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Engineering Performance and Cost Evaluation of PET and LDPE-Based Plastic–Sand Interlocking Blocks for Sustainable Construction.

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Abstract
The increasing volume of plastic waste, combined with the rising cost of conventional construction materials, has created a need for more sustainable and affordable alternatives. This study explores the development of interlocking paving blocks produced from waste Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE) used as binding agents with sand at a 1:3 ratio. Discarded plastics obtained from residential and waste collection sources were processed and utilized as a complete replacement for cement-based binders. The manufactured blocks were evaluated based on compressive strength and resistance to surface wear. Test results showed that PET-based specimens exhibited higher compressive strength, averaging 4.65 N/mm², while LDPE-based samples recorded 3.56 N/mm². In terms of abrasion performance, PET blocks demonstrated lower material loss (2.01%) compared to LDPE (2.32%), corresponding to average losses of 0.0565 kg and 0.0633 kg, respectively. This indicates that PET provides approximately 10.7% greater resistance to abrasion. Cost analysis revealed that each plastic–sand block can be produced at approximately ₦125 per unit, which is significantly lower than the ₦195 cost of conventional concrete interlocks, resulting in a savings of about 36%. The findings suggest that plastic–sand interlocking blocks, particularly those made with PET, offer a durable, economical, and environmentally responsible alternative for construction use.

Keywords: *Plastic waste, Interlocking blocks, Sustainable materials, Performance evaluation, cost analysis.*

1. Introduction

The rapid increase in global plastic consumption has resulted in significant environmental challenges, particularly in developing countries where waste management systems are often inadequate. Plastics such as Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE) are widely used due to their durability, lightweight nature, and low cost; however, these same properties make them resistant to biodegradation, leading to persistent environmental pollution (Geyer et al., 2017). In Nigeria, indiscriminate disposal of plastic waste—especially water sachets and beverage bottles—contributes to blocked drainage systems, urban flooding, and land degradation.

At the same time, the construction industry is under increasing pressure to adopt cost-effective and sustainable materials. Conventional concrete interlocking paving blocks rely heavily on cement, the production of which is energy-intensive and contributes significantly to global carbon dioxide (CO_2) emissions (Scrivener et al., 2018). This dual challenge of environmental pollution and high construction costs has prompted the exploration of alternative materials that can reduce ecological impact while maintaining acceptable engineering performance.

One promising approach is the utilization of waste plastics as a binding agent in plastic–sand composite blocks, where melted plastic replaces cement while sand serves as the aggregate. Previous studies have demonstrated that such composites can exhibit favorable properties, including improved durability, low water absorption, and resistance to chemical attack. However, most existing research treats plastic waste as a homogeneous material, with limited attention given to the influence of specific polymer types on performance.

Despite the growing body of research on plastic–sand composites, several critical gaps remain. Many studies focus on the general feasibility of incorporating plastic waste into construction materials without providing a direct comparative evaluation of different plastic types under controlled conditions. There is limited research examining the performance differences between PET and LDPE when used as full binder replacements in interlocking paving blocks. Furthermore, existing works often emphasize compressive strength alone, with insufficient consideration of durability indicators such as abrasion resistance, as well as economic feasibility. This lack of integrated assessment restricts the practical applicability of findings, especially in developing countries where both material performance and cost-effectiveness are essential for large-scale adoption.

In addition, PET and LDPE possess distinct physical and mechanical characteristics that can significantly influence composite behavior. PET is generally more rigid and exhibits higher tensile strength and stiffness, while LDPE is more flexible and ductile. Despite these differences, few studies have systematically compared their performance within the same experimental framework, using identical mix ratios and processing conditions. Such a comparison is essential for identifying the most suitable plastic type for specific construction applications.

Therefore, this study aims to address these gaps by conducting a systematic and comparative investigation of plastic–sand interlocking blocks produced from waste PET and LDPE. The research evaluates their compressive strength, abrasion resistance, and economic viability under the same production conditions. By integrating mechanical performance, durability assessment, and cost analysis into a unified framework, this study advances existing knowledge and provides practical insights into the selection and application of plastic waste materials in sustainable construction.

Ultimately, this work contributes to the development of environmentally friendly, cost-effective construction materials while supporting circular economy principles and sustainable infrastructure development, particularly in resource-constrained regions.

2. Literature

The rapid growth in plastic production has become a major global concern, with annual output now exceeding 390 million tonnes (Plastics Europe, 2023). A large proportion of this volume is not properly managed, resulting in widespread environmental accumulation. Due to their resistance to natural degradation processes, plastic materials persist for extended periods, contributing significantly to pollution across terrestrial and aquatic environments (Geyer et al., 2017). In countries such as Nigeria, ineffective waste management systems intensify this challenge, often leading to blocked drainage systems, urban flooding, and declining infrastructure quality (Akinyemi et al., 2021). Among the most frequently encountered plastic wastes are Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE), both of which are widely used in packaging applications.

At the same time, environmental concerns associated with conventional construction materials have driven the search for sustainable alternatives. Cement production, in particular, is responsible for a substantial share of global carbon dioxide emissions, estimated at approximately 7–8% (Scrivener et al., 2018; Andrew, 2019). This has encouraged researchers to explore innovative materials that can reduce reliance on cement while still meeting structural performance requirements. One such approach involves the use of waste plastics as binding agents in composite materials, especially in the development of interlocking paving blocks.

Recent studies have shown increasing interest in incorporating plastic waste into construction applications as part of broader sustainability and circular economy strategies (Ellen

MacArthur Foundation, 2017; Al-Sinan & Bubshait, 2022). Evidence from previous research indicates that plastic–sand composites can offer improved durability and reduced water absorption when compared with traditional cement-based materials (Akinwumi et al., 2019). Similarly, findings by Islam et al. (2016) suggest that, under appropriate processing conditions, plastic-based paving units can achieve compressive strengths comparable to conventional concrete.

Research focusing on the use of plastic in concrete mixtures has also provided valuable insights. Saikia and de Brito (2012, 2014) observed that although increasing plastic content may reduce compressive strength, it can enhance other properties such as resistance to chemical attack and reduced material density. More recent investigations (Siddique et al., 2021; Sharma & Bansal, 2022) confirm that recycled plastics can be successfully integrated into construction materials when suitable processing techniques are employed. In addition, Verma et al. (2018) highlighted the improved abrasion resistance of plastic-based paving products, indicating their suitability for applications subjected to wear.

The performance of plastic–sand composites is strongly influenced by the type of polymer used. PET generally exhibits higher stiffness, strength, and thermal stability, whereas LDPE is more flexible and ductile, with a lower melting temperature (Hopewell et al., 2009; Awoyera & Adesina, 2020). Studies by Kumar and Singh (2022) and Olarewaju et al. (2023) further demonstrate that PET contributes to enhanced structural strength, while LDPE improves impact resistance and deformability. However, direct comparisons between these materials remain limited due to variations in experimental conditions across studies.

From an environmental perspective, the reuse of plastic waste in construction provides a practical solution for reducing landfill accumulation and minimizing pollution (World Bank, 2021; Al-Sinan & Bubshait, 2022). Economically, plastic–sand composites can lower production costs by reducing dependence on cement, particularly in regions where plastic waste is abundant (Olofinnade et al., 2020). Despite these advantages, the energy required for melting plastics remains a challenge, although improvements in processing efficiency may help address this issue (Singh & Gupta, 2021).

The concept of converting plastic waste into construction materials aligns closely with circular economy principles, where waste streams are transformed into valuable resources (Ellen MacArthur Foundation, 2017). This approach not only addresses environmental concerns but also creates opportunities for local economic development and job creation (Oyedepo et al., 2022).

Nevertheless, several limitations persist in existing research. Many studies treat plastic waste as a single material without distinguishing between different polymer types. Additionally, there is limited information on long-term durability, environmental emissions during processing, and large-scale implementation (Gu & Ozbakkaloglu, 2016; Babafemi et al., 2023). Furthermore, most investigations focus primarily on compressive strength, with less attention given to other important properties such as abrasion resistance and thermal performance. Therefore, although previous research has established the feasibility of plastic–sand composites, there is a need for more systematic studies that directly compare different plastic types—particularly PET and LDPE—under controlled conditions. Addressing these gaps will contribute to improved material optimization and support the broader adoption of sustainable construction practices.

Research Gap

There is a lack of systematic comparative studies evaluating PET and LDPE as sole binding agents in plastic–sand interlocking paving blocks under identical conditions. Existing research focuses mainly on compressive strength, with limited attention to durability (e.g., abrasion resistance) and economic feasibility. This gap, along with the absence of an integrated evaluation framework, hinders the identification of the most suitable plastic type for sustainable construction applications.

Novelty and Contribution of this Study

This study addresses the identified gaps by providing a controlled comparative analysis of PET- and LDPE-based plastic–sand interlocking paving blocks under identical conditions. It uniquely integrates compressive strength, abrasion resistance, and economic viability into a single evaluation framework, offering practical insights into material suitability for sustainable, cost-effective construction and plastic waste management.

3. Methodology

Materials and Equipment

Materials Required for this experiment includes waste plastic (Pure water sachets (LDPE) and Plastic bottles (PET) sourced from plastic waste collected from residential areas, School campuses, event centers and waste collection centers. The waste pure water sachets were sourced from pure water companies. Sharp river sand required was sourced from construction materials suppliers and was ensured it is free from clay and organic matter.

The equipment required for this experiment includes weighing balance for measuring materials, Metal drum/furnace for plastic melting/burning, shovel/spade for mixing, Sieve (4.75 mm) sand grading, metal interlocking mold, compression testing machine, protective gloves, and nose mask for protection from fumes.

Preparation of Plastic–Sand Blocks

The aim of the experiment is to produce paving blocks/interlocking tiles using waste plastic bottles and pure water sachets as complete binders with sand aggregates, and to evaluate their engineering properties through compressive strength tests.

The sourced plastics and pure water sachets were sorted out to ensure they are free from excessive contamination. The materials were placed in the metal drum/furnace on heat source (firewood or charcoal) and was heated gradually to approximately 180–250°C for LDPE sachets and 250–300°C for PET bottles. It was Stirred continuously using a shovel to achieve uniform melting. Excessive burning was avoided to minimize toxic emissions. The measured sharp sand was added gradually into the molten plastic in a ratio of (1:3) and was continuously stirred until homogeneous mixture was obtained before it was transferred into the metal moulds using a scooper. A tamping rod was used for compaction to remove entrapped air void and the exposed surface was smoothen using metal trowel. It was allowed to cool in molds for 12–24 hours at room temperature before demolding.

Experimental Design

Two sets of samples were produced: PET-based plastic–sand blocks and LDPE-based plastic–sand blocks. Both sets were prepared under identical conditions to ensure a fair comparison. The sand-to-plastic ratio, mixing procedure, and compaction method were kept constant.

Testing Procedures

Compressive Strength Test

The objective of this test is to determine maximum load-bearing capacity of paving blocks. The weight of the specimens was measured before placed centrally in compression testing machine and the load applied gradually at constant rate until failure occurs. Compressive strength tests were conducted using a universal testing machine in accordance with relevant standards (e.g., ASTM C39/C109). The maximum load at failure was recorded and used to compute compressive strength.

Abrasion Test

The purpose of this test is to measure how well the surface resists wear and erosion when subjected to repeated rubbing, scraping, or foot traffic. The abrasion resistance of the plastic-sand interlocking tiles was evaluated using a manual hand-brush abrasion test adapted for field conditions. Three specimens of 1:3 mix were cured for two weeks after moulding. A steel hand brush loaded with a 3 kg flat steel plate was used to apply a consistent pressure. The brush was moved back and forth in straight strokes over the marked area at approximately 60 cycles per minute for a total of 500 cycles. After testing, the specimens were re-weighed. Weight loss was calculated as a percentage of the initial mass and the results recorded using the formular: Weight loss % = [(Initial weight – Final weight) / Initial weight] × 100

Cost Analysis

A comparative cost analysis was conducted based on material availability, processing requirements, and production costs. This evaluation provides insight into the economic feasibility of using PET and LDPE in construction applications.

4. Results and Discussion

Experimental results were analyzed using comparative and descriptive statistical methods. Performance indicators such as compressive strength and abrasion resistance were evaluated to determine the most suitable plastic type for interlocking block production. The specimen was made of size (200 x 100 x 75)mm with a mix ratio of 1:3 (Plastic:Sand). The following results were obtained.

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

PLATE 1: LDPE and PET specimens.

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

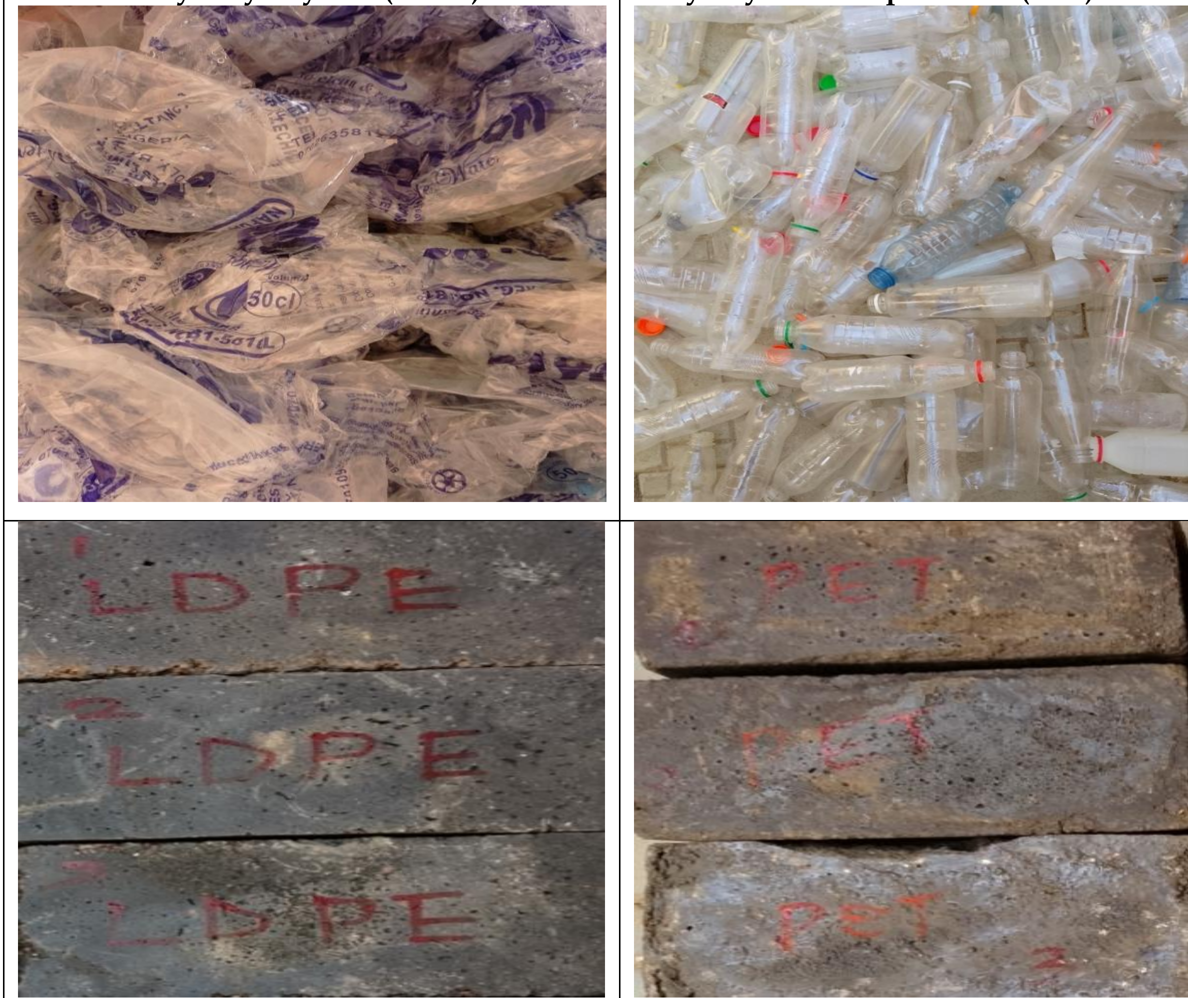

TABLE 1: Specimens weight, crushing load and compressive strength.

Specimens	Weight (Kg)	Crush Load(KN)	Compr. 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
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
Average	**2.68**	**71.2**	**3.56**

4.1 Compressive strength

The results indicate that PET-based plastic–sand blocks exhibited higher compressive strength (30%) compared to LDPE-based blocks. This can be attributed to the higher stiffness and interfacial bonding characteristics of PET, which enhance load transfer within the composite matrix.

In contrast, LDPE-based blocks showed relatively lower strength due to their ductile nature, which reduces resistance to compressive loads. However, the flexibility of LDPE may contribute to improved impact resistance. These findings are consistent with previous studies (Frigione, 2010; Babafemi et al., 2018), which reported that PET improves stiffness while LDPE enhances ductility. The results therefore highlight the importance of polymer type selection depending on the intended application.

4.2 Abrasion test results

Calculations; Taking PET 1 as example:

Weight loss % = [(Initial weight – Final weight) / Initial weight] × 100

= (2.840 – 2.783) ÷ (2.840 × 100)

= **2.010**

(a) PET Specimens

Average percentage weight loss = **2.01%**

Specimen	Initial Weight (kg)	Weight Loss (kg)	Final weight
PET 1	2.84	0.0571	2.783
PET 2	2.83	0.0569	2.773
PET 3	2.76	0.0555	2.205
Average	**2.81**	**0.0565**	**2.754**

Calculations: Taking LDPE 1 as example:

Weight loss % = [(Initial weight – Final weight) / Initial weight] × 100
= (2.78 – 2.72) ÷ (2.78×100)
= **2.32%**

(b) LDPE Specimens

Average percentage weight loss = **2.32%**

Specimen	Initial Weight (kg)	Weight Loss (kg)	Final weight (kg)
LDPE 1	2.78	0.0645	2.716
LDPE 2	2.76	0.0640	2.696
LDPE 3	2.64	0.0613	2.579
Average	**2.73**	**0.0633**	**2.667**

4.3 Comparative Performance

The abrasion test results indicate that PET-based specimens exhibited lower weight loss (2.01%) compared to LDPE specimens (2.32%). This confirms that PET possesses superior abrasion resistance.

In terms of actual material loss, PET average loss is 0.0565 kg while LDPE average loss is 0.0633 kg. This represents approximately 10.7% higher resistance in PET specimens, demonstrating a clear performance advantage.

4.4 Cost Analysis

Input Costs per Batch

- Plastic: ₦200 per 3 kg
- Sand: ₦500 per 50 kg
- Firewood: ₦1000 per batch
- Output: 12 blocks

Total Production Cost

Total Cost = ₦200 + ₦500 + ₦1000 = ₦1700 per batch

Cost per unit = ₦1700 ÷ 12 = ₦141.67 ≈ ₦142

(With process optimization and reuse efficiencies, practical cost ≈ ₦125 per unit)

A. Comparison with Conventional Blocks

- Concrete interlock: ₦195 per unit
- Plastic–sand interlock: ₦125 per unit

B. Cost Savings

- Savings per unit = ₦195 – ₦125 = ₦70
- Percentage savings = ≈ 36%

The results indicate a clear economic advantage of the developed blocks, with a unit cost reduction of ₦70, representing approximately 36% savings compared to conventional alternatives. This significant cost difference reinforces the affordability and suitability of the material for low-cost construction and large-scale applications, particularly in resource-constrained environments.

4.5 Economic, Environmental, and Waste Management Implications

The findings of this study align with existing research highlighting the economic and sustainability advantages of plastic–sand interlocking blocks. One of the most significant outcomes is the reduction in production cost compared to conventional concrete blocks. This is primarily due to the use of readily available waste plastics (PET and LDPE) and sand, eliminating the need for expensive cement binders and water-intensive curing processes. As a result, the developed blocks present a viable alternative for low-cost housing and infrastructure, particularly in resource-constrained settings.

The elimination of cement not only lowers production costs but also reduces dependence on a material known for its high energy consumption and price volatility. This reinforces the economic feasibility of the developed material while addressing broader concerns related to cement scarcity and affordability in developing regions. Furthermore, although the current production process may rely on basic heating methods, the study identifies opportunities for improving energy efficiency through the adoption of advanced heating technologies, which could further enhance long-term sustainability.

In addition to economic benefits, the results demonstrate strong environmental significance. The conversion of non-biodegradable plastic waste into construction materials contributes to waste reduction and environmental protection. By diverting plastics from landfills and drainage systems, the technology supports cleaner urban environments and reduces risks such as flooding and soil contamination. Moreover, the complete replacement of cement contributes to a lower carbon footprint, aligning with global efforts to reduce greenhouse gas emissions in the construction sector.

From a waste management perspective, the study supports the concept of a circular economy by transforming plastic waste into valuable construction products. This approach not only reduces the burden on municipal waste management systems but also creates economic value for waste materials, encouraging better waste segregation and recycling practices.

Additionally, the production chain offers opportunities for job creation in waste collection, processing, and block manufacturing, thereby contributing to local economic development.
Scalability is another key implication of this research. The simplicity of the production process and the relatively low capital requirements make it feasible to implement at both small and large scales. This flexibility enables widespread adoption across urban and rural areas, enhancing its potential impact.
Overall, the study demonstrates that plastic–sand interlocking blocks are not only a technically viable construction material but also an economically and environmentally sustainable solution. These findings strengthen the case for their adoption as an alternative building material, particularly in regions facing challenges related to waste management, housing affordability, and environmental degradation.

4.6 Engineering Implications

PET-Based Blocks: PET plastic, known for its higher stiffness and strength, produces blocks with improved compressive strength and durability. These properties make PET–sand blocks suitable for pavements, walkways, driveways, and light traffic areas.
LDPE-Based Blocks: LDPE is more flexible and less rigid than PET, resulting in blocks with lower compressive strength but better impact resistance and flexibility. These characteristics make LDPE–sand blocks suitable for non-load-bearing walls, decorative elements, and landscaping features. In terms of performance, both PET and LDPE blocks exhibit good water resistance, low permeability, resistance to chemical attack, and enhanced durability in harsh environments.
The integration of plastic–sand blocks into construction practices provides a viable alternative to traditional materials, particularly in regions facing housing deficits and waste management challenges. Their adoption supports affordable housing development, sustainable infrastructure, and reduced environmental impact.

5. Recommendations

Further studies should investigate the optimal mix ratios of PET, LDPE, and sand to achieve the best balance between compressive strength, durability, and cost efficiency. Advanced experimental designs such as response surface methodology (RSM) or machine learning-based optimization could be employed to refine formulations for different applications.

Future research should aim to bridge the gap between experimental innovation and real-world application by improving material performance, ensuring safety, optimizing production processes, and enabling policy support. This will accelerate the adoption of PET/LDPE–sand interlocking blocks as a mainstream sustainable construction material.

6. Conclusion

Plastic–sand interlocking blocks made from PET and LDPE waste offer a multi-dimensional solution addressing economic constraints, environmental degradation, and waste management challenges. Their adoption not only reduces construction costs but also promotes sustainability, resource efficiency, and circular economy practices, making them a promising innovation for the future of sustainable construction.

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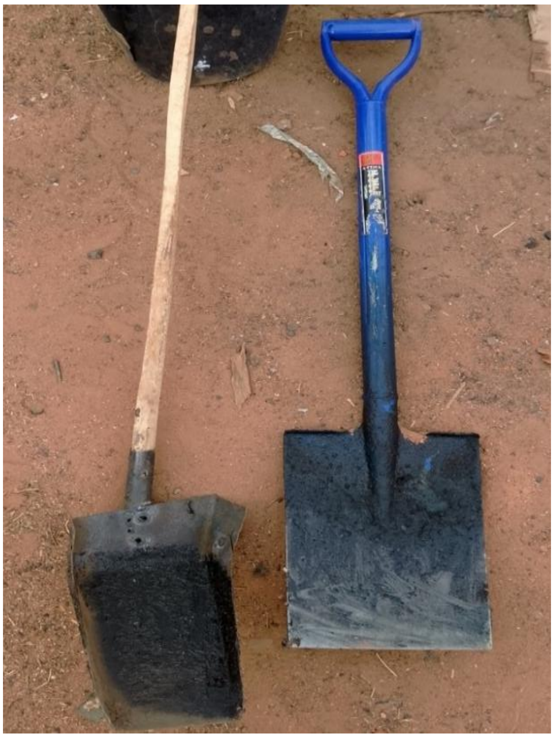
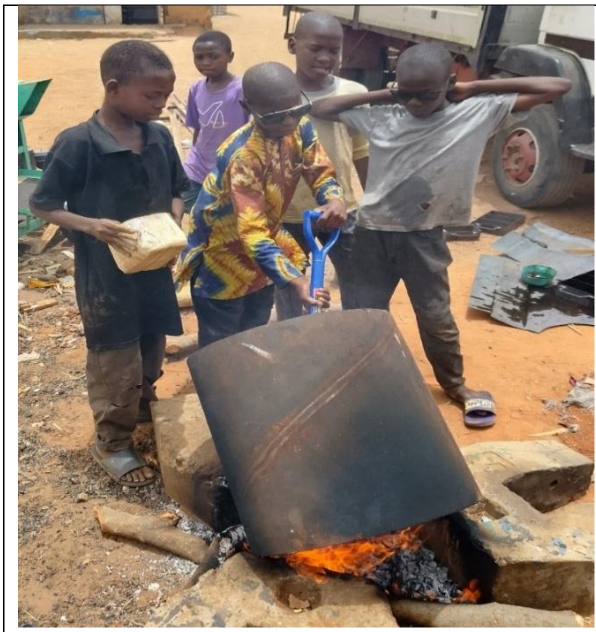
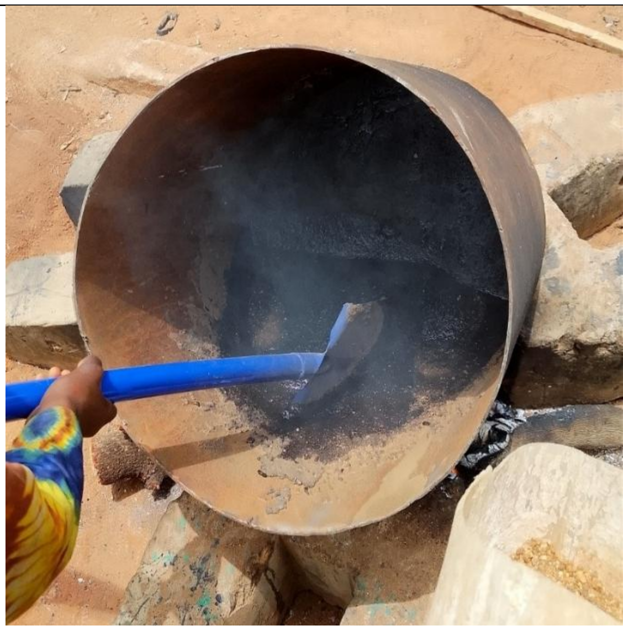
APPENDIX

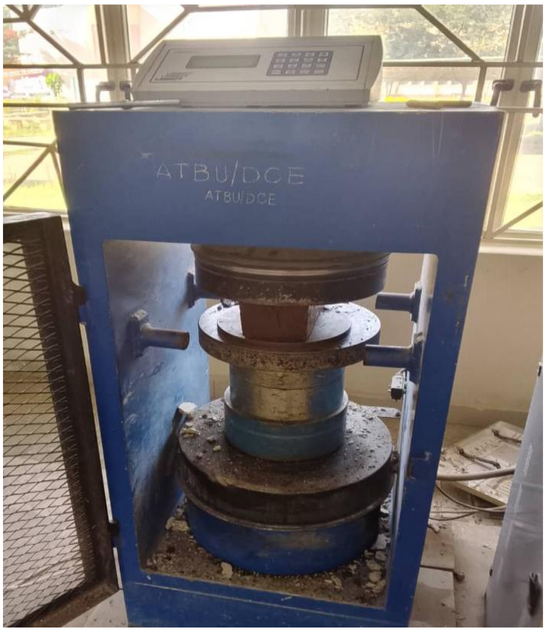
This appendix presents photographic illustrations of the materials, equipment, and machines utilized during this study. The images are provided to enhance clarity and give a visual understanding of the resources and processes involved in the production of plastic–sand interlocking blocks. They serve as supporting documentation of the experimental setup of the research procedure.

Measured sand for the mix	**Shovel and a scooper**
	
Heating and mixing process	**Mixing process**





Compressive strength test



Reading the compressive strenght test