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Plastic Waste-Based Paving Blocks: Towards A Sustainable Circular Construction Material

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A B S T R A C T

This study introduces a method using layered plastic blending technology to combine three primary types of plastic waste (PET, PP, and LDPE) with sand. The objective is to analyze the effects of plastic-sand composition variations on the mechanical properties of paving blocks, including water absorption, compressive strength, and abrasion resistance. The research was conducted experimentally through a plastic melting and hot-mixing process with sand using four composition ratios: 100% plastic: 0% sand, 75% plastic: 25% sand, 50% plastic: 50% sand, and 25% plastic: 75% sand. Results indicate that the 75% plastic: 25% sand mixture has the highest compressive strength of 11.64 MPa. The 100% plastic: 0% sand mixture exhibited the lowest absorption (<3%) and the best abrasion resistance (<0.062 mm/min). Increasing sand content generally reduced mechanical performance due to the inadequate distribution of plastic in coating the aggregate particles. Overall, plastic waste-based paving blocks demonstrate strong potential as an alternative construction material. Nevertheless, long-term environmental durability testing is recommended to ensure their applicability under real field conditions.

1. Introduction

Plastic waste represents a critical global issue, particularly in developing countries [1], [2], including Indonesia. Inadequate plastic waste management leads to severe environmental degradation. Data from the World Economic Forum (WEF) only 5% of plastic is recycled, 40% send to landfills and the remainder pollutes ecosystems, including marine environments [3]. Indonesia is one of the largest contributors to global plastic waste, generating an estimated 5.4 million tons of plastic waste annually [4].

As global plastic production continues to increase each year, plastic waste is a critical global environmental concern. Due to the non-biodegradable nature, plastic waste accumulates persistently in terrestrial and marine environments. Consequently, innovative strategies are required to address this growing challenge, one approach involves the use of plastic waste as a material alternative in the industry [8].

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Conventional paving blocks typically produced from a mixture of cement, sand, and water. However, these materials are energy-intensive and contribute substantially to carbon emissions during the manufacturing process [9]. Substituting part of these components with waste-derived materials, such as recycled plastic, can mitigate environmental impacts while fostering the development of more sustainable construction products [10].

This study develops an integrated melting method using layered plastic blending technology to combine polypropylene (PP), polyethylene terephthalate (PET) and low-density polyethylene (LDPE) each of which possesses distinct physical and thermal properties, into a single integrated melting process. This approach enables the utilization of heterogeneous plastic waste without requiring strict separation, despite the differing melting points of each plastic type, while still producing a homogeneous and structurally stable paving block mixture. When blended in specific proportions and processed through heating or compression molding, the plastic components can function simultaneously as both a binder and an aggregate, depending on the manufacturing technique used [11].

Numerous previous studies have explored the utilization of plastic waste as a material for paving blocks, either by using a single type of plastic or limited blends. However, studies that systematically integrate heterogeneous plastics such as PET, PP, and LDPE within a single integrated melting process, while simultaneously evaluating compressive strength, abrasion resistance, and water absorption, remain relatively limited. In addition, the thermal interactions among plastics with different melting points in blending systems without strict separation have not been extensively analyzed.

Therefore, this study aims to address the existing technical data gap concerning the performance of heterogeneous plastic composites as paving block materials, particularly with respect to the interaction of thermal and mechanical properties among different plastic types. This research examines the effects of incorporating PET, PP, and LDPE plastic waste on the compressive strength, abrasion resistance, and water absorption of paving blocks through an experimental approach. The findings are expected to enrich the national technical database and support the development of more practically applicable environmentally friendly construction materials within the construction sector.

2. Research Method

This study adopts an experimental method to examine the effects of varying material mixtures of plastic and sand, which were varied using four weight-based composition ratios relative to sand [13] as described in Table 1. The purpose of these variations was to evaluate the extent to which molten plastic can replace the role of cement as a binding agent in paving block structures and to identify the optimal proportion that yields the most favorable physical and mechanical characteristics.

The equipment used in this study included a plastic shredding machine, a No. 4 sieve representing the maximum diameter of fine aggregate, a pan used as a melting container for plastic, paving molds, a container box, a Universal Testing Machine (UTM) type CDI-200 and an abrasion testing device type HL-8818.

Table 1. Mixture Variations of Plastic Waste-Sand Paving Blocks (2025)

No	Sample Type	Mix Variation	Number of Samples		
			Compressive Strength	**Water Absorption**	**Abrasion Resistance**
1	PB100	100% Plastikc: 0% Sand	5	5	5
2	PB75	75% Plastic : 25% Sand	5	5	5
3	PB50	50% Plastic : 50% Sand	5	5	5
4	PB25	25% Plastic : 75% Sand	5	5	5

The proportion of each plastic type (PP, PET and LDPE) was uniformly distributed within the total plastic content incorporated into the mixture. This balanced allocation was implemented to prevent any single plastic type from dominating the composition, thereby ensuring consistency in the material characteristics across all variations. Furthermore, this approach facilitates an objective evaluation of

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material performance, as the contribution of each plastic type is assumed to be equivalent within the mixture matrix.

Each variation was cast into paving block specimens consisting of five samples for each variation and each type of test, using molds measuring 20 × 10 × 8 cm. The specimens were then tested, including compressive strength using a Universal Testing Machine (UTM), water absorption through the immersion method, and abrasion resistance using an abrasion testing machine.

3. Description and Technical

The production process begins with heating or melting the plastic waste in a metal pan at 130 °C to 250 °C. [14], [15], while continuously stirring to ensure uniform heat distribution. Once the plastic reaches sufficient temperature or has fully melted, the pre-measured sand is gradually added into the pan to prevent clumping of the mixture, thereby achieving good homogeneity.

After the plastic-sand mixture becomes uniformly blended and reaches a plastic, workable consistency, it is immediately placed into the paving block mold [16]. The molding process is carried out using a conventional pressing machine to apply adequate pressure, ensuring proper compaction of the mixture. All mixing and molding procedures must be performed swiftly because plastic has a relatively short hardening time once removed from its molten state [17].

Evaluation of the produced paving block samples was conducted to assess their physical properties, such as water absorption capacity, as well as compressive strength and abrasion resistance. The results of these evaluations serve as the basis for determining the optimal mixture composition for utilizing plastic waste as an alternative material in paving block production.

Compressive strength tests were conducted on five specimens using a Universal Testing Machine (UTM). Each specimen was placed between two loading plates and subjected to an incrementally applied load until failure occurred (cracking or crushing). The compressive strength was determined in accordance with the following equation:

$$\sigma = P/A$$

Description:
σ = Compressive strength (MPa)
P = Maximum load (N)
A = Loaded surface area (mm^2)

Water absorption testing was conducted by immersing the paving block specimens in water for 24 hours until full saturation was achieved. After immersion, each specimen was weighed in its saturated condition. The water absorption value was subsequently calculated as:

$$\text{Water Absorption (\%)} = (W_2 - W_1)/W_1 \times 100\ \%$$

Description:
W_1 = Dry weight (g)
W_2 = Weight after immersion (g)

Abrasion resistance testing was performed using an abrasion testing machine. Each specimen was rotated for a specified duration against an abrasive surface to simulate wear caused by friction. The difference in weight before and after testing was used to calculate the abrasion resistance value using the following equation:

$$D = 1.26\ G \times 0.0246$$

Description:
D = Abrasion loss (mm/min)
G = Mass loss (g/min).

The test results were subsequently compared with the Indonesian National Standard (SNI 03-0691-1996) for concrete paving blocks to assess compliance with the required quality criteria. This

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evaluation aimed to identify the plastic waste-sand mixture proportion that provides the best mechanical performance and is most feasible for practical application.

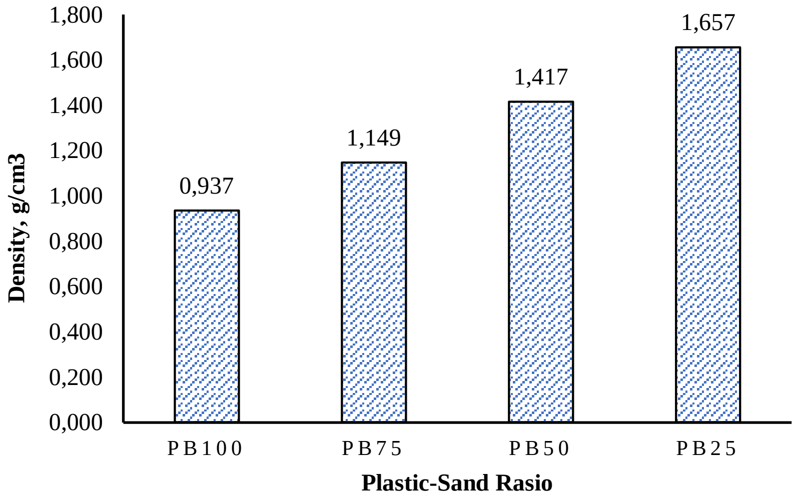
Table 2. Quality Standards for Paving Blocks Based on SNI-03-0696-1996

Quality	Compressive strenght (MPa)		Wear resistance (mm/menit)		Water absoption (%)	Usege
	Average	Min	Min	Average		
A	40	35	0.09	0.103	3	Pavement
B	20	17	0.130	0.149	6	Parking areas
C	15	12.5	0.160	0.184	8	Pedestarian
D	10	8.5	0.219	0.251	10	Parks

Source : Standar Nasional Indonesia [18]

4. Results and Discussions

4.1 Density



Source : Results of Data Analysis
Figure 1. Density of paving block

The density graph of paving blocks made from plastic waste shows a significant trend: as the proportion of sand in the mixture increases, the density of the paving blocks also rises markedly. This reflects the role of sand as a solid filler capable of filling voids within the plastic matrix, resulting in a denser and more compact structure. This condition aligns with findings in the literature: the use of recycled plastics in paving blocks generally tends to reduce density compared to conventional materials, as plastics such as polyethylene have a much lower specific gravity than mineral aggregates [19].

The increase in density at higher plastic-to-sand ratios (such as the PB50 and PB25 compositions shown in the graph) not only indicates better compaction but also has positive mechanical implications. In a study conducted by Kibiina et al. [20] it was found that PET-based paving blocks with an optimal sand ratio exhibited sufficiently high density alongside superior compressive strength [20].

However, there is a trade-off: although higher density has the potential to improve compressive strength, an increased plastic content can also reduce mechanical properties if the proportion is too high, since plastics often exhibit weak bonding with granular aggregates if not properly optimized. An experimental study on plastic-sand blocks that completely replaced cement with plastic found that the mixture ratio significantly influenced density, compressive strength, and water absorption properties [21].

4.2 Compressive Strength of Paving Blocks

In contrast to most findings reported in the international literature, the results of this study demonstrate that paving block mixtures with higher plastic content exhibit greater compressive strength. As shown in Figure 2, the mixture containing 75% plastic and 25% sand achieved the highest compressive strength

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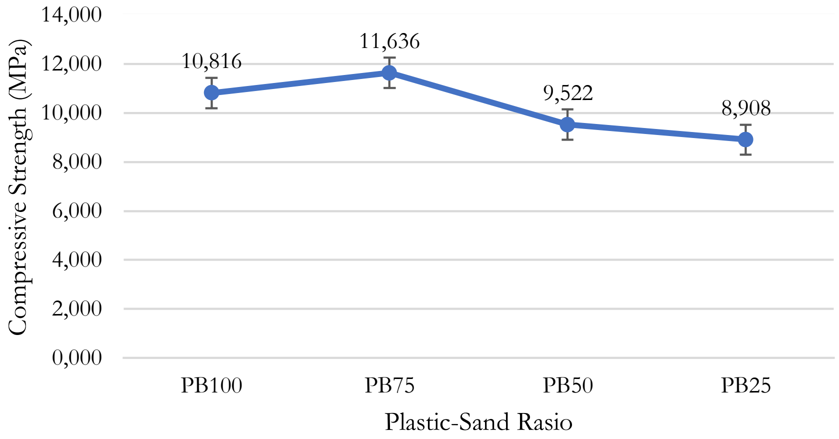
of 11.64 MPa, followed by the 100% plastic mixture with a value of 10.82 MPa. Conversely, an increase in sand content is associated with notable strength reduction, with compressive strength decreasing to 8.91 MPa at a plastic-to-sand ratio of 25%:75%. According to SNI 03-0691-1996, both the 100% plastic mixture and the 75% plastic: 25% sand mixture can be classified under quality Class D, as they meet the minimum average compressive strength requirement of 10 MPa.



Source : Results of Data Analysis

Figure 2. Average compressive strength with varying plastic-to-sand ratios

The findings of this study contradict most previous research, which generally indicates that increasing the proportion of sand or aggregates tends to enhance compressive strength, particularly when plastic is used as a thermoplastic binder. Iftikhar et al. [21] observed that the maximum compressive strength 17.04 MPa occurred at a composition of 30% LDPE and 70% sand, while higher plastic contents were associated with a reduction in strength. Similarly, Aneke and Shubangu [22] found that plastic bricks achieved compressive strengths of up to 29 MPa at a ratio of 30% plastic : 70% sand, but higher plastic proportions led to the formation of micro-voids and a reduction in mechanical performance.

The discrepancy between those studies and the present results may be attributed to several factors. First, the plastic composition used in this study consisted of a mixture of PET, PP, and LDPE, each possessing different viscoelastic properties and interparticle bonding capabilities [23]. This thermoplastic blend may more effectively coat and bind aggregate particles, potentially forming a denser and more homogeneous matrix when the plastic fraction is dominant [24]. Second, the processing parameters, including melting temperature, heating duration, molding time, and compaction pressure, play a critical role in establishing interparticle cohesion. If these parameters are not optimized, the addition of sand may disrupt plastic bonding and introduce internal voids, which in turn lowers the compressive strength of the produced paving blocks.

While Kumi-Larbi Jnr et al. [25] reported that interlocking blocks made from polyethylene achieved optimal compressive strength at 30-40% plastic, the present study indicates that a 75% plastic composition yielded superior performance. This suggests that mixed-plastic formulations may have an optimum point that differs significantly from that of single-polymer systems.

Overall, the findings suggest that compressive strength in recycled plastic-based construction materials is influenced by type of plastic, mixture composition, and processing conditions, thereby contributing new perspectives to the scientific literature.

4.3 Water Absorption

Figure 3 presents the water absorption results of paving blocks produced with various plastic-to-sand ratios, categorized under quality classes A (3%) and B (6%) according to SNI 03-0691-1996. The specimens composed of 100% plastic exhibited the lowest water absorption, whereas the mixture containing 25% plastic: 75% sand showed the highest absorption. Referring to the standard, the minimum limit for water absorption in quality class A is 3%, and the maximum allowable absorption for class D is 10% [18]. A notable decrease in water absorption was observed as the proportion of plastic increased.

These findings are consistent with previous studies. For instance, paving blocks made from PP-based plastics demonstrated low water absorption, recorded at 10.77% for high PP content [26], while

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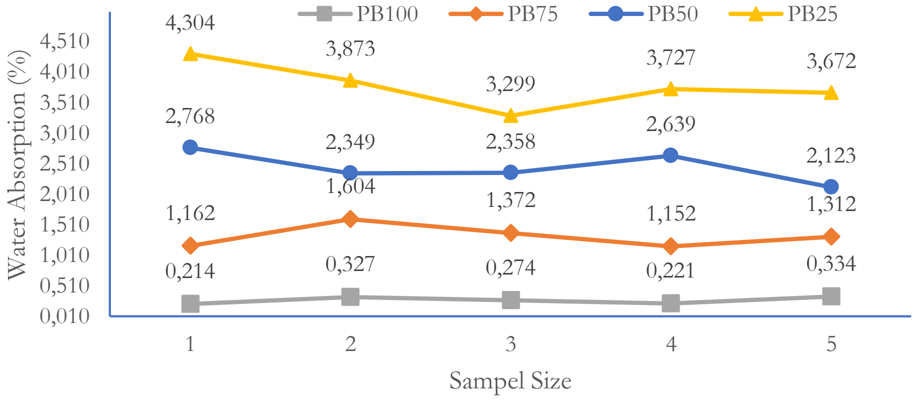
polymer-plastic composites have been reported to achieve absorption values as low as 0.35% [27]. This behavior is likely associated with the non-hygroscopic characteristics of plastic, which function as a binding matrix capable of sealing internal pores within the paving block structure, thereby limiting water penetration into the material [28], [29].

High water absorption indicates greater internal porosity, which allows water to fill voids and may subsequently reduce compressive strength while increasing the risk of structural deterioration, such as cracking or spalling [28], [30], [31]. Conversely, paving blocks with lower water absorption exhibit superior durability due to their improved resistance to chemical reactions, mechanical loads, and external physical stressors [27], [29].

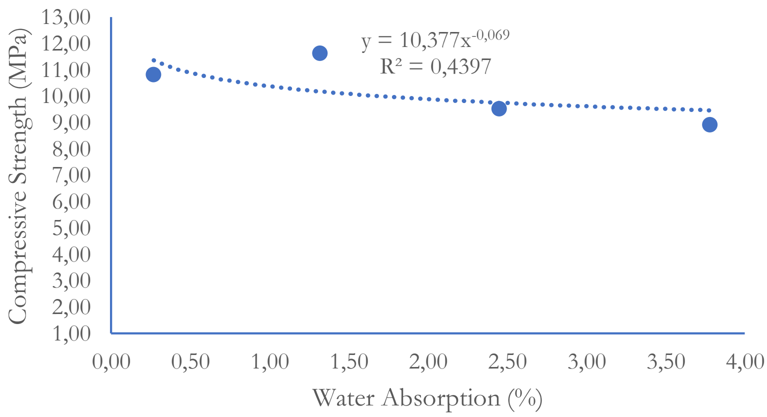


Source : Results of Data Analysis

Figure 3. Percentage of Water Absorption in Paving Block Samples at Different Plastic–Sand Ratios

Figure 4 illustrates the relationship between compressive strength and water absorption percentage in plastic-sand paving block samples. The regression equation obtained, y = 10.377x - 0.069, with a coefficient of determination (R^2 = 0.3942), indicates that although the statistical correlation is relatively weak; however, it suggests a trend in which increased water absorption may be associated with higher compressive strength. This behavior can be attributed to the nature of thermoplastic composites in which water does not penetrate the hydrophobic plastic matrix but is retained only within the micro-voids between sand particles [32]. When the sand particles are densely and uniformly distributed, the melted plastic binder is still able to form a strong internal structure even when capillary porosity increases.

This finding appears to be consistent with those reported in several previous studies. For example, Iftikhar et al. [21] eported that LDPE-sand paving blocks with an optimal ratio of 30:70 exhibited higher compressive strength despite having greater water absorption compared to samples made with pure plastic.



Source : Results of Data Analysis

Figure 4. Percentage of Water Absorption in Paving Block Samples at Different Plastic–Sand Ratios

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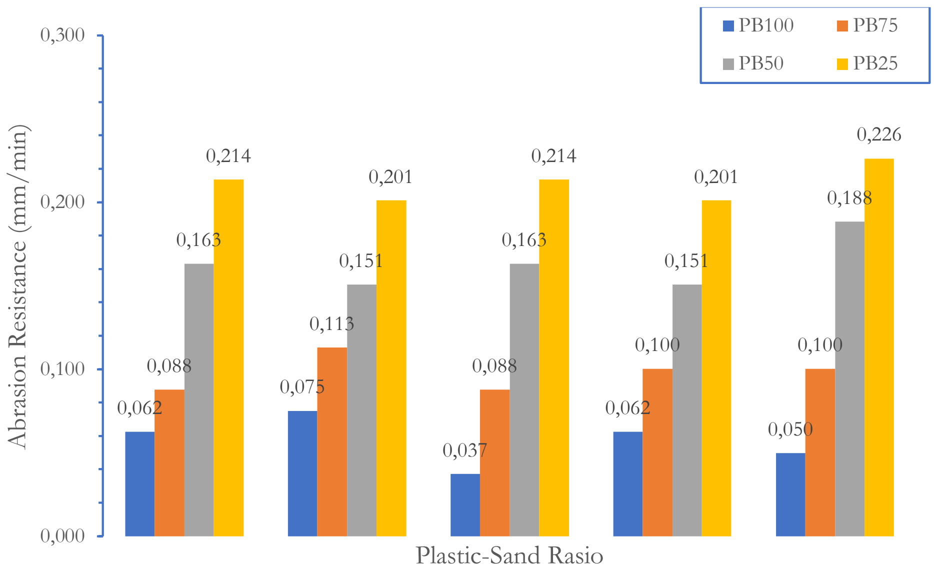
4.4 Abrasion Resistance

The variation in abrasion resistance values of the plastic–sand paving blocks presented in Figure 5 indicates that increasing the sand content results in a significant reduction in abrasion resistance. The abrasion loss of the PB100 mixture ranges from 0.037 to 0.062 mm/min, whereas the PB25 mixture shows a substantial increase, reaching 0.201–0.226 mm/min. This trend demonstrates that higher plastic content greatly enhances abrasion resistance. This improvement is attributed to the thermoplastic characteristics of materials such as LDPE and PP, which exhibit elastic behavior and superior resistance to surface friction. Based on SNI 03-0691-1996, the PB100 and PB75 mixtures fall within Quality Class A, the PB50 mixture is classified as Class C, and the PB25 mixture is categorized as Class D.

These findings appear to be consistent with those reported by Soni et al. [33], who reported that specimens containing higher proportions of LDPE exhibited the lowest abrasion loss, primarily due to the elastic properties of LDPE and the adequate presence of filler particles within the composite structure.



Source : Results of Data Analysis

Figure 5. Abrasion resistance values of paving blocks with various plastic - sand mixture ratios

The exponential increase in abrasion rate with a higher proportion of sand in the plastic-sand mixture, as illustrated in Figure 6, follows the regression equation $y = 0.039e^{0.4422x}$ ($R^2 = 0.9655$). This result suggests a very strong correlation between the variables. As the sand fraction increases, the surface structure becomes rougher and more abrasive because the amount of molten plastic is no longer sufficient to uniformly coat the sand particles. Consequently, the exposed sand grains act as weak points under frictional forces, accelerating the abrasion rate [33], [34], [35]. Structurally, molten plastic at elevated temperatures functions as a binder that forms an interconnected network among aggregate particles. When the proportion of plastic is adequate, a dense matrix is formed that encapsulates the sand uniformly, thereby enhancing cohesion and abrasion resistance. Conversely, when sand becomes dominant in the mixture, the matrix becomes unstable, leading to a significant increase in wear [36].

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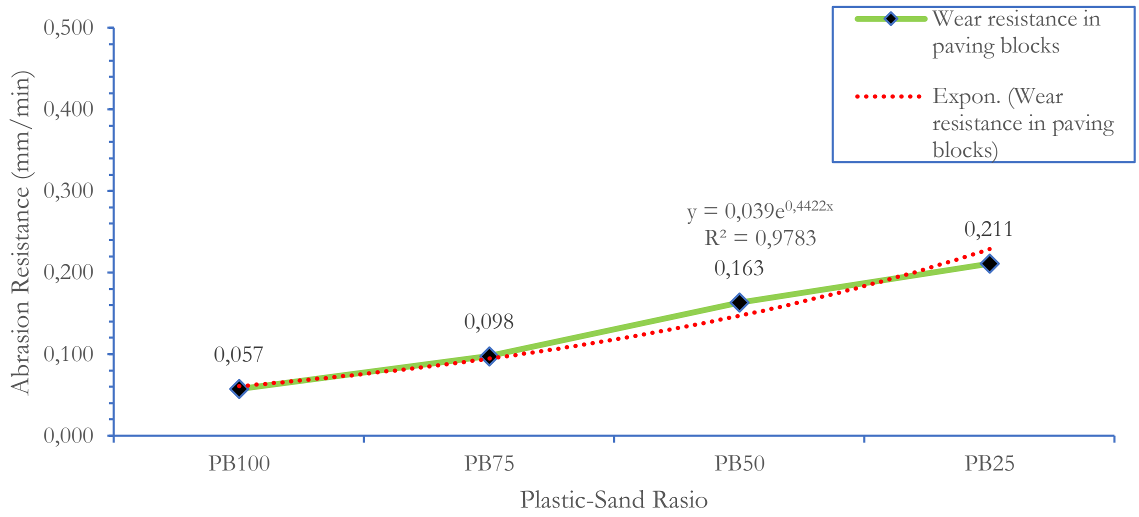

Source : Results of Data Analysis

Figure 6. Average Abrasion Resistance Percentage of Plastic–Sand Paving Blocks

5. Conclusion and Suggestion

5.1 Conclusion

This study suggests that the incorporation of PET, PP, and LDPE waste plastics as binders in paving blocks influences their mechanical and physical properties. Variations in the plastic-sand ratio resulted in distinct performance outcomes in terms of compressive strength, abrasion resistance, and water absorption. The 75% plastic : 25% sand composition (PB75) achieved the highest compressive strength of 11.64 MPa, meeting the requirements for Quality Class D under SNI 03-0691-1996. Meanwhile, the best water absorption and abrasion resistance values were obtained from PB100 (100% plastic), with <3% water absorption and <0.062 mm/min abrasion loss, respectively, indicating strong hydrophobic behavior and high wear resistance. An increase in sand content was found to reduce the overall mechanical performance, as the molten plastic was no longer sufficient to uniformly coat the sand particles. This led to higher internal porosity and increased susceptibility to friction-induced wear. Therefore, the 75% plastic and 25% sand mixture is identified as the most optimal proportion, offering the best balance between structural strength, abrasion resistance, and water durability.

5.2 Suggestion

Future research may focus on assessing the long-term durability of paving blocks under field conditions, particularly in tropical climates characterized by high humidity and heavy rainfall. Additionally, environmental and economic life-cycle assessments are recommended to ensure that the proposed paving block technology is not only technically robust but also environmentally sustainable and economically viable for large-scale industrial adoption.

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