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Exploring the Utilization of Plastic Sand in Construction to Drive Sustainable Practices and Foster a Circular Economy

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This research explores utilizing waste plastics in construction to promote a circular economy and mitigate plastic waste's environmental footprint in Nigeria's urban centers. Innovative bricks made from low-density polyethylene bags and sand offer thermal and sound insulation properties, pollution control, and cost reduction. The eco-friendly bricks demonstrate beneficial properties: lightweight, porous structure, low thermal conductivity, and high mechanical strength comparable to conventional bricks.The experimental process involved combining cement, sand, and waste plastic/nylon (0-15% by weight) with fly ash, followed by underwater curing and baking. Results show compressive strengths of 19.5 MPa (0% waste), 19.46 MPa (5% waste), 20.3 MPa (10% waste), and 21.1 MPa (15% waste). The bricks exhibit reduced water absorption capacity (0.085-0.34%) and lower efflorescence values.The innovative bricks offer numerous benefits: enhanced strength and durability, reduced environmental impact, and economic value for manufacturers. They contribute to sustainable construction practices, reducing sand extraction and plastic waste accumulation. This research showcases the potential for eco-friendly bricks to enhance energy efficiency in buildings and promote a sustainable ecosystem for plastic waste management.
Keywords: Plastic waste, recycled materials, sustainable construction, reinforced bricks, concrete.

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1. Introduction

Utilization of Plastic Sand in Construction

The use of plastic sand in construction is gaining attention as a sustainable practice to reduce plastic waste and promote a circular economy. Studies have shown that plastic sand can be used as a replacement for natural sand in concrete and other construction materials. Plastic Sand as a Construction Material: Al-Sinan and Bubshait (2022) reviewed the use of plastic sand as a construction material, highlighting its potential to reduce waste and promote sustainability, Recycled Plastic as Fine Aggregate: Almeshal et al. (2020) found that recycled plastic can be used as a fine aggregate in cementitious composites, reducing the need for natural sand, Engineering Properties of Concrete with Waste Recycled Plastic: Babafemi et al. (2018) studied the engineering properties of concrete with waste recycled plastic, finding it a viable alternative to traditional materials. Mortar and Concrete Composites with Recycled Plastic: Mercante et al. (2018) reviewed the use of recycled plastic in mortar and concrete composites, highlighting its potential for sustainable construction. Use of Plastic Waste as Aggregate: Saikia and de Brito (2012) explored the use of plastic waste as aggregate in cement mortar and concrete preparation. - Plastic Sand Bricks: Suriyaa et al. (2021) studied the strength behavior of plastic sand bricks, finding them a viable alternative to traditional bricks.

Mechanical and Market Study: Sanchez-Echeverri et al. (2021) conducted a mechanical and market study on sand/recycled-plastic cobbles, highlighting their potential for sustainable construction. Green-Efficient Masonry Bricks: Aneke and Shabangu (2021) developed green-efficient masonry bricks using scrap plastic waste and foundry sand. Behavior of Sand-Filled Plastic Bottled Clay Panels: Kim et al. (2019) studied the behavior of sand-filled plastic bottled clay panels for sustainable homes. Use of Recycled Plastics in Concrete: Gu and Ozbakkaloglu (2016) reviewed the use of recycled plastics in concrete, highlighting its potential for sustainable construction. Main Challenges to Concrete Recycling: Badraddin et al. (2021) identified the main challenges to concrete recycling in practice, including the use of plastic waste. Study of Sand-Plastic Composite: Tufa et al. (2021) studied the compressive strength of sand-plastic composite using optimal mixture design of experiments. Valorization of Plastic Waste: Ikechukwu and Naghizadeh (2022) explored the valorization of plastic waste for masonry bricks production, highlighting its potential for sustainable construction.

2. Material And Methods

1. Collection of Materials.
2. Batching.
3. Melting.
4. Mixing.
5. Moulding.
6. curing.

Figure 1. Dump sites for waste plastics collection in Owerri Imo.

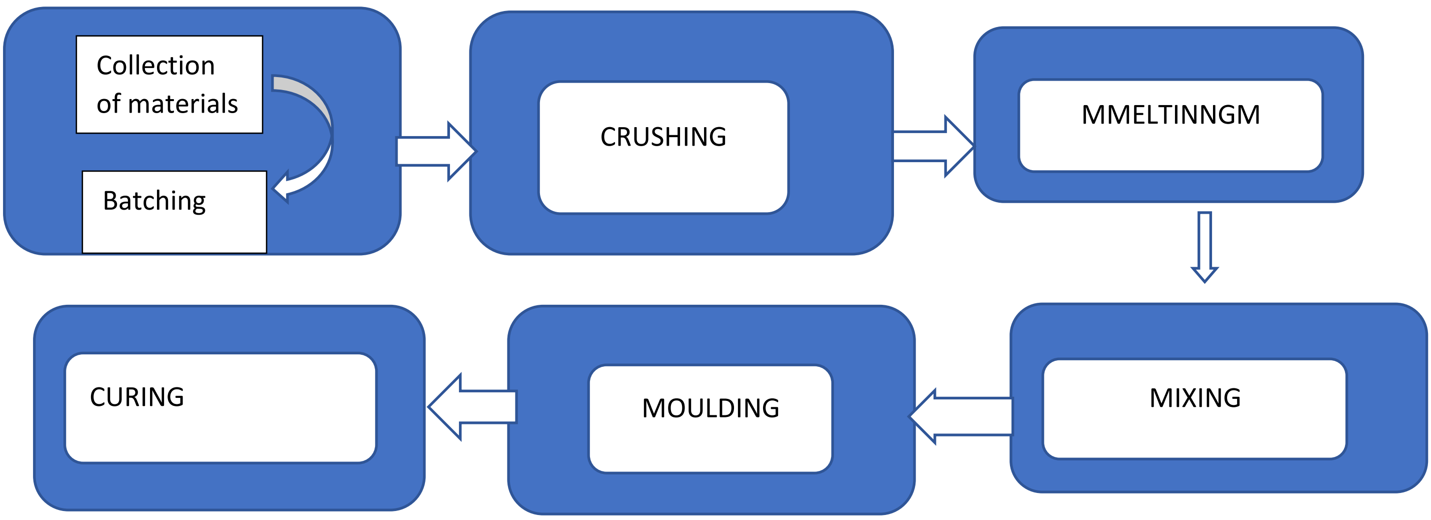

Figure 2: Plastic Brick Production Process

1. Collection of waste plastic materials
2. Bleaching (cleaning and preparation)
3. Crushing (shredding into smaller pieces)
4. Melting (heat transformation)
5. Moulding (shaping into brick form)
6. Mixing (with additives like fly ash for enhanced properties)
7. Curing (cooling and solidification)

3. Results And Discussion

Mix Design Process:

Optimal plastic:sand ratios (1:2, 1:3, 1:4) determined for strength and durability. Tested using compressive testing machine (CTM) for structural integrity and compressive strength

Table 1 plastic bricks Mix Design (Nnadikwe & Okure ,2023)

SI(NO)	SANDS(KG,S)	PLASTIC (KG,S)	CEMENT(KG,S)	FLYASH(KG,S)	PLASTIC %
Y	4.078	0.273	0.885	6.01	5
X	3.916	0.435	0.885	6.01	10
Z	3.754	0.587	0.885	6.01	15

Mix Design Analysis.

Table 1 shows varying plastic brick compositions (Y, X, Z) with 5%, 10%, and 15% plastic content. As plastic increases, sand decreases, while cement and fly ash increase. Fly ash enhances sustainability and durability. Precise ratios crucial for desired brick properties

Composition Analysis:

a. Y (5% plastic): Balanced mix, moderate plastic content
b. X (10% plastic): Higher plastic content, may alter strength and durability
c. Z (15% plastic): Highest plastic content, explores effects on strength, flexibility, and sustainability



Figure 3a displays the gathering of plastic bottles, Figure 3b demonstrates the segregation process of plastic bottles, and Figure 4a showcases the compacting of plastic bottles into bales before crushing

Figure 4b illustrates the process of compressing plastic bottles before crushing, while Figure 5a shows sand sourced from the Uyo River. In Figure 5b, the activity of categorizing and organizing materials is depicted.

Plastic Nylon Waste

Fig 5C, nylon waste is crushed, followed by the crushing of plastic waste in Fig 5D.

Plastic Sand Production Process:

1. Collected plastic waste from Owerri West, Imo, Nigeria
2. Sorted, cleaned, and melted at 120-150°C
3. Mixed with river sand and poured into brick molds (19x9x9 cm)
4. Cured for 29 days (air drying + immersion)

The Properties Of Polyethylene And Polypropylene Are:

Polyethylene:

1. High chemical resistance
2. Flexible and lightweight
3. Good electrical insulating properties
4. Resistant to moisture and impact
5. Recyclable

Polypropylene:

1. High heat resistance
2. Good chemical resistance
3. Lightweight and durable
4. Resistant to fatigue and stress cracking
5. Recyclable

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Table 2 Chemical And Mechanical Properties Of Plastic.(Nnadikwe & Okure,2023)

Material Properties.	Polyethylene(PE)	Polypropylene(pp)
Melting Temp.	110-148%	131-172oC.
Flexural modulus	0.2-1-6GPA.	1.6-2.6 GPA
IMPACT STRENTH.	6-26KJ.	40-59KJ
Tensile strength	12-49Mpa	41-59Mpa
Compressive strength	3-14MPA	10-34MPA
Elongation at break.	200-800%	300-600%

The properties of polyethylene (PE) and polypropylene (PP) based on the given table:

Melting Temperature:

1. Polyethylene (PE): Melting temperature ranges from 110-148°C.
2. Polypropylene (PP): Melting temperature ranges from 131-172°C. Analysis: Polypropylene has a slightly higher melting temperature range compared to polyethylene, indicating better heat resistance.

Flexural Modulus:

1. PE: Flexural modulus ranges from 0.2-1.6 GPa.
2. PP: Flexural modulus ranges from 1.6-2.6 GPa. Analysis: Polypropylene exhibits higher flexural modulus values, indicating greater stiffness and resistance to deformation compared to polyethylene.

Impact Strength:

1. PE: Impact strength ranges from 6-26 kJ.
2. PP: Impact strength ranges from 40-59 kJ. Analysis: Polypropylene shows significantly higher impact strength values than polyethylene, suggesting better resistance to impact and toughness.

Tensile Strength:

1. PE: Tensile strength ranges from 12-49 MPa.
2. PP: Tensile strength ranges from 41-59 MPa. Analysis: Polypropylene has higher tensile strength values, indicating better resistance to stretching or pulling forces compared to polyethylene

Compressive Strength

1. PE: Compressive strength ranges from 3-14 MPa.
2. PP: Compressive strength ranges from 10-34 MPa. Analysis: Polypropylene demonstrates higher compressive strength values, indicating better resistance to squeezing forces.

Elongation At Break:

PE: Elongation at break ranges from 200-800%.PP: Elongation at break ranges from 300-600%. Analysis: Polyethylene shows a wider range ofelongation values, suggesting better ability to stretch before breaking compared to polypropylene.

Table 3 : Chemical Components of Polyethylene (PE) and Polypropylene(PP)(Nnadikwe & Okure,2023)

Chemical Component.	Polyethylene(PE)	Polypropylene(pp)
Hydrogen	13.7-15.7%	13.7-15.7%
Carbon	86.1-98.4%	87.0-89.5%
Other	0-3.6%	0.-3.8%

Chemical Composition:

Polyethylene (PE):

1. Hydrogen: 13.7-15.7%

2. Carbon: 86.1-98.4%
3. Other: 0-3.6%

Polypropylene (PP):

1. Hydrogen: 13.7-15.7%
2. Carbon: 87.0-89.5%
3. Other: 0-3.8%.

Tables 4: physical properties of cement(Nnadikwe & Okure,2023)

Serial (number)	Standards	Tests
1	28% to 37%	Consistency in standard quality.
2	595minutes.	The final time setting
3	3.21 to 3.13	The specific gravity.
4	35minutes	The final time setting
5	Really Not less than 94%	The Fineness.

Cement Physical Properties:

a. Initial Setting Time: 35 minutes
b. Final Setting Time: 595 minutes
c. Fineness: ≥ 94%
d. Specific Gravity: 3.13-3.21
e. Standard Consistency: 28-37% water content

Fly Ash & River Sand:

a. Fly Ash: Fine powder from coal combustion, used as cement substitute, enhances concrete strength & durability.
b. River Sand: Natural, high-quality aggregate, but scarce due to depletion & regulations. Quarrying supports Nigeria's economy, but needs sustainable practices

Table 5: The Sand Properties(Nnadikwe & Okure,2023)

SERIAL NUMBER>	COMPOSITION(TEXTURE)	WEIGHT OF %
1	SAND COARSE (4.85-2.0MM)	7.7
2	SAND MEDIUM COARSE (2.00-0.425MM)	83.6
3	SAND FINE (0.525-0.085)	20.8

Sand Properties:

a. Medium Coarse (2.00-0.425mm): 83.6%
b. Fine (0.525-0.085mm): 20.8%
c. Coarse (4.85-2.0mm): 7.7%

Medium-coarse sand dominates, influencing sand's overall properties and use

Table 6 . Chemical Composition of fly as(Nnadikwe & Okure,2023)

SERIAL NO.	PERCENTAGE	COMPONENT.
1	36- 39	Sio2
2	0.6- 1.6	SO3
3	1 -6.5	MgO
4	23- 38	AL2O3
5	0.6- 3	Fe2O3
6	6 -17	CaO

Fly Ash Chemical Composition:

a. Silicon Dioxide (SiO_2): 36-39%
b. Aluminum Oxide (Al_2O_3): 23-38%
c. Calcium Oxide (CaO): 6-17%

d. Magnesium Oxide (MgO): 1-6.5%
e. Iron Oxide (Fe2O3): 0.6-3%
f. Sulfur Trioxide (SO3): 0.6-1.6%

These components influence fly ash's reactivity, strength, and environmental impact

Fly Ash Composition:

SiO2, Al2O3, Fe2O3, CaO, MgO, SO3 - these components determine fly ash's reactivity, fineness, and durability, making it suitable for concrete, roads, and sustainable construction

Table 7: The Physical Properties of fly Ash(Nnadikwe & Okure)

The Serial(No)	Standards	Tests
1	2.65	The specific gravity
2	Percentage.	The fineness

Fly Ash Physical Properties:

a. Specific Gravity: 2.65 (lighter than water)
b. Fineness: % (impacts reactivity and performance)

These properties determine fly ash's suitability for construction, agriculture, and other uses

Compressive Strength Test:

Evaluates plastic bricks' ability to withstand loads, ensuring structural integrity, load-bearing capacity, and durability for safe construction

The water absorption test: is a vital assessment of plastic bricks' quality and durability. It measures the amount of water that a plastic brick can absorb, which is crucial in evaluating its:

1. Water resistance
2. Durability
3. Potential for degradation
4. Structural integrity

Excessive water absorption can lead to:

1. Reduced strength
2. Decreased durability
3. Increased risk of structural issues
4. Potential for water damage

The efflorescence test:is a crucial evaluation of plastic bricks' quality and appearance. It assesses the likelihood of soluble salts migrating to the surface of the brick, causing unsightly white deposits. This test is important because efflorescence can:

1. Affect the appearance of the bricks
2. Impact their longevity
3. Reduce their aesthetic appeal

The crushing test:is a vital evaluation of plastic bricks' mechanical properties and durability. By simulating intense pressure conditions, this test assesses the brick's ability to:

1. Withstand crushing forces
2. Resist deformation or breakage
3. Maintain its structural integrity

The results of the crushing test provide essential insights into the plastic brick's:

1. Mechanical properties
2. Durability
3. Performance characteristics
4. Quality and reliability

Figure 6. Melted Plastic And Nylon

Compressive Strength Formula:

Compressive Strength = Maximum Load (N) / Cross-Sectional Area (m^2)

Calculates brick strength at different curing intervals (7, 14, 29 days) to assess durability and performance

Curing Period:

Allows plastic bricks to harden, achieving maximum strength. Duration varies (7, 14, 28 days), depending on production process and materials

The curing period is essential for:

1. Allowing the plastic material to fully harden
2. Achieving maximum strength and durability
3. Enhancing the brick's resistance to water and moisture
4. Improving the brick's overall performance and quality

The testing setup : for evaluating the compressive strength of plastic bricks involves:

1. Calibrated compression testing machine with a capacity of 3000 kN
2. Uniform load application at a rate of 2.9 kN/min
3. Bricks placed in the machine to undergo compressive loading

This setup allows for:

1. Accurate measurement of compressive strength
2. Consistent testing conditions
3. Reliable evaluation of brick performance

By using a calibrated machine with a controlled loading rate, the test ensures precise results, enabling a reliable assessment of the plastic bricks' compressive strength and their suitability for construction applications.

The maximum load: is the highest load applied to the brick during the compression test, at which point the brick fails, either by:

1. Deformation (crushing or flattening)
2. Fracture (breaking or cracking)

By determining the maximum load, you can evaluate the brick's:

1. Compressive strength
2. Load-carrying capacity
3. Resistance to deformation and fracture

The compressive strength calculation formula is:

Compressive Strength = (Maximum Load in Newtons x 1000) / Cross-Sectional Area of the Specimen in mm^2

This formula allows you to calculate the compressive strength of the bricks in units of megapascals (MPa) or Newtons per square millimeter (N/mm^2).

The water absorption test involves the following steps:

1. Initial Drying: The bricks are dried in an oven at a temperature of 100°C to 120°C until they reach a constant weight. This step ensures that all moisture is removed from the bricks, providing a dry baseline for the test.

This step is crucial in determining the brick's water absorption properties, as it allows for:

a. Removal of any initial moisture present in the brick
b. Standardization of the brick's dry weight
c. Accurate measurement of water absorption

The next step in the water absorption test is:

1. Weighing: After drying, the bricks are cooled to room temperature and weighed (W1) to determine their initial dry weight. This initial weight serves as a reference point for the upcoming water absorption test.

This step is important because it:

a. Provides a precise measurement of the brick's dry weight
b. Establishes a baseline for comparison with the weight after water absorption
c. Enables calculation of the percentage of water absorption

The water absorption test continues with:

1. Water Immersion: The dried and weighed brick (W1) is then immersed completely in clean water for 24 hours at a temperature of 27±2°C. This allows the brick to absorb water under controlled conditions.

This step is crucial in determining the brick's water absorption properties, as it:

a. Allows the brick to absorb water uniformly and consistently
b. Enables the brick to reach its maximum water absorption capacity
c. Provides a controlled environment for testing, minimizing external factors that could affect the results

1. Weighing After Immersion: After 24 hours, the brick is removed from the water, any traces of water are wiped off, and the brick is weighed immediately (W2). This weight (W2) reflects the total weight of the brick after absorbing water.

This step is important because it:

a. Measures the weight of the brick after water absorption
b. Provides the total weight of the brick, including the absorbed water
c. Allows for the calculation of the percentage of water absorption

The water absorption percentage is calculated using the formula:

Water Absorption (%) = ((W2 - W1) / W1) x 100

Where:

W1 is the initial dry weight of the brick

W2 is the weight of the brick after water immersion

This formula calculates the percentage increase in weight due to water absorption, providing a quantitative measure of the brick's water absorption properties.

The acceptance criteria: for water absorption in bricks is typically set at a maximum of 12% of their weight. If the water absorption percentage is equal to or less than 12%, the bricks meet the standard requirement for water absorption.

By following this method, you can:

1. Accurately determine the water absorption characteristics of the bricks
2. Assess their quality and durability
3. Evaluate their suitability for various construction applications

The formula for calculating water absorption in percentage weight, highlighting the importance of:

1. W1 (initial weight of the dried brick)
2. W2 (weight of the brick after immersion in water)

The efflorescence test: is a crucial procedure for evaluating the susceptibility of bricks to efflorescence, a phenomenon characterized by the formation of white salt deposits on the surface. The test involves:

1. Positioning the brick vertically with one end submerged in water (2.5 cm depth)
2. Placing the setup in a warm, well-ventilated environment (20-30°C) until the water is fully absorbed and evaporated
3. Repeating the process for a second cycle to ensure thorough testing
4. Evaluating the brickwork by calculating the percentage of white spots (salt deposits) on the surface area
5. Classifying the brick as "efflorescent" if white spots or salt deposits are present, or "not efflorescent" if no disparities are detected

The soundness test: is a simple yet effective way to evaluate the quality and durability of bricks. By striking two bricks against each other, you can determine if they:

1. Produce a clear, ringing sound
2. Remain intact without breaking or cracking

A positive result indicates that the bricks are:

1. Structurally sound
2. Of good quality
3. Able to withstand impact without damage
4. Likely to be durable and long-lasting

The soundness test is a valuable assessment tool because it:

1. Evaluates the brick's ability to absorb impact without breaking
2. Indicates the brick's resistance to cracking and damage
3. Provides a quick and easy way to assess brick quality

By conducting this test, We gain confidence in the bricks' ability to perform well in construction projects, ensuring a strong and durable structure.

The crushing test:is a vital assessment for evaluating the suitability of bricks for construction purposes. This test:

1. Determines the compressive strength of the brick
2. Evaluates the brick's load-bearing capacity
3. Assesses the brick's durability
4. Helps construction professionals make informed decisions about brick quality and suitability

The test procedure involves:

1. Placing a brick in a compression testing machine
2. Applying pressure until the brick breaks
3. Measuring and recording the compression strength from the machine's gauge
4. Ability to withstand compressive forces
5. Resistance to deformation and damage
6. Suitability for various construction applications

4. Test Results

Table 8: The Compressive strength test(Nnadikwe & Okure,2023)

Numbers of sample.	% plastics	The strength of compressive.
1	0	19.5
2	5	19.46

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Numbers of sample.	% plastics	The strength of compressive.
3	10	20.3
4	15	21.1

Table 8: Compressive Strength Test (Nnadikwe & Okure, 2023)

a. Numbers of sample: Refers to the individual brick samples tested
b. % plastics: Indicates the percentage of plastic content in the brick samples (0%, 5%, 10%, or 15%)
c. The strength of compressive: Represents the compressive strength of each brick sample in units of Newtons (N) or megapascals (MPa)

Analysis:

1. Control sample (0% plastics): The compressive strength is 19.5 N/MPa, which serves as a reference point for comparison with the other samples.
2. 5% plastics: The compressive strength is 19.46 N/MPa, which is slightly lower than the control sample. This suggests that the addition of 5% plastics may have a minimal impact on the brick's compressive strength.
3. 10% plastics: The compressive strength increases to 20.3 N/MPa, indicating that the addition of 10% plastics may have a positive effect on the brick's compressive strength.
4. 15% plastics: The compressive strength further increases to 21.1 N/MPa, suggesting that higher plastic content may lead to higher compressive strength.

Trends and Observations:

a. The compressive strength of the bricks appears to increase with increasing plastic content.
b. The addition of plastics beyond 10% may lead to a more significant increase in compressive strength.
c. The results suggest that the optimal plastic content for achieving higher compressive strength may be between 10% and 15%.

Limitations and Future Work:

a. The sample size is limited to four data points, and more extensive testing would be beneficial to confirm these trends.
b. The test results only consider compressive strength and do not account for other essential properties like water absorption, efflorescence, or durability.

Figure 7 Ecofriendly Brick From Plastic

Eco-friendly bricks can be made from plastic in the following ways

a. Eco bricks are made by compressing soft plastic waste into empty plastic bottles and can be used to make furniture, walls and other simple structures.

b. Plastic and other waste products can be combined with cement and other building materials to create a sustainable building material.
c. Plastic bottles can be used as a mold for bricks made from a mixture of cement, sand, and stubble (agricultural waste).
d. Waste plastic polybags can be used to make bricks, either on their own or combined with other materials

Tables 9: The Water absorption(Nnadikwe & Okure,2023)

Number of samples	Water Absorption	% of plastic
1	0.34	0
2	0.25	5
3	0.22	10
4	0.20	15

Water Absorption Results:

a. 0% plastic sand: 0.34% (high)
b. 5% plastic sand: 0.25% (26% decrease)
c. 10% plastic sand: 0.22% (35% decrease)
d. 15% plastic sand: 0.20% (41% decrease)

Adding plastic sand reduces water absorption, improving durability and resistance to weathering

7. Conclusion

The research showcases plastic sand bricks made from waste plastic as a sustainable solution for construction. These bricks exhibit superior quality, durability, and compressive strength (5.6 N/mm^2), outperforming traditional materials like Fly Ash bricks and clay bricks. With zero water absorption, they're ideal for structural applications. This innovative approach tackles environmental pollution, reduces clay usage, and provides a cost-effective alternative. The plastic sand bricks offer a competitive advantage, aligning with sustainable development principles. By adopting this technology, the construction industry can reduce its environmental footprint while creating durable structures. This transformative material has the potential to revolutionize sustainable construction practices.

Recommendations for Plastic Sand Bricks

1. Further Testing: Assess long-term durability, thermal properties, and environmental resistance.
2. Scale-Up Production: Explore cost-effective manufacturing and partnerships for large-scale production.
3. Environmental Impact: Evaluate sustainability benefits, including waste reduction and energy savings.
4. Market Strategy: Develop a plan for market introduction, collaborations, and showcasing benefits.
5. Regulatory Compliance: Ensure compliance with industry standards and obtain necessary certifications.

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