PHYSICAL BEHAVIOUR OF WOOD PLASTICE COMPOSITE MADE OF RECYCLED HIGH-DENSITY POLYETHYLENE (HDPE)

(Sifat Fisis Kayu Komposite Plastik yang Terbuat dari Bahan Polietilen Kerapatan Tinggi [HDPE])

YUYU RAHAYU[1]✉, WAHYU SETIAWAN[2], ENDRA GUNAWAN[1], SUSILO BUDI HUSODO[1]
[1]Forestry Faculty, University of Papua, Jl. Gunung Salju Amban, Manokwari, Papua Barat 98314
[2]Balai Pelaksana Penyediaan Rumah Papua II, Lembah Hijau, Manokwari, Papua Barat
✉Penulis Korespondensi: Email y.rahayu@unipa.ac.id
Diterima: 18 Mar 2023| Disetujui: 19 Sept 2023

Abstrak. Penelitian ini bertujuan untuk melihat karakteristik fisik dari komposit papan plastik yang dibuat dari limbah plastik HDPE dan serbuk kayu yang diperoleh dari limbah kayu pengolahan pada perusahan meubel lokal di Manokwari. Serbuk kayu yang digunakan dikelompokan menjadi tiga yaitu yang berasal dari kayu Matoa, Merbau, dan Pulai. Plasik yang digunakan adalah plastik HDPE limbah dari botol minuman air mineral. Penelitian ini menunjukkan bahwa komposit yanh dihasilkan dengan menggunakan pres panas memiliki sifat fisika yang memenuhi standar Jepang (JIS) dan standard Indonesia (SNI). Nilai penterapan air dan kerapatan juga diukur di dalam penelitian ini. Kerapatan dari komposit yang dihasilkan melebihi target kerapatan yang diinginkan, sedangkan untuk penyerapan air menunjukkan nilai rataan yang tinggi. Karakter pengembangan setelah perendaman bervariasi dai 5.75%-25.58% setelah perendaman 2 jam, sedangkan untuk perendaman 24 jam menunjukkan nilai yang bervariasi antara 7,57%–28,53%. Penelitian ini menunjukkan bahwa komposit yang dihasilkan merupakan komposit non-struktural untuk penggunaan interior.

Kata Kunci: HDPE, papan plastik, limbah kayu, kadar air, sifat fisik

Abstract. *This paper investigated the physical characteristics of wood–plastic composites, which were made using recycled high-density polyethylene (HDPE) and using wood flour from Pometia sp (Matoa), Intsia sp (Merbau) and Alstonia sp (Pulai) as filler. The sawdust was taken from local furniture industry and the HDPE was collected from recycled plastic bottles of mineral water. Composite panels were made from recycled HDPE through hot-press moulding produced excellent stability based on JIS and SNI Standard, especially for moisture content and swelling characteristics. The water absorption and targeted density were also measured. In this study we found that the water absorption and the density of the composite exceeded our expectation. The composites showed high variation average for water absorption. For the swelling behavior, the value is varied from 5.74% to 25.57% after 2 hours soaking and varied between 7.56% to 28.53% after 24 hours soaking. This study has shown the composites had a high possibility to be used for interior and non-structural purposes.*

Keywords: *HDPE, wood plastics composite, wood waste, water content, physical characteristics*

INTRODUCTION

The production of plastics wide world is approximately 400 million tons per annum (Qualman 2017). In Indonesia, based on BPS Report, it is revealed that the production of plastics in Indonesia reached 4.68 million tones annually and the plastics waste is reached more than 66 million tons per year (BPS 1999) and this number keeps increasing. This leads to the huge sum amount of plastics waste in Indonesia. Endeavors have been made to reuse the post-consumer plastics in arrange to decrease the natural affect and utilization of plastic.

In wood industry, a huge sum of wood waste is resulted at diverse stages of the wood handling and utilization is basically predetermined to be burnt and for landfill only. In Indonesia, the total production of lumber reached 2.6 million cubic annualy (Sutarman 2016). Furthermore, Sutarman Assumed that 54.24% of the total production is wastes. It means that we have1.4 million cubic wood waste per year.

The use of waste wood in the form of wood dust in wood plastic composites (WPCs) helps to reduce the huge amount of the wood squanders and the finance aspect to handle the disposal of wood wastes (Miller *et al.,* 1994), There are a number of previous studies on the fortification of HDPE with wood fiber and other lignocellulose materials with respect to the result about mechanical properties, dimensional solidness, interfacial holding and solidness (Adhykary *et al.,* 2008; Nasharudin *et al*., 2023). And most of the results inform us that the Wood Plastics Composites (WPC) showed a good dimensional stability and proper mechanical properties.

Due to its easy availability, low density, biodegradability, renewability, high stiffness, and low cost, wood dust is becoming more popular as a sort of filler for polymers. Furthermore, wood fibers' regenerative and biodegradable properties promote their rapid decomposition through composting or cremation. The development of wood plastic composites (WPCs) and their application in a variety of industries has gained a lot of attention in recent decades due to the benefits of wood fiber.

In this work, the influence of fiber types (Matoa, Merbau and Pulai), plastics contents (20, 30, and 40 w t%), fiber sizes (60 and 80 mesh) and the use of hot press on the physical properties of wood plastic composite panels were studied.

RESEARC METHOD

Observed Variables

In this study, physical properties of wood plastic composit were observed. We observed moisture content, density, water absorption and the board swelling after 2 and 24 hours soaking.

1. Wood plastics composite (WPC) manufactured:

WPC were produced in a two-stage process. For the first stage, wood particles were mixed with HDPE flour using certain composition (20%, 30% and 40% of plastics) until we gained a homogeny mixture. The blend design for compounding of material can be seen in table 1. The scond stage is conditioning, where the finished particle board sheets were cooled on the provided shelves prior the sampling process. Sheets of particle boards that have conditioned are then prepared for the testing process. Particle board sheets which been formed using

10 × 10 × 0.5 cm mold are then inserted into the pressing machine. The WPC was pressed for ± 25 minutes using 200 °C for temperature. We used 70 kg/cm^2 pressure. The target of density was 900 kg/m^3.

Table 1. Compositions of the studied formulations

No.	Sample Code	HDPE (Wt%)	WD (Wt%)
1.	Mer 60 (20%)	20	80
2.	Mer 60 (30%)	30	70
3.	Mer 60 (40%)	40	60
4.	Mer 80 (20%)	20	20
5.	Mer 80 (30%)	30	30
6.	Mer 80 (40%)	40	40
7.	Mt 60 (20%)	20	20
8.	Mt 60 (30%)	30	30
9.	Mt 60 (40%)	40	40
10.	Mt 80 (20%)	20	20
11.	Mt 80 (30%)	30	30
12.	Mt 80 (40%)	40	40
13.	P 60 (20%)	20	20
14.	P 60 (30%)	30	30
15.	P 60 (40%)	40	40
16.	P 80 (20%)	20	20
17.	P 80 (30%)	30	30
18.	P 80 (40%)	40	40

*Every sample was repeated for three times

Physical Properties Testing

a. *Water content*

The moisture content of the sample is calculated by the following formula:

$$Mc = \frac{W0 - Wt}{Wt} x\ 100\%$$

Where ***Mc*** is Moisture contents in percent, ***W0*** is the the sample weigh before dried and ***Wt*** is sample weigh after dried.

b. *Density*

We calculated the WPC density using the following equation:

$$\rho = \frac{M}{V}$$

ρ is the WPC density in gr/cm^3, ***M*** stands for Mass and ***V*** is the Volume of the sample

c. *Water absorption and maximum swelling after 2 and 24 hours soaking*

The water absorption (WA) test was carried out using the following steps. Before testing, the weight of each specimen was measured and conditioned samples of each composite type were soaked in distilled water at room temperature for 2 and 24 h. The value of the water absorption in percentage was calculated using the following equation:

$$Wa = \frac{Wt - Wo}{Wo} x\ 100\%$$

Wa is water absorption, ***Wt*** is the sample weight after soaked and ***Wo*** is the sample weight before soaked and to calculate the maximum swelling, the following formula was used:

$$Ms = \frac{Tt - To}{To} x\ 100\%$$

Ms represents the Maximum Swelling, ***Tt*** stands for the sample thickness after soaked and ***To*** is the sample thickness prior the soaking process. For each measured variable we did the anova to see difference for each treatment (Wood species, HDPE ratio and the size of wood particle).

RESULT AND DISCUSSION

WPC's Density

In this study, we found that the WPC density is varied between 0.97 gr/cm^3 and 1.22 gr/cm^3. The lowest density came from pulai with combination of plastics density 20% and the highest produced from Merbau with plastics ratio of 30%. Surprisingly, we found that Merbau with plastics 40% showed lower density compared to Merbau 30%. It is assumed that the materials were unevenly mixed which resulted to the variation of density in resulting WPC. The WPC density with wood particle size of 80 mesh ranges from 0.9304 gr/cm^3 to 1.0181 gr/cm^3 with an average of 0.9817 gr/cm^3. The lowest density was found on Merbau WPC with an adhesive ratio of 20% while the highest was on Matoa WPC with an adhesive ratio of 40%.

The density of 80 mesh WPC and 60 mesh are similar. We found that the increasing proportion of adhesive tends to increase the density**.** The finding of affect of the increase of the adhesive is inline with Haygreen and bowyer (1989) which stated that the density and the stability of particle board will increase when we add more adhesive to the mixture. The average of WPC density from this study has met the expected target of 0.9 gr/cm^3. This leads to the conclusion that the density of WPC generated from furniture industry waste with plastic waste adhesives has met the Japanese standard Association (2003) and Indonesian Industrial Standard (SII) 0797 – 83).

Moisture Content

The results of the analysis variant (table 2.), showed that the interaction between the wood species and particle size, interaction of wood species the adhesive ratio gave a significant influence to the moisture content of WPC as also found by Escobar *et al*. (2007). In the other hand, the interaction between the wood dust size and the adhesive ratio did not affect to the WPC moisture content. Yet, the interaction amongst the three factors (Particle size, wood species and adhesive ration) showed a significant influence the water content of the WPC.

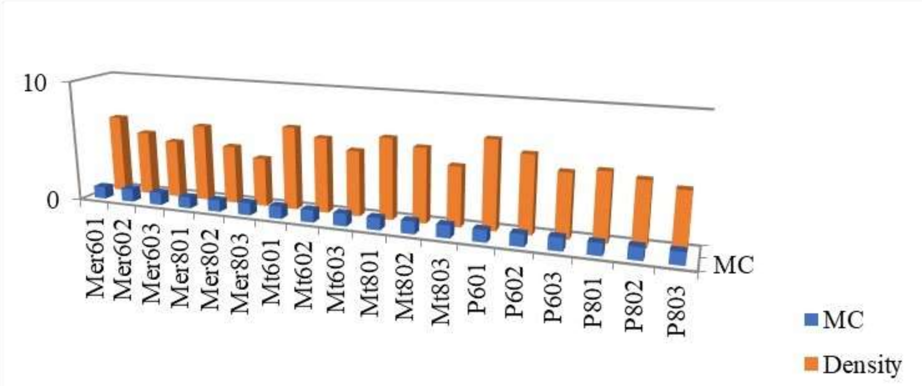
Tabel 2. Analysis of variance for MC

Source	DF	Seq SS	Adj SS	Adj	F	P
A	2	3,1684	3,7212	1,8606	5,40	0,009
B	1	5,3805	5,4395	5,4395	15,80	0,000
C	2	25,8194	25,5304	12,7652	37,07	0,000
A*B	2	1,5801	1,6076	0,8038	2,33	0,111
A*C	4	1,8592	1,7560	0,4390	1,27	0,298
B*C	2	0,0243	0,0514	0,0257	0,07	0,928
A*B*C	4	1,0659	1,0659	0,2665	0,77	0,549
Error	36	12,3975	12,3975	0,3444		
Total	53	51,2952				

The average water content of WPC ranges from 42.67% to 65.012%, the highest water content is found on Merbau particle boards with an adhesive ratio of 20% while the lowest on Merbau particle boards with an adhesive ratio of 40%. Water content tends to decrease along with increasing adhesive ratios because Polyetylene plastic has hydrophobic properties that block the entry of water into the particle board, so that with the greater amount of polyetylene plastic makes the water absorption smallerthan the WPC with lesser amount of plastices ratio (Prayitno 1995).

The Duncan *Post-Hoc* test showed that Mer 80 (40%), Mer 60 (40%) dan P 80 (40%) are the combination that gave smaller water content of WPC. We assumed, that those combinations are the best combination to gain expected water content. In general, the study showed that the average water content value has met the expected target of < 13%. This shows that the moisture content of the produced WPC met the Japanese standards Japanese standard

Association (2003) and Indonesian Industry Standards (SII) 0797-83.



	Mer601	Mer602	Mer603	Mer801	Mer802	Mer803	Mt601	Mt602	Mt603	Mt801	Mt802	Mt803	P601	P602	P603	P801	P802	P803
MC	1	1,1	1	0,9	0,9	1	1	1	1	1	1	1	1	1	1	1	1	1
Density	6,4	5,3	4,7	6,3	4,7	4	6,8	6,1	5,3	6,6	6	4,8	7,1	6,2	5,1	5,4	5	4,6

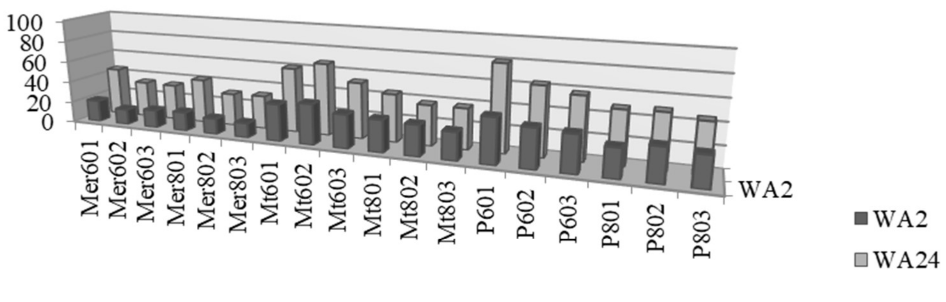
Figure 1. The average moisture contents

Water Absorption

The results showed that the value of water absorption decreased with the increasing ratio of adhesives, this is in line with Maloney (1993), Prayitno (1995) that with the presence of a large number of adhesives will cause a decrease in water absorption. Water absorption is directly proportional to thick development, the higher the thick development, the higher the water absorption (Subyanto *et al*., 2003).

From the image above, it can be seen that the absorption of water in WPC made of Pulai wood shows a high absorption value. The high value of water absorption is due to the low density of Pulai. In contrast with Pulai WPC, the low value of water absorption in Merbau is basicly due to the high density of Merbau.

Duncan *Post Hoc* tests showed that 2-hour immersion water absorption tests at Mer 60 (30%), Mer 80 (30%) and Mer 80 (40%) treatments had the lowest water absorption when compared to other treatments. While in 24-hour immersion the treatment of Mer 80 (30%) and Mer 80 (40%) is the treatment that has the lowest water absorption when compared to other treatments. With reference to the Duncan result, the treatment of Mer 80 (30%) and Mer 80 (40%) is the best treatment for the physical properties of water absorption (2 hours and 24 hours).

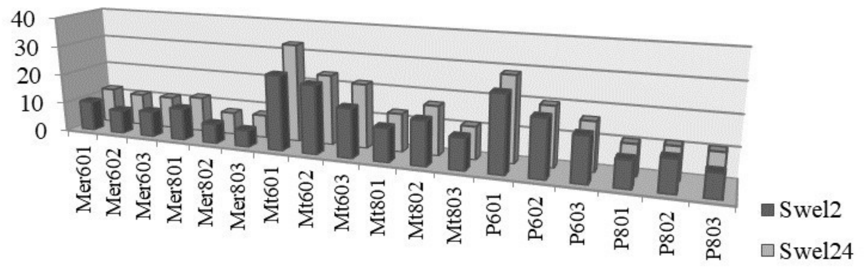


	Mer601	Mer602	Mer603	Mer801	Mer802	Mer803	Mt601	Mt602	Mt603	Mt801	Mt802	Mt803	P601	P602	P603	P801	P802	P803
WA2	21	15	17	18	15	14	35	38	31	30	29	26	42	36	34	26	31	28
WA24	45	34	34	42	31	31	61	67	52	44	38	38	80	64	58	49	50	45

Figure 2. The average value of water absorption

Swelling Charasteristics

The results of the anova of 2 hours of thick immersion showed that the interaction between wood type with adhesive ratio, interaction between wood type with sawdust size, and interaction between the size of wood dust with adhesive ratio gives a real influence on the value of developing thickness after 2 hours of soaking.



	Mer601	Mer602	Mer603	Mer801	Mer802	Mer803	Mt601	Mt602	Mt603	Mt801	Mt802	Mt803	P601	P602	P603	P801	P802	P803
Swel2	10	8,1	8,8	11	6,7	5,7	25	23	17	11	15	11	26	19	15	9	11	8
Swel24	12	11	11	12	7,6	7,8	33	24	22	13	17	11	29	20	16	10	11	10

Figure 3. The average value of swelling characteristics

While the interaction of the three factors did not significantly influence the WPC's swelling behaviour. While in 24-hour immersion, the interaction between wood species with the size of the sawdust and the interaction between the size of wood paticle and the adhesive ratio gives a noticeable influence on the value of the thickness development after 24-hour immersion. While the interaction between the wood species with the adhesive ratio and the interaction between the three factors did not have a real influence.

The average value of particle board swelling behaviour ranges from 7.32% to 14.83%. The highest thick development is found on Pulai particle boards with an adhesive ratio of 20% while the lowest is found on Merbau wood particle boards with an adhesive ratio of 30%. While in 24 hours of immersion thick development ranges from 8.47% to 15.05%. The highest thick development is found on the Matoa wood waste particle board with an adhesive ratio of 20% while the lowest on the Merbau wood waste particle board with an adhesive ratio of 40%.

Table 3. Duncan *post hoc* result for physical characteristic of WPC

Treatments	**Wa (%)**	**Den (gr/cm^3)**	**Pt 2 hours (%)**	**Pt 24 hours (%)**	**Da 2 hours (%)**	**Da 24 hours (%)**
Mer 60 (20)%	6.43 **defg**	1.01 **cdef**	10.23 **abc**	11.97 **abc**	20.51 **bc**	45.11 **bcde**
Mer 60 (30)%	5.27 **abcdef**	1.08 **g**	8.06 **ab**	10.97 **ab**	14.61 **a**	34.09 **ab**
Mer 60 (40)%	4.47 **ab**	1.05 **fg**	8.79 **ab**	10.93 **ab**	16.83 **ab**	33.71 **ab**
Mer 80 (20)%	6.25 **cdefg**	0.93 **a**	10.92 **abcd**	11.87 **abc**	17.84 **ab**	41.79 **abcd**
Mer 80 (30)%	4.74 **abc**	0.95 **ab**	6.70 **ab**	7.57 **a**	14.89 **a**	30.59 **a**
Mer 80 (40)%	3.97 **a**	0.93 **a**	5.74 **a**	7.78 **a**	13.75 **a**	31.41 **a**
Mt 60 (20)%	6.76 **fg**	1.01 **cdef**	25.32 **fg**	33.02 **f**	34.55 **fgh**	60.50 **fgh**
Mt 60 (30)%	6.11 **cdefg**	1.01 **cdef**	23.09 **fg**	23.63 **de**	37.91 **hi**	67.37 **hi**
Mt 60 (40)%	5.30 **abcdef**	1.01 **cdef**	16.59 **de**	21.59 **de**	31.36 **efg**	52.22 **defg**
Mt 80 (20)%	6.56 **efg**	0.97 **abcd**	11.34 **bcd**	12.80 **abc**	29.83 **def**	44.48 **bcde**
Mt 80 (30)%	6.01 **bcdefg**	1.01 **cdef**	14.95 **cde**	16.55 **bcd**	28.62 **de**	37.61 **abc**
Mt 80 (40)%	4.79 **abcd**	1.02 **def**	10.72 **abc**	10.92 **ab**	25.69 **cd**	37.69 **abc**
P 60 (20)%	7.11 **g**	0.96 **abc**	25.58 **g**	28.53 **ef**	41.79 **i**	80.00 **i**
P 60 (30)%	6.20 **cdefg**	0.97 **abcd**	19.23 **ef**	19.89 **cd**	36.03 **gh**	63.55 **gh**
P 60 (40)%	5.08 **abcdef**	1.03 **efg**	15.07 **cde**	16.18 **bcd**	34.14 **fgh**	57.76 **efgh**
P 80 (20)%	5.42 **abcdefg**	0.96 **abc**	9.04 **abc**	10.32 **ab**	26.47 **de**	48.83 **cdef**
P 80 (30)%	5.04 **abcde**	0.99 **bcde**	10.77 **abcd**	10.91 **ab**	30.94 **ef**	49.71 **cdefg**
P 80 (40)%	4.57 **ab**	0.99 **bcde**	7.96 **ab**	10.45 **ab**	28.12 **de**	45.35 **bcde**

Note: The numbers in the same column followed by the same letter show no significance difference in 0.05

From this study, we found that the value of thickness development is inversely proportional to the density value of the resulting particle board, the higher the density, the smaller the swelling. It is contradictive with the opinion of Subiyanto *et al*. (2003), He stated that the value of density and thick development is directly proportional. This result due to the complexity mechanism of swelling behavior of wood particles that related to the presence of adhesives. The adhesives prevented the thickness development of the WPC whicih is similar to Syamani *et al*. (2008) in Hasni (2008).

Duncan *post hoc* test showed that the treatment of Ma 80 (30%) and Ma 80 (40%) have the lowest thick development compared to other treatments at 2-hour immersion and at 24-hour immersion. These ratios are suggested as the best treatment for the physical properties of the thick development of particle boards. The average development value of plastic particle board thickness does not all meet the expected target of > 12% (JIS A 5908 (2003)) and > 20% for Indonesian Industrial Standard (SII) 0797-83.

CONCLUSION

After the physical test, we conclude that WPC made from Merbau gave the best physical characterstics compared to Pulai and Matoa. It is showed with combination of Merbau 80 (30%) dan Merbau 80 (40%) that produced particle boards with the best physical properties and meets Japanese standards as well as Indonesian national standard. The research also found that the influence of wood particle size and adhesive ratio is directly proportional, the higher the adhesive ratio and wood particle size will produce stable particle board. Particle board produced from wood particle with HDPE as adhesive classified as non-structural particle boards that have a single layer with the interior usage purpose as wall partitions and ceilings.

REFFERENCES

Adhikary, K.B., Pang, S., and Staiger, M.P. (2008). Dimensional stability and mechanical behavior of wood-pastic composites based on recycled and virgin high-density polyethylene (HDPE). *Composites: Part B*, 39: 807-815. doi:10.1016/j.compositesb.2007.10.005.

Escobar, M.P., Galindo, F.G., Wadso, L., Najera, J.R., and Sjoholm, I. (2007). Effect of long-term storage and blanching pre-treatments on the osmotic dehydration kinetics of carrots (Daucus carota L. cv. Nerac). *Journal of Food Engineering*, 81(2): 313-31. https://doi.org/10.1016/j.jfoodeng.2006.11.005.

Hasni, R. (2008). *Pembuatan papan partikel dari limbah plastik dan sekam*. [Skripsi]. Fakultas Kehutanan Institut Pertanian Bogor. Jawa Barat.

Haygreen J.G., dan Bowyer, J.J. (1989). *Hasil hutan dan ilmu kayu*. Terjemahan Sutjipto. H. Universitas Gadjah Mada. Yogyakarta.

Japan Standards Association. (2003). *JIS A 5908: Particleboards*. h*ttps://archive.org/details/jis.a.5908.e.2003***.**

Maloney, T.M. (1993). *Modern particleboard and dry process fiberboard manufacturing*. Miller Freeman Inc. San Francisco. USA.

Miller, N.A., Stirling, C.D., and Langford, V.S.M. (1994). *Pinus radiata fibre/thermoplastic composite materials*. In: Proceedings of the Second Pacific Rim Bio-Based Composite Symposium. Vancouver, Canada; 1994: 47–54.

Nasharudin, N.A.M., Sulaiman, N.F., Mohammad N.S., Jaafar, W.N.R.W., Abu, F., and Surip, S.N. (2023). The effect of heat treatment and chemical treatment on natural fibre to the durability of wood plastic composites - A review. *Journal of Materials Exploration And Findings*, 2(2): 35-47. doi: https://doi.org/10.7454/jmef.v2i2.1023.

Prayitno, T.A. (1995). *Teknologi papan mineral*. Fakultas Kehutanan Universitas Gadjah Mada. Yogyakarta.

Qualman, D. (2017). *Global plastics production 1917 to 2017*. https://www.darrinqualman.com/global-plastics-production/global-plastic-production-1917-to-2017/.

Subiyanto B., Saragih, R., and Husin, E. (2003). Utilization of coconut coir dust as water and oil absorbent materials such as particle board panels. *J. Tropical Wood Science And Technlogy,* 1: 26-34.

Sutarman, I.W. (2016). Pemanfaatan limbah industri pengolahan kayu di Kota Denpasar (Studi kasus pada CV Aditya). *Jurnal PASTI*, 10(1): 15 – 22.