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Design and Performance Evaluation of Plastic–Sand Interlocking Blocks Using Waste Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE) for Sustainable Construction

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Abstract
The increasing generation and improper disposal of plastic waste, coupled with the environmental impacts associated with conventional construction materials, have created a need for sustainable alternatives that can simultaneously address waste management and construction-material demands. This study investigated the production and comparative compressive performance of plastic–sand interlocking paving blocks manufactured using waste Polyethylene Terephthalate (PET) from discarded plastic bottles and Low-Density Polyethylene (LDPE) from pure-water sachets. The innovative procedure involved using waste PET and LDPE as complete polymeric binders, without cement or water, and combining each plastic type separately with sharp sand at a controlled 1:3 plastic-to-sand ratio. The plastics were sorted, cleaned, melted at controlled temperature ranges, mixed with sand, compacted in a 200 × 100 × 75 mm interlocking moulds, and allowed to cool before testing. Four specimens were produced for each plastic type and subjected to compressive-strength testing. PET specimens recorded an average weight of 2.81 kg, crushing load of 92.9 kN, and compressive strength of 4.65 N/mm², while LDPE specimens recorded 2.68 kg, 71.2 kN, and 3.56 N/mm², respectively. PET therefore demonstrated approximately 30.6% higher compressive strength and 30.5% higher crushing load than LDPE. The superior PET performance is attributed primarily to its greater rigidity, higher structural stability, and more effective load transfer within the plastic–sand composite, whereas the greater flexibility of LDPE may reduce resistance to compressive loading. The study contributes comparative experimental evidence on the performance of two commonly available plastic wastes under the same production conditions and provides a context-specific approach for converting locally available plastic waste into interlocking construction products. The findings indicate that PET-based blocks have greater potential for paving and other light-duty applications where higher compressive strength is required, while LDPE-based blocks are more appropriate for lightweight and non-load-bearing applications. The study provides a basis for further investigation of mix-ratio optimization, durability, abrasion resistance, water absorption, fire behaviour, and long-term environmental performance.

Keywords: *Plastic waste recycling; PET; LDPE; plastic–sand composite; compressive strength; sustainable construction.*

1.0 Introduction

The construction industry is one of the largest consumers of natural resources and a major contributor to environmental degradation through material extraction, energy consumption, and waste generation. Rapid urbanization, population growth, and increasing infrastructure development have intensified the demand for conventional construction materials such as cement, aggregates, and sand. The environmental and economic costs associated with these materials have encouraged researchers to investigate alternative construction technologies that can reduce resource consumption while maintaining acceptable engineering performance [1].

At the same time, plastic waste has become a major environmental challenge. Plastic products are extensively used because of their durability, low weight, flexibility, and relatively low production cost. However, these characteristics also make most plastics resistant to natural degradation. Consequently, discarded plastic materials accumulate in landfills, drainage channels, water bodies, and urban environments, creating environmental and public-health concerns [2], [3]. In developing countries, inadequate waste-collection and recycling systems further increase the quantity of plastic waste entering the environment.

Plastic bottles, which are commonly manufactured from Polyethylene Terephthalate (PET), and pure-water sachets, which commonly contain Low-Density Polyethylene (LDPE), constitute significant components of plastic waste streams in Nigeria. Their uncontrolled disposal contributes to environmental pollution and can obstruct drainage systems, thereby increasing the risk of urban flooding. Finding productive applications for these waste materials is therefore important for improving resource efficiency and supporting sustainable waste-management practices.

One potential approach is the conversion of waste plastics into construction materials. Plastic–sand composites have attracted attention because molten plastic can function as a binder, replacing conventional cementitious binders in selected applications. This approach transforms waste plastic into a useful construction component while reducing the demand for conventional binding materials. Previous studies have reported promising engineering properties of plastic–sand products, including compressive strength, moisture resistance, abrasion resistance, and relatively low water absorption [4]–[6].

However, the performance of plastic–sand composites depend strongly on the type of plastic used, plastic-to-sand ratio, melting temperature, mixing procedure, compaction, and resulting composite structure. PET and LDPE possess different physical and thermal characteristics. PET is relatively rigid and structurally stable, whereas LDPE is softer and more flexible. These differences can influence bonding with sand particles, density, load transfer, deformation, and ultimately compressive strength. Previous studies have reported varying performance depending on the plastic type and production conditions [5], [6]. This indicates the need for controlled comparative investigations in which different plastic wastes are produced under comparable conditions.

The motivation for this study therefore arises from two related problems: the increasing accumulation of PET and LDPE waste and the need for affordable, locally producible construction materials. The innovative aspect of the experimental procedure is the separate use of PET and LDPE waste as complete polymeric binders for sand, without cement or water, under the same specimen dimensions, plastic-to-sand ratio, moulding procedure, and compressive-strength testing conditions. This enables a direct comparison of the engineering performance of the two plastic waste streams.

The study forms part of an Institutional Based Research (IBR) project of the Federal Polytechnic Bauchi, Nigeria, with particular emphasis on the Research Village as a centre for learning, innovation, experimentation, and practical demonstration. The Research Village provides an environment in which research outputs can be demonstrated, reproduced, and used as teaching resources. The study consequently has both research and educational relevance because the resulting technology can provide a practical example of converting locally available waste into construction materials.

The major contribution of this study is the generation of comparative experimental data on PET- and LDPE-based plastic–sand interlocking blocks produced using the same 1:3 plastic-to-sand ratio and specimen dimensions. The study establishes the relative compressive performance of the two plastic types and identifies their potential application areas. In particular, the results demonstrate that PET specimens achieved substantially higher average crushing load and compressive strength than LDPE specimens under the experimental conditions adopted. These findings provide a basis for subsequent investigations involving mix-ratio optimization and other durability and performance parameters.

2.0 Literature Review

2.1 Plastic Waste and Environmental Sustainability

Plastic pollution is one of the major environmental challenges associated with modern consumption patterns. Plastics are extensively used because they are inexpensive, durable, lightweight, and versatile. However, their resistance to natural degradation results in long-term accumulation in the environment [2]. Global plastic production has increased substantially over the past decades, while collection, recycling, and environmentally safe disposal have not increased at the same rate [3]. Improper disposal of plastic waste can block drainage channels, contribute to flooding, contaminate terrestrial and aquatic environments, and create conditions for the fragmentation of plastics into smaller particles. These challenges demonstrate the need to move beyond disposal-based waste management toward approaches that recover and reuse plastic materials.

A circular-economy approach seeks to retain materials within productive use for as long as possible. Converting waste plastics into construction products represents one potential circular-economy pathway because materials that would otherwise be discarded are transformed into functional products.

2.2 Plastic Waste in Construction Materials

The use of plastic waste in construction has received increasing research attention. Waste plastics have been incorporated into concrete, asphalt, bricks, paving blocks, tiles, and other construction products. One important approach is the production of plastic–sand composites in which molten plastic functions as the binder.

Al-Sinan and Bubshait [4] reviewed the use of plastic sand as a construction material and highlighted its potential contribution to circular-economy objectives. The approach can reduce the quantity of plastic waste requiring disposal while creating alternative construction products.

Awoyera et al. [5] similarly examined the sustainable use of plastic waste in construction and demonstrated the potential of recycled plastics in building-material applications. Iftikhar et al. [6] investigated plastic–sand paver blocks and reported that plastic waste can be used to manufacture eco-friendly paving products with useful engineering properties.

Kumi-Larbi et al. [7] investigated waste plastics in plastic-bonded sand interlocking blocks for wall construction in developing countries. Their work demonstrates the potential of plastic-bonded sand products as an alternative construction technology, particularly in contexts where plastic waste is abundant and conventional construction materials may be expensive.

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2.3 PET and LDPE as Binders

PET and LDPE have different physical and mechanical characteristics, which can affect the performance of plastic–sand composites. PET is comparatively rigid and has greater structural stiffness, whereas LDPE is softer and more flexible. These differences can affect the ability of each polymer to encapsulate and bond sand particles and to transfer applied loads through the composite.

Nnorom et al. [8] examined the physico-mechanical properties of sand–plastic interlocking paving bricks and demonstrated that plastic type and composition influence the resulting engineering properties. Their findings support the need to consider the characteristics of the polymer binder when designing plastic–sand construction materials.

Although previous research has examined plastic–sand products, differences in plastic type, mix ratio, specimen dimensions, processing temperature, compaction, and testing procedures make direct comparisons between studies difficult. The present study addresses this issue by producing PET and LDPE specimens under the same experimental conditions.

2.4 Environmental and Construction Benefits

The use of waste plastic as a construction binder can provide several potential benefits. First, it diverts plastic waste from landfills, drainage systems, and other uncontrolled disposal locations. Second, it can reduce dependence on conventional cement-based binders for selected applications. Third, plastic–sand products may offer lightweight and moisture-resistant characteristics that can be useful in particular construction applications.

Bilir et al. [9] reviewed the incorporation of waste materials into interlocking concrete block paving and emphasized the importance of evaluating mechanical and durability performance when developing alternative paving products.

However, the environmental benefits of plastic–sand products should not be assumed automatically. Their overall sustainability depends on factors such as plastic collection, cleaning, transportation, energy consumption during melting, emissions, durability, service life, and end-of-life management.

2.5 Research Gap

Previous studies have demonstrated the potential of plastic–sand composites, but variations in plastic type and production conditions make it difficult to establish the relative performance of PET and LDPE under identical conditions. Furthermore, concerns remain regarding long-term durability, fire resistance, ultraviolet exposure, thermal degradation, abrasion, and possible environmental impacts associated with plastic weathering [10].

The present study addresses part of this gap by experimentally comparing PET- and LDPE-based interlocking blocks manufactured using the same plastic-to-sand ratio, specimen dimensions, moulding procedure, and compressive-strength test. The study therefore provides controlled comparative evidence of the effect of plastic type on crushing load and compressive strength.

3.0 Materials and Equipment

The materials used in the study were waste PET, waste LDPE, and sharp river sand. The PET was obtained primarily from discarded plastic bottles, while LDPE was obtained from used pure-water sachets. The waste plastics were collected from residential areas, school campuses, event centers, waste collection centers, and pure-water companies.

The sharp river sand was obtained from construction-material suppliers. The sand was selected to be free from visible clay, organic matter, and other contaminants. The sand was passed through a 4.75 mm sieve to obtain the required grading.

The equipment used included Weighing balance; Metal drum/furnace for melting the plastics; Shovel/spade and metal mixing rod; 4.75 mm sieve; Metal interlocking moulds; compression testing machine; thermometer; tamping rod; metal trowel; scooper; and Protective gloves and nose mask.

4.0 Experimental Methods

4.1 Preparation of Plastic Waste

The collected PET bottles and LDPE sachets were sorted to remove unwanted materials and excessive contamination. The materials were cleaned and prepared for melting. PET and LDPE were processed separately to prevent cross-contamination and to permit direct comparison of the performance of each plastic type.

4.2 Melting of Plastic

The plastics were placed separately in a metal drum/furnace and heated gradually. LDPE was heated within approximately 180–250 °C, while PET was heated within approximately 250–300 °C. The molten plastic was continuously stirred using a metal rod to promote uniform melting. Excessive burning was avoided as far as practicable to reduce degradation and unwanted emissions.

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4.3 Mixing with Sand

Sharp sand was gradually added to the molten plastic at a plastic-to-sand ratio of 1:3 by proportion. The mixture was continuously stirred until a relatively homogeneous plastic–sand composite was obtained. The use of the same ratio for both PET and LDPE allowed the influence of plastic type to be examined while keeping the plastic-to-sand proportion constant.

4.4 Moulding and Compaction

The hot composite was transferred into a metal interlocking moulds measuring 200 × 100 × 75 mm. A tamping rod was used to compact the material and reduce entrapped air voids. The exposed surface was then levelled using a metal trowel. The moulded specimens were allowed to cool at room temperature for approximately 12–24 h before demoulding. Four specimens were produced for each plastic type.

4.5 Compressive Strength Test

The compressive-strength test was conducted to determine the maximum load that each specimen could withstand before failure. Each specimen was weighed and centrally positioned in the compression testing machine. Load was applied gradually until failure occurred. The maximum crushing load was recorded.

The compressive strength was calculated using:

Compressive Strength = Crushing Load / Loaded Area

For PET specimen 1:

Compressive Strength = (84.9 × 1000) / (200 × 100)

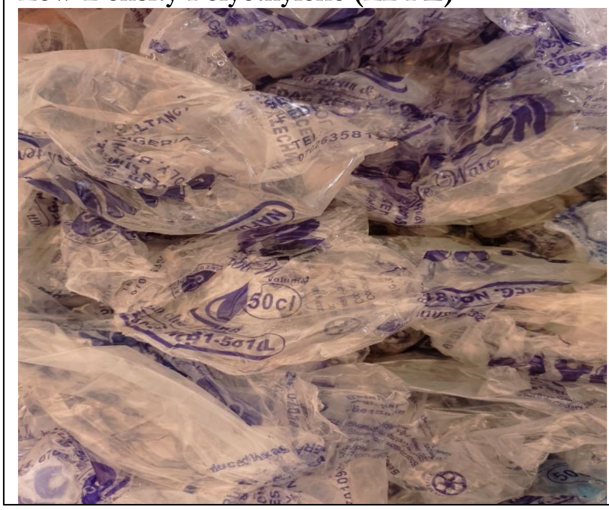
= **4.25 N/mm²**

The same procedure was used to calculate the compressive strength of the remaining specimens. The mean values were subsequently determined.

5.0 Results

5.1 Weight, Crushing Load and Compressive Strength

Table 1 presents the measured weight, crushing load, and calculated compressive strength of the PET and LDPE specimens while **Plate 1** presents the LDPE & PET plastics and the samples of the molded interlocks.

Low-Density Polyethylene (LDPE)	**Polyethylene Terephthalate (PET)**
	

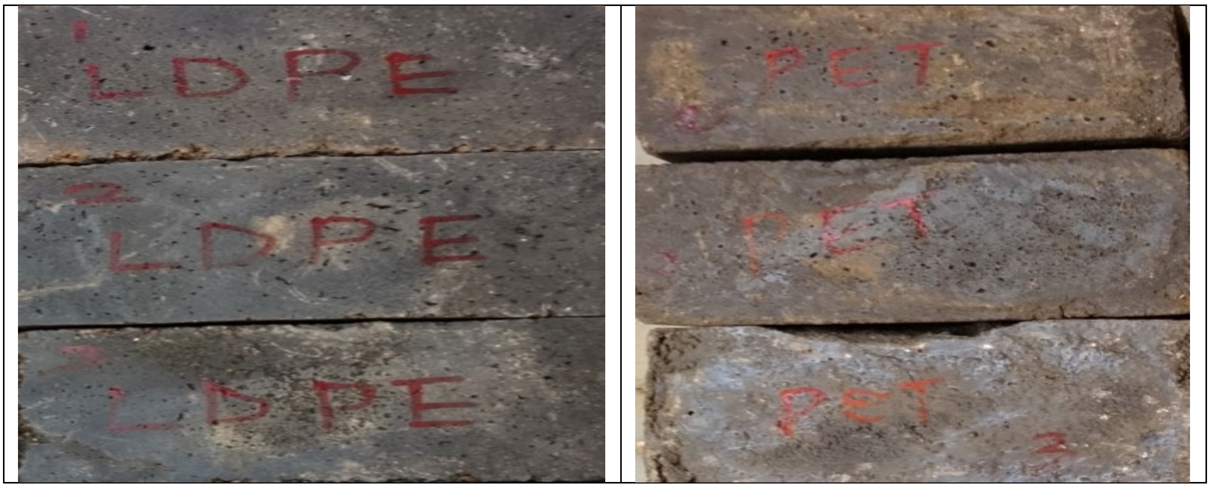


Plate 1: LDPE and PET specimens

Table 1: Weight, Crushing Load and Compressive Strength of Specimens

Specimen	Weight (kg)	Crushing Load (kN)	Compressive Strength (N/mm²)
PET 1	2.84	84.9	4.25
PET 2	2.83	96.5	4.83
PET 3	2.76	99.6	4.98
PET 4	2.82	90.7	4.54
PET Average	**2.81**	**92.9**	**4.65**
LDPE 1	2.76	67.0	3.35
LDPE 2	2.78	73.9	3.70
LDPE 3	2.64	75.7	3.79
LDPE 4	2.55	68.1	3.41
LDPE Average	**2.68**	**71.2**	**3.56**

The results show that PET specimens achieved a higher average crushing load and compressive strength than LDPE specimens. PET recorded an average crushing load of 92.9 kN and compressive strength of 4.65 N/mm², whereas LDPE recorded 71.2 kN and 3.56 N/mm².
The difference in average compressive strength is: 4.65 − 3.56 = 1.09 N/mm²
The percentage improvement of PET over LDPE is: [(4.65 − 3.56) / 3.56] × 100 = 30.6%
Similarly, the percentage difference in crushing load is approximately: [(92.9 − 71.2) / 71.2] × 100 = 30.5%
Thus, under the experimental conditions adopted, PET specimens were approximately 30.6% stronger in compression and sustained approximately 30.5% greater crushing load than LDPE specimens.

6.0 Discussion of Results

6.1 Comparative Performance of PET and LDPE

The results demonstrate a clear difference between the two plastic types. PET achieved an average compressive strength of 4.65 N/mm², while LDPE achieved 3.56 N/mm². The PET specimens therefore exhibited approximately 30.6% higher compressive strength.

This finding is consistent with the general understanding that the physical and mechanical properties of the polymer binder influence the behaviour of plastic–sand composites. Nnorom et al. [8] demonstrated that plastic type and composition affect the Physico-mechanical properties of sand–plastic interlocking paving bricks. Similarly, Iftikhar et al. [6] reported useful engineering performance for plastic–sand paver blocks, confirming the potential of waste plastic as a binder for paving applications.

The present results extend these findings by directly comparing PET and LDPE under the same specimen dimensions and plastic-to-sand ratio.

6.2 Why PET withstand a Higher Crushing Load than LDPE

The higher average crushing load of PET specimens (92.9 kN) compared with LDPE specimens (71.2 kN) can be attributed primarily to differences in the mechanical characteristics of the two polymers.

PET is relatively rigid and possesses greater stiffness than LDPE. When incorporated into the sand matrix, its greater rigidity can provide stronger resistance to deformation under compressive loading. The PET binder may therefore transfer applied loads more effectively between the sand particles.

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LDPE, in contrast, is relatively soft and flexible. Under compressive loading, greater deformation can occur before failure. This flexibility may reduce the efficiency of load transfer through the plastic–sand matrix and consequently result in lower crushing loads.

The slightly higher average weight of the PET specimens (2.81 kg) compared with LDPE specimens (2.68 kg) may also indicate differences in composite compactness and material packing. However, weight alone does not establish the cause of the higher strength. The difference is more reasonably interpreted in combination with the mechanical characteristics of PET and LDPE and the observed crushing-load results.

The higher PET performance is also consistent with the general findings of previous studies showing that polymer type and composite composition influence the strength and physical properties of plastic–sand products [6], [8].

Therefore, the higher crushing load should not simply be attributed to the fact that PET specimens were heavier. Rather, it is likely associated with the combined effects of polymer rigidity, composite structure, bonding, compaction, and load-transfer characteristics.

6.3 Performance of PET Specimens

The PET specimens recorded compressive strengths ranging from 4.25 to 4.98 N/mm^2, with an average of 4.65 N/mm^2.

The relatively narrow range indicates reasonably consistent performance among the four specimens. The highest value of 4.98 N/mm^2 was obtained from PET 3, which also recorded the highest crushing load of 99.6 kN.

The relatively consistent PET results suggest that the production process produced specimens with comparable material composition and physical characteristics. Nevertheless, the sample size was limited to four specimens, and therefore the results should be interpreted as experimental evidence under the specified conditions rather than as a universal strength value for all PET–sand blocks.

6.4 Performance of LDPE Specimens

The LDPE specimens recorded compressive strengths between 3.35 and 3.79 N/mm^2, with an average of 3.56 N/mm^2.

The lower strength relative to PET is consistent with the more flexible nature of LDPE. Although flexibility may be beneficial for some lightweight applications, excessive deformation under compressive loading can reduce the ability of the material to resist high loads.

The LDPE specimens also showed a slightly wider range of strength values than the PET specimens. This variation may be associated with differences in melting, mixing, compaction, or the distribution of sand particles within the composite. However, additional specimens and statistical testing would be required to establish the significance of this variation.

6.5 Relationship to Previous Research

The findings support previous research demonstrating the feasibility of using waste plastics as binders in sand-based construction products. Al-Sinan and Bubshait [4] identified plastic–sand materials as a potential pathway for sustainable construction and circular-economy applications. Kumi-Larbi et al. [7] similarly demonstrated the potential of plastic-bonded sand interlocking blocks in developing-country contexts.

The present study differs from general investigations of plastic–sand blocks by directly comparing PET and LDPE produced under controlled and comparable conditions. This comparison is important because the two plastics are readily available in the Nigerian waste stream but possess different physical characteristics.

The findings also reinforce the recommendation that plastic type should be considered when selecting waste polymers for construction applications. PET appears more appropriate where greater compressive resistance is required, while LDPE may be considered where lower weight and greater flexibility are advantageous.

6.6 Engineering Implications

The average compressive strengths of 4.65 N/mm^2 for PET and 3.56 N/mm^2 for LDPE demonstrate that both materials can produce consolidated plastic–sand blocks with measurable load-bearing capacity.

However, the results alone are insufficient to classify the blocks for unrestricted structural applications. Their suitability must be established against the relevant standards and through additional tests such as abrasion resistance, water absorption, durability, dimensional stability, fire performance, and long-term weathering.

Based on the present compressive-strength results, PET-based products demonstrate greater potential for paving and other light-duty applications where higher compressive resistance is desirable. LDPE-based products may be more suitable for lightweight and non-load-bearing applications.

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7.0 Novelty and Contribution to Knowledge

The novelty of this study lies in the controlled comparative evaluation of PET and LDPE plastic wastes sourced from discarded bottles and pure-water sachets, respectively under the same 1:3 plastic-to-sand ratio, specimen dimensions, moulding process, and compressive-strength testing conditions. The study provides experimental evidence that PET-based blocks achieved a higher average compressive strength of **4.65 N/mm²**, compared with **3.56 N/mm²** for LDPE, indicating that PET is more suitable where greater compressive resistance is required, while LDPE may be appropriate for lightweight and non-load-bearing applications. It further demonstrates a practical pathway for converting locally available plastic waste into useful construction materials and provides context-specific evidence relevant to ***the Federal Polytechnic Bauchi and its Research Village.*** The findings also establish a baseline for future research on mix ratios, processing temperatures, compaction methods, durability, and life-cycle performance. However, the study does not claim to establish a universal optimum plastic-to-sand ratio, as the 1:3 ratio was used as the controlled basis for comparing PET and LDPE and for providing a foundation for subsequent optimization studies.

8.0 Limitations of the Study

The study is limited by the investigation of only one plastic-to-sand ratio (1:3), which prevents the determination of the optimum mix ratio. In addition, the assessment focused mainly on compressive strength, while other important properties such as water absorption, impact resistance, fire behaviour, UV resistance, and long-term durability were not evaluated. In addition, a detailed life cycle and emissions assessment of the plastic melting process was not undertaken, including energy consumption and potential emissions. These limitations provide opportunities for further research and optimization of plastic–sand interlocking blocks.

9.0 Conclusion

This study experimentally evaluated plastic–sand interlocking blocks produced using waste PET and LDPE as complete binders at a 1:3 plastic-to-sand ratio. The specimens measured 200 × 100 × 75 mm and were subjected to compressive-strength testing.

The PET specimens recorded an average weight of 2.81 kg, average crushing load of 92.9 kN, and average compressive strength of 4.65 N/mm². The LDPE specimens recorded an average weight of 2.68 kg, crushing load of 71.2 kN, and compressive strength of 3.56 N/mm².

Under the experimental conditions, PET therefore achieved approximately 30.6% higher compressive strength and 30.5% higher crushing load than LDPE. The higher PET performance is attributed principally to its greater rigidity and structural stability, which can enhance resistance to deformation and load transfer within the plastic–sand composite. The comparatively flexible nature of LDPE provides lower resistance to compressive loading.

The results demonstrate that waste PET and LDPE can be converted into consolidated plastic–sand interlocking products without cement or water as the primary binder. PET demonstrated the better compressive performance of the two materials and therefore has greater potential for applications requiring comparatively higher compressive resistance. LDPE, with its lower strength and lighter average weight, is more appropriate for lightweight and non-load-bearing applications.

However, the present results do not establish that either material is suitable for all structural applications. Further testing against relevant construction standards is required before wider structural use. Durability, abrasion resistance, water absorption, fire performance, ultraviolet exposure, and long-term environmental behaviour should be investigated.

10.0 Recommendations

Based on the findings of the study, the following four recommendations are made:

1. PET-based blocks should be prioritized where higher compressive resistance is required, while LDPE-based blocks should initially be limited to lightweight and non-load-bearing applications pending further testing.
2. Further experimental studies should investigate different plastic-to-sand ratios, such as 1:2, 1:4, and 1:5, to determine their effects on strength, weight, durability, and production cost.
3. Comprehensive engineering and environmental assessments should be conducted, including water absorption, abrasion, impact resistance, dimensional stability, fire and thermal performance, long-term durability, energy consumption, and emissions during production.
4. Further research and pilot production should be undertaken at the local level, particularly at the Research Village of the Federal Polytechnic Bauchi, using larger sample sizes to improve statistical reliability and assess the practical scalability of the technology.

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