

# EFFECT OF WASTE PLASTIC AS A BINDER ON COMPRESSIVE STRENGTH, WATER ABSORPTION, AND ABRASION RESISTANCE OF PAVING BLOCKS

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**Abstract.** The increasing accumulation of plastic waste has become a serious environmental problem, particularly in developing countries where waste management systems remain limited. A large proportion of plastic waste ends up in landfills or pollutes terrestrial and marine environments due to its non-biodegradable nature. One potential solution to this issue is the utilization of plastic waste as an alternative material in the construction sector. This study aims to evaluate the potential use of plastic waste as a binding material in the production of paving blocks and to analyze its influence on the mechanical and physical properties of the resulting product. This research employed an experimental laboratory approach using plastic waste consisting of polyethylene terephthalate (PET), polypropylene (PP), and low-density polyethylene (LDPE), processed through a melting method and mixed with fine sand. The mixture compositions included 100% plastic, 75% plastic : 25% sand, 50% plastic : 50% sand, and 25% plastic : 75% sand. The produced specimens were then tested for compressive strength, water absorption, and abrasion resistance in accordance with relevant testing standards. The results indicate that the mixture containing 75% plastic and 25% sand exhibited the most optimal performance, with a compressive strength of 11.64 MPa, water absorption of 1.32%, and abrasion resistance of 0.098 mm/min. In general, a higher plastic proportion improved compressive strength and reduced material porosity. These findings demonstrate that plastic waste has strong potential as an environmentally friendly alternative material for sustainable paving block production.

*Keywords : Plastic waste, Paving blocks, Compressive strength, Water absorption, Abrasion resistance.*

## 1. INTRODUCTION

Plastic waste continues to pose a major environmental challenge in many developing countries. The ongoing growth in global plastic production has led to a substantial increase in waste that is highly resistant to decomposition, thereby impacting both terrestrial and aquatic ecosystems as well as human health. Inadequate plastic waste management contributes significantly to marine pollution and deteriorates soil quality due to its slow degradation rate and the accumulation of microplastics [1], [2]. Moreover, only a small fraction of global plastic waste is actually recycled through formal waste management systems [3].

Indonesia, as one of the major contributors to global plastic waste, faces significant challenges in managing this type of waste [4], [5]. The accumulation of plastic in landfill sites not only leads to soil degradation and water contamination but also poses a threat to local ecosystems through the release of hazardous substances and the physical disruption of soil structures [6].

In response to this issue, increasing attention has been directed toward converting plastic waste into a valuable resource through circular economy approaches in the construction sector. One potential solution is the use of recycled plastics as a component in building materials, particularly for the production of paving blocks [7]. This strategy not only reduces reliance on natural aggregates and cement, whose manufacturing processes generate significant carbon emissions, but also helps minimize the accumulation of plastic waste in landfills and the surrounding environment [8], [9].

Several experimental studies have shown that plastics such as PET, PP, and LDPE can be utilized in paving block mixtures. For example, recent studies indicate that the incorporation of PET plastic waste in paving blocks can influence mechanical properties such as compressive strength and water absorption, although the resulting products may still meet certain quality standards [10]. In addition, other studies on the use of recycled plastics as binder materials or as substitutes for aggregates have demonstrated that specific mix formulations are capable of producing paving blocks with good abrasion resistance and relatively low water absorption [11].

A number of studies in the literature report that incorporating plastic waste as an aggregate component in lightweight concrete can lower the overall density of the material and broaden the development of sustainable construction materials. Nevertheless, this modification is commonly associated with a decrease in compressive strength, mainly attributed to the higher porosity introduced into the concrete matrix [12]. In addition, several review studies emphasize that careful optimization of the plastic content, improvement of plastic surface properties, and the use of appropriate processing techniques are essential to mitigate the negative effects on mechanical performance and long-term durability [13].

In Indonesia, while several studies have explored the use of plastic in paving blocks, for example by partially replacing fine aggregates with PET, research investigating the long term performance of these materials under tropical climatic conditions is still very scarce [14]. In addition, most existing studies rely on conventional approaches, such as limited substitution of sand or cement, and do not integrate multiple types of plastics with varying melting points and physical characteristics into a single, unified production process.

Consequently, this study introduces an integrative method that combines PET, PP, and LDPE using a smart melting technique followed by multi-layer mixing. This approach allows for the utilization of mixed plastic waste without the need for rigorous sorting, while enhancing the microstructure and uniformity of the resulting paving blocks. The study will assess how varying plastic ratios influence compressive strength, abrasion resistance, and water absorption through standardized testing procedures.

## 2. METHODS

This study employs a quantitative experimental approach conducted entirely in the laboratory [15]. Through this approach, each variation of the mixture between liquid plastic and sand is tested to examine how the composition affects its physical and mechanical properties, specifically compressive strength, water absorption, and abrasion resistance.

The population in this study comprises all paving blocks that can be produced from mixtures of liquid plastic and sand with various composition ratios. From this population, four mixture variations were selected: 100% plastic, 75% plastic : 25% sand, 50% plastic : 50% sand, and 25% plastic : 75% sand, based on the proportion of plastic by weight relative to sand.

The plastic waste used in this study consisted of a mixture of polyethylene terephthalate (PET), polypropylene (PP), and low density polyethylene (LDPE). To minimize phase separation due to differences in melting temperatures, the processing was carried out based on the thermal characteristics of each polymer. The optimum processing temperature was determined through preliminary trial heating, considering the melting ranges of LDPE (110-130°C), PP (160-170°C), and PET (250-260°C). The operating temperature was controlled within an effective range that allowed the lower-melting polymers to fully melt and act as the binding matrix, while the higher-melting polymers remained in a softened state to ensure homogeneous dispersion without thermal degradation.

Mechanical hot mixing was employed in the production process. The shredded plastics were first melted and continuously stirred until a homogeneous mixture was achieved, after which sand was gradually added while maintaining constant mixing to ensure uniform aggregate distribution and prevent segregation. The polymer blend ratio within the plastic fraction was set at 33.33% LDPE, 33.33% PP, and 33.33% PET (by weight sand) and was kept constant across all plastic-sand mixture variations to maintain experimental consistency.

For each mixture variation, five specimens were prepared, resulting in a total of 20 samples for each type of test. This number was applied consistently across all testing procedures, including compressive strength testing, water absorption testing, and abrasion resistance testing. Thus, each test was conducted using 20 specimens, ensuring more reliable and representative results in evaluating the influence of plastic-sand composition on the properties of the paving blocks.

### 2.1 Materials

Plastic waste was collected, cleaned, and then cut into small pieces to facilitate the melting process as shown in Figure 1. Fine sand was used as the aggregate. The main equipment consisted of a metal pan for melting, a heater, a stirring tool, paving block molds, a press machine, a digital scale, a soaking tank, a Universal Testing Machine (UTM), and an abrasion machine.



Figure 1. Plastic waste sorting and shredding process

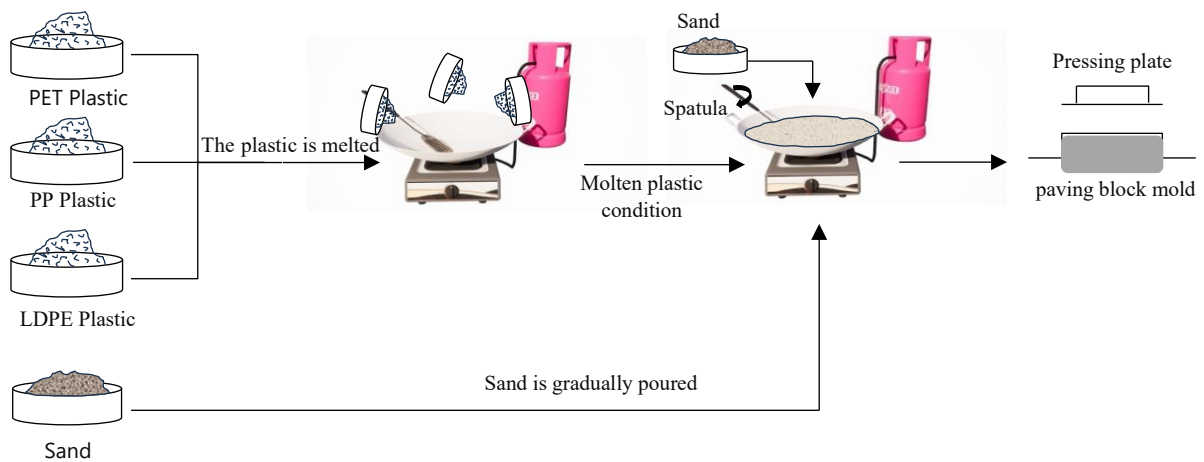


Figure 2. Steps in the production process of paving blocks from plastic waste-sand mixtures

**2.2 Sample Preparation Procedure**

The paving block was prepared according to the production diagram as seen in Figure 2. The initial stage involved melting the plastics using a metal. Detailed composition of each ingredients is shown in Table 1. Each type of plastic was processed individually according to its melting temperature to prevent thermal degradation and ensure optimal melting. LDPE was melted at 110-130°C, PP at 160-170°C, and PET at 250-260°C. Each plastic was maintained in a molten state for approximately 10-15 minutes after reaching the target temperature, with slow and continuous stirring to ensure uniform heat distribution.

Table 1. Mix Design Paving Block

No.	Mix Variation	Plastic Weight (gram)			Sand Weight (gram)	
		PET	PP	LDPE		
1	100	0	736	491	507	-
2	75	25	552	368	380	673
3	50	50	368	245	253	1346
4	25	75	184	123	127	2018

Once the plastic reached a stable liquid state, sand was gradually added while stirring for approximately 5-7 minutes until a visually homogeneous mixture was obtained. The gradual addition of sand aimed to prevent agglomeration and ensure an even distribution of aggregates within the plastic matrix. The homogeneous mixture was then transferred into paving block molds and compacted using a conventional press. Specimens were allowed to cool at room temperature until fully hardened before testing. Homogeneity of the mixture was confirmed through visual inspection of the fracture surface, which showed evenly distributed sand without large voids or material segregation.

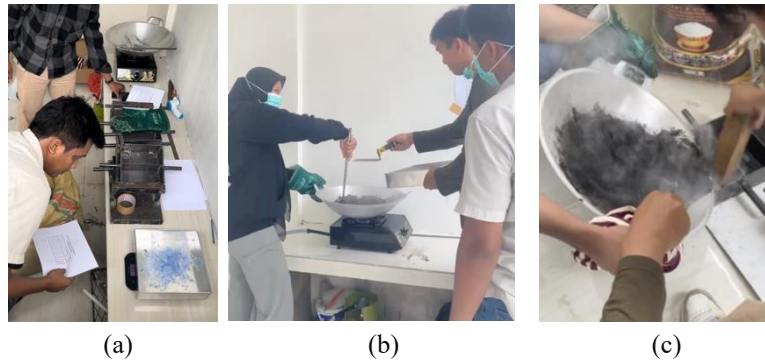


Figure 3. (a) Plastic weighing process, (b) Melting process, (c) Molding process

The molds were subjected to pressure using a conventional pressing machine to compact the mixture thoroughly. After this process, the specimens were left to cool at room temperature until fully hardened before testing. The complete process of sample preparation is shown in Figure 3.

### 2.3 Testing Procedures

#### a. Compressive Strength (SNI 1974:2011)

Each sample was placed in a Universal Testing Machine (UTM). Load was applied gradually until the specimen showed signs of failure. The compressive strength value was calculated using the equation:

$$\sigma = P/A \tag{1}$$

Description:

$\sigma$  = Compressive strength (MPa)

P = Maximum applied load (N)

A = Loaded surface area (mm<sup>2</sup>)

#### b. Water Absorption

Prior to testing, samples were weighed in their dry condition. Then, each sample was immersed in clean water for 24 hours. The weight after immersion was recorded, and the water absorption value was calculated using the formula:

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\% \tag{2}$$

Description:

W<sub>1</sub> = Dry weight (g)

W<sub>2</sub> = Weight after immersion (g)

#### c. Abrasion resistance (SNI 03-0028-1987)

Abrasion testing was conducted using a standard abrasion machine. Samples were rotated or rubbed against an abrasive surface for a specified duration. The difference in weight before and after the test was used to calculate the wear rate.

$$D = 1.26 G \times 0.0246 \tag{3}$$

Description:

D = Abrasion loss (mm/min)

G = Mass loss (g/min)

## 3. RESULTS AND DISCUSSION

### 3.1 Compressive Strength Of Paving Blocks

This section presents the results of compressive strength and water absorption tests on variations of plastic-sand-based paving blocks, and discusses the influence of plastic composition on the material's mechanical performance. The analysis was conducted to identify the optimal mix ratio and to understand the strengthening mechanisms occurring within the composite structure.

The data presented in Figure 5 and Figure 6 show that compositions with higher plastic content yield better compressive performance. The mixture with 75% plastic and 25% sand recorded the highest compressive strength at 11.64 MPa. The 100% plastic composition also exhibited a relatively high compressive strength of 10.82 MPa. However, when the sand proportion increased, the performance declined significantly; the 25% plastic and 75% sand ratio reached only 8.91 MPa, making it the variation with the lowest value.

This phenomenon indicates that under the processing conditions used, plastic appears to act as a more dominant binding matrix compared to sand. This finding aligns with studies on plastic-sand interlocking blocks, which report that an increased plastic fraction can produce a more compact structure because the molten polymer is able to coat and bind sand grains more uniformly, thereby enhancing the compressive strength of the material [16]. Similar results have been observed in PET-sand brick research, where a polymer matrix processed at

appropriate melting temperature can form a dense and stable structure, thus contributing significantly to mechanical strength despite a lower aggregate content [17]. Furthermore, other studies have demonstrated that increasing the proportion of certain plastics (e.g., HDPE or PET) in the mixture can improve mechanical performance and material durability, provided that the composition and melting process are properly controlled [18].

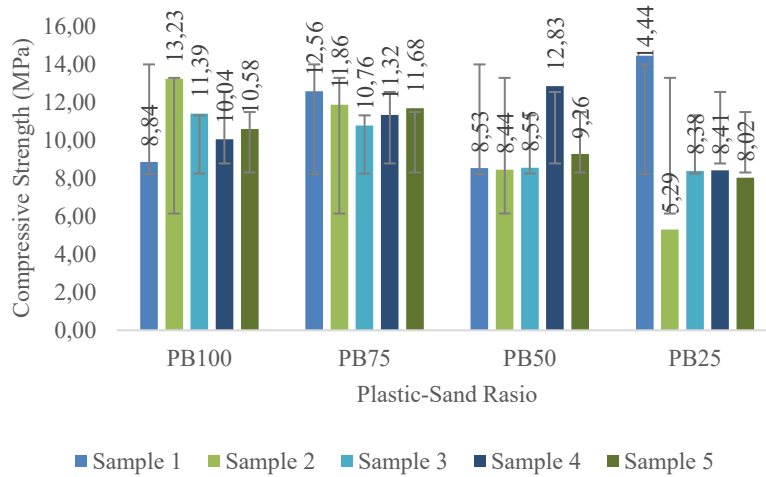


Figure 4. Compressive strength variations of paving blocks with different plastic-sand ratios

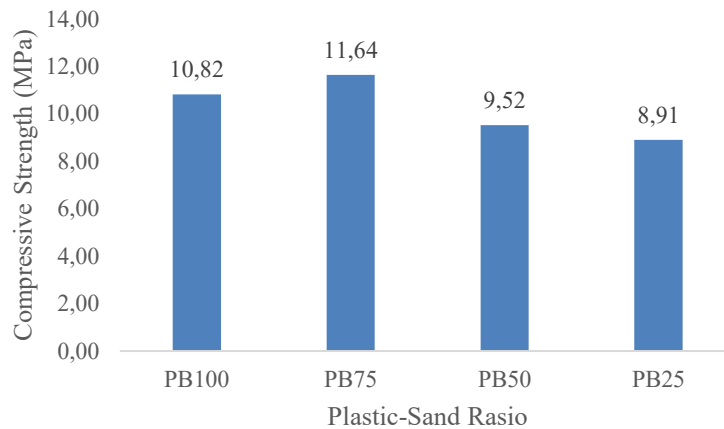


Figure 5. Average compressive strength of paving blocks with varying plastic-sand ratios

The 75% plastic composition performs better than 100% plastic because it provides an optimal balance between the plastic binder and the sand aggregate. At this ratio, the plastic is sufficient to coat and adhere to the sand grains evenly, allowing the load to be distributed more effectively throughout the material. The bond between the plastic and sand helps spread stress uniformly, reducing weak points that could lead to cracking. In contrast, the 100% plastic composition lacks enough sand as a structural filler, so even though the plastic matrix is dense, overall stiffness and stress distribution are less effective. Therefore, the 75% plastic : 25% sand ratio produces a composite structure that is more stable, compact, and mechanically stronger.

When the compressive strength values are compared with the SNI 03-0691-1996 standard, two variations 100% plastic and 75% plastic : 25% sand have met the minimum requirement for Quality Class D, which stipulates an average compressive strength above 10 MPa. Therefore, these two compositions have the potential for application in light to medium-duty uses, particularly in pedestrian areas, residential yards, or public facilities with low loading.

These finding also indicate that the liquid plastic-based bonding system in this study tends to perform optimally when the aggregate content is not excessively high, as an excess of sand can hinder the formation of a compact polymer matrix. This factor should be carefully considered in the further development of plastic waster based paving block products.

3.2 Water Absorption

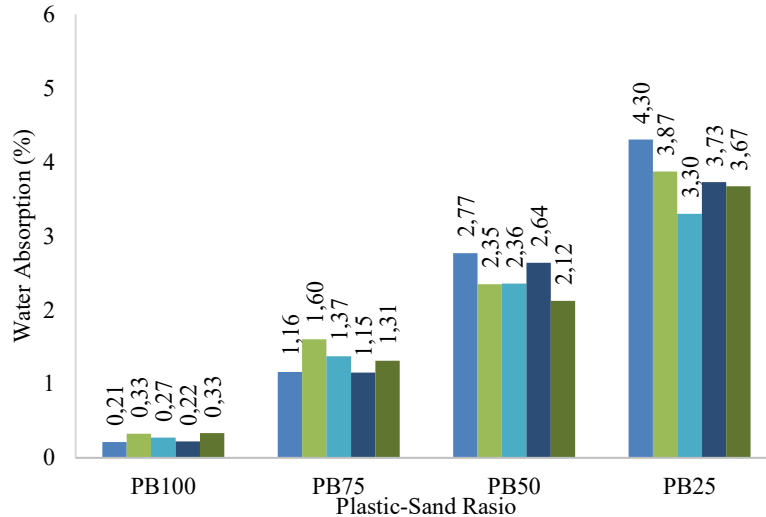


Figure 6. Percentage of water absorption in paving block samples with various plastic

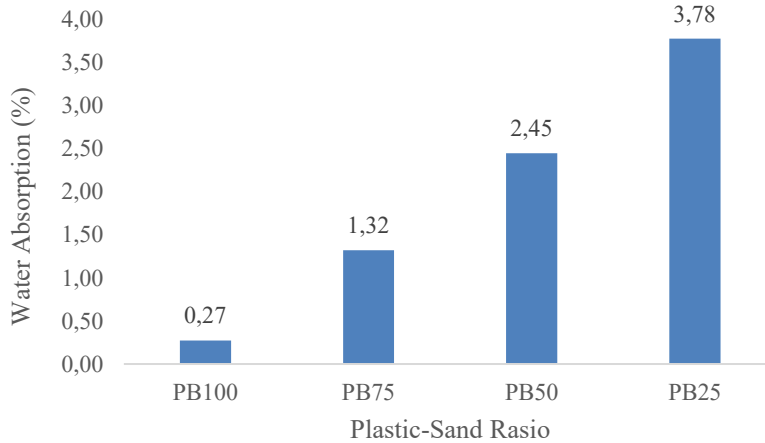


Figure 7. Average water absorption of paving blocks with varying plastic-sand ratios

This section discusses the results of water absorption tests on plastic-sand based paving blocks. Water absorption is an important indicator for assessing the material’s resistance to water penetration, which affects the durability and quality of the paving blocks. The analysis was conducted to evaluate the influence of varying plastic-to-sand ratios on the blocks’ water absorption capacity, in order to identify the optimal composition. The test results were subsequently compared with the SNI 03-0691-1996 standard to assess the material’s compliance in terms of quality class.

Figure 7 and Figure 8 illustrates an interesting pattern of water absorption in paving blocks with varying plastic-sand mixture ratios. The 100% plastic composition exhibited the lowest absorption rate, whereas the block with a 25% plastic : 75% sand ratio showed the highest water absorption. This decrease in absorption is consistent with the increasing proportion of plastic. Compared to the SNI 03-0691-1996 standard, the water absorption values of the high-plastic-content variations fall within Quality Classes A (3%) and B (6%), while the maximum limit for Class D according to the standard is 10%.

These findings reinforce the hypothesis that plastic in the mixture acts as a matrix filler that seals pores and reduces water penetration. This is consistent with the results reported by Mildawati (2023), who found that the addition of waste PP in paving blocks led to increased water absorption, and at low plastic proportions, porosity rose drastically [19]. Similarly, a study using recycled LDPE demonstrated that at a pure plastic composition (100%), water absorption was very low, approximately 0.317% [20].

The low water absorption in blocks with dominant plastic content is likely due to the non-hygroscopic nature of the polymer: molten plastic can form a coating layer around sand grains, reducing capillary pores within the material. This is supported by pragmatic research, such as the study by Fauzi & Mustakim, which showed that polypropylene-based paving blocks exhibit relatively low water absorption at certain ratios due to a sufficiently dense polymer-sand bonding [21].

The effect of low water absorption is crucial from a structural feasibility perspective; the reduced internal porosity makes the blocks more resistant to chemical reactions, physical stresses, and mechanical loads. This factor contributes to a longer service life by limiting water ingress, which can cause cracking. Conversely, increased water absorption in blocks with higher sand content indicates higher porosity, which can accelerate the decline in compressive strength and increase the risk of structural damage such as cracking or breaking over time.

**3.3 Abrasion Resistance**

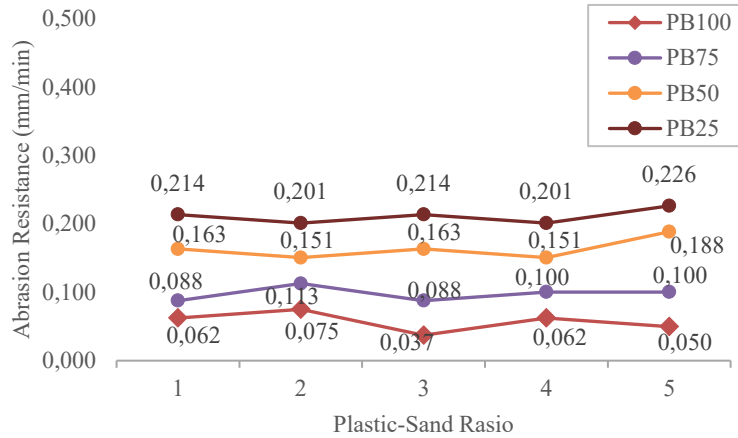


Figure 8. Percentage of abrasion resistance of paving blocks with various plastic-sand mixture ratios

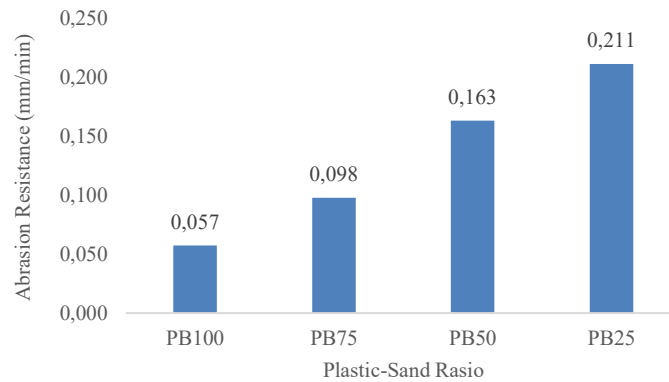


Figure 9. Average abrasion resistance of paving blocks with varying plastic-sand ratios

This section presents the results of abrasion tests on plastic-sand based paving blocks. Abrasion resistance is a key parameter for evaluating surface durability and long-term performance under frictional wear. The analysis focuses on the effect of varying plastic-to-sand ratios on the rate of material wear, highlighting the role of plastic in enhancing surface strength. The results provide insight into optimal compositions that improve abrasion resistance, which is critical for practical applications under different load and traffic conditions.

Figure 9 and Figure 10 illustrates the abrasion trends of paving blocks with varying plastic-to-sand ratios: the higher the sand proportion, the faster the material wears. For instance, in the PB100 variation (100% plastic), the abrasion rate ranges between 0.037 and 0.062 mm/min, whereas in PB25 (25% plastic : 75% sand), the wear rate sharply increases to approximately 0.201-0.226 mm/min. These findings clearly demonstrate that a high plastic content significantly enhances the abrasion resistance of paving blocks.

The thermoplastic properties of LDPE and PP make the material more flexible, so when friction occurs, the surface is less prone to cracking or breaking. Plastics tend to distribute and absorb shear forces, thereby reducing abrasion. This is supported by previous research where Rajat Akrawal et al. (2023) reported that paver blocks with a high plastic proportion (LDPE/PP) exhibited lower abrasion values compared to mixtures with low plastic content [22].

Table 2. Paving Block Quality Standards of SNI-03-0691-1996

Grade	Compressive Strength (MPa)		Abrasion Resistance (mm/menit)		Average Water Absorption (%)
	Average	Min	Min	Average	
A	40	35	0.09	0.103	3

B	20	17	0.130	0.149	6
C	15	12.5	0.160	0.184	8
D	10	8.5	0.219	0.251	10

According to the SNI 03-0691-1996 standard, the PB100 and PB75 variations are classified as Quality Class A, PB50 falls into Class C, and PB25 is categorized as Class D due to its relatively high abrasion (Table 2.). These results demonstrate that selecting the plastic ratio is not merely a matter of material substitution but is closely related to physical durability against abrasion. The low wear coefficient of blocks with dominant plastic content can be a significant advantage in applications requiring resistance to friction, such as pedestrian sidewalks or other light-use areas.

#### 4. CONCLUSION

This study demonstrates that plastic waste can effectively function as a binder material for paving blocks, where an increased plastic proportion results in improved mechanical performance. Among the tested variations, the 75% plastic : 25% sand composition exhibited the most optimal performance, with a compressive strength of 11.64 MPa, water absorption of 1.32%, and abrasion resistance of 0.098 mm/min. The 100% plastic variation also showed high performance, with a compressive strength of 10.82 MPa and abrasion rates between 0.037 and 0.062 mm/min, while the low-plastic mixture (25%) experienced a significant decline in performance, with a compressive strength of 8.91 MPa, water absorption of 3.78%, and abrasion rates of 0.201–0.226 mm/min. Therefore, the best performance was achieved at the 75% plastic : 25% sand ratio, indicating the optimal combination of strength, abrasion resistance, and water absorption. According to SNI 03-0691-1996, the PB100 and PB75 variations meet Class A quality, PB50 falls into Class C, and PB25 is categorized as Class D. Overall, a high plastic ratio has been proven to produce paving blocks with low porosity, high abrasion resistance, and better mechanical performance, indicating the great potential of plastic waste as a sustainable construction material. These paving blocks have specific prospective applications as materials for sidewalks, pedestrian pathways, parking areas, light-duty roads, and as an eco-friendly alternative in modular or prefabricated construction systems.

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