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Environmentally Friendly Paving Block Based on Wood Waste: The Effect of Rubber Wood Waste Content on the Physical-Mechanical Properties of Paving Block

Daffa Naufalian Fauzi[1], Bagus Saputra[1], Melya Riniarti[1], Duryat Duryat[1], Intan Fajar Suri[1], Wahyu Hidayat[1,✉]

[1] Department of Forestry, Faculty of Agriculture, University of Lampung, Lampung, INDONESIA

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Corresponding Author:
✉ wahyu.hidayat@fp.unila.ac.id
(Wahyu Hidayat)

ABSTRACT

The wood sawing industry generates significant waste, consisting of wood chips, wood scraps, and sawdust. This research aims to evaluate the effect of rubber wood sawdust addition on the moisture content, water absorption capacity, and compressive strength of paving blocks. The study was conducted in August–September 2023, starting with preparing raw materials, composition planning, and test specimen fabrication. The parameters in this study included density testing, moisture content, water absorption capacity, and compressive strength. The density test results for treatments P0 were 1.11 g/cm^3, P1 1.09 g/cm^3, P2 1.07 g/cm^3, P3 1.08 g/cm^3, and P4 1.09 g/cm^3. The moisture content test yielded values of 11.38% for P0, 12.56% for P1, 12.94% for P2, 13.24% for P3, and 13.80% for P4. The water absorption capacity values obtained were, for P0, 5.17%; P1, 5.40%; P2, 6.36%; P3, 8.11%; and P4, 9.27%. Compressive strength tests produced values for P0 at 7.19 N/mm^2, P1 at 5.67 N/mm^2, P2 at 4.22 N/mm^2, P3 at 3.48 N/mm^2, and P4 at 3.07 N/mm^2. The addition of rubber wood sawdust to paving blocks significantly influences density, moisture content, water absorption capacity, and compressive strength values.

1. INTRODUCTION

The increase in Indonesia's population will lead to a rise in the demand for housing. Housing remains a primary need for urban and rural residents (Mungkasa, 2008). This aligns with the increased utilization of wood as a construction material, both for structural and non-structural applications (Abidin *et al*., 2018; Purba & Lubis, 2018). Sawn timber is generally used for structural purposes. Sawn timber has a rectangular shape with specific dimensions produced through the process of cutting logs (BSN, 1999).

Sawn timber comes from the sawmill industry, where this industry processes logs into sawn timber (Aditya *et al*., 2019). The sawmill industry is the largest producer of wood waste (> 50% of raw materials) compared to other wood processing industries. Waste from the sawing process has certain shapes and dimensions that should still be utilizable, but are often discarded due to limitations in wood processing technology at that time (Wulandari, 2019). The waste produced by the sawmill industry includes slabs, wood pieces, and sawdust (Sutarman, 2016; Wulandari, 2019).

Rejuvenation of rubberwood trees (*Hevea brasiliensis*) is carried out on trees that are no longer productive in producing latex by cutting down old trees and replanting them with new rubber plants (Faizal *et al*., 2014; Ridjayanti *et al*., 2023). The rejuvenation process generates waste in the form of trunks, branches, leaves, and roots of rubber trees

(Matangaran & Anggoro, 2012). Furthermore, industries that utilize rubberwood as their raw material also produce significant waste, such as the sawmill industry (32–53%), veneer industry (56–59%), and medium density fiberboard (MDF) industry (75–90%) (Bazenet *et al*., 2021; Director General of Forestry Business Development, 2009). Therefore, the abundant potential of rubberwood waste biomass needs to be optimized to prevent accumulation, maintain environmental sustainability, and obtain diverse benefits.

The waste produced by the sawmill industry has now become a resource widely utilized by the community (Pandey, 2022). The use of offcuts from the sawmill industry has been focused on making fences, while offcuts and wood pieces are used as firewood and charcoal (Maurits *et al*., 2023; Rianto *et al*., 2019). Currently, sawdust is also used as a growing medium for white oyster mushrooms by the community (Wahyuningsih *et al*., 2022), but its utilization is still not optimal. Therefore, adding rubberwood sawdust (*Hevea brasiliensis*) is considered important in producing paving blocks to reduce the waste generated by the sawmill industry. The advantages of adding sawdust are its affordable price and ability to absorb water to maintain water balance when used as a raw material for paving blocks (Bahkhtiar, 2016).

The composition of a paving block typically involves a blend of cement or comparable hydraulic binders, water, and aggregates, with the possibility of incorporating additional elements that do not impair the overall quality of the paving block (BSN, 1996). This study's main goal is to evaluate how adding rubberwood sawdust (*Hevea brasiliensis*) affects the paving blocks' moisture content, compressive strength, and ability to absorb water.

2. RESEARCH MATERIALS AND METHODS

2.1. Research Materials and Equipment

This study uses rubberwood sawdust (*Hevea brasiliensis*), sand, and cement (Ordinary Portland Cement Type I; PT. Semen Baturaja (Persero) Tbk., Palembang). The rubberwood sawdust is filtered using a sieve to separate it from other particles with a 5 mesh sieve. The equipment used in this research includes a rectangular paving block mold with dimensions of 21 cm (length) x 10 cm (width) x 6 cm (height), scales, hoe, universal testing machine ((M500-50AT, Testometric, Rochdale, United Kingdom), oven, water bath, writing tools, sieve, caliper, measuring cylinder, and camera.

2.2. Production of Paving Blocks

Material preparation involves cleaning the rubberwood sawdust and sand from impurities such as soil or other debris, then drying the rubberwood sawdust and sand until they reach equilibrium moisture content. The mix design is a combination of the constituent material compositions. The composition of the paving block materials is shown in Table 1. The production of paving blocks is carried out using a manual mold. The process of making test specimens begins with thoroughly mixing the prepared materials. The mixture is then placed into the mold, and pressure is applied using a metal plate. The finished paving blocks are then placed in a safe location.

Table 1. Composition of paving block materials

Treatment	Composition of materials (%)			Amount
	Rubberwood Sawdust	Sand	Cement	
P0	0	70	30	20
P1	10	60	30	20
P2	20	50	30	20
P3	30	40	30	20
P4	40	30	30	20

2.2. Testing of Paving Blocks

2.2.1. Density

The density test is conducted on samples measuring 10 cm × 21 cm × 6 cm, with each treatment performed in triplicate at air-dry weight. The density is calculated using Equation 1 based on Giancoli (2001).

$$KR = M/V \quad (1)$$

where the values of KR, M, and V represent the density (g/cm^3), dry weight (g), and volume (cm^3) of the specimen, respectively.

2.2.2. Moisture Content

The moisture content test was conducted to obtain the moisture content present in the paving blocks. The moisture content test is performed in triplicate for each treatment, and the moisture content is calculated using Equation 2 based on SNI 8675-2018.

$$KA = \frac{BA - BKO}{BKO} \times 100\% \quad (2)$$

where KA is the moisture content (%), BA is the initial weight (g), and BKO is the oven-dry weight (g).

2.2.3. Water Absorption

The water absorption test determines the porosity within the test specimen. The water absorption test was performed in triplicate for each treatment, and water absorption was calculated using Equation 3 (Cahyono & Rohman, 2013).

$$DSA = \frac{MB - MK}{MK} \times 100\% \quad (3)$$

where *DSA* is the water absorption (%), *MB* is the wet weight (g), and *MK* is the dry weight (g).

2.2.4. Compressive Strength

The compressive strength test is performed using a compressing testing machine (CTM), with each treatment repeated three times. Compressive strength is calculated using Equation 4 based on SNI 03-0691-1996.

$$FC = F/A \quad (4)$$

where the constants FC, F, and A represent the compressive strength (N/mm^2), compressive force (N), and surface area (mm^2), respectively.

2.3. Data Analysis

The utilization of analysis of variance (ANOVA) is a fundamental component of data analysis. Analysis of Variance (ANOVA) is a statistical method used to examine disparities among multiple populations. In order to evaluate statistically significant disparities among the average values of density, moisture content, water absorption, and compressive strength, post hoc tests, such as Duncan's multiple range test, are employed (SPSS version 24; SPSS Inc., Chicago, IL, USA).

3. RESULTS AND DISCUSSION

The visual appearance of the produced paving blocks can be seen in Figure 1.

3.1. Density of Paving Blocks

The results of the density testing of paving blocks can be seen in Figure 2. Treatment P0 had the highest density value at 1.11 g/cm^3, as cement has a higher density than rubberwood sawdust and sand (Da Silva *et al*., 2015; Sojobi, 2016). P2 with a combination of 20% rubberwood sawdust, 50% sand, and 30% cement had the lowest density value at 1.07 g/cm^3, which is attributed to the additional materials in the composition of the paving block affecting its density (Raheem *et al*., 2017). Putri *et al*. (2019) explained that density in paving blocks can affect the quality.

Research conducted by Djamaluddin *et al*. (2020), using organic materials such as tea ash waste as a cement mixture in paving block production, showed decreased density with increasing tea ash waste added. This is consistent with the study by Khan *et al*. (2020), which stated that increasing the composition of sawdust by 25% can decrease the density of concrete blocks by 17.6%. Overall, the low density of the composite material used (rubberwood sawdust) decreases the density of the produced paving blocks. The low density value will also affect other properties of the paving block, such as compressive strength, moisture content, and water absorption (Djamaluddin *et al*., 2020; Ling, 2011). Overall, the results indicate that the analysis of variance at a 5% confidence level has no significant effect on each treatment.

Image 1. The paving blocks that have been molded with the composition (a) P0, (b) P1, (c) P2, (d) P4, and (e) P5.

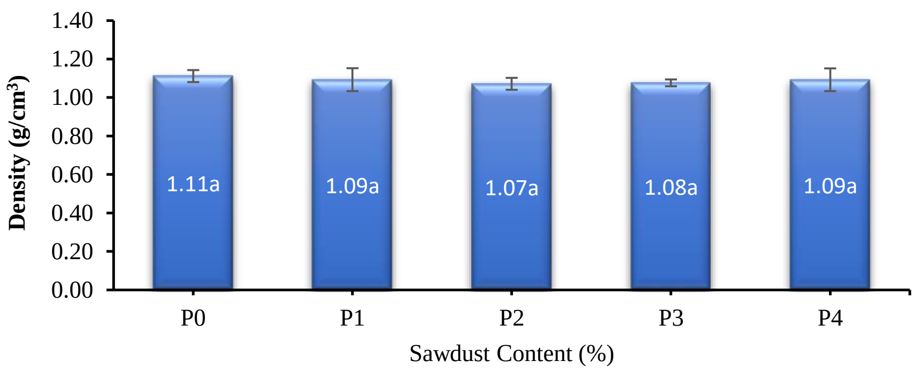

Image 2. The influence of sawdust content on the density of paving blocks. The same letters indicate no significant difference at a 5% confidence level in each addition of sawdust.

3.2. Moisture Content of Paving Blocks

Moisture content is the ratio of the weight of air-dried paving blocks to the weight of oven-dried paving blocks (Ayat, 2020; Fendika, 2019). Moisture content has a significant effect on the strength and quality of paving blocks. The results of the moisture content test can be seen in Figure 3. The moisture content of paving blocks increases with the addition of rubberwood sawdust composition. P0 has the lowest moisture content at 11.38%, while P4 has the highest at 13.80%. The moisture content in paving blocks is influenced by the composition of the constituent materials used.

Wood is a material that absorbs and releases water, known as hygroscopic properties (Suri *et al*., 2023). This property depends on the type of wood and the surrounding environment (Bahanawan *et al*., 2020; Saputra *et al*., 2022). The moisture content of the constituent materials used will affect the paving blocks' quality. Sawdust with excessively high moisture content will affect the density value of the paving block; the higher the moisture content, the higher the resulting density. Overall, the results indicate that the analysis of variance at a 5% confidence level has no significant effect on each addition of sawdust.

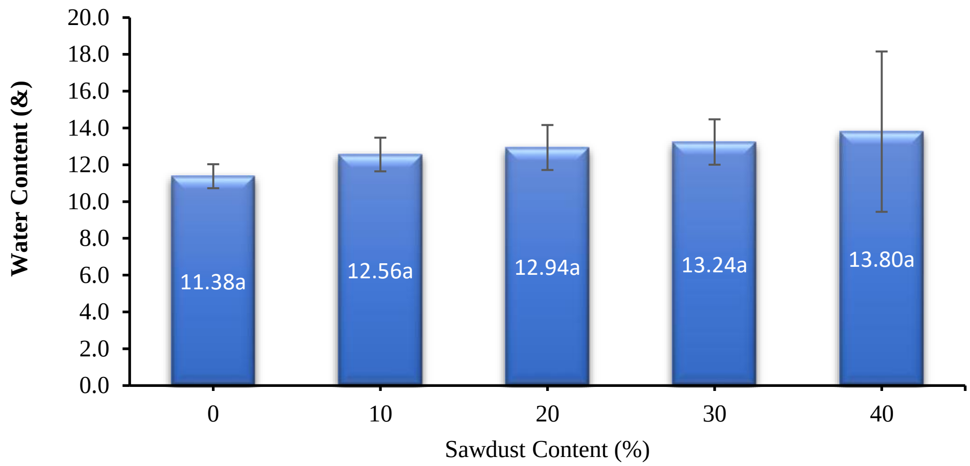

Image 3. The influence of sawdust content on the moisture content of paving blocks. The same letters indicate no significant difference at a 5% confidence level in each addition of sawdust.

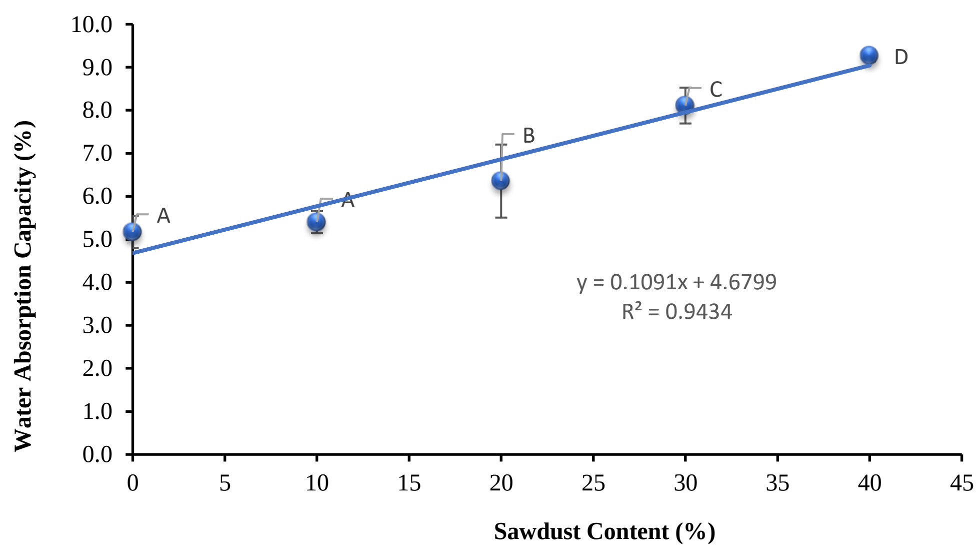

Image 4. The influence of sawdust content on the water absorption capacity of paving blocks. Different letters indicate significant differences at a 5% confidence level in each addition of sawdust.

3.3. Water Absorption of Paving Blocks

The results of the water absorption test can be seen in Figure 4. The test results show an increase in water absorption with the addition of sawdust composition in paving blocks. Based on the comparison of research results with SNI standards, it is shown that the water absorption of paving blocks added with sawdust indicates a decrease in quality. Treatment P0 (0% sawdust addition) and treatment P1 (10% sawdust addition) fall into quality group B. Treatment P2 (20% sawdust addition) falls into quality group C, treatment P3 (30% sawdust addition), and treatment P4 (40% sawdust addition) fall into group D. The results of the analysis of variance at a 5% confidence level show that the addition of sawdust composition affects the increase in the water absorption value of paving blocks (p=0.00). The regression analysis results show an R^2 value of 0.9434, indicating a high correlation between the addition of rubberwood sawdust and the increase in the water absorption value of paving blocks. Similar research was also conducted by Rosadi *et al*. (2023) by adding teakwood sawdust (*Tectona grandis*). The water absorption values obtained with the addition of sawdust at 2% were 6.89%, with 4% sawdust addition obtaining a water absorption value of 10.08%, with 6% sawdust addition obtaining a water absorption value of 11.8%, and with 8% sawdust addition obtaining a water absorption value of 16.62%.

That aligns with the research by Khan *et al*. (2020), which stated that increasing the composition of sawdust by 25% can increase the water absorption of concrete blocks by 92.51%. Paving blocks containing sawdust tend to have more brittle properties than the control sample (P0), resulting in higher water absorption. The increase in water absorption capacity in each treatment is caused by the amount of sawdust used. The more sawdust used, the lower the density of the paving blocks (Gencel *et al*., 2012). The water absorption value of paving blocks will affect their suitable use; paving blocks with a water absorption value of around 10% can be used for pedestrian walkways/sidewalks, and values up to 40% for park applications if water absorption is a concern (Djamaluddin *et al*., 2020).

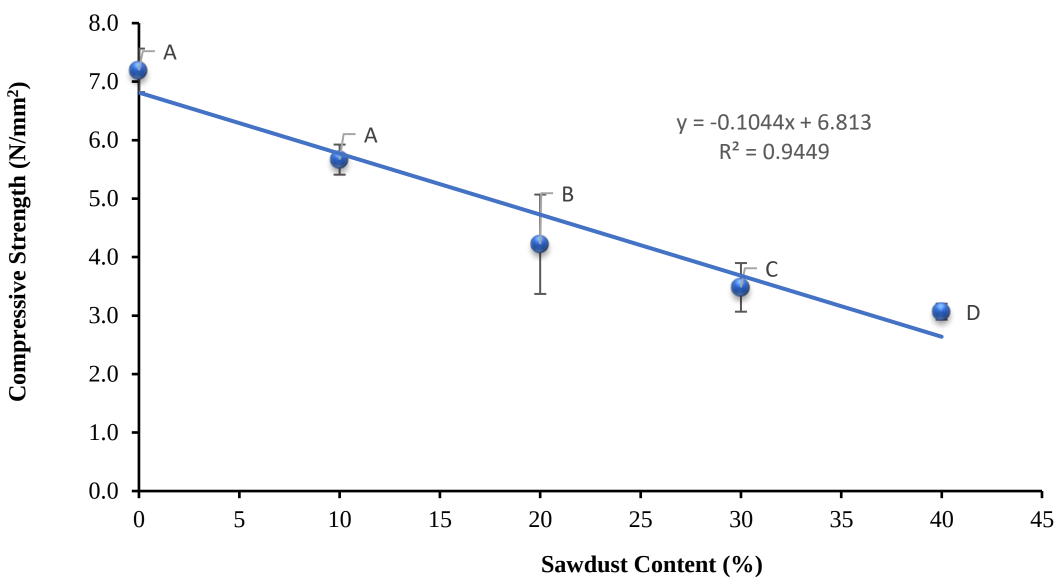

Image 5. The influence of sawdust content on the compressive strength of paving blocks. Different letters indicate significant differences in the decrease of compressive strength of paving blocks at a confidence level of 5% for each addition of sawdust.

3.4. Compressive Strength of Paving Blocks

Compressive strength is the primary mechanical property of concrete that can be determined through testing (Alifsyah *et al*., 2023). The results of the compressive strength test can be seen in Figure 5. Based on the test results, the compressive strength value decreases with the increasing composition of rubberwood sawdust. According to the comparison of research results with SNI standards, the compressive strength of paving blocks added with sawdust indicates a decrease in quality. Treatment P0 (0% sawdust addition), treatment P1 (10% sawdust addition), treatment P2 (20% sawdust addition), treatment P3 (30% sawdust addition), and treatment P4 (40% sawdust addition) have not met the compressive strength value specified by SNI. The results of the analysis of variance at a 5% confidence level show that the addition of sawdust composition affects the increase in the water absorption value of paving blocks ($p=0.00$). The regression analysis results also indicate an R^2 value of 0.9449, showing a high correlation between the addition of rubberwood sawdust and the decrease in compressive strength value of paving blocks. The highest compressive strength value is found in P0, with a combination of 70% sand and 30% cement, which is 7.19 MPa, while P4, with a combination of 40% sawdust, 30% sand, and 30% cement, has a compressive strength value of 3.07 MPa. This is consistent with the research by Zulkarnaen & Mariani (2016), which stated that there is a decrease in compressive strength with the increasing amount of sawdust used in the composition of paving block production. Rosadi *et al*. (2023) also reported that the addition of teakwood sawdust (*Tectona grandis*) by 2% obtained a compressive strength value of 16.05 MPa, with 4% sawdust addition obtaining a compressive strength value of 5.57 MPa, with 6% sawdust addition obtaining a compressive strength value of 4.51 MPa, and with 8% sawdust addition, the compressive strength value obtained was 2.41 MPa.

Compressive strength greatly influences the durability of paving blocks (Djamaluddin *et al*., 2020). If the ratio between sawdust and cement is high, then the hygroscopic properties of sawdust will increase the porosity of the paving block, thus weakening the bond between the cement mixture and aggregate (Mayooran *et al*., 2017; Sadek *et al*., 2017). This can lead to a decrease in the compressive strength of paving blocks with the increasing use of sawdust as a substitute for cement. The decrease in compressive strength can also be caused by the porous and coarse particle size of sawdust. Reducing the particle size can increase the fineness of the material, which can help improve strength by acting as micro fillers and enhancing the pore structure of the cement matrix (Djamaluddin *et al*., 2020).

4. CONCLUSION

The addition of sawdust to paving blocks affects density, moisture content, water absorption, and compressive strength. The highest density value (1.11 g/cm^3) was found in treatment P0. The lowest moisture content was recorded in treatment P0 at 11.38%. The lowest water absorption value was also observed in treatment P0 at 5.17%, while the highest water absorption value was 9.27%. The highest compressive strength was obtained in treatment P0, at 7.19 MPa, while the lowest was in treatment P4, at 3.07 MPa. The addition of sawdust proportionally affects the quality of the paving block, as evidenced by the decrease in compressive strength, increase in moisture content and water absorption, and decrease in compressive strength of the paving block. Further research could include additional measurement parameters for paving blocks and explore the production of paving blocks using biomass-based compositions.

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