JTEP Jurnal Keteknikan Pertanian,
Vol. 12 No. 3, p 352-361, 2024
P-ISSN 2407-0475 E-ISSN 2338-8439

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.012.3.352-361

Utilization a Mixture of Palm Oil and Shellfish Industrial Waste in Producing Paving Blocks

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Article Info

Submitted: 27 June 2024
Revised: 5 November 2024
Accepted: 12 November 2024
Available online: 26 November 2024
Published: Desember 2024

Keywords:
Industrial Waste, Paving Block

How to cite:
Aisyah, S., Imelda, D., Faisal, B., Hakim, M. A. (2024). Utilization a Mixture of Palm Oil and Shellfish Industrial Waste in Producing Paving Blocks. Jurnal Keteknikan Pertanian, 12(3): 352-360. https://doi.org/ 10.19028/jtep.012.3.352-361.

Abstract

Population growth in Indonesia will lead to an increased demand in the development sector. This growth must be balanced by environmentally friendly development practices. Therefore, there is a need for alternative uses of industrial waste for other finished materials. Concrete bricks (Paving blocks) are building construction materials that cover or pave the ground. Boiler ash is one of the solid wastes of the palm oil industry which comes from the remains of burning shells and fibers in boiler machines. Palm oil shells are also one of the solid wastes of the palm oil industry, which comes from the separation between fiber and shells, which occurs in the Light Tenera Dust Separator machine (LTDS). Seashells can be considered solid waste. According to the research findings, paving blocks treated with S1 and S2 exhibit water absorption capacities that comply with the SNI 03-0691-1996 standards, which stipulate a maximum of 8% for C grade, suitable for pedestrian use. Paving blocks treated with S3 also met the SNI 03-0691-1996 standards, with a maximum absorption of 10% for the D grade, which is ideal for covering plants and home gardens. Lower water absorption rates indicate higher quality paving blocks. Variance analysis revealed that the water absorption capacity significantly impacts the quality of the paving blocks. The compressive strength test showed that the paving blocks with S2 treatment had the highest strength, averaging 2,10 MPa. The lowest compressive strength, averaging 1,01 MPa, was observed in the paving blocks treated with S3.

Doi: https://doi.org/10.19028/jtep.012.3.352-361

1. Introduction

The growing population of Indonesia will increase the demand in the development sector. Population growth requires a focus on environmentally sustainable development. Consequently, alternative uses or modifications of materials are essential to address the challenges, particularly the

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severe environmental pollution and increasing amount of industrial and household waste that can be repurposed into other finished materials (Saputra, 2019).

Concrete bricks, also known as paving blocks, are essential construction materials that are used to cover or pave surfaces. Paving blocks are commonly used in various settings including parking areas, bus stops, ports, residential roads, sidewalks, courtyards, shopping complexes, and another pavement needs (Yanita et al., 2022). According to SNI 03-0691-1996, a paving block is a composite building material made from a mixture of Portland cement or a similar hydraulic binder, water, and aggregate, with additional substances as needed, without compromising the quality of the paving block. The use of paving blocks has advantages and disadvantages. They are significantly less dense than concrete (Luthfizar et al., 2019), which is beneficial in certain applications. Other advantages include ease of installation, high permeability compared to asphalt and concrete, quick construction time, and cost-effectiveness (Muladi et al., 2023). The advantages and benefits of paving blocks include the following: a). Paving blocks can be manufactured mechanically, semi-mechanically, or manually molded. b). They help to maintain the water balance in the soil, thereby supporting the structures built above them. c). Paving blocks are lighter than concrete and asphalt. d). Their high absorption capacity ensures the availability of groundwater. e). The installation process is relatively simple. f). These are easy to maintain and can be reassembled after the disassembly. However, paving blocks also have certain disadvantages. Improper installations can lead to uneven surfaces, causing vehicles to operate poorly. Paving blocks are categorized into three types according to their thickness: 1). It is 60 mm thick and is generally used for light traffic loads with limited frequencies, such as motorcycles and pedestrians. 2). 80 millimeters, such as cars, pickup trucks, and buses, are typically used for medium traffic loads with a moderate frequency. 3). 100 mm is usually employed for very heavy traffic loads such as large trucks and loaders (Anggoro et al., 2023). The classification of paving blocks according to SNI 03-0691-1996 includes a) grade paving blocks, generally used for roads; b) B Grade paving blocks, generally used for parking lots; c) C Grade paving blocks, generally used for pedestrians; and d) D Grade paving blocks, generally used for parks and other uses (Baharuddin et al., 2021).

Boiler ash, a byproduct of the palm oil industry, is generated from the combustion of shells and fibers in boiler machines. The incineration of oil palm fruit shells and fibers results in high-temperature combustion residues, with the silica (SiO_2) content reaching up to 61% (Opirina and Sari, 2018). An elevated silica content is essential for concrete production. Boiler ash is utilized as a sand substitute in paving block manufacturing due to its filling and binding properties in concrete formulation. Moreover, the silica in boiler ash contributes to the hardness of paving blocks (Baharuddin et al., 2021).

Palm oil shells are a byproduct of the palm oil industry, resulting from the separation of fibers and shells in a Light Tenera Dust Separator (LTDS) machine. Currently, their utilization is limited, with

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applications primarily in boiler combustion for crude palm oil (CPO) processing, as a component in steam power plants, and as a material for paving. Despite these uses, a significant amount of palm oil shell waste remains (Anggoro et al., 2023).

Seashells are a form of solid waste that is typically underutilized and often discarded. The increasing presence of shells significantly disrupts the environment of fishing villages and diminishes the natural beauty of beaches (Luthfizar et al., 2019). Currently, their applications are limited to decorative purposes, animal feed additives, and mixtures of cosmetic ingredients. However, seashells contain silica compounds that can be processed and utilized as partial replacements for cement, thereby enhancing the quality of paving blocks (Maulana et al., 2024). Cement is a substance with adhesive and cohesive properties that serves as a binding material commonly utilized in combination with sand, gravel, and water. Portland cement is composed of lime, silica, alumina, and iron oxide. Water acts as a mixer and lubricant between aggregate particles, thereby facilitating their compaction. The water used must be clean and free of mud, clay, organic matter, organic acids, or other impurities. Portland cement consists of materials containing lime (CaO), silica (SiO2), alumina (Al2O3), a small amount of magnesia (MgO), and sometimes alkali. Iron oxidation is sometimes used to control composition, whereas gypsum (CaSO4. 2H2O) was added to regulate the setting time of cement. Elevated but not excessive levels of lime tend to decelerate the setting process while yielding a high initial strength. Conversely, a deficiency in lime results in weak cement, and if combustion is incomplete, leads to rapid bonding. Finer cement has a larger grain surface area, which increases its weight, accelerates its reaction with water, and requires larger amounts of water. The chemical compound SiO2 (silica) acts as a binding element in building materials and can enhance the quality of paving blocks. Generally, cement is fine, and less than 80% of the grains can pass through a 44-micron sieve. Various methods can be employed to determine the fineness of cement grains. The most straightforward and effective method to achieve this is sifting. Water serves as a mixing agent and acts as a lubricant among aggregate particles, facilitating compaction and supporting the chemical reactions necessary for the binding process. The standard SNI 03-0691-1996 requires the use of high-quality water in the production of paving blocks, as follows: a) The water utilized must be clean and devoid of mud, clay, organic materials, organic acids, and other impurities. In addition, they did not contain hazardous chloride ions. These water quality standards are in accordance with SNI 03-0691-1996 as follows: a) should be free of mud and other floating debris. b) contains no more than 15 g/L of salts, including acids and organic substances, that can damage concrete. c) contains no more than 0.5 grams per liter of chloride (Cl). d) contained less than 1 g/L sulfate compounds. Proper utilization of water for the production of paving blocks is crucial. Excessive water usage leads to numerous air bubbles post-hydration, thereby compromising the strength of paving blocks. Conversely, insufficient water hinders the complete hydration process and weakens the final product. Water acts as an

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essential raw material, facilitating the chemical reactions necessary for the cement to react properly and harden.

Sand is a fine aggregate that serves as filler in cement mixtures. Fine aggregates consist of rock material with grain diameters ranging from 0.00 to 5.00 mm, derived from the natural disintegration of rock (natural sand) or produced by the stone crushing industry using crushing machines. According to SNI 03-2847-2002, as cited in Anggoro et al. (2023), fine aggregate is defined as "natural sand resulting from the natural disintegration" of rock or sand produced by the stone crushing industry and has a maximum grain size of 5.0 mm.

Sand serves as a fine aggregate and acts as a filler within the cement mixture. Its purpose is to minimize cement consumption, enhance durability and strength, and mitigate the shrinkage of paving blocks (Yanita et al., 2022). Sand characteristics significantly affect the quality and properties of the resulting paving blocks (Mahdi et al., 2022).

Given the substantial waste generated by the palm oil and shellfish industries, along with the favorable characteristics of cement and sand, which significantly enhance the quality of paving blocks, there is growing interest among researchers in exploring the potential of combining these wastes as foundational materials and additives in the production of paving blocks.

2. Materials and Methods

The materials used in this study were sand, cement, water, boiler ash from the palm oil industry, palm oil shells, and seashells.

2.1 Researech Methods

a. Boiler ash processing process

Boiler ash has always been utilized from fly ash dust collectors where it is still mixed between fine and coarse ash. Therefore, sieving is necessary to separate the fine ash from the coarse ash. The resulting fine ash was used as the material to produce paving blocks.

Boiler ash, originating from fly ash dust collectors, comprises a blend of fine and coarse particles. Consequently, it is essential to conduct sieving operations to effectively segregate fine ash from the coarse ash.

b. Process of processing palm oil shells

1. Palm oil shells derived from LTDS are characterized by intact cores that remain embedded within the shell structure.
2. The palm oil shells were subsequently incinerated until they were transformed into charcoal.
3. Charcoal derived from palm oil shells was pulverized using a mortar and subsequently sifted to yield palm oil shell ash.

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c. Seashell prossing prosess
   1. Shells extracted from shellfish were collected.
   2. The shells were cleaned and dried.
   3. After drying, the shells were crushed and sifted to produce shell ash.

d. Manufacturing concrate paving blocks
   1. The production of paving blocks involves the following formulations (Table 1).

Table 1. Formulations paving block

Treatment	Formulations (%)				
	Boiler ash	Palm shell ash	Shell ash	Cement	Sand
S1	20	25	15	20	20
S2	25	20	15	20	20
S3	20	20	20	20	20

   2. The mixture was thoroughly stirred until it was uniformly combined, and water was gradually added until a homogeneous mixture was obtained.
   3. Subsequently, a paving block mold 20 cm in length, 6 cm in height, and 10 cm in width was prepared.
   4. The mold was then filled with the prepared mixture to ensure compaction. The contents were carefully extracted from the mold to prevent damage to the paving blocks.
   5. The mold was then exposed to sunlight for approximately 28 days. During this period, the paving blocks were watered twice daily to facilitate curing.
   6. Following the drying phase, compressive strength and water absorption tests were conducted six times each.

The compressive strength values of the paving blocks were determined in accordance with SNI-03-0691-1996, using the following equation:

$$\text{Compressive Strength} = \frac{P}{L} \quad (1)$$

Whereas: P = Compressive Strength (N), L = Compression Area (mm^2)

The calculation of water absorption in paving blocks is based on SNI-03-0691-1996, namely:

$$W\text{ater absorption} = \frac{mb - mk}{mk} \quad (2)$$

Whereas: mb = wet mass, mk = dry mass

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3 Results and Discussions

The paving blocks produced were subjected to ANOVA and Duncan tests to assess the impact of boiler ash, palm oil shell ash, and shell ash on parameters such as water absorption and compressive strength. These parameters were subsequently compared with the standards specified in SNI 03-0691-1996.

3.1 Water absorption capacity of paving blocks

The water absorption capacity test assesses the ability of paving blocks to absorb water under different proportions of waste from the palm oil industry. The procedure involved immersing the paving blocks in a basin filled with water for 24 h. After soaking, the paving blocks were lifted and dried for 24 h, followed by the subsequent process weighing of the dried material. Subsequently, the blocks were removed, dried, and weighed to determine their dry weights (Yanita et al., 2022). The calculation of the water absorption capacity was based on the comparison between the dry and wet weights of the blocks, each meticulously measured using a digital scale.

Table 2. Paving block water absorption test results

Treatment	Test						Total	Average
	1	2	3	4	5	6		
S1	8,65	7,9	8,93	7,48	9,15	7,75	49,86	8,31
S2	10,93	8,24	9,62	10,64	10,31	8,98	58,72	9,79
S3	10,32	9,87	10,25	11,29	9,58	10,63	61,94	10,32

In table 2 above, the results of the water absorption test for paving blocks treated with S1 and S2 align with the specifications outlined in SNI 03-0691-1996. According to this standard, quality C paving blocks designed for pedestrian use must not exceed 8% of water absorption. Similarly, paving blocks treated with S3 conformed to SNI 03-0691-1996, with a maximum allowable water absorption of 10% for quality D blocks intended to cover plants and home gardens. Lower water absorption indicates higher quality of the produced paving blocks (Dewi et al., 2023).

This phenomenon occurs because a lower absorption capacity in paving blocks indicates a denser material structure, enhancing their strength and reducing the number of pores, thereby decreasing water absorption (Anggoro et al., 2023). The data revealed that, as the proportion of boiler ash and shells in the paving block mixture increased, the water absorption capacity also increased (Hardini et al., 2021). Thus, incorporating boiler ash into the production of paving blocks enhances their water-absorption properties. Water absorption tests on these paving blocks indicated their suitability for use as ground cover for plants and home gardens, given their significant water absorption capacity, ranging from 10,32% to a low of 8,31%. Consequently, the inclusion of boiler ash contributes to the

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water absorption process, leading to higher water uptake in the paving blocks. Variations in the composition of materials in paving blocks demonstrate that the water absorption capacity of these blocks is significantly affected (Fikroni et al., 2023).

3.2 Compressive strength of paving blocks

The compressive strength of paving blocks is equal to that of concrete, denoting the load capacity per unit area (Muladi et al., 2023). Thus, the intensity of the load sustained by the concrete per unit area results in the fragmentation of the concrete specimen because the force exerted by the pressing machine can be construed as the compressive strength measurement of the paving block. The determination of the compressive strength of a paving block involves assessing two key parameters: the compressive area and compressive load. The former is measured using dimensional tools, such as a ruler (length and width), whereas the latter utilizes a Forney tool. Testing the paving block compressive strength in accordance with ASTM C-192 aims to ascertain the maximum load that these blocks can withstand (Meileni et al., 2022). In addition, this test seeks to ascertain the compressive load capacity of the resultant paving blocks. Results of variance analysis of the compressive strength of the paving blocks. The statistical analysis revealed significant variations in the compressive strengths of the paving blocks. The compressive strength of paving blocks shows that the compressive strength of paving blocks has a significantly different effect (Nofrianto and Hutrio, 2023).

Table 3. Paving block compressive strength test results

Treatment	Test						Total	Average
	1	2	3	4	5	6		
S1	1,37	1,42	1,32	1,47	1,32	1,37	8,26	1,38
S2	2,53	1,89	1,84	2,47	2,00	1,84	12,58	2,10
S3	0,95	1,05	0,89	1,03	1,11	1,05	6,08	1,01

The results in Table 3 indicate that the paving blocks treated with S2 achieved the highest compressive strength, averaging 2,10 MPa. This result is attributed to the significant proportion of boiler ash, which acts as a partial binder for sand (Anggoro et al., 2023). Conversely, the paving blocks treated with S3 exhibited the lowest compressive strength, averaging MPa, largely because of the high content of shell ash containing silica, similar to that of sand. Furthermore, according to SNI 03-0691-1996, the compressive strength results for paving blocks treated with S1, S2, and S3 did not satisfy the requirement of at least 8,5 MPa. Therefore, it can be concluded that incorporating a mixture of PKS waste in the form of boiler ash, palm oil shells, and seashells, ranging from 15-25% composition, does not significantly impact the compressive strength of paving blocks as per the standards outlined in SNI 03-0691-1996. Based on currently available methods and materials, the application of waste products turned to paving blocks is acceptable. The production met certain criteria and characteristics, such as the compressive strength. The amount of waste material mixed with cement or by-products

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exhibits a significant and advantageous pattern. The compressive strength is achievable and can be concluded placed in the required category between 7 N/mm2 (Mohamad et al., 2022)

4. Conclusion

Based on the findings of this research, it was determined that testing the water absorption capacity of paving blocks treated with S1 and S2, in accordance with SNI 03-0691-1996, revealed that C-quality paving blocks designed for pedestrian use have a maximum allowable absorption of 8%. Meanwhile, the paving blocks treated with S3 met the standards for D quality, intended to cover plants and home gardens, with a maximum absorption of 10%. A lower water absorption indicates a higher paving block quality, characterized by a denser structure and improved strength owing to fewer pores. Statistical variance analysis confirmed the significant impact of the water absorption capacity on paving blocks. Analysis of compressive strength tests on paving blocks shows that those treated with S2 exhibit the highest average strength of 2,10 MPa, attributed to the significant proportion of boiler ash acting as a partial binder for sand. Conversely, paving blocks treated with S3 displayed the lowest average compressive strength of 1,01 MPa, primarily because of the higher proportions of shell ash, which contains silica and has a similar content to sand. According to the SNI 03-0691-1996 standards, all treatments (S1, S2, and S3) failed to meet the required compressive strength of at least 8,5 MPa.

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