PERFORMANCE OF INTERLOCKING PAVEMENT BLOCKS WITH WASTE PET AS A PARTIAL REPLACEMENT FOR COARSE AGGREGATE

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Abstract:
The massive generation of non-biodegradable plastic waste, particularly Polyethylene Terephthalate (PET) from bottles, poses a significant environmental challenge. This research explores an innovative solution by utilizing waste PET flakes as a partial replacement for coarse aggregate in interlocking pavement blocks, promoting sustainable construction. Concrete mixes with a 1:3:4 (cement: fine aggregate: coarse aggregate) ratio were prepared, where coarse aggregate was replaced by PET at 0%, 5%, 10%, and 15% by volume. The resulting blocks were tested for workability, compressive strength, and water absorption in accordance with BS EN 1338:2003. The results indicated that the workability of the fresh concrete mix decreased significantly with the addition of PET. The compressive strength initially increased, with a 5% PET replacement achieving a strength of 17.2 N/mm², slightly higher than the control mix (16.9 N/mm²). At 10% replacement, the strength (16.8 N/mm²) remained comparable to the control, identifying it as the optimal dosage. However, a further increase to 15% led to a strength reduction to 14.9 N/mm². Notably, water absorption decreased consistently with higher PET content, reaching 1.8% for the 15% mix compared to 4.1% for the control. The study concludes that a 10% replacement of coarse aggregate with waste PET is optimal for producing interlocking blocks suitable for light-traffic applications, offering a viable method to reduce plastic waste while creating a lighter and more water-resistant paving material.

Keywords: Plastic waste, PET, sustainable pavement, interlocking blocks, compressive strength, water absorption.

Introduction

Plastic has become a cornerstone of modern life, but its durability is also the source of a mounting environmental crisis. Global production now exceeds 300 million tons annually, with a staggering amount designed for single-use before being discarded (Geyer, Jambeck, & Law, 2017). This creates a profound waste challenge, as these materials can persist in the environment for centuries. Each year, millions of tons of this waste find their way into our oceans, harming marine ecosystems and entering the food chain (Jambeck et al., 2015). While plastic's versatility and low cost are undeniable, its resistance to degradation demands innovative solutions for its end-of-life management.

In line with the global Sustainable Development Goals (SDGs), researchers are exploring ways to divert plastic waste into productive applications, particularly within the construction industry. Integrating plastic into building materials like concrete, bricks, and asphalt presents a promising path toward a more circular economy (Siddique, Khatib, & Kaur, 2008; Saikia & de Brito, 2012). This approach not only reduces landfill burden but also conserves natural resources by replacing virgin aggregates or binders.

The development of interlocking pavement blocks is a particularly fitting application for this concept. Previous studies have investigated using various types of plastic waste, such as PET bottles and polyethylene films, as partial replacements for sand or cement. The findings, however, have been mixed. For example, research has consistently shown that incorporating plastic aggregates often reduces the overall compressive strength of the concrete (Choi et al., 2005; Batayneh, Marie, & Asi, 2007). Yet, these same studies frequently note beneficial properties like reduced weight, lower water absorption, and improved ductility. This suggests that while high-strength structural applications may be challenging, there is significant potential for use in non-critical applications like light-traffic pavements, walkways, and water-retaining structures.

This study focuses on Polyethylene Terephthalate (PET), commonly used in beverage bottles. PET is a suitable candidate for this purpose because of its chemical composition—consisting only of carbon, hydrogen, and oxygen—which means it does not release toxic fumes when melted at controlled temperatures (Gawande et al., 2012). Its inherent resistance to chemicals and its ability to act as a binding agent in a molten state further support its use in composite materials.

While the idea of using plastic in paving blocks is not new, the optimal formulation for balancing sustainability with mechanical performance remains an active area of research. Many existing studies report a general decline in strength with increased plastic content, but there is a need to identify specific replacement levels that meet standard requirements for particular applications. The potential for a slight enhancement of properties at lower replacement percentages also warrants deeper investigation.

Therefore, this research aims to systematically evaluate the performance of interlocking pavement blocks made with waste PET as a partial replacement for coarse aggregate. We specifically investigate the effects of replacing 0%, 5%, 10%, and 15% of the coarse aggregate by volume on the workability, compressive strength, and water absorption of the blocks. The goal is to determine an optimal mix that effectively utilizes plastic waste while meeting the necessary benchmarks for use in sustainable, light-duty paving solutions.

Literature review

The growing urgency to manage plastic waste has spurred significant research into its potential as a secondary raw material in the construction sector. The body of literature exploring the integration of plastic waste into concrete and masonry units is substantial, with studies investigating its use as a replacement for aggregates, a partial binder, or an additive. This review synthesizes previous work relevant to the development of plastic-infused paving blocks, focusing on the effects on mechanical properties, durability, and practical feasibility.

A consistent finding across numerous studies is the trade-off that occurs when plastic waste is used as a partial replacement for conventional aggregates. While this substitution consistently improves properties like weight reduction and water resistance, it often leads to a reduction in mechanical strength. Choi et al. (2005) found that using PET bottle aggregates reduced the compressive strength of concrete by up to 33% compared to conventional mixes. Similarly, Batayneh et al. (2007) reported a strength reduction of up to 70% when 20% of sand was replaced by plastic waste. This decline is frequently attributed to the weaker bond between the cement paste and the hydrophobic plastic surface compared to the bond with natural aggregates (Siddique et al., 2008). However, the extent of this strength reduction is highly dependent on the replacement percentage. Jo et al. (2008) noted that the inclusion of less than 10% plastic waste by volume did not cause a significant variation in the concrete's mechanical features, suggesting a potential threshold for viable application.

Beyond aggregate replacement, researchers have also innovated by using molten plastic as a primary binding agent. For instance, Maneeth et al. (2014) manufactured plastic-soil bricks using 60-80% molten plastic as a binder, supplemented with bitumen. They achieved a compressive strength that, while lower than standard concrete blocks, exceeded the strength of traditional laterite stone, demonstrating the potential for creating new composite materials for non-structural applications. Other studies have combined plastic with industrial by-products like fly ash and quarry dust (Nivetha et al., 2006).

When the focus shifts specifically to paving blocks, research highlights the importance of economic viability alongside technical performance. Sohani et al. (n.d.) utilized Low-Density Polyethylene (LDPE) as a binder with river sand, finding a significant reduction in water absorption and production cost compared to conventional blocks, although the compressive strength was suitable only for light-traffic areas. The economic advantage is a recurring theme, with studies like Rai et al. (2012) showing that admixtures like superplasticizers can help mitigate strength loss.

Collectively, these studies confirm that plastic waste can be viably incorporated into construction materials. However, a clear research gap remains. Many studies do not fully adhere to specific paving block standards, and the optimal replacement percentage for coarse aggregate in standard-compliant, interlocking blocks is not well-established. Therefore, this study seeks to address these gaps by systematically investigating the use of locally sourced PET waste, rigorously testing the products against a recognized standard to identify an optimal mix for practical application.

Methodology

This section outlines the materials used, the mix proportions, the sample preparation process, and the testing procedures employed to investigate the properties of interlocking pavement blocks incorporating waste PET as a partial replacement for coarse aggregate.

Materials

The materials used in this study comprised Ordinary Portland Cement (Dangote grade 42.5) as the primary binder; laterite soil as the fine aggregate; and crushed granite with a nominal size of 20mm as the coarse aggregate. The plastic waste consisted of PET bottles sourced locally. These bottles were cleaned, with labels and caps removed, and were cut into flakes small enough to pass a 25mm sieve but be retained on a 20mm sieve to match the size of the coarse aggregate. Potable water from a local well was used for mixing and curing.

Mix Proportions and Sample Preparation

The concrete mix design was based on a ratio of 1:3:4 (cement: fine aggregate: coarse aggregate) by volume, targeting a strength grade of M20 as per common practice for light-traffic paving blocks. Coarse aggregate was partially replaced by PET flakes at levels of 0%, 5%, 10%, and 15% by volume. The 0% replacement mix served as the control.

For each replacement percentage, a total of 9 cube specimens (100 mm x 100 mm x 100 mm) were cast. After casting, the specimens were demoulded after 24 hours and subjected to water curing by complete immersion until testing at 7, 14, and 28 days.

Testing Methods

The tests conducted on the aggregates and the hardened concrete specimens are described below. The testing protocol was guided by the British Standard BS EN 1338:2003 for concrete paving blocks.

Tests on Aggregates: Aggregate Crushing Value (ACV): This test was performed to determine the resistance of the PET flakes to gradual compressive load. The test was carried out using a standard compression machine with a cylindrical mold of 115mm diameter and 180mm depth, applying a load of 40 tonnes for 10 minutes. The setup is shown in Figure 1a.

Aggregate Impact Value (AIV): This test was conducted to assess the resistance to sudden impact. A standard impact testing machine with a hammer weight of 13.5-14 kg falling from a height of 380 mm for 15 blows was used. The setup is shown in Figure 1b.

Figure 1: Experimental setup for aggregate tests: (a) Aggregate Crushing Value (ACV) test apparatus; (b) Aggregate Impact Value (AIV) test apparatus.

Tests on Fresh Concrete:
Slump Test: The workability of each concrete mix was assessed using a standard slump cone immediately after mixing.

Tests on Hardened Concrete:
Compressive Strength Test: This was the primary test for evaluating the mechanical performance. Three cubes from each mix proportion were tested at 7, 14, and 28 days of curing using a compressive testing machine. The compressive strength (σ) was calculated using the formula:

σ = Failure Load (N) / Surface Area (mm^2)

Water Absorption Test: This test was conducted to evaluate the durability of the blocks. After curing, the saturated mass (M_1) of the specimens was measured after immersion in water for 72 hours. The specimens were then oven-dried to a constant mass (M_2). Water absorption (W_a) was calculated as:

$W_a = [(M_1 - M_2) / M_2] * 100\%$

Density: The dry density of each specimen was calculated from its dry mass and volume.

Results and Discussions
This section presents the experimental results of the tests conducted on the concrete specimens, including the properties of the plastic aggregate, the workability of the fresh concrete, and the key mechanical and physical properties of the hardened concrete after 7, 14, and 28 days of curing.

Properties of the Plastic Aggregate
Tests were conducted on the processed PET flakes to characterize their suitability as an aggregate substitute. The physical properties are summarized in Table 1. The Aggregate Impact Value (AIV) test, which measures resistance to sudden shock, yielded an average value of 49.95% (Table 2). Similarly, the Aggregate Crushing Value (ACV) test, which determines the resistance to gradual compressive load, resulted in an average value of 12.5%. These high values for AIV and ACV indicate that the PET flakes are less resistant to impact and crushing compared to conventional mineral aggregates, a factor that influences the overall concrete strength.

Table 1: Physical properties of plastic palate

Specific gravity	1.29
Texture	Predominantly smooth
colour	greenish

Table 2: Mechanical Properties of PET Flakes as Aggregate

Test	*Sample1 Result*	*Sample 2 Result*
Aggregate Impact Value	49.1%	50.8%
Aggregate Crushing Value	***12.3%***	***12.7%***

Workability of Fresh Concrete

The workability of the concrete mixes, assessed by the slump test, is shown in Table 3. The control mix (0% PET) exhibited medium workability with a slump of 65 mm. In contrast, all mixes containing PET (5%, 10%, 15%) showed a very low slump of approximately 5 mm, indicating a significant reduction in workability with the introduction of plastic aggregate.

Table 3: Slump Test Results

Slump Test Results		
%	Slump (mm)	Degree of Workability
0%	65	Medium
5%	5	Very Low
10%	5	Very Low
15%	5	Very Low

The slump plummeted from 65 mm (medium workability) for the control mix to just 5 mm (very low workability) for all PET-containing mixes. This can be attributed to the non-absorbent, hydrophobic nature of plastic and the likely angular shape of the flakes, which increase inter-particle friction and reduce the flowability of the mix.

Compressive Strength

The compressive strength development of the concrete cubes over the curing period is presented in Table 4 and visualized in Figure 1. The 28-day compressive strength of the control mix was 16.9 N/mm².

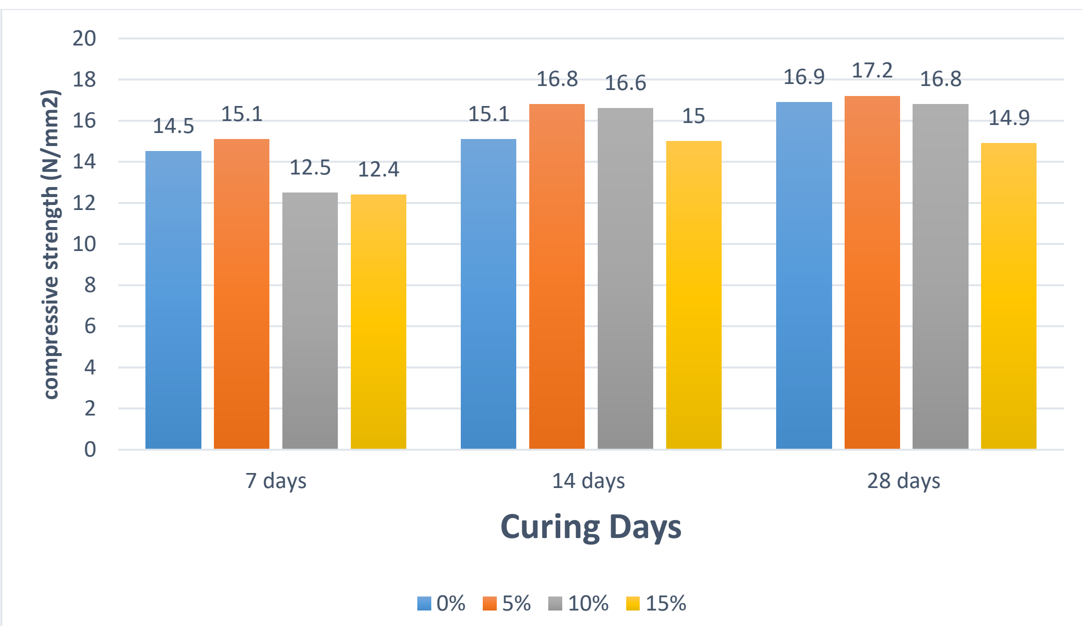

Figure 2: A bar chart showing variation of compressive strengths for all mix

The 5% PET replacement mix achieved a slightly higher 28-day compressive strength (17.2 N/mm²) than the control (16.9 N/mm²). This initial increase could be due to the PET flakes filling voids and creating a better-packed aggregate structure, a phenomenon sometimes observed with low percentages of non-absorptive materials. However, as the replacement level increased to 10% and 15%, the compressive strength decreased to 16.8 N/mm² and 14.9 N/mm², respectively.

The primary reason is the weaker bond between the cement paste and the smooth, hydrophobic surface of the plastic, compounded by the lower inherent crushing strength of the PET aggregate itself (as indicated by the high ACV). Despite the decrease, the 10% mix still nearly matched the control's strength, suggesting it as a viable replacement level for applications where M20 grade concrete is specified.

Water Absorption and Density

The results for water absorption and density are summarized in Table 5. The water absorption of the control mix was 4.1% after 28 days. The incorporation of PET led to a clear reduction in water absorption, with values decreasing to 3.5%, 2.5%, and 1.8% for the 5%, 10%, and 15% mixes, respectively. This trend is attributed to the hydrophobic nature of plastic, which impedes water penetration.

A corresponding decrease in the density of the specimens was also observed as the PET content increased (Table 5). The 28-day density dropped from 2980 kg/m³ for the control mix to 2700 kg/m³, 2620 kg/m³, and 2460 kg/m³ for the 5%, 10%, and 15% PET mixes, respectively. This confirms the production of lighter-weight concrete, which is expected due to the lower specific gravity of PET (1.29) compared to the natural coarse aggregate it replaced.

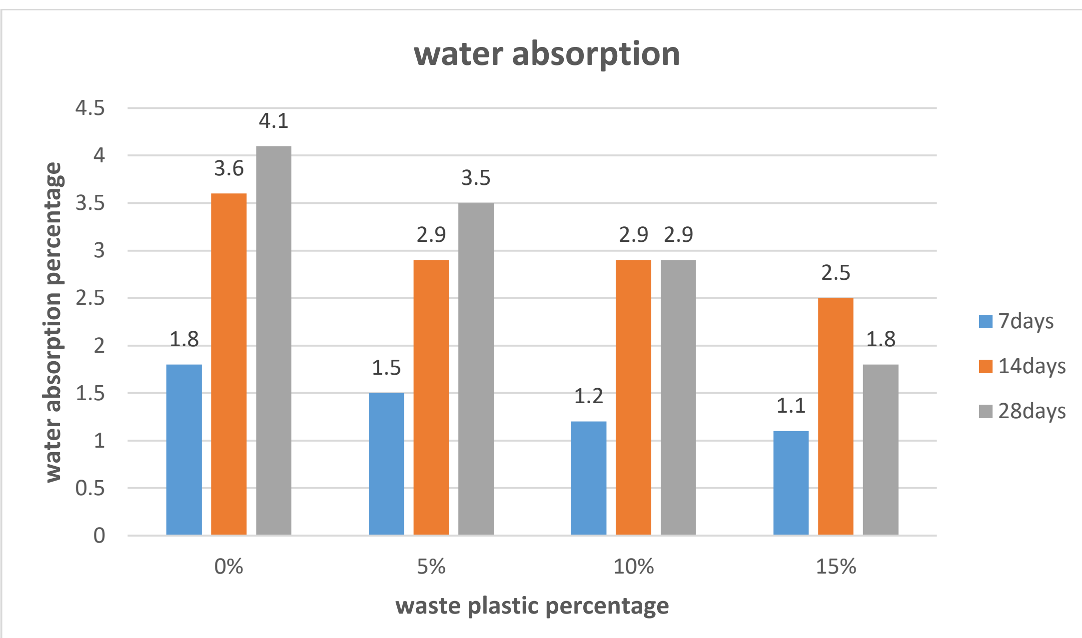

Figure 3: A graph showing variation of water absorption with PET percentage

Table 4: Water Absorption and Density after 28 days of curing

PET content (%)	Water absorption (%)	Density (kg/m^3)
0%	4.1	2980
5%	3.5	2700
10%	2.5	2620
15%	1.8	2460

Conclusion

This study successfully investigated the utilization of waste PET bottles as a partial replacement for coarse aggregate in interlocking pavement blocks. Based on the experimental results and subsequent discussion, the following conclusions can be drawn:

Feasibility and Optimal Percentage: The incorporation of waste PET in concrete is technically feasible. The optimum percentage replacement of coarse aggregate with PET flakes was found to be 10% by volume. At this level, the 28-day compressive strength (16.8 N/mm²) was nearly equivalent to the control mix (16.9 N/mm²), meeting the target strength for M20 grade concrete suitable for light-traffic applications.

Mechanical Properties: While the plastic aggregate itself exhibited lower resistance to impact and crushing compared to natural granite, its use at up to 10% replacement did not significantly compromise the composite's strength. The initial slight strength increase at 5% replacement suggests potential for improved packing, but higher percentages led to a decline due to the weaker bond between the cement paste and the plastic.

Enhanced Durability and Weight Reduction: The inclusion of PET yielded significant benefits, including a marked reduction in water absorption and a decrease in density. The 15% PET mix showed a 56% reduction in water absorption and a 17% reduction in weight compared to the control, indicating the production of a more water-resistant and lightweight concrete.

Based on these findings, it is recommended that concrete with 10% PET replacement be used in the production of interlocking pavement blocks for pedestrian walkways, cycle paths, and other light-traffic areas. For applications where high strength is not critical but water resistance and light weight are prioritized, such as in landscaping or drainage surrounds, a higher replacement percentage of 15% could be considered. Also, use of chemical or physical treatment to improve the adhesion between PET flakes and the cement matrix is recommended. Further investigations should be carried out on other long-term durability properties, such as resistance to freeze-thaw cycles and abrasion.

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