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Development of low-cost plastic-modified concrete pavers for applications in Zambia

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ABSTRACT

This study investigated the use of shredded Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE) plastic waste as a partial replacement for fine aggregates in concrete pavers, addressing both environmental concerns about plastic pollution and the need for affordable construction materials. The study developed M30-grade concrete mixes with plastic replacements of 10%, 20%, and 30% by volume, testing their workability, compressive strength, and aggregate properties using standardized protocols. The results revealed that although increasing the plastic content reduced compressive strength, pavers incorporating 10% to 20% fine plastic aggregates still achieved an average compressive strength of 20 MPa and a minimum of 17 MPa, making them suitable for equipment parking or light-traffic applications. The incorporation of plastic also decreased workability and material density while improving water resistance. This study demonstrates the potential of utilizing waste plastics in concrete paver production to promote environmental sustainability and reduce construction costs. A 10–20% plastic content is recommended for pedestrian pathways, with standardized preparation methods for plastic waste and field trials in tropical climates essential to ensure consistency and assess long-term performance.

Keywords: Low-cost concrete pavers, recycled LDPE/HDPE, sustainability, compressive strength, waste management

INTRODUCTION

Concrete paving blocks serve as essential components in modern road infrastructure, valued for their durability and cost-effectiveness (Edayadiyil, J., et al., 2021). However, their widespread use faces two critical sustainability challenges. Firstly, conventional production methods relying on Portland cement contribute significantly to environmental degradation, accounting for 8% of global CO_2 emissions (Rodgers, 2018). Secondly, rising material costs for concrete paving blocks create financial burdens for institutions, particularly resource constrained universities. Therefore, waste plastics can be an alternative to concrete aggregates.

These challenges intersect with a growing global plastic waste crisis. Each year, over 300 million tonnes of plastic waste are generated worldwide, with less than 10% being recycled

(Geyer et al., 2017). Zambia's annual waste production is around 3.6 million tonnes of which 14 % is waste plastic. This presents both a pressing environmental problem and a potential opportunity. Previous research has explored using plastic waste as a partial aggregate substitute in concrete offering possible solutions to both plastic pollution and construction material shortages (Siddique, 2008; Khandelwal, 2019). This dual-benefit approach could simultaneously address infrastructure maintenance challenges while contributing to environmental sustainability goals.

Concrete pavers must meet specific strength requirements to ensure structural reliability under various usage conditions. In Indonesia, such requirements are outlined in the *SNI 03-0691-1996* standard by the *Badan Standardisasi Nasional* (1996). This standard classifies concrete pavers into four grades (A to D) based on their minimum and average compressive strength values, which correspond to different application environments such as roads, equipment parking areas, pedestrian pathways, and garden surfaces.

The present study adopted the Indonesian standard (SNI 03-0691-1996) to evaluate the compressive strength of concrete pavers. This choice was informed by the practicality and clarity of the Indonesian classification system, which is particularly suitable for implementation in resource constrained contexts like Zambia. The standard's approach aligns well with the infrastructure demands of developing countries and supports testing methods commonly available in local laboratories. The classification used is presented in Table 1.1.

Table 1.1: Classification of Paving Bricks According to SNI 03-0691-1996

Grade	**Compressive Strength (MPa)**	
	Average	Minimum
A (for roads)	40	35
B (for equipment packing)	20	17
C (for pedestrians)	15	12.5
D (for gardens and other uses)	10	8.5

Additionally, according to the *Low Volume Roads Manual for the Design of Pavement in Zambia* (Road Development Agency, 2023), concrete pavers with a thickness of 70 mm intended for use on low-volume roads are required to have a compressive strength of at least 25 MPa. However, the manual does not clearly indicate whether this value represents the minimum or average strength requirement.

Despite this specification, comprehensive performance standards for concrete pavers in Zambia remain limited and poorly documented. As a result, many engineers and practitioners rely on international benchmarks such as the British Standard BS EN 1338:2003 (Purwanto et al., 2008).

Among its various provisions, the BS EN 1338:2003 standard evaluates the quality of concrete pavers based on two critical mechanical properties:

- Splitting tensile strength (T) ≥ 3.6 MPa
- Failure load per unit length (F) ≥ 250 N/mm

Splitting Tensile Strength (T) calculated as:

$$T = 0.637 \times k \times (P / S) \qquad \text{Equation 1}$$

And failure Load per unit length (F) calculated as:

$$F = P / l \qquad \text{Equation 2}$$

where:

- T = splitting tensile strength (MPa)
- F = failure load per unit length (N/mm)
- P = maximum failure load (N)
- S = l × t = failure area (mm²)
- l = mean failure length (mm), measured at the top and bottom
- t = block thickness at failure plane, averaged from three points
- k = correction factor (e.g., k = 1.0 for t = 80 mm)

These calculations ensure consistency in evaluating the strength of concrete pavers, especially in contexts where local standards are either unavailable or not easily accessible.

Despite this potential, significant research gaps remain. Existing studies have primarily focused on mechanical properties, often neglecting practical implementation factors (Gu and Ozbakkaloglu, 2016 ; Edayadiyil, J., et al., 2021; Harsoor, R., et al., 2022).
Specifically, two key limitations emerge:
(1) Unvalidated optimal mix designs for high-traffic pedestrian zones, and
(2) Limited data on performance in tropical climates like Zambia.
To address one of the identified research gaps, the objective of this study is to determine the optimal plastic waste content (ranging from 10% to 30%) that can be incorporated into concrete pavers without compromising the required compressive strength for equipment parking or light-traffic applications. This will help in the reduction of the generated plastic waste in Zambia as well as the quarrying of aggregates.
The remainder of this paper is organized as follows: Section 2 reviews relevant literature on plastic-modified concrete. Section 3 details the materials and methods used. Section 4 presents and discusses the results. Section 5 concludes with findings, limitations, and recommendations for future research and practical implementation.

LITERATURE REVIEW

Plastic Waste as a Construction Material

Global plastic waste management remains a critical environmental challenge, with less than 10% of annual production being recycled (Tanet al., 2025). The construction industry has emerged as a potential solution pathway, with numerous studies investigating plastic waste as partial aggregate replacements in concrete (García et al., 2023; Uche et al., 2023; Kushwaha and Rathore, 2024; Ajayi and Babafemi, 2024). This approach offers dual benefits: diverting non-biodegradable waste from landfills while reducing demand for natural aggregates.

Mechanical Properties

Research demonstrates that plastic incorporation affects concrete's key mechanical characteristics, particularly in terms of strength performance and workability (Uche et al., 2023; Kushwaha and Rathore, 2024; Ajayi and Babafemi, 2024). Most studies indicate that the compressive strength of concrete tends to decline when the plastic content exceeds 10–15% (Uche et al., 2023; Kushwaha and Rathore, 2024; Ajayi and Babafemi, 2024). Khandelwal (2019) highlights that this reduction becomes more pronounced at higher substitution levels. Additionally, the extent of strength loss is influenced by the type of plastic used. For instance, Polyethylene Terephthalate (PET) tends to retain strength better than Low-Density Polyethylene (LDPE), as noted by Sharma and Singh (2021), suggesting that PET may be more compatible with structural concrete applications.
In terms of workability, research findings are more varied. Some studies, such as that by Hama and Hilal (2017), report enhanced workability at lower plastic concentrations, attributing the improvement to the smoother surface texture and lower density of plastic particles. Conversely, other researchers, including Lee et al. (2022), observe a decrease in cohesion and consistency at higher plastic replacement levels, potentially due to poor bonding between plastic and cement paste. These contrasting outcomes emphasize the importance of optimizing plastic content and particle characteristics to balance both strength and workability in concrete mixes.

Durability Characteristics

Plastic-modified concrete offers notable durability advantages and trade-offs. Its water resistance improves due to enhanced hydrophobic properties (Aldahdooh et al., 2018). However, abrasion resistance tends to decrease, leading to reduced surface durability (OECD, 2023). On the positive side, plastic-modified pavers show superior impact resistance compared to conventional pavers (Tapkire et al., 2014). Studies in tropical climates confirm that these durability traits remain effective even under high humidity and temperature conditions (Babafemi et al., 2022; Nguyen et al., 2023; Ajayi and Babafemi, 2024).

Research Gaps and Innovation Potential

Despite promising results, there are three key gaps hindering the practical implementation of plastic-modified concrete. Scalability is a concern, as most studies are conducted at the laboratory scale without established production protocols (Zhang et al., 2022). There is also a lack of data on long-term performance, particularly regarding environmental degradation patterns (Okafor

et al., 2023). Additionally, economic viability remains unclear, with a notable absence of comprehensive cost-benefit analyses.
This study addresses one of these gaps through systematic testing of 10-30% plastic mixtures using standardized methods.

METHODS

Figure 3.1 provides a summary of the methods, outlining the process from material collection to the analysis of the final product plastic modified concrete pavers. The detailed method is described in the subsequent sections.

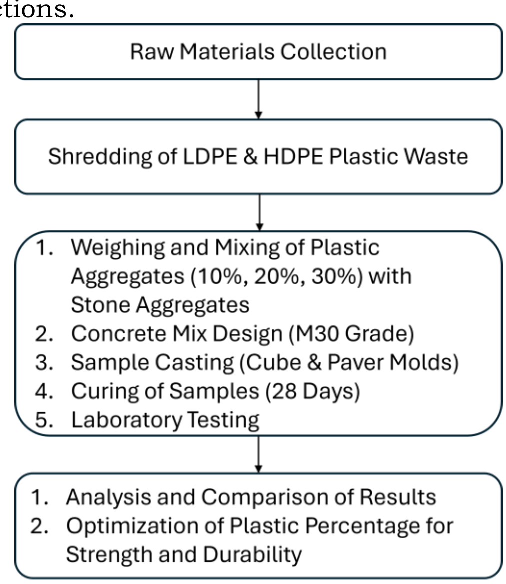

Figure 3.1: Flowchart of the Methodology

Materials Selection and Preparation

The experimental materials were carefully selected based on their local availability and compliance with relevant technical standards to ensure both cost-effectiveness and structural integrity of the concrete pavers.
Zambezi Portland Cement (ZPC), grade 3X 42.5N CEM II (A-L), was chosen for its proven performance and sustainable attributes. This cement delivers a characteristic compressive strength of 42.5 MPa at 28 days, making it well-suited for structural concrete applications. The presence of up to 20% limestone filler enhances the mix's workability, allowing for easier mixing, placement, and finishing. Furthermore, the local production of ZPC contributes to reduced transportation costs and a lower carbon footprint, aligning with the project's goal of promoting environmentally responsible construction solutions.

Both fine and coarse aggregates were carefully selected to meet technical standards and ensure mechanical performance. The fine aggregates consisted of natural river sand, sieved to a maximum particle size of 4.75 mm and conforming to ASTM C33 specifications. This ensured consistent grading and optimal particle distribution within the concrete matrix. Coarse aggregates comprised crushed granite with particle sizes ranging from 13 mm to 19 mm. These aggregates exhibited an Aggregate Crushing Value (ACV) of 26.3%, as determined in accordance with BS 812-110:1990. This value indicates sufficient resistance to crushing, making the aggregates suitable for use in durable concrete products such as pavers.

Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE**)** plastic waste were selected as partial replacements for fine aggregates, rather than other commonly found plastics like Polyethylene Terephthalate (PET). This selection was based on both local waste availability and material compatibility with concrete. According to Mwanza and Mbohwa (2019), LDPE and HDPE account for more than 65% of plastic waste in Zambian municipal streams, making them abundant and economically viable for recycling. Furthermore, these plastics have demonstrated enhanced bonding with cement matrices, especially in tropical climates, as highlighted by Nguyen et al. (2023), thereby making them more appropriate for infrastructure applications in such environments.

To ensure the quality and uniformity of the plastic material, a systematic preparation protocol was followed. Initially, the plastic waste was ethically sourced from authorized municipal collection points within Kabwe. It was then manually sorted and washed to remove contaminants, including labels, organic debris, and non-plastic materials. After cleaning, the plastic was shredded using a commercial granulator into particles measuring between 3 mm and 5 mm in size. This particle range was selected to facilitate effective integration with fine aggregates during mixing and to achieve uniform distribution within the concrete mix. A final density separation step using a sodium chloride (NaCl) solution with a density of 1.2 g/cm^3 was performed to ensure material purity. The resulting shredded plastic content is illustrated in Figure 3.2.

Figure 3.2: Shredded Plastic Fine Aggregate Content

Concrete Mix Design

The study employed a design mix of M30-grade concrete with a water-cement ratio of 0.45, proportioned in accordance with IS 10262:2009. The control mix proportions are presented in Table 3.1.

Table 3.1: Concrete Mix Proportions

Component	Weight Ratio
Cement	1
Fine Aggregates	0.75
Coarse Aggregates	1.5
Water-Cement Ratio	0.45

Three experimental mixes were prepared by replacing 10%, 20%, and 30% of fine aggregates by volume with processed fine plastic aggregates. The mixing procedure followed the guidelines of BS 1881:1970.

Specimen Preparation and Curing

Table 3.3 presents the physical properties of the pavers containing 0%, 10%, 20%, and 30% fine plastic aggregates.

Table 0.2: Effect of Fine Plastic Aggregate Content on Mass, Volume, and Density of Paver Concrete Mixes

Fine Plastic Aggregate	Mass (kg)	Volume (m^2)	Density (kg/m^2)
0%	5.040	0.003168	1591
10%	4.967	0.003168	1568
20%	4.894	0.003168	1545
30%	4.822	0.003168	1522

Two types of specimens' pavers (240 × 165 × 80 mm) and cubes (150 × 150 × 150 mm) were produced, with 12 of each cast in mineral oil-coated steel molds. Pavers were compacted using electromechanical vibration, while cubes were rodded in three layers. Curing involved an initial 24-hour period at 27 ± 2°C and >90% RH, followed by 28 days of water immersion at 25–32°C, with daily monitoring of conditions.

Testing Protocol

Concrete workability was evaluated using the slump test (ASTM C143), with three trials per mix conducted at 25 ± 2°C. Compressive strength for the concrete cube (150 × 150 × 150 mm) was assessed at 28 days as per BS 1881: Part 4, using three cubes per mix and a loading rate of 15 MPa/min. Strength was calculated using the formula

$$f_c = P_{max} / A \qquad \text{Equation 3}$$

where P_{max} is the failure load and A is the cross-sectional area. According to Badan Standardisasi Nasional (1996), Grade B pavers—with a minimum compressive strength of 17 MPa and an average of 20 MPa are suitable for equipment parking and light-traffic applications.

Quality Assurance and Ethics

Strict quality control measures were implemented to ensure data reliability, Ethical compliance was maintained through a formal waste sourcing agreement with Kabwe Municipal Council, provision of full personal protective equipment for workers, and the application of environmental safeguards such as water recycling and air filtration. All waste was managed by licensed processors in accordance with Zambia Environmental Protection Agency regulations, and the study received ethical approval from Mulungushi University institutional review committee (MU-REC/2023/07).

Data analysis

This study employed One-Way ANOVA (Analysis of Variance) to statistically evaluate the effect of varying plastic content on the compressive strength of concrete. The goal

was to determine whether the incorporation of plastic waste at different levels (0%, 10%, 20%, and 30%) resulted in statistically significant differences in concrete strength (Montgomery, 2019).
A One-Way ANOVA test was conducted using statistical software Microsoft Excel to assess whether there were statistically significant differences in mean compressive strength among the four groups.

Null Hypothesis (H_0): There is no significant difference in mean compressive strength between concrete mixes with different plastic content.

Alternative Hypothesis (H_1): At least one group has a mean compressive strength significantly different from the others.

The test calculated the F-statistic and p-value, comparing between-group variance to within-group variance.

A significance level (α) of 0.05 was used. A p-value below this threshold indicated a rejection of the null hypothesis, confirming significant differences in strength between groups.

RESULTS AND DISCUSSION

Fine Aggregates

The recycled shredded fine aggregates used in this study were predominantly retained on the 1.18 mm sieve, confirming their particle size suitability for concrete paver production. The calculated uniformity coefficient (Cu = 3.0) and coefficient of curvature (Cc = 1.02) indicate a moderately uniform particle size distribution, rather than a fully well-graded one, as illustrated in Figure 4.1.

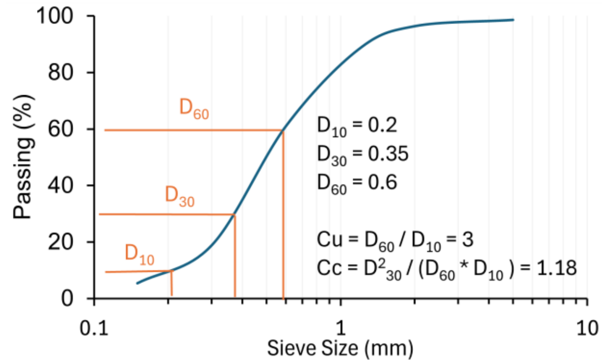

Figure 01: Particle Distribution Curve for Fine Aggregates

Although the recycled fine aggregates used in this study are not perfectly graded, their moderately uniform gradation is considered acceptable for concrete production. Research by Neville (2011) and Shetty (2005) indicates that such gradation improves particle packing, reduces voids, and enhances workability. There are key qualities for achieving consistent surface finish and density in concrete pavers. Furthermore, studies by Siddique (2008) and Khatib (2009) show that appropriate aggregate gradation contributes to improved durability and compressive strength. Therefore, the aggregate characteristics observed in this study are suitable for producing durable and sustainable plastic modified concrete pavers.

Coarse Aggregates

The sieve analysis of the coarse aggregates resulted in a fineness modulus (FM) of 4.09, indicating an average particle size range between 13 mm and 19 mm (see Table 4.1)

Table 01: Sieve Analysis of Coarse Aggregates

Sieve Size (mm)	% Cumulative Retained	% Cumulative
19	0	0
13.2	18.8	18.78
11.2	71.29	90.07
4.75	9.85	99.92
0.15	0.07	99.99
Pan	0.01	100.00
Sum Total	**100**	**408.76**

The intermediate particle size range of the coarse aggregates (13–19 mm) provides an effective balance between surface area and mechanical interlock, facilitating strong bonding with the cement paste. This interfacial bond is essential for efficient load transfer and improved mechanical performance in precast elements such as plastic modified concrete pavers. These findings align with Neville (2011) and Shetty (2005), who noted that medium-sized aggregates help reduce internal stress concentrations and enhance structural stability. Therefore, the selected coarse aggregates are well-suited to support the mechanical demands of pavers subjected to pedestrian and light vehicular traffic.

The average Aggregate Crushing Value (ACV) was found to be 26.3%, which is well below the 30% threshold recommended by BS 812-110 for structural applications (see Table 4.2).

Table 02: Aggregate Crushing Values for the Coarse Aggregates

Sample	Weight of Sample Before Crushing (g)	Weight of the crushed Sample (g)	Aggregate Crushing Value (%)
1	3500	906.5	25.9
2	3500	934.5	26.7
Average Aggregate Crushing Value			**26.3**

The aggregate crushing value (ACV) results indicate that the aggregates possess adequate strength to withstand compressive loads, making them suitable for non-structural applications like plastic modified concrete pavers. As highlighted by Neville (2011) and Gambhir (2013), lower ACV values reflect higher aggregate integrity, which supports long-term performance and reduces maintenance requirements. Khatib (2009) adds that durable aggregates are particularly beneficial in regions with limited infrastructure upkeep, such as tropical or developing areas. Therefore, using these strong aggregates enhances both the mechanical reliability and sustainability of concrete pavers by extending their service life and minimizing replacement needs.

Slump Test

The slump test was carried out as described by ASTM (2014) test procedure. The slump test revealed a reduction in workability as the proportion of recycled plastic increased from 10% to 30%. Specifically, slump values decreased from 70 mm at 10% plastic to 55 mm at 30%, despite maintaining a constant water-to-binder ratio (see Figure 4.2 and Figure 4.3).

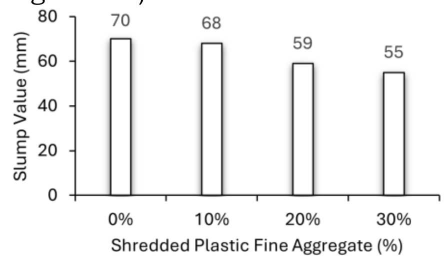

Figure 4.2: Slump Values for different Shredded Plastic Fine Aggregate

Figure 003: Measuring the Slump Height of Plastic Modified Concrete

The observed reduction in workability is primarily due to the irregular shape, non-absorbent surface, and hydrophobic nature of shredded fine plastic aggregates, which hinder cohesion and flowability in the concrete mix. This trend aligns with findings by Siddique et al. (2008) as well as Ismail and Al-Hashmi (2008), who reported similar effects when incorporating plastic waste into concrete. While decreased slump may pose challenges for compaction and surface finish, the workability remains acceptable for low-traffic applications such as pedestrian walkways and garden paths. To further improve workability without compromising sustainability, the mix design can be optimized using plasticizers or by adjusting component ratios.

Compressive Strength Test

The concrete cube compressive strength results indicated a progressive reduction in strength with increasing recycled plastic content, as shown in Figure 4.4.

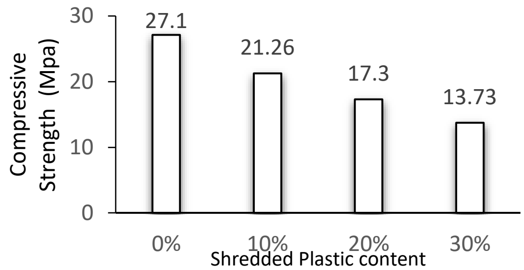

Figure 4.4: Compressive Strength of Plastic Modified Concrete Cubes

The incorporation of 10%, 20%, and 30% recycled plastic fine aggregates resulted in compressive strengths of approximately 21 MPa, 17 MPa, and 14 MPa, respectively. This downward trend is primarily due to the weak bond between plastic particles and the cement matrix, as well as the reduced density of the mix caused by the lightweight and hydrophobic nature of plastic. These factors hinder interfacial bonding and lower overall concrete strength.

Similar reductions in compressive strength have been reported by Siddique (2008) and Khatib (2009) when plastic waste was used as a partial aggregate replacement. Despite the decline, all recorded values exceed the typical minimum strength requirement (10–15 MPa) for non-structural applications such as paving blocks. Thus, with plastic content optimized at or below 20%, recycled plastic fine aggregates offer a viable and sustainable alternative for eco-friendly paver production without significantly compromising performance.

Due to resource limitations, the plastic modified concrete pavers were not subjected to direct compressive strength testing. Instead, the compressive strength was estimated using an empirical model based on the relationship between cube strength and equivalent paver strength, as documented in previous study by Lumingkewas et al. (2023). This approach provides a practical alternative for estimating compressive strength of the pavers where laboratory testing is constrained.

According to Lumingkewas et al. (2023), several factors including density, water content, clay content, mix composition, thickness, curing conditions, aggregate size and type, compaction level, and admixtures significantly affect the compressive strength of concrete. In their study, an empirical model was developed to relate the compressive strength of concrete cubes to that of concrete pavers, incorporating the influence of paver thickness and concrete density. The model is expressed as:

$\sigma(cube) = \beta * \sigma(paver)$ *Equation 4*

where β is a coefficient defined as a quadratic function of the concrete density (γ):

$\beta = c * \gamma^2 + d * \gamma + e$ *Equation 5*

σ (cube)= compressive strength of the cube
σ (paver)= compressive strength of the pavers

Here, *c*, *d*, and *e* are coefficients based on a standard mix of 1:2:3 (cement:sand:coarse aggregate) with a water-cement ratio of 0.45. In the present study, a modified mix of 1:0.75:1.5 was used, incorporating 10%, 20%, and 30% fine plastic aggregates by volume with a water-cement ratio of 0.5. It was assumed that the differences in mix composition and water-cement ratio had negligible effects on the applicability of the model.

Figure 4.5 presents the estimated compressive strength of the plastic-modified concrete pavers, derived from the corresponding cube strength results using the applied empirical model: $\sigma(cube) = \beta * \sigma(paver)$

As illustrated in Figure 4.5, the estimated compressive strength of the plastic-modified concrete pavers is consistently higher than that of the corresponding concrete cubes. This difference is attributed to the specimen size effect, where smaller or thinner specimens (such as pavers) tend to exhibit higher apparent strength due to reduced stress gradients and more efficient load distribution—a phenomenon also reported by Banerjee et al. (2015).

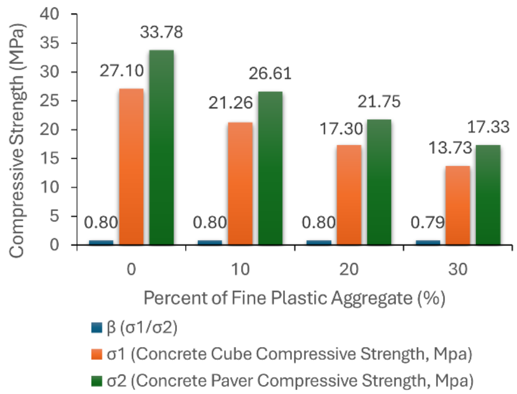

Figure 05: Compressive Strength of Plastic Modified Concrete Cubes and Plastic Modified Concrete Pavers

Despite the variation in absolute strength, the ratio between cube compressive strength and paver compressive strength (denoted as β) remains relatively constant across all mixes containing 0%, 10%, 20%, and 30% fine plastic aggregates. This consistency may be explained by the relatively small differences in the densities of the mixes, which influence the stress distribution and internal compaction characteristics similarly across all plastic content levels.

After carrying out one way ANOVA statistical analysis on the obtained concrete strength as shown on Figure 4.4 wit respective percentage of fine plastic aggregates, F-statistic value was found to be 4075.26 while the p-value was determined as 4.50×10^{-13}. This shows a higher F-statistic and a lower p-value below 0.05. Therefore, we reject the null hypothesis. This shows a significant difference in compressive strength between at least two of the plastic contents levels. This indicates that increasing the plastic content from 0% to 30% leads to a significant and consistent reduction in compressive strength. The results clearly demonstrate that plastic waste negatively impacts the compressive strength of concrete.

CONCLUSION

This study investigated the use of plastic waste as a partial replacement (10%–30% by volume) for fine aggregates in concrete pavers, aiming to determine the optimal plastic content that meets compressive strength requirements for light-traffic and equipment parking applications. In accordance with SNI 03-0691-1996 standards specifically the Grade B classification (average 20 MPa, minimum 17 MPa) the findings indicate that pavers with up to 20% plastic waste retain the necessary structural integrity for such uses.
While plastic incorporation reduces workability and compressive strength due to weak plastic-cement bonding and lower material density, mixes containing 10–20% plastic remain suitable for non-structural applications like pedestrian walkways and light equipment parking. These results align with prior research and highlight the feasibility of using plastic waste in sustainable construction, particularly in developing regions facing environmental and budgetary challenges.

The study presents a dual advantage: waste reduction and cost-effective material production, offering practical insights for manufacturers and engineers working on eco-friendly infrastructure. However, limitations was mainly the variability in plastic quality
Recommendations and Future Work
For immediate implementation:

- A 10–20% plastic content is recommended for pedestrian pathways.
- Standardized preparation methods for plastic waste should be established to ensure consistency.
- Field trials are crucial to assess long-term performance in tropical climates.

Future research should explore the following key areas to support broader adoption of plastic-modified concrete pavers:

- Long-term durability of pavers under diverse environmental conditions, particularly in tropical climates.
- Methods to improve the bond between plastic waste and cement paste to enhance mechanical performance.
- A comprehensive cost-benefit analysis for large-scale production and use, particularly for institutional and municipal infrastructure.
- The influence of different plastic types (e.g., LDPE, HDPE, PET) on workability, strength, and durability.
- The development of standardized quality control protocols for plastic-modified concrete production.
- Environmental impact assessments, including the potential generation and leaching of microplastics over time, to

ensure that sustainability gains are not offset by unintended long-term pollution risks.

In conclusion, this study assessed the use of plastic waste (10%–30%) as a partial replacement for fine aggregates in concrete pavers. It found that up to 20% plastic content meets strength requirements for light-traffic applications under SNI 03-0691-1996 standards. The results support sustainable, cost-effective construction, particularly for non-structural uses in developing regions.

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