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Analysis of Wear Resistance in Eco-Friendly Paving Blocks Utilizing Multilayer Aluminum–LDPE Plastic Waste

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Abstract

The growing demand for sustainable construction materials has encouraged research on the utilization of multilayer aluminum plastic waste and low-density polyethylene (LDPE) waste as substitution materials in paving block production. This study investigates the abrasion resistance of eco-friendly paving blocks with three composition variations (V1: 65% plastic–35% sand/ash; V2: 57.5%–42.5%; V3: 50%–50%). The waste materials were processed through melting, blending, and molding with fine aggregates and combustion ash. The results show that the optimal composition (V1) achieved an abrasion resistance value of 0.0771 mm/min, meeting Class B quality according to SNI 03-0691-1996. The improvement in abrasion resistance is attributed to the thermoplastic behavior of LDPE, which forms a continuous binding matrix that reduces porosity and microcrack formation, and the rigid aluminum phase, which enhances surface hardness and friction resistance. The synergistic interaction between these materials leads to a denser microstructure and stronger interparticle bonding.From an economic perspective, the substitution of conventional cement with plastic waste reduces material costs and supports circular economy practices, particularly for small-scale production units such as community-based waste banks.These findings demonstrate that multilayer aluminum–LDPE waste-based paving blocks are suitable for applications subjected to light-to-moderate traffic loads and provide a sustainable alternative for reducing non-biodegradable waste accumulation.

Keywords: *abrasion resistance; eco-friendly paving block; multilayer plastic waste; LDPE; waste-based construction material; circular economy*

Abstrak

Meningkatnya kebutuhan terhadap material konstruksi berkelanjutan telah mendorong penelitian mengenai pemanfaatan limbah plastik multilayer aluminium dan limbah *low-density polyethylene* (LDPE) sebagai material substitusi dalam produksi paving block. Penelitian ini bertujuan untuk menganalisis ketahanan aus paving block ramah lingkungan dengan tiga variasi komposisi, yaitu V1 (65% plastik–35% pasir/abu), V2 (57,5%–42,5%), dan V3 (50%–50%). Material limbah diproses melalui tahapan peleburan, pencampuran, dan pencetakan bersama agregat halus serta abu hasil pembakaran. Hasil penelitian menunjukkan bahwa komposisi optimal (V1) menghasilkan nilai ketahanan aus sebesar 0,0771 mm/menit, yang memenuhi kriteria mutu B sesuai dengan standar SNI 03-0691-1996. Peningkatan ketahanan aus ini dipengaruhi oleh sifat termoplastik LDPE yang mampu membentuk matriks pengikat kontinu sehingga mengurangi porositas dan pembentukan retak mikro, serta keberadaan fase aluminium yang bersifat kaku yang berkontribusi dalam meningkatkan kekerasan permukaan dan ketahanan terhadap gesekan. Interaksi sinergis antara kedua material tersebut menghasilkan struktur mikro yang lebih rapat dan ikatan antarpartikel yang lebih kuat. Dari perspektif ekonomi, substitusi semen konvensional dengan limbah plastik mampu menurunkan biaya material serta mendukung penerapan prinsip ekonomi sirkular, khususnya pada unit produksi skala kecil seperti bank sampah berbasis masyarakat. Temuan ini menunjukkan bahwa paving block berbasis limbah multilayer aluminium–LDPE layak digunakan pada aplikasi dengan beban lalu lintas ringan hingga sedang, serta memberikan alternatif berkelanjutan dalam upaya mengurangi akumulasi limbah non-biodegradabel.

Kata kunci: ketahanan aus; paving block ramah lingkungan; limbah plastik multilayer; LDPE; material konstruksi berbasis limbah; ekonomi sirkular.

1. Introduction

The development of infrastructure in urban areas necessitates the availability of construction materials that are not only technically reliable but also aligned with sustainability principles. One of the most widely used materials for pedestrian walkways, parking areas, and residential environments is paving block, owing to its ease of installation and relatively low cost. However, the production of conventional paving blocks still relies heavily on Portland cement and large quantities of natural aggregates, leading to increased exploitation of mineral resources and higher carbon emissions [1].

Meanwhile, the volume of post-consumer plastic waste continues to rise annually. Multilayer aluminum plastic and low-density polyethylene (LDPE) are widely used in packaging and are difficult to decompose. These materials contribute significantly to environmental pollution if not properly managed [2][3]. Therefore, their utilization as alternative construction materials presents both environmental and economic benefits.

Several previous studies have demonstrated the potential of recycled plastics in paving block production. The incorporation of LDPE has been reported to improve flexibility and reduce microcrack formation [4][5]. Research shows that the addition of LDPE in small percentages can improve compressive strength while influencing water absorption characteristics [6]. Other studies reported abrasion resistance values ranging from 0.038 to 0.060 mm/min using plastic-based paving materials [7].

Furthermore, cement-free paving blocks using plastic waste as a binder have shown promising results in improving material performance and sustainability [8][9]. The use of plastic waste has also been proven to enhance durability properties such as abrasion resistance and water resistance [10].

Recent studies have further explored the integration of plastic waste and industrial by-products in construction materials, highlighting improvements in durability and environmental performance [11][12][13]. In addition, the use of composite materials combining plastic and other fillers has demonstrated enhanced mechanical behavior and wear resistance [14][15].

However, studies specifically examining the combined use of multilayer aluminum–LDPE in relation to abrasion resistance remain limited. Therefore, this study aims to analyze the abrasion resistance of eco-friendly paving blocks produced from multilayer aluminum–LDPE waste.

2. Material and Method

This study employed the following equipment and materials.

2.1. Equipment and Materials

The equipment used included molds, a pressing machine, a furnace, and a heating pan.The primary materials consisted of multilayer aluminum plastic waste (sourced from used detergent packaging, food wrappers, and candy wrappers) and LDPE plastic waste (obtained from post-consumer plastic packaging). Prior to use, the plastic waste was thoroughly washed and cut into small pieces. Additional materials included sand and combustion ash.

2.2. Mixture Composition and Paving Block Manufacturing Procedure

Three mixture variations, namely V1, V2, and V3, were prepared in this study. Specimen V1 contained 65% aluminum–LDPE and 35% sand–ash. In specimen V2, the aluminum–LDPE content was reduced to 57.5%, while the sand–ash fraction was increased to 42.5%. Specimen V3 was designed with an equal proportion of aluminum–LDPE and sand–ash, each accounting for 50%.These variations were intended to evaluate the influence of aluminum–LDPE proportion on the abrasion resistance of paving blocks.

The paving block manufacturing procedure was conducted as follows:

LDPE plastic waste was melted at a temperature of 110 °C.

Multilayer aluminum plastic waste was melted at 660 °C, then sieved and mechanically blended.

1. The molten plastics were mixed with sand and ash in a furnace and heated at 200 °C for 15 minutes to ensure homogeneity.

2. The mixture was poured into standard paving block molds with dimensions of 20 × 10 × 6 cm.
3. The molds were closed and subjected to pressing.
4. The molded specimens were immersed in water.
5. The paving blocks were removed and allowed to cool until a stable room temperature was reached.
6. Finally, the paving blocks were demolded.

The paving block fabrication process was carried out according to the workflow as shown in Figure 1.

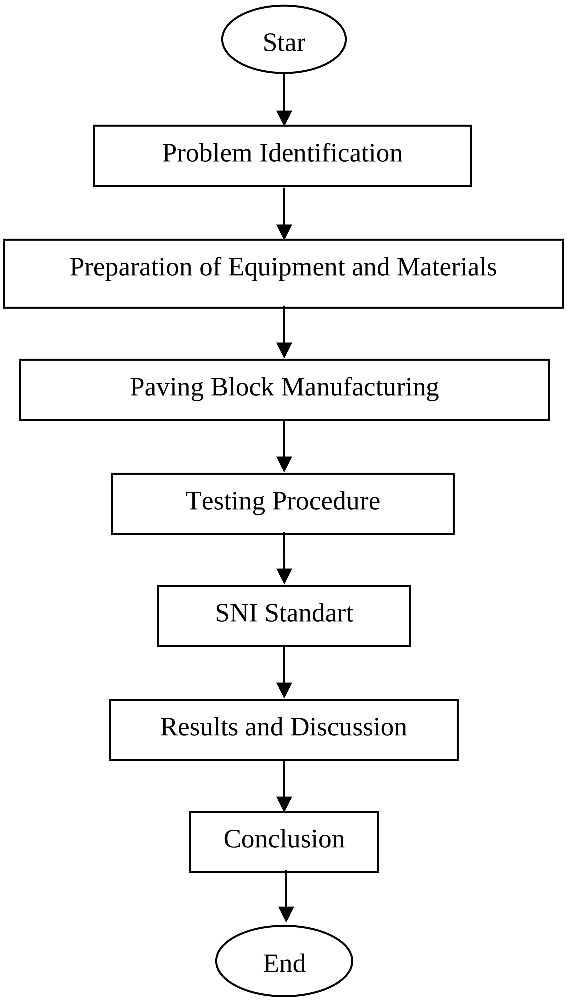


Figure 1. Research Flowchart

2.3. Principle of Abrasion Resistance Testing

The abrasion resistance test was conducted using a wear testing apparatus to evaluate the ability of paving blocks to withstand friction and surface wear induced by vehicle traffic. The fundamental principle of this test involves applying controlled artificial friction to the surface of the paving block using an abrasion device or wheel abrasion tester in accordance with EN 1338, or a wheel abrasion machine compliant with SNI/EN standards. During the testing process, the surface of the paving block undergoes gradual material removal, resulting in a reduction in mass or thickness. The abrasion resistance test was conducted using a wear testing apparatus in accordance with relevant standards such as ASTM and SNI/EN testing procedures [12][13]. Abrasion resistance is calculated using the following equation:

$$Ka = 1{,}26\ (mm/gr)\ x\ G + 0{,}0246 \quad (1)$$

Where:

Ka = abrasion resistance (mm/min).

G = mass loss per unit time (g/min)

2.4. Paving Block Fabrication

Figures 2 and 3 illustrate the LDPE plastic waste, multilayer aluminum plastic waste, and the resulting paving block products. These figures show that paving blocks produced from a mixture of multilayer aluminum–LDPE plastic waste combined with sand and ash exhibit relatively uniform shapes and sufficiently dense surfaces. This observation indicates that the mixing and molding processes were conducted in accordance with the established procedures, allowing for a homogeneous distribution of materials within the molds.

An examination of the paving block surfaces reveals that mixtures with higher LDPE content (such as variation V1) tend to produce smoother and slightly glossy textures. This behavior can be attributed to the plastic characteristics of LDPE, which melts and coats the sand aggregates during the melting process, thereby reducing surface porosity. Such a condition contributes to improved abrasion resistance, as fewer open pores decrease the likelihood of sand particle detachment under frictional forces.

In contrast, variations with higher proportions of sand and ash (V2 and V3) display rougher surfaces with more pronounced sand grains. This suggests that the LDPE layer coating the aggregate particles is relatively thinner, causing interparticle bonding to rely more heavily on mechanical interlocking. As a result, this condition may lead to lower abrasion resistance, as sand particles are more susceptible to detachment when subjected to repeated frictional loading.

Figure 2. Raw Materials Used in the Study: LDPE Plastic Waste and Multilayer Aluminum Plastic Waste

Figure 3. Paving Block Products after Manufacturing

2.5. Data Analysis

The mean values and standard deviations were calculated for each mixture variation. The obtained abrasion resistance results were then compared with the quality limits specified in the relevant SNI standard. Subsequently, an analysis was conducted to evaluate the significance of the influence of multilayer aluminum plastic and LDPE plastic waste composition on abrasion resistance.

3. Results and Discussion

This section presents the results and discussion of the study, focusing on the analysis of abrasion resistance of eco-friendly paving blocks produced from multilayer aluminum–LDPE plastic waste. The discussion emphasizes the relationship between material characteristics, mixture composition, and the resulting abrasion resistance performance, as well as the implications for the potential application of these paving blocks as sustainable alternative construction materials.

Abrasion Resistance Testing

The abrasion resistance of each mixture variation was calculated using Equation (1). The results were subsequently organized into tables and graphical representations, as shown in Table 1 and Figure 2.

$$Ka = 1{,}26\ (mm/gr)\ x\ G + 0{,}0246$$

Sample Calculation

Given:

G = 0,1250 gr/min

K a = 0,0327 mm/min

$$Ka = 1{,}26\left(\frac{mm}{gr}\right)x0{,}1250 + 0{,}0246$$

= 0,1821 mm/min

The calculated abrasion resistance values for each specimen are presented in Table 1.

Table 1. Abrasion Resistance of Each Mixture Variation

No	Variation	Weight (gr)		Mass Loss, G (gr/min)	Ka (mm/min)	Average Ka (mm/min)
		Initial	Final			
1	**V1**	**99**	**98**	**0.1250**	**0.1821**	**0.0771**
		85	**85**	**0.0000**	**0.0246**	
		100	**100**	**0.0000**	**0.0246**	
2	**V2**	**81**	**80**	**0.1250**	**0.1821**	**0.1296**
		87	**87**	**0.0000**	**0.0246**	
		82	**81**	**0.1250**	**0.1821**	
3	**V3**	**81**	**80**	**0.1250**	**0.1821**	**0.1821**
		86	**85**	**0.1250**	**0.1821**	
		72	**71**	**0.1250**	**0.1821**	

The abrasion resistance tests were conducted on three mixture variations (V1, V2, and V3), with three specimens evaluated for each variation. The calculated results indicate distinct differences in the average abrasion resistance among the tested compositions. Variation V1 exhibited an average abrasion resistance value of 0.0771 mm/min, with most specimens showing relatively minimal mass loss. Notably, two out of the three specimens experienced zero mass loss, resulting in very low abrasion resistance values. When classified according to paving block quality standards, this variation meets the requirements for Class B quality as specified in SNI 03-0691 [9][14].

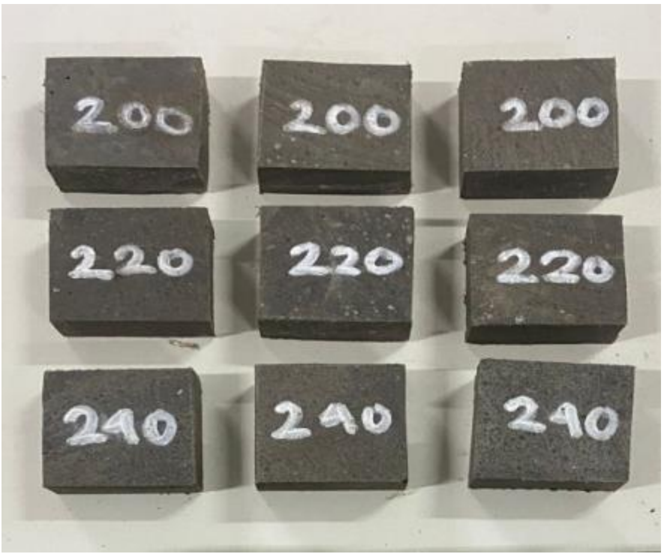
Variation V2 demonstrated an average abrasion resistance value of 0.1296 mm/min. In this variation, a combination of specimens with zero mass loss and specimens experiencing measurable abrasion was observed, leading to a higher average value compared to V1. Variation V3 produced the highest average abrasion resistance value, reaching 0.1821 mm/min, in which all specimens underwent significant material loss during the testing process. Overall, an increasing trend in average abrasion resistance values was observed as the material composition shifted from V1 to V3.

The results indicate that material composition plays a critical role in determining the abrasion resistance of paving blocks. Variation V1 was identified as the most optimal composition due to the balance between the plastic properties of LDPE and multilayer plastic, which effectively fill surface pores. The high dominance of C–H bonds from LDPE, combined with a well-distributed aluminum phase, enhances surface hardness and reduces aggregate detachment, thereby maintaining strong interparticle bonding. In contrast, variations V2 and V3 exhibited reduced C–H content from LDPE and less uniform aluminum distribution, leading to decreased surface hardness and accelerated aggregate release.

Furthermore, the combination of aluminum waste and multilayer plastic produces a synergistic effect on surface abrasion resistance. Aluminum particles function as rigid fillers that increase micro-scale roughness and strengthen interparticle bonding, while LDPE acts as a thermoplastic binder that reduces porosity and water absorption. The interaction between these two materials results in paving blocks with improved resistance to surface friction and abrasion.

Among the three variations, V1 was found to be the most effective composition for enhancing abrasion resistance, making it more suitable for applications such as residential roads or parking areas subjected to light to moderate loads. These findings demonstrate novelty compared to previous studies, which predominantly focused on the use of a single type of waste material. Studies by [2][15] reported that the use of pure LDPE waste improved abrasion resistance but significantly reduced compressive strength. Meanwhile, [5] found that the incorporation of aluminum powder into lightweight concrete increased surface hardness but tended to raise porosity levels.

In the present study, the combined use of both materials achieved a balance between mechanical strength and abrasion resistance, offering a new alternative formulation for eco-friendly paving blocks. Given the simplicity of the manufacturing process, these results have strong potential for implementation at the small-scale industrial level or within community-based waste banks, contributing to circular economy practices and reducing the accumulation of difficult-to-recycle multilayer plastic waste. Photographs of the specimens before and after abrasion testing are presented in Figures 4a and 4b.



(a)

(b)

Figure 4. Abrasion Test Results, (a) Before abrasion testing, (b) After abrasion testing

The improvement in abrasion resistance observed in variation V1 can be explained from both physical and material interaction perspectives. The melted LDPE acts as a thermoplastic binder that encapsulates sand and ash particles, forming a dense matrix structure. This process significantly reduces internal voids and limits the detachment of aggregate particles under frictional loading. From a microstructural standpoint, the reduction in porosity leads to increased density and improved load transfer between particles. Consequently, the material exhibits higher resistance to surface wear. In contrast, mixtures with lower plastic content (V2 and V3) tend to have weaker bonding due to insufficient coating of aggregates, resulting in higher material loss during abrasion testing.

Additionally, the presence of aluminum layers contributes to enhanced abrasion resistance through its relatively high hardness and ability to act as micro-reinforcement within the composite matrix. The interaction between ductile LDPE and rigid aluminum creates a synergistic effect, combining flexibility and surface strength. This mechanism prevents brittle failure and reduces crack propagation under repeated friction. These findings are consistent with previous studies, but the present work provides additional insight into the combined effect of multilayer aluminum and LDPE, which has not been extensively explored in earlier research.

From an economic standpoint, the use of multilayer aluminum plastic and LDPE waste offers significant cost advantages compared to conventional paving block production. The reduction or elimination of cement usage lowers raw material costs, as cement is one of the most expensive components in conventional mixtures. Furthermore, the raw materials used in this study are derived from post-consumer waste, which is often available at low or negligible cost through waste banks. This creates an opportunity for community-based production systems to generate value-added products from waste materials. In addition, the relatively simple manufacturing process, which does not require high-pressure or complex curing methods, reduces energy consumption and production costs. Therefore, the proposed paving block formulation is not only technically feasible but also economically viable, particularly for small-scale industries and circular economy initiatives.

4. Conclusion

The innovative use of multilayer aluminum plastic waste and LDPE plastic waste as constituent materials in paving block mixtures has proven effective in enhancing abrasion resistance beyond the standard quality threshold. The optimal composition was achieved with a 65% proportion of multilayer aluminum plastic and LDPE waste, resulting in an abrasion resistance value of 0.0771 mm/min. These results highlight the potential of multilayer aluminum–LDPE waste not only as an alternative construction material but also as a scalable solution for sustainable waste management and low-cost infrastructure development.

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