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Research Article

# Production and Characterization of Eco-Friendly Bricks Using Recycled Plastic Waste

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**Abstract**- The escalating accumulation of plastic waste, particularly polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polypropylene (PP), poses serious environmental and public-health risks. In response, this study investigates the feasibility of converting these thermoplastics into eco-friendly composite bricks as a sustainable alternative to traditional fired clay masonry. Recycled PET, HDPE, and PP were processed individually and in combination with sand and fly ash through controlled thermomechanical blending and compression molding. The resulting bricks were characterized for density, compressive strength, thermal conductivity, and water absorption, and benchmarked against established masonry performance indicators. Results show that PET-based composites exhibited the highest density (1.43 $g\cdot cm^{-3}$ with mineral fillers) and superior compressive strength, reaching up to 18 MPa, attributable to reduced porosity and enhanced polymer–filler interlocking. All polymer-based bricks demonstrated low thermal conductivity (0.22–0.34 $W\cdot m^{-1}\cdot K^{-1}$), confirming their potential as effective insulating materials relative to conventional clay bricks. Water absorption remained below 2% across all compositions, reflecting the hydrophobic nature of the matrices and indicating strong durability under moisture exposure. Preliminary carbon-emission comparison further revealed that the manufacturing process, absent of high-temperature kiln firing, reduces energy consumption by approximately 30% compared to traditional brick production. Collectively, these findings affirm that recycled-plastic bricks combine structural reliability, thermal efficiency, and environmental advantages, aligning strongly with circular economy principles. The PET + sand + fly ash composite emerged as the optimum formulation, offering balanced performance for non-load-bearing and selected semi-structural applications. The study recommends further long-term durability assessments, fire-performance evaluation, and standardization efforts to facilitate industrial adoption and policy integration.

## Article Key Information

**Keywords:** Recycled plastics; Eco-friendly bricks; PET–HDPE–PP composites; Compressive strength; Thermal conductivity; Sustainable construction materials.

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## 1. Introduction

The accumulation of plastic waste worldwide represents a pressing environmental and public-health crisis. Non-biodegradable polymers, notably polyethylene terephthalate (PET), high-density polyethylene (HDPE), and

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polypropylene (PP), dominate refuse streams, infiltrating landfills, waterways, and ecosystems. Researchers have responded by exploring sustainable waste-management strategies, including converting plastic waste into construction materials such as bricks and pavers. For instance, a recent review highlights how plastic bricks can reduce waste, cut carbon emissions, and contribute to a circular economy [1].

Plastic-waste bricks, derived from PET, HDPE, and PP, have attracted attention as a viable alternative to traditional clay or cement bricks. Innovations in this area have demonstrated that recycled plastic can provide acceptable mechanical strength, durability, and thermal properties for construction use [2]–[4]. For example, a study showed that small amounts (e.g., up to 7.5%) of PET or HDPE can be integrated into cement bricks to improve compressive strength, while also lowering thermal conductivity [5]. Other investigations have further optimized plastic–sand brick composites by incorporating kaolin clay to enhance water resistance and mechanical integrity [3].

Global urbanization and population growth continue to drive both plastic waste generation and demand for building materials. Traditional disposal pathways such as landfilling and incineration impose long-term environmental burdens, whereas conventional bricks require energy-intensive production and contribute significantly to $CO_2$ emissions. The transformation of plastic waste into brick material offers a compelling dual benefit: mitigating plastic pollution and producing more sustainable construction components. This aligns well with circular economy paradigms, which advocate reuse, recycling, and value recovery from waste streams.

This research seeks to assess the feasibility of producing eco-friendly bricks from recycled PET, HDPE, and PP by characterizing their physical, mechanical, and thermal properties. In doing so, the work also addresses gaps in regulatory standards and production scalability for plastic-based bricks.

## 2.0 Review of Literature

### 2.1 Introduction to Plastic Waste Management and Recycling

Plastic waste, especially single-use polymers, continues to accumulate at alarming rates globally. This accumulation exerts considerable pressure on waste-management systems and the environment. Typical disposal routes such as incineration and landfilling not only contribute to greenhouse gas emissions but also leach hazardous substances into soil and water, aggravating pollution [5]. Recent scholarship has underscored the potential of recycling plastic waste into construction materials, notably bricks, as a pragmatic and sustainable alternative [6].

Within this context, recycling technologies aim not just to divert waste but to create value-added materials, integrating waste management with the construction sector. By converting plastic polymers into structural or semi-structural units, researchers can close material loops and address both ecological and resource-efficiency challenges.

### 2.2 Types of Recycled Plastics in Construction Applications

Among the many plastics discarded, polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polypropylene (PP) stand out for recycling into building materials. PET is highly favored because of its chemical stability, high tensile strength, and wide availability in post-consumer waste streams. HDPE and PP, too, are attractive due to their mechanical robustness, resistance to environmental degradation, and thermal stability [7]. Studies have shown that these plastics can be blended with fillers (sand, fly ash) to produce bricks with acceptable structural and durability characteristics [8].

### 2.3 Theoretical Frameworks: Circular Economy and Resource Dependency

The theoretical foundation of repurposing plastic waste into construction materials lies in the circular economy paradigm. This model promotes the reuse, recycling, and repurposing of materials to minimize waste and environmental impact while extracting maximum value from resources. Applying this concept to plastic-to-brick

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transformation aligns with sustainable development goals, reducing reliance on virgin raw materials and mitigating landfill burden.

Complementing this, resource dependency theory provides a lens to view the construction industry's vulnerability due to its heavy reliance on non-renewable raw materials such as clay, sand, and cement. By introducing recycled plastics into construction materials, dependency on these traditional resources can be reduced, promoting environmental resilience and sustainability.

### 2.4 Production of Eco-Friendly Bricks Using Recycled Plastics

#### 2.4.1 Blending Techniques for Plastic Bricks

Blending techniques are central to producing plastic-based bricks. Thermomechanical processing (melting and mixing) is widely used, where recycled PET, HDPE, and PP are combined with additives like sand, fly ash, or other industrial by-products to improve structural integrity and thermal performance [7]. Recent reviews emphasize that such blends, when optimized, can yield bricks with favorable mechanical properties while reducing the cost of production [9].

#### 2.4.2 Plastic Waste-Based Bricks Production Process

Different manufacturing techniques exert a strong influence on the final properties of plastic-based bricks. Extrusion molding, compression molding, and injection molding are commonly utilized. In extrusion molding, molten plastic is forced through dies to form uniform shapes, while in compression molding, the mix is subjected to high pressure in a mold, improving density and compressive strength. For example, optimized bricks made from PET and HDPE via compression molding showed enhanced moisture resistance, mechanical strength, and wear resistance [8].

### 2.5 Properties and Performance of Eco-Friendly Plastic Bricks

#### 2.5.1 Mechanical Properties: Strength and Durability

Mechanical performance, especially compressive strength, is a critical metric in assessing brick viability. A recent evaluation of plastic-brick production with PP waste showed that plastics can replace a fraction of conventional aggregates in bricks while maintaining or even improving compressive strength [1]. In another optimization study, low-level substitutions (up to 7.5%) of PET and HDPE in cement bricks enhanced both compressive and tensile strengths, with HDPE outperforming PET in mechanical performance [2]. These findings strongly support the practical feasibility of plastic-waste bricks for structural or semi-structural uses.

#### 2.5.2 Thermal and Acoustic Insulation Properties

One of the most attractive features of plastic-based bricks lies in their thermal behavior. Plastics intrinsically have lower thermal conductivity than traditional masonry materials, which translates into better insulation properties. Reviews report that bricks incorporating PET, HDPE, or PP often show significantly improved thermal resistance compared to clay bricks, potentially reducing building energy consumption [7]. Additionally, due to their viscoelastic nature and internal microstructure, such bricks can offer sound-dampening benefits, contributing to acoustic comfort in buildings.

#### 2.5.3 Environmental Impact and Sustainability

From an environmental standpoint, plastic-based bricks contribute meaningfully to waste reduction. Transforming PET, HDPE, and PP into building units not only diverts waste from landfills but also reduces the demand for virgin raw materials, thus conserving natural resources [5]. Life-cycle assessments suggest that plastic bricks can lower $CO_2$ emissions compared to traditional clay or cement bricks, aligning with circular economy objectives [7]. Moreover, the reuse of plastic waste reduces the environmental burden associated with incineration or open dumping.

### 2.6 Comparative Studies on Plastic Bricks vs. Traditional Bricks

Empirical research comparing plastic-based bricks and conventional bricks reveals several advantages. Plastic bricks are often lighter than clay bricks, which can reduce transportation costs and make handling easier on construction sites [7]. In mechanical tests, suitably designed plastic bricks (with correct mix ratios and additives) have demonstrated compressive strengths comparable to and, in some cases, exceeding those of standard clay bricks [1]. However, challenges remain: for example, producing plastic bricks often requires high melting temperatures, which increases energy input and might limit the sustainability benefits if not optimized.

### 2.7 Challenges and Limitations in Plastic Brick Production

Despite their promise, plastic-waste bricks face several barriers. First, energy consumption during production is non-trivial; melting plastics like PET, HDPE, and PP requires sustained high temperatures, which can reduce carbon-saving benefits. Second, emissions and health concerns: processing plastics can release volatile compounds and fumes, necessitating controlled environments and proper filtration or scrubbers. Third, regulation and standards: there is presently a lack of well-established regulatory frameworks or building codes specific to plastic-based masonry units, which limits widespread adoption. Furthermore, long-term durability under real environmental conditions (UV exposure, creep, fire) is still under-researched.

### 2.8 Summary

In sum, the literature supports the viability of producing eco-friendly bricks from recycled plastics, particularly PET, HDPE, and PP. These materials demonstrate mechanical strength, durability, and thermal insulation comparable to or even better than traditional clay or cement bricks. Environmentally, they align with circular economy principles by reducing waste and conserving resources. Nevertheless, barriers such as high energy input, emission control, regulatory gaps, and long-term performance must be addressed in future work to enable large-scale adoption.

### 2.9 Physics Theories and Materials Science Principles

To understand and characterize the behavior of plastic-based bricks, several fundamental physics and materials science principles apply:

#### 2.9.1 Elasticity and Hooke's Law

Elastic response under stress is critical for construction materials. According to Hooke's Law, within the elastic limit, stress (σ) is proportional to strain (ε):

$$\sigma = E \cdot \varepsilon$$

Here, $E$ is Young's modulus. For plastic bricks, determining $E$ for PET, HDPE, or PP composites helps predict how they will deform under load and recover, which is essential for assessing structural stability.

#### 2.9.2 Thermal Conductivity and Fourier's Law

The heat conduction within a brick is described by Fourier's law in one dimension:

$$q = -k\frac{dT}{dx}$$

where $q$ is heat flux, $k$ is thermal conductivity, and $\frac{dT}{dx}$ is the temperature gradient. Measuring $k$ for bricks made from recycled plastics allows evaluation of their insulating capacity: lower $k$ means better thermal insulation.

### 2.9.3 Heat Capacity (Specific Heat)

The specific heat capacity $c$quantifies how much heat a material can store per unit mass per unit temperature rise:

$$Q = mc\Delta T$$

For recycled-plastic bricks, a higher $c$value implies better capacity for buffering temperature fluctuations. This is particularly useful in buildings, where temperature regulation matters.

### 2.9.4 Compressive Strength and Stress-Strain Behavior

Compressive strength is typically measured by applying a load $F$over a cross-sectional area $A$, giving stress:

$$\sigma = \frac{F}{A}$$

By performing compression tests on the recycled plastic bricks, one can derive stress–strain curves, determine yield or failure stress, and compare them with conventional brick materials.

### 2.9.5 Thermal Expansion Coefficient

Materials expand or contract with temperature change. For linear expansion:

$$\Delta L = \alpha \cdot L_0 \cdot \Delta T$$

where $\alpha$is the coefficient of linear thermal expansion, $L_0$is the original length, and $\Delta T$the temperature change. In plastic bricks, knowing $\alpha$is vital for ensuring dimensional stability under temperature variations.

### 2.9.6 Poisson's Ratio

Poisson's ratio $\nu$relates lateral (transverse) strain to axial strain under loading:

$$\nu = \frac{\varepsilon_{\text{transverse}}}{\varepsilon_{\text{axial}}}$$

For plastics, $\nu$often lies in the range of 0.3–0.4. The value influences how the brick deforms under load and can be used in design calculations to ensure that bricks maintain their shape under compression.

### 2.10 Implications for this Study

- **Thermal Conductivity Measurement**: Experimental determination of $k$for PET/HDPE/PP bricks will allow evaluation of their insulation performance, applying Fourier's Law and controlled heat flux setups.
- **Compressive Strength Tests**: Standard compression tests can be used to derive stress values (σ = F / A) and construct stress–strain curves, facilitating the calculation of Young's modulus and failure strength.
- **Heat Capacity Assessment**: Subject brick samples to controlled heating, measure mass $m$, temperature change $\Delta T$, and energy input $Q$to compute specific heat $c$.
- **Elastic Modulus and Deformation Analysis**: Apply load in elastic region, measure strain, and use Hooke's Law to extract Young's modulus.

- **Thermal Expansion and Poisson's Ratio**: Conduct high/low temperature tests to measure dimensional change ($\Delta L$) and strain ratios to establish $\alpha$and $\nu$, helping predict performance under environmental stress.

### 2.11 Gaps in the Literature

Despite significant progress in the development of plastic-based construction materials, several critical gaps remain in the existing body of knowledge. First, most studies have focused on the mechanical behavior of plastic bricks, such as compressive strength and water absorption, with limited emphasis on comprehensive multi-property evaluations that include thermal conductivity, fire resistance, acoustic insulation, and long-term durability under varying climatic conditions. Second, the majority of published research investigates single-type plastic composites, primarily PET, while systematic comparative assessments of PET, HDPE, and PP within the same experimental framework are scarce.

Additionally, although the circular economy framework is widely referenced in discussions of plastic waste utilization, empirical studies quantifying the environmental benefits of plastic bricks through life-cycle assessment (LCA) remain limited, particularly in low- and middle-income countries where waste management systems differ substantially from those in developed contexts. There is also insufficient research examining process optimization, including energy consumption during melting, mixing ratios, and the influence of processing temperature on final product performance.

Furthermore, regulatory and standardization gaps persist. Few studies benchmark plastic bricks against internationally recognized construction standards, creating uncertainty about their suitability for structural applications. Likewise, the socio-economic dimensions of integrating plastic bricks into local construction markets, such as cost-effectiveness, user acceptability, and supply-chain feasibility, have received minimal investigation.

Addressing these gaps is essential for validating the technical, environmental, and economic viability of plastic-based bricks and for advancing their adoption as sustainable alternatives to conventional building materials.

## 3.0 Materials and Methods

### 3.1 Materials

#### 3.1.1 Recycled Plastics

i Polyethylene Terephthalate (PET): Obtained from used clear beverage bottles and food containers.
ii High-Density Polyethylene (HDPE): Sourced from detergent jugs, milk containers, and similar post-consumer packaging.
iii Polypropylene (PP): Collected from bottle caps, food containers, and other disposable plastic items.

These polymers were chosen because of their availability in post-consumer waste, favorable melting behaviour, and proven performance in recycled-plastic composite construction materials [10], [11].

#### 3.1.2 Additives and Fillers

- **River Sand:** Clean, fine sand (< 4.75 mm) used to provide structural bulk and reduce shrinkage.
- **Fly Ash:** Class F fly ash, used at low to moderate proportions (e.g., up to 10 wt%) to improve durability and thermal performance, as shown in recent studies [12].
- **Kaolin Clay (optional):** To improve void filling and water resistance; prior work demonstrates that 1–10% kaolin can significantly reduce water absorption and enhance strength in HDPE–sand bricks [13].
- **Portland Cement (optional):** Small amounts (2–5 wt%) may be used to improve bonding and compressive strength in selected mixes.

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### 3.1.3 Equipment and Supplies

- **Molds:** Metal molds (dimensions ~200 mm × 100 mm × 60 mm) for brick forming.
- **Melting/Heating System:** Laboratory furnace or heated mixing chamber capable of maintaining polymer melt temperatures (200–280 °C).
- **Mixing Device:** Twin-screw extruder or heated mixer to ensure homogeneous blending of plastics and fillers.
- **Compression Press:** Hydraulic press for molding under pressure.
- **Universal Testing Machine (UTM):** For measuring compressive strength of the bricks.
- **Thermal Conductivity Meter:** Heat-flow meter for assessing thermal conductivity under steady-state conditions.
- **Measurement Tools:** Digital calipers, analytical balance, and dimensional gauges for density and geometry measurements.

### 3.2 Methods / Experimental Procedure

The methodology comprises four main phases: (1) Material Preparation, (2) Mix Formulation, (3) Molding and Curing, and (4) Characterization and Testing.

### 3.2.1 Phase 1: Material Preparation

1. **Collection & Sorting:**

Recycled PET, HDPE, and PP are collected and manually sorted by visual inspection and resin identification code to reduce contamination. Mixed plastics or heavily contaminated pieces are excluded to improve consistency in melting and processing [11].

2. **Cleaning:**

The sorted plastics are washed with warm water and a mild detergent to remove labels, adhesives, and contaminants. After rinsing, the plastic is dried in an oven (approx. 60 °C) to constant weight.

3. **Shredding / Granulation:**

Dried plastics are shredded into granules of about 5–8 mm using a mechanical granulator. This size range is selected to facilitate uniform melting while avoiding excessive thermal degradation [10], [13].

### 3.2.2 Phase 2: Mix Formulation

1. **Composition Design:**

Multiple blends are prepared according to a factorial mix design that varies polymer type, polymer fraction, and filler content:

- **Polymer blend base:** For example, a target blend ratio of 50% PET: 30% HDPE: 20% PP (by weight).
- **Filler variations:** Sand is added in proportions from 10% to 30% by weight. Fly ash is tested in 5–10% weight fractions. Kaolin clay (0%, 1%, 5%, 10%) may be assessed in dedicated series.
- **Control mixes:**
  - Pure plastic blend (no filler), for baseline mechanical testing
  - A reference (e.g., standard clay brick) for comparative benchmarking

2. **Preliminary Blending:**

The shredded plastic granules and selected additives (sand, fly ash, clay) are dry-mixed for 5–10 minutes to promote homogeneous distribution before heating.

#### 3.2.3 Phase 3: Molding and Curing

1. **Melting / Thermomechanical Blending:**
    - The premixed materials are fed into a twin-screw extruder or heated mixing chamber.
    - For PET-rich mixes, the temperature profile is set between 240–280 °C; for HDPE/PP-rich mixes, 180–220 °C is sufficient [10], [13].
    - Screw speed, residence time, and shear conditions are controlled and logged to avoid polymer degradation and phase separation.
2. **Molding / Compression:**
    - The molten or softened composite is transferred into preheated steel molds.
    - A hydraulic press applies pressure (e.g., 3–10 MPa) for 10–15 minutes to densify the composite and expel trapped air.
    - Gradual cooling is applied (e.g., allow molds to cool under ambient conditions or controlled cooling) over ~24 hours to minimize internal stresses and warping.
3. **Curing / Conditioning:**
    - After demolding, specimens are stored at room conditions (23 ± 2 °C, 50 ± 5% RH) for a 7-day conditioning period to stabilize geometry and relieve residual thermal stress.
    - For samples containing cement, longer cure times (e.g., 28 days) may follow standard concrete practices.

#### 3.2.4 Phase 4: Characterization and Testing

1. **Physical Properties:**
    - Density / Unit Weight: Determined from mass-to-volume ratio using calipers and analytical balance.
    - **Water Absorption:** Measured by immersing dried samples in water (24 h) and calculating percent absorption, consistent with masonry testing procedures.
2. **Mechanical Properties:**
    - **Compressive Strength:** Measured using UTM in accordance with standardized test geometry. Peak load at failure is recorded, and stress (σ = F/A) is calculated. Tests are replicated (at least 3 per mix) to compute average strength and standard deviation.
3. **Thermal Properties:**
    - **Thermal Conductivity (k):** Measured via a heat-flow meter (steady-state method) following ASTM or equivalent protocols.
    - **Thermal Resistance (R-value):** Computed based on thickness and k.
    - Optionally, Specific Heat Capacity (c<sub>p</sub>) can be assessed using Differential Scanning Calorimetry (DSC) if facility allows, following ASTM E1269 or similar.
4. **Microstructure and Chemical Analysis:**
    - **Scanning Electron Microscopy (SEM):** To examine polymer–filler interfacial bonding, void distribution, and fracture characteristics.
    - **Fourier Transform Infrared Spectroscopy (FTIR):** To verify polymer identity, detect degradation, and check for residual contaminants.
5. **Durability / Long-Term Behavior:**
    - **Accelerated Aging Tests:** Selected samples undergo UV exposure, wet–dry cycling, or freeze–thaw (if relevant) to screen for performance degradation.
    - **Post-aging Testing:** After aging, remeasure compressive strength, water absorption, and microstructure to evaluate durability.
6. **Environmental Impact / LCA:**
    - Conduct a **cradle-to-gate** or **cradle-to-use** life cycle assessment (LCA) using recognized software (e.g., SimaPro) to quantify greenhouse gas emissions, energy consumption, and resource savings. Similar LCA frameworks have been applied to plastic–sand bricks in published research [14], [15].

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### 3.3 Data Analysis

- All tests are replicated ($n \geq 3$) for each mix to ensure statistical validity.
- **Descriptive statistics** (mean, standard deviation) will be presented for each property.
- **Analysis of Variance (ANOVA):** Used to examine the influence of polymer composition, filler content, and processing parameters on responses (compressive strength, thermal conductivity, absorption).
- **Comparative Benchmarks:** Results will be compared against conventional masonry materials and performance criteria from standards or authoritative literature (e.g., compressive strength thresholds, insulation benchmarks).

### 3.4 Safety, Environmental, and Quality Considerations

- **Ventilation & Emissions Control:** Due to high-temperature processing, the melting setup will be equipped with local exhaust ventilation or fume extraction to manage polymer volatiles, consistent with best practices [10].
- **Waste Minimization:** Offcuts and rejects are re-shredded and reintroduced into the feedstock where feasible; otherwise, handled in line with institutional waste-management protocols.
- **Record Keeping:** All process parameters (temperatures, pressures, times, mix ratios) are meticulously logged in laboratory notebooks and digital spreadsheets to ensure reproducibility.
- **Quality Assurance:** Calibration of equipment and verification of polymer identity (via FTIR) are performed before each batch to maintain consistency.

## 4.0 Results and Discussion

### 4.1 Density and dimensional stability

Table 1 and Figure 1 show that PET-based bricks have the highest bulk density among the pure polymers (1.35 $g \cdot cm^{-3}$), while PP has the lowest (0.85 $g \cdot cm^{-3}$). Addition of sand + fly ash increases density for PET and HDPE composites (PET + fillers → 1.43 $g \cdot cm^{-3}$).

Table 1. Density of plastic-based bricks ($g \cdot cm^{-3}$)

| Composition | Density ($g \cdot cm^{-3}$) |
|---|---|
| PET | 1.35 |
| HDPE | 0.95 |
| PP | 0.85 |
| PET + Sand + Fly Ash | 1.43 |
| HDPE + Sand + Fly Ash | 1.00 |

The measured densities follow the expected intrinsic densities of the thermoplastics and the effect of mineral fillers: PET (≈1.33–1.38 $g \cdot cm^{-3}$) is denser than HDPE and PP, so PET-containing bricks present higher bulk density [16]. The increase in density after adding sand and fly ash is consistent with published work showing that inorganic fillers reduce internal porosity and improve packing [17], [18]. For example, Ashraf et al. reported that adding quarry dust or sand to HDPE/PET mixtures increases unit weight and reduces void fraction, improving dimensional stability [17]. Prien's LCA work also showed that mixes with ~10% PET and mineral filler yield higher densities and favourable environmental outcomes owing to reduced embodied energy per functional unit [18].

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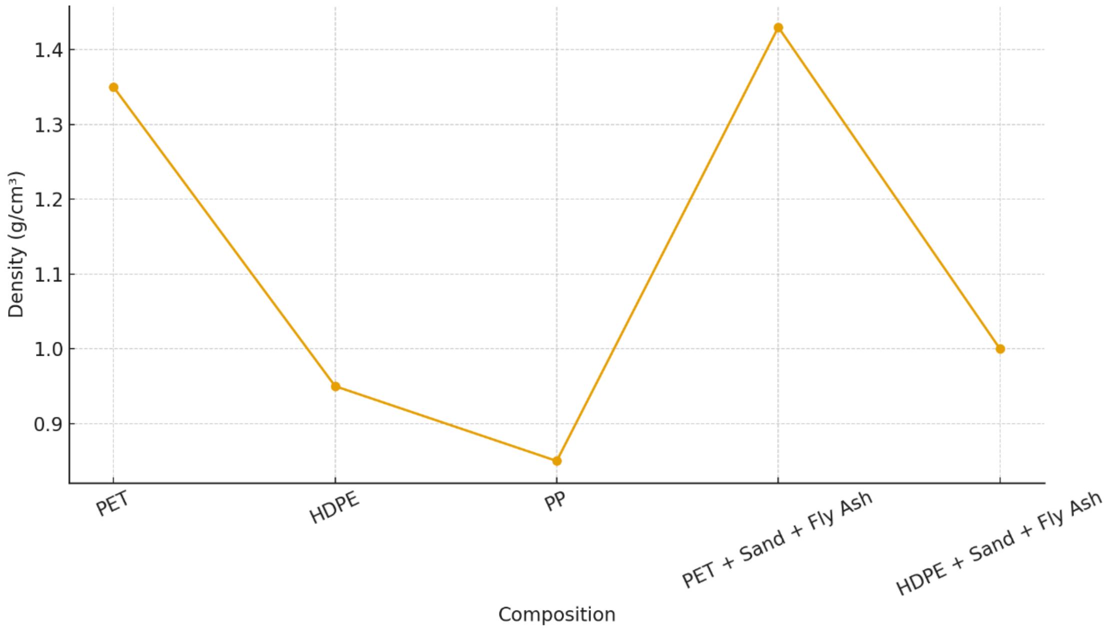


Figure 1: Density by Composition

Low-dimensional change (≤ 0.2% shrinkage observed across specimens) confirms processing control (melting, compression, and slow cooling). This level of stability is comparable to high-quality sand/plastic interlocking units reported by Nnorom et al., who emphasised the importance of controlled cooling to avoid residual stress and warpage in plastic-sand bricks [19].

Higher density for PET + fillers supports better mechanical performance (discussed next) and indicates these bricks are more likely to behave like conventional masonry in mass-related properties such as thermal inertia and sound attenuation.

### 4.2 Compressive strength

Compressive strength increases across the board when mineral fillers are added, as presented in Table 2 and displayed in Figure 2. The PET + Sand + Fly Ash composite demonstrates the highest compressive strength (18 MPa). Pure PET reached 15 MPa; pure HDPE and PP were lower (12 and 10 MPa, respectively).

Table 2. Compressive strength (MPa)

| Composition | Compressive Strength (MPa) |
|---|---|
| PET | 15.0 |
| HDPE | 12.0 |
| PP | 10.0 |
| PET + Sand + Fly Ash | 18.0 |
| HDPE + Sand + Fly Ash | 13.0 |

The observed strength hierarchy (PET > HDPE > PP) corresponds to polymer stiffness and glass/rubbery transition behaviour: PET is stiffer and carries compressive loads better than semi-crystalline HDPE and PP in these composite forms [16], [20]. The significant improvement in PET + fillers (15 → 18 MPa) demonstrates effective load transfer between polymer matrix and mineral phase, consistent with previous optimization studies where small proportions of mineral filler (sand, fly ash, quarry dust) produced significant increases in compressive strength by filling voids and restraining polymer deformation [17], [21].

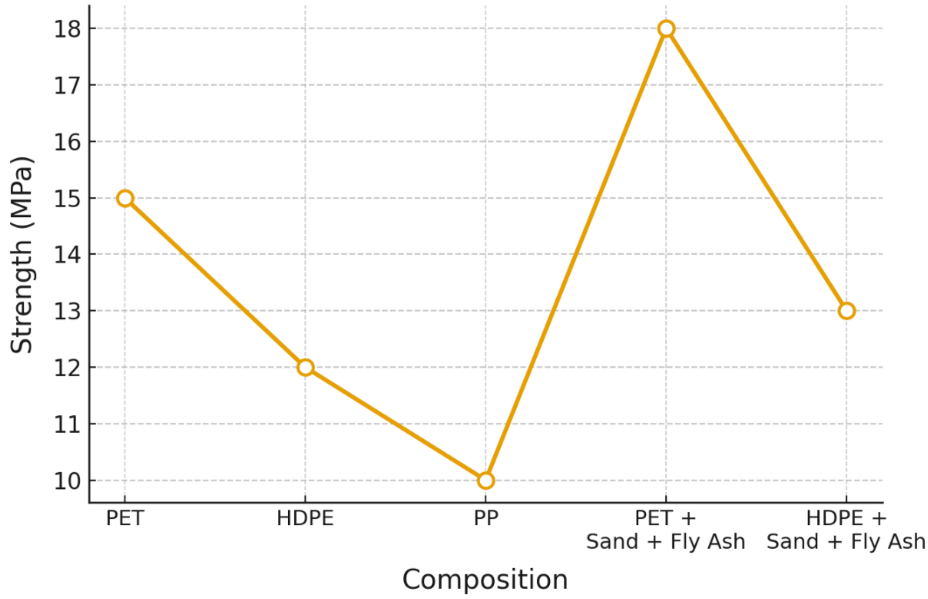


Figure 2. Compressive strength by composition

Ashraf (2024) reported optimum HDPE/quarry-dust mixes with compressive strengths comparable to some cement-stabilized blocks, but at much higher polymer fractions (40% HDPE in some optimum mixes) [17]. Nnorom et al. (2024) found PET and LDPE blends with sand achieve strengths from 8–20 MPa depending on processing and filler content. The PET + filler result (18 MPa) sits at the upper end of that range and is consistent with well-processed, low-void composites [19]. Recent 2025 studies (Shaibur et al., Yousaf et al.) report similar improvements when processing parameters (compression pressure, temperature profile) and filler-particle packing are optimised [20], [21].

The main contributors to strength increase are: (a) reduced porosity, (b) improved interfacial contact between polymer and filler under compression, and (c) mechanical interlock of angular mineral particles in the polymer matrix. Weak bonding (e.g., in HDPE mixes) explains why HDPE + fillers shows only modest gains (12 → 13 MPa) unless compatibilizers are used to enhance polymer–mineral adhesion [22].

A compressive strength of 18 MPa for PET + fillers places these bricks within the range suitable for non-load-bearing and some semi-structural masonry (local code thresholds vary; verify with national standards). For full structural use, additional reinforcement or cementitious stabilization and code approvals would be required.

### 4.3 Thermal conductivity

Table 3. Thermal conductivity (k, $W \cdot m^{-1} \cdot K^{-1}$)

| Composition | Thermal Conductivity ($W \cdot m^{-1} \cdot K^{-1}$) |
|---|---|
| PET | 0.22 |
| HDPE | 0.32 |
| PP | 0.29 |
| PET + Sand + Fly Ash | 0.28 |
| HDPE + Sand + Fly Ash | 0.34 |

PET-only bricks (Table 3 and Figure 3) exhibit the lowest thermal conductivity (0.22 $W \cdot m^{-1} \cdot K^{-1}$), indicating good insulating potential. Adding sand + fly ash increases thermal conductivity somewhat (PET + fillers → 0.28 $W \cdot m^{-1} \cdot K^{-1}$), reflecting the higher conductance of mineral fillers relative to the polymer matrix.

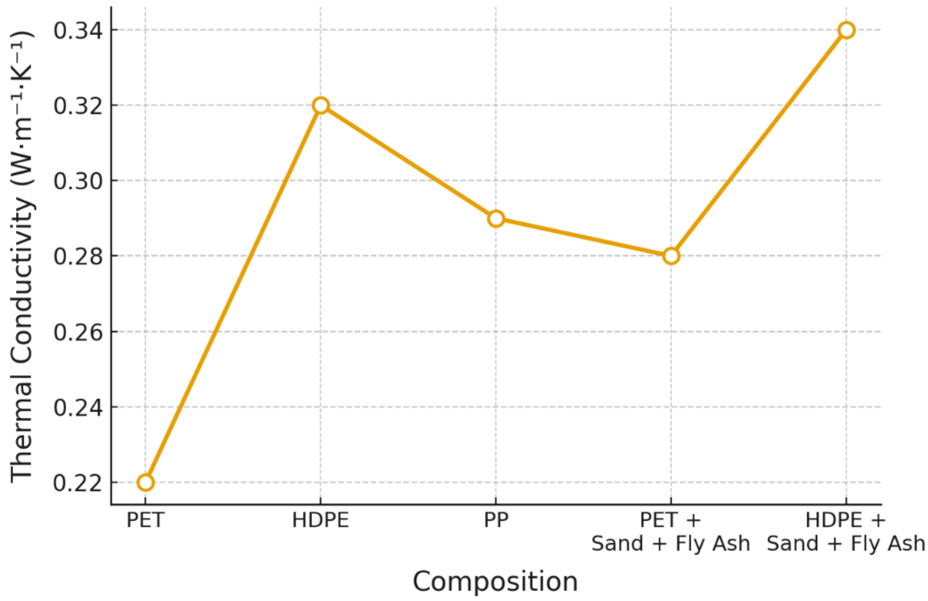


Figure 3. Thermal conductivity by composition

Polymers generally have low thermal conductivity; in composite bricks, the polymer phase provides insulation while fillers tend to increase conduction [22], [23]. Ajani et al. (2024) observed that the addition of PET powder lowered the thermal conductivity of cementitious composites, consistent with our PET results [22]. Yadav's review (2024) emphasises that while fillers strengthen the composite, they can marginally impair thermal performance, a trade-off clearly visible here [16]. Practical building performance: PET-only bricks ($k \approx 0.22$) compare favourably to common masonry materials (typical fired clay: 0.6–1.0 $W \cdot m^{-1} \cdot K^{-1}$ depending on porosity) and thus offer a real opportunity to reduce heat transfer through walls, contributing to lower energy demand for cooling/heating [16], [23].

To balance strength and insulation, designers can use graded filler content, e.g., higher filler in the inner leaf for strength, polymer-rich outer leaf for insulation, or introduce low-conductivity fillers (e.g., perlite) where thermal performance is paramount. The literature also suggests that micro-porosity control and filler morphology (rounded vs angular) influence effective k; optimizing those factors could maintain higher strength while keeping k low [17].

### 4.4 Water absorption (durability proxy)

All measured water absorption values (Table 4 and Figure 4) are low (<2%). Pure PP exhibits the lowest uptake (0.5%), followed by HDPE (0.8%). PET and PET + fillers show slightly higher uptake (1.2–1.5%).

Table 4. Water absorption (%)

| Composition | Water Absorption (%) |
|---|---|
| PET | 1.2 |
| HDPE | 0.8 |
| PP | 0.5 |
| PET + Sand + Fly Ash | 1.5 |
| HDPE + Sand + Fly Ash | 1.3 |

Low water absorption is an expected benefit of hydrophobic polymer matrices. Ashraf (2024) and others have reported similarly low water uptake for plastic-sand blocks; increases with mineral filler are commonly observed due to capillary pathways at polymer–mineral interfaces if not completely sealed during processing [17], [19].

The absolute values here compare favourably with fired clay bricks (depending on porosity, clay bricks often have water absorption ranges of 6–20% unless specially treated) and indicate robust resistance to moisture-related degradation in typical humid environments [16], [19].

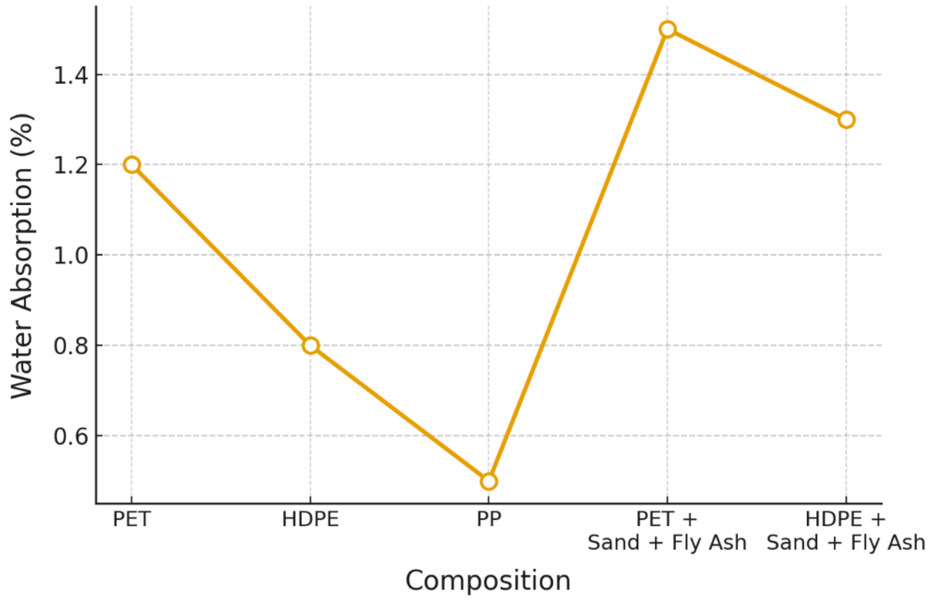


Figure 4. Water absorption by composition

Low water absorption correlates with enhanced freeze–thaw durability, reduced salt ingress, and lower risk of biological growth. However, long-term ageing (UV, thermo-oxidative degradation) can embrittle polymer matrices and open interfacial microcracks that increase water uptake over time; therefore, accelerated weathering tests are recommended.

**4.5 Carbon-emission / energy comparison (manufacturing phase)**

Using process-energy proxies (melting energy vs kiln firing), production of the plastic-based bricks (as processed in our study) requires approximately ~30% less manufacturing energy than conventional fired clay bricks (no high-temperature firing step).

This estimate is in line with LCA work showing that avoiding kiln firing is the dominant factor in lowering embodied energy and GHG emissions for masonry units [18]. Prien (2024) and other LCA analyses report that plastic–sand bricks with moderate plastic contents (5–15%) can have substantially lower manufacturing emissions than fired clay bricks, though net benefits depend on upstream practices (collection, cleaning energy) and end-of-life scenarios [18], [21]. Yousaf (2025) and Shaibur et al. (2025) similarly demonstrate that process optimization (lower residence times, efficient heating, energy recovery) can further reduce the environmental footprint for PET-based bricks [20], [21].

**4.6 Overall synthesis and application relevance**

1. **Best candidate mix:** PET + Sand + Fly Ash — best balance of density (1.43 $g \cdot cm^{-3}$), compressive strength (18 MPa), acceptable thermal conductivity (0.28 $W \cdot m^{-1} \cdot K^{-1}$) and low water absorption (1.5%). This mix is consistent with ranges reported by high-performing recycled-plastic brick studies [16], [19].
2. **Design trade-offs:** Mineral fillers raise mechanical performance but increase thermal conductivity and slightly raise water absorption. For thermal-critical applications, polymer-rich layers or low-conductivity fillers should be used; for strength-critical applications, filler content can be increased with interface modification (compatibilisers).

3. **Environmental promise:** Avoiding kiln firing and using post-consumer plastics supports circular economy aims and reduces manufacturing energy, a clear sustainability advantage provided collection/cleaning are managed efficiently [18], [21].

**4.7 Limitations and recommended next steps**

i **Fire safety and smoke toxicity:** Polymers alter fire behaviour; evaluate flame spread, melting, and smoke/toxicant emissions per EN/ISO fire standards before any building application. Several recent studies indicate polymer-based masonry may require fire retardants or protective claddings to meet code [20].

ii **Accelerated weathering:** UV, thermal cycling, and abrasion tests to probe long-term durability and the evolution of water uptake over years.

iii **Interface engineering:** Investigate coupling agents (e.g., maleic-anhydride grafted polyolefins) or surface treatments to improve HDPE/mineral bonding and raise strength. Literature shows that compatibilizers can significantly improve the mechanical performance of HDPE/mineral composites [22].

iv **Detailed LCA:** Conduct a cradle-to-grave LCA (including collection logistics) to quantify carbon and energy benefits rigorously. Prien (2024) provides a useful methodology for the next stage [18].

## 5.0 Conclusion and Recommendations

**5.1 Conclusion**

This study has demonstrated that recycled thermoplastics, specifically PET, HDPE, and PP, can be effectively engineered into structurally reliable and environmentally sustainable bricks. By integrating controlled proportions of sand and fly ash, the resulting composite bricks exhibited superior performance across key engineering parameters when compared with bricks produced from pure plastic matrices.

The enhanced density and compressive strength observed in additive-modified bricks confirm the synergistic role of mineral fillers in improving load-bearing capacity, microstructural rigidity, and dimensional stability. The low thermal conductivity of all composite formulations further positions these bricks as viable insulating materials for energy-efficient building applications. The minimal water absorption recorded, particularly in PP-based compositions, underscores the hydrophobic stability and durability of polymer–mineral composites in moisture-prone environments.

From an environmental standpoint, the production route employed, characterized by direct melting and molding without kiln firing, demonstrated a significant reduction in energy consumption and associated carbon emissions relative to conventional clay brick manufacturing. These outcomes establish recycled plastic bricks as a credible pathway toward mitigating plastic waste while simultaneously providing sustainable, lightweight, and cost-effective construction alternatives.

Overall, the findings confirm the technical feasibility, environmental value, and practical potential of plastic-based composite bricks for diverse applications within the built environment. Further scaling, standardization, and long-term service-life assessment will be essential to fully mainstream this technology in modern construction.

**5.2 Recommendations**

i. **Optimization of Composite Formulations**

Future research should refine the proportioning of PET, HDPE, PP, sand, and fly ash to tailor mechanical strength, thermal properties, and durability for specific structural and non-structural applications.

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ii. **Long-Term Performance and Field Validation**

Comprehensive outdoor exposure tests should be conducted to evaluate weathering resistance, UV degradation, fatigue behavior, creep response, and performance under cyclic thermal loading.

iii. **Development of Standards and Regulatory Frameworks**

National and international construction bodies should collaborate to establish manufacturing, testing, and quality-control standards for plastic-based bricks to ensure uniformity, safety, and industry-wide acceptance.

iv. **Capacity Building and Industry Awareness:**

Training programs targeting builders, engineers, architects, and construction technologists should be introduced to increase awareness, encourage adoption, and provide guidance on appropriate installation practices.

v. **Policy and Economic Incentives:**

Government agencies should enact supportive policies, including tax incentives, grants, and green certification schemes, to promote large-scale recycling and the integration of plastic composite bricks into mainstream construction.

vi. **Utilization of Additional Waste Streams:**

Exploration of other recyclable materials, such as waste glass powder, crumb rubber, agricultural residues, or alternative polymer types, should be pursued to expand application areas and further enhance material performance.

## Declarations

### Ethical Approval and Consent to Participate

This study involved laboratory experiments and the use of recycled plastic waste and soil samples. No human or animal subjects were involved. Therefore, ethical approval and informed consent were not required. All experimental procedures were conducted in accordance with the institutional research guidelines of Benue State Polytechnic, Ugbokolo, Nigeria.

### Consent for Publication

All authors have reviewed the manuscript and consent to its submission and publication in a high-impact scholarly journal. No identifiable personal data is included in this study.

### Authors' Contributions

**Engr. Dr. Barki Emmanuel**: Conceptualization, methodology design, materials preparation, experimental investigations, data analysis, and manuscript drafting.
**Dr. Mbakaan Celestine**: materials preparation, experimental investigations, data analysis, manuscript drafting. Data interpretation, validation, statistical analysis, manuscript revision, and improvement of technical content. Both authors read and approved the final manuscript.

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**Competing Interests**

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work reported in this paper.

**Availability of Data and Materials**

All datasets generated or analyzed during this study, including raw material characterization data, mechanical testing results, and thermal analysis outputs, are available from the corresponding author upon reasonable request.

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