOR (Material of Role) of particleboard derived from sawdust, when combined with PP plastic waste in three different proportions, satisfies the criteria set by SNI and JIS. Particleboard made from sawdust, without the use of adhesive, with a mixture proportion of 60%: 40% and 50%: 50%, meets the criteria set by SNI and JIS. However, particleboard made from sawdust with the addition of PET plastic waste does not meet the criteria set by SNI and JIS. An increased amount of plastic trash in the mixture leads to a drop in the MOR value, suggesting that there is binding between the plastic waste particles, resulting in a decrease in the MOR value. The security feature improves nighttime driver sight [26].

3.2.2. Modulus of Elasticity (MOE)

The MOE test results for the particle board varied between 31,883.78 kgf/cm^2 and 162,614.07 kgf/cm^2, as seen in figure 6:

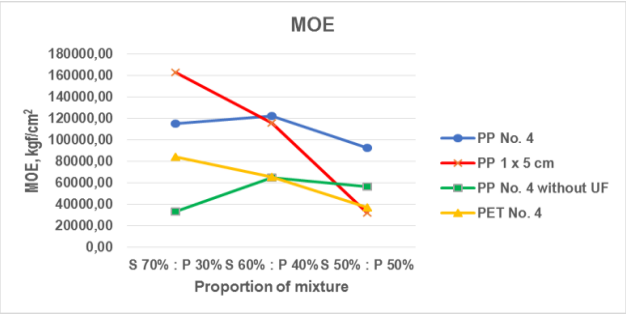

Figure 6. Modulus of Elasticity average value

Particle boards composed entirely of plastic waste mixtures exhibit MOE values that satisfy the criteria set by SNI and JIS. However, it is observed that the MOE values tend to diminish as the quantity of plastic waste in the mixture increases. This observation suggests that the inclusion of plastic waste in the mixture leads to a decrease in the bonding strength between sawdust and plastic waste. This is attributed to the greater affinity of plastic waste for binding to other plastic waste particles compared to sawdust.

3.2.3. Internal Bonding

Particle board internal bonding tests yielded average values ranging from 0.29 kgf/cm^2 to 5.28 kgf/cm^2; the complete results can be seen in figure 7 below:

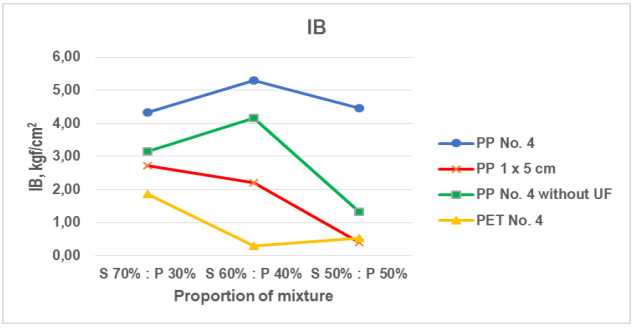

Figure 7. Internal Bonding average value

The IB of particle board with the addition of PP plastic waste passes the No. 4 sieve, and all met the criteria of SNI and JIS. The IB of particle board with the addition of PP plastic waste measuring 1 cm x 5 cm and PP without UF adhesive with a mixture proportion of 70%: 30% and 60%: 40% fulfill the criteria of SNI and JIS, but the proportion of the mixture of 50%: 50% does not meet the criteria SNI and JIS. IB of particle board with the addition of PET plastic waste with a mixture proportion of 70%: 30% meets SNI and JIS criteria, but the mixture proportion of 60%: 40% and 50%: 50% does not meet SNI and JIS criteria, this shows that the more plastic waste in the mixed, IB value will decrease because the more plastic waste in the mixture, causing the plastic waste to bind to each other so that less plastic waste binding the sawdust.

3.2.4. Screw Holding Power

The results of the screw-holding power test indicate an average value that varies between 6.6 kgf and 91.95 kgf, as seen in figure 8:

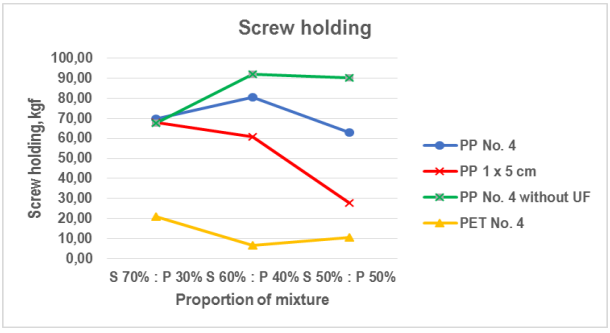

Figure 8. Screw holding power average

The screw holding power of particle board testing, with and without the addition of PP plastic waste using UF

adhesive, met the criteria set by SNI and JIS. However, the particle board with a size of 1 cm x 5 cm and a mixture proportion of 50%:50% did not meet the criteria. On the other hand, the particle board with the addition of PET plastic waste did not meet the criteria set by SNI and JIS. This indicates that the use of UF adhesive to hold PP plastic waste and without UF adhesive provided sufficient strength to prevent screws from being easily removed from the particle board. However, the addition of PET plastic waste indicated that the PET did not melt properly to bind sawdust.

4. Conclusions

From the results of the tests that have been carried out, the following conclusions are obtained:

- PP plastic waste has the potential to be used as a substitute for UF adhesives, in addition to lower production costs to protect the environment from plastic waste.
- The temperature for melting PP is lower than that required for melting PET.
- The particle board density values meet SNI and JIS criteria from all mix proportions and variations.
- The water content of the particle board as a whole is quite low and satisfies the requirements set by SNI and JIS.
- The water absorption ranges from 0.13% to 0.35 even though SNI and JIS do not require it.
- The swelling in thickness of particleboard made from sawdust with a mixture of PP plastic waste, all three meet SNI and JIS criteria; particleboard made from sawdust with a mixture of PET plastic waste with a ratio of 50%: 50% does not meet SNI and JIS criteria.
- The MOR of particle board made from sawdust with the addition of PP plastic waste measuring 1 cm x 5 cm and PP passing No. Sieve. Four with three mixture proportions fulfil SNI and JIS criteria, particle board made from sawdust with the addition of PP plastic waste without adhesive with a mixture proportion of 60%: 40% and 50%: 50% meet SNI and JIS criteria, 70%: 30% do not meet SNI and JIS criteria. The MOR of particle board with the addition of PET plastic waste needs to meet the criteria of SNI and JIS [27].
- The material of interest (MOE) of particle board, when incorporating PP and PET plastic waste, satisfies the standards set by SNI and JIS.
- The inclusion of PP plastic waste in particle board results in the passage of the IB via a No. 4 filter. The particle board, when combined with PP plastic waste measuring 1 cm x 5 cm and PP without UF adhesive in mixture proportions of 70:30% and 60:40%, satisfies the criteria set by SNI and JIS. However, the particle board with a mixture proportion of 50:50% does not meet the criteria set by SNI and JIS. The incorporation of PET plastic waste into particle board, with a mixture proportion of 70%:30%, satisfies the requirements set by SNI and JIS. However, the mixture proportions of 60%:40% and 50%:50% do not fulfill the criteria set by SNI and JIS.
- The screw holding capacity of particle board, when supplemented with PP plastic waste, satisfies the standards set by SNI and JIS, with the exception of PP of dimensions 1 cm x 5 cm, which does not fulfill the SNI and JIS criteria when used in a mixed ratio of 50%:50%. However, particle board containing PET plastic waste fails to fulfill the standards set by SNI and JIS.
- Plastic that is cut and heated can become aerosolized and may cause health problems if inhaled by workers or consumers. Potential risks include respiratory tract irritation, long-term health issues, or even toxicity depending on the type of plastic used.
- Implement strict safety protocols for handling aerosolized materials, including adequate ventilation and the use of personal protective equipment (PPE) by workers.

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