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Experimental Evaluation of Rubber-Plastic Solid Sandcrete Blocks under Marine Water Exposure

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ABSTRACT

This study experimentally evaluates the performance of solid sandcrete blocks incorporating recycled polyethylene terephthalate (PET) plastic and crumb rubber as partial replacements for fine aggregate under marine water exposure. A Taguchi L9 orthogonal array was employed to design nine mixes, with replacement levels ranging from 0% to 15% for each waste material. The blocks were tested for water absorption and compressive strength after 14 days of curing. Results indicate that the inclusion of these hydrophobic waste materials significantly enhances water resistance; a mix with 20% plastic and 20% rubber reduced water absorption by 32% compared to the conventional sscontrol block. However, a substantial trade-off was observed in compressive strength, which decreased significantly with increasing waste content. All modified mixes failed to meet the Nigerian Industrial Standard (NIS 87:2004) for load-bearing blocks (3.45 MPa), with strengths falling as low as 0.94 MPa. Statistical analysis identified an optimal mix with 7.5% plastic and 7.5% rubber, offering a balance of improved durability (9.12% absorption) and a compressive strength of 1.85 MPa. The study concludes that while these rubber-plastic sandcrete blocks are unsuitable for structural applications, their superior resistance to water ingress makes them a viable, sustainable material for non-structural applications in marine environments.

7. INTRODUCTION

Sandcrete block is a predominant masonry unit used as walling material in the construction of shelters and other infrastructures, particularly in West Africa (Abdel et al., 2020). Conventionally, it is made from a mixture of Portland cement and sharp sand in a ratio typically between 1:5 to 1:8, with a minimum amount of water (Rodriguez, 2023). The consideration of composite blocks incorporating waste materials helps to advance sustainable construction practices by reducing environmental pollution and adding value to waste products (Ameh and Nwaigwe, 2017). The global consciousness towards eco-friendly constructions has driven the discovery of alternative and sustainable uses for waste materials like plastic and rubber (Jassim, 2017).

Building failures, often linked to substandard materials, have resulted in significant loss of lives and properties in Nigeria (Odeyemi et al., 2017). Furthermore, Nigeria faces environmental challenges such as flooding and pollution caused by indiscriminate disposal of rubber-tyre and plastic waste. This study is justified by the increasing demand for durable, eco-friendly construction materials suitable for coastal applications. Marine environments pose significant challenges to conventional materials due to high salinity, moisture, and temperature variations, which accelerate degradation (Abdulwahab and Tunde, 2017). By incorporating recycled rubber and plastic into sandcrete blocks, there is potential to enhance durability, reduce environmental impact through waste repurposing, and provide a sustainable alternative for marine construction (Jassim, 2017). However, the performance of such composites under prolonged marine exposure needs comprehensive evaluation to ensure structural safety and guide material innovation.

Previous research has explored the use of these materials. For instance, Abdel et al. (2020) investigated recycling waste plastic bags as a cement replacement in bricks and blocks. Jassim (2017) focused on producing plastic cement from polyethylene waste. This study navigates a different path by using plastic (PET) and rubber as partial aggregate replacements in sandcrete blocks, specifically evaluating their performance under marine water exposure to improve serviceability in water-logged environments. The minimum compressive strength of sandcrete stated in the Nigeria Industrial Standard (NIS 87:2004) ranges between 2.5N/mm² for non-load bearing and 3.45N/mm² for load-bearing blocks.

2. MATERIALS AND METHODS

2.1. Materials

Materials Four primary materials were used for the production of the solid sandcrete blocks: cement, fine aggregate (sand), crumb rubber, and plastic waste.

2.1.1: Fine Aggregates

Natural sharp sand conforming to ASTM C33 was obtained from a quarry in Ikorodu, Lagos State, Nigeria.

2.1.2: Crumb Rubber

Processed from waste automobile tires, sourced from a recycling plant in Abule-Egba, Lagos State. The rubber was sieved to pass a 4.75mm sieve.

2.1.3: Water

Potable tap water used for mixing was obtained from the Civil Engineering Laboratory at Lagos State University of Science and Technology, Ikorodu, Lagos State. Clean, uncontaminated water is essential in concrete production to ensure proper hydration of cement and to avoid adverse chemical reactions. Laboratory-grade potable water adheres to standard specifications, thereby enhancing the quality and strength of the concrete produced.

2.1.4: Plastic

Shredded Polyethylene Terephthalate (PET) from post-consumer water bottles, obtained from a waste collection facility in Ikeja, Lagos State. The plastic was washed, dried, and shredded to a maximum size of 5mm.

2.1.5: Cement

Dangote 3X Ordinary Portland Cement (42.5R grade), purchased from a licensed distributor in Lagos State, Nigeria.

2.2: Mix Design and Experimental Plan

This study adopted a 1:6 cement-to-sand mix ratio by weight, a common ratio for non-structural sandcrete blocks in Nigeria as it provides a balance between cost and minimum strength requirements Rodriguez, 2023. The optimal proportions of plastic and rubber as partial sand replacements were determined using a Taguchi L9 (3^3) orthogonal array design in Minitab 19 software. This design was chosen to efficiently analyze the effect of three factors (Sand, Plastic, Rubber replacement levels) each at three levels (0%, 7.5%, 15% for Plastic and Rubber; sand content was adjusted accordingly), requiring only 9 experimental runs instead of a full factorial 27. The mix proportions for the nine experimental designs are shown in Table 1.

Table 1: Taguchi L9 Orthogonal Array Mix Design

Run Order	Sand (%)	Plastic (%)	Rubber (%)	Cement (%)
1	100	0	0	100
2	100	0	7.5	100
3	100	0	15	100
4	92.5	7.5	0	100
5	92.5	7.5	7.5	100
6	92.5	7.5	15	100
7	85	15	0	100
8	85	15	7.5	100
9	85	15	15	100

2.3 Sample Preparation and Testing Procedures

Sample Preparation and Curing For each mix, the dry constituents (sand, rubber, plastic) were first mixed homogeneously. Cement was then added and mixed further. Water was added gradually to achieve a uniform, workable mix. The mixture was placed in standard 450mm x 225mm x 225mm block moulds and compacted in three layers. For conventional cement-sand blocks, wet curing was adopted by covering with damp burlap for 24 hours before demoulding, then water curing for 13 days. For rubber-plastic modified blocks, membrane curing was adopted by sealing them in plastic sheets to prevent moisture loss, as water immersion could prematurely affect the hydrophobic additives. All blocks were cured for 14 days before testing.

2.3.1: Sieve Analysis

Sieve analysis is a widely used laboratory method for determining the particle size distribution of granular materials such as soil or aggregates. Conducted on sand, rubber, and plastic according to ASTM D422-63. The process began with the careful collection of a representative soil sample. The sample was first oven-dried at a temperature of 105–110°C for at least 24 hours to eliminate moisture content, ensuring accurate weight measurements during sieving. Once the shaking process was completed, the mass of soil retained on each sieve was carefully collected and weighed. The weight retained on each sieve was then used to calculate the cumulative percentage passing each sieve size. These values were plotted on a semi-logarithmic graph to form the particle size distribution curve. From this curve, key particle sizes were determined, specifically D10 (the particle size at which 10% of the sample is finer, D30 and D60 where obtained from the curve.

2.3.2: Water Absorption Capacity

The water absorption test is a crucial laboratory procedure used to determine the porosity and durability of concrete or block samples. Conducted after 14 days of curing according to ASTM C140. Blocks were oven-dried, weighed (W_dry), immersed in marine water (collected from the Lagos Lagoon) for 24 hours, then weighed again (W_sat).

$$\text{Absorption} = [(W_{sat} - W_{dry}) / W_{dry}] * 100\% \quad (1)$$

2.3.3: Compressive Strength Test

Conducted on a 150mm x 150mm sampled cube from each block type at 14 days using a compressive testing machine according to BS EN 12390-3.

3. RESULTS AND DISCUSSION

3.1: Sieve Analysis and Specific Gravity Results

Sieve Analysis (Figure 1) and Specific Gravity Sieve analysis results showed that the sand had a coefficient of uniformity (Cu) of 3.2 and a coefficient of curvature (Cc) of 1.4. According to the Unified Soil Classification System (USCS), since Cu < 6, the sand is poorly graded (SP). The rubber (Cu = 2.6, Cc = 0.9) and plastic (Cu = 4.4, Cc = 1.38) were also found to be poorly and moderately graded, respectively. The limited range of particle sizes in all materials can affect inter-particle bonding and density within the block matrix.

The specific gravity was found to be 2.44 for sand,0.96 for rubber, and 0.97 for plastic. The lower values for rubber and plastic confirm their lightweight nature, which directly contributes to the reduced density of the composite blocks. The lower values for rubber and plastic confirm their lightweight nature, which directly contributes to the reduced density of the composite blocks.

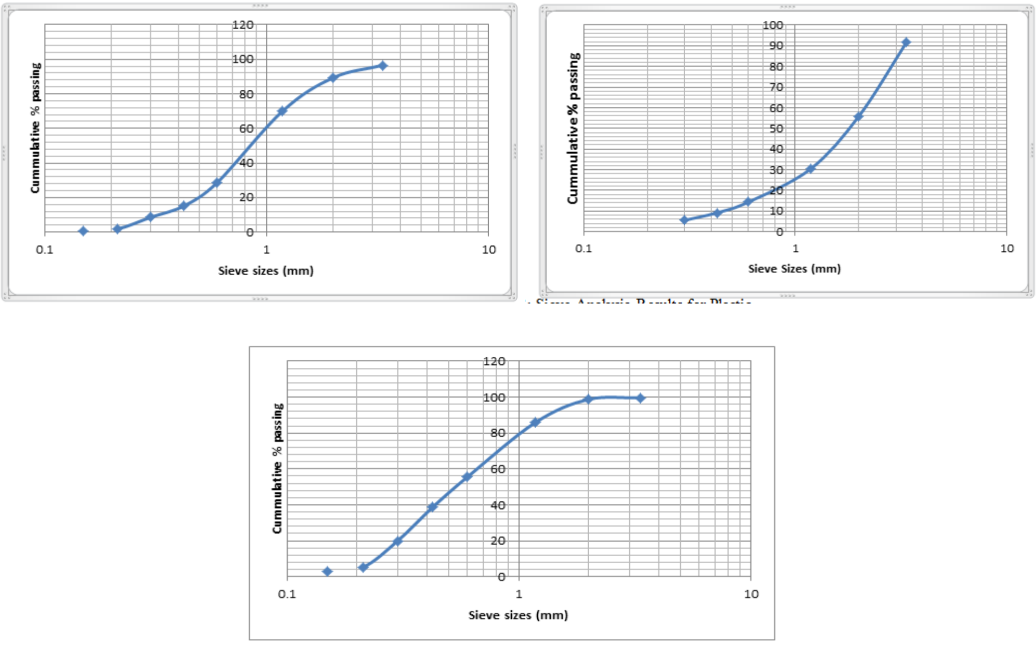

Figure 1: Sieve Analysis Result (Sand, Plastic and Rubber from top left)

3.2: Water Absorption Capacity Result

Water Absorption Performance Water absorption tests revealed that the inclusion of hydrophobic plastic significantly improved the block's resistance to water ingress. The results for key mixes are summarized in Table 2.

Table 2: Water Absorption Test

Mix ID	Sand (%)	Plastic (%)	Rubber (%)	Absorption Capacity (%)
Control	100	0	0	11.31
A	80	20	20	7.68
B	92.5	7.5	7.5	9.12
C	85	5	10	10.38

The control mix exhibited high absorption (11.31%), indicating the poor quality of the sand used. The mix with 20% plastic and 20% rubber (Mix A) showed a remarkable 32% reduction in absorption (7.68%), outperforming conventional sandcrete blocks which typically absorb 10-15% water. This is attributed to the hydrophobic nature of plastic, which reduces capillary action and pore connectivity. The optimal Taguchi mix with 7.5% each of plastic and rubber (Mix B) also showed improved performance with 9.12% absorption.

3.3: Compressive Strength Test Result

Results Compressive strength results shown in Table 3, demonstrated a clear negative correlation with waste content.

Table 3: Compressive Strength Results at 14 Days

Mix ID	Sand (%)	Plastic (%)	Rubber (%)	Load (kN)	Strength (MPa)
Control	100	0	0	230.0	5.11
Mix 3	100	0	15	95.0	2.11
Mix 5	92.5	7.5	7.5	83.3	1.85
Mix 6	92.5	7.5	15	47.5	1.06
Mix 9	85	15	15	42.5	0.94

The control mix (5.11 MPa) exceeded the NIS 87:2004 requirement of 3.45 MPa for load-bearing blocks. However, all modified mixes fell below this threshold. The strength reduction is severe at higher replacement levels, with Mix 9 (15% each) achieving only 0.94 MPa. This is due to the poor bond between the cement paste and the non-polar, smooth surfaces of the plastic and rubber particles, creating weak zones in the matrix.

3.4: Statistical and Correlation Analysis

The signal-to-noise(S/N) ratio analysis (Figure 2) from the Taguchi method identified the optimal mix for balanced properties as 7.5% plastic and 7.5% rubber (Mix 5). Pearson correlation analysis revealed a very strong negative correlation between plastic content and compressive strength (r = -0.981, p-value = 0.019). A linear regression model was developed: Compressive Strength (MPa) = 4.92 - 0.186(Plastic %) - 0.107(Rubber %) The model had an R^2 value of 66.85%, indicating that approximately 67% of the variability in strength is explained by the waste content. The p-value for the model was 0.182, suggesting the relationship, while strong, should be interpreted with caution due to the small sample size and other potential influencing factors not captured in the model.

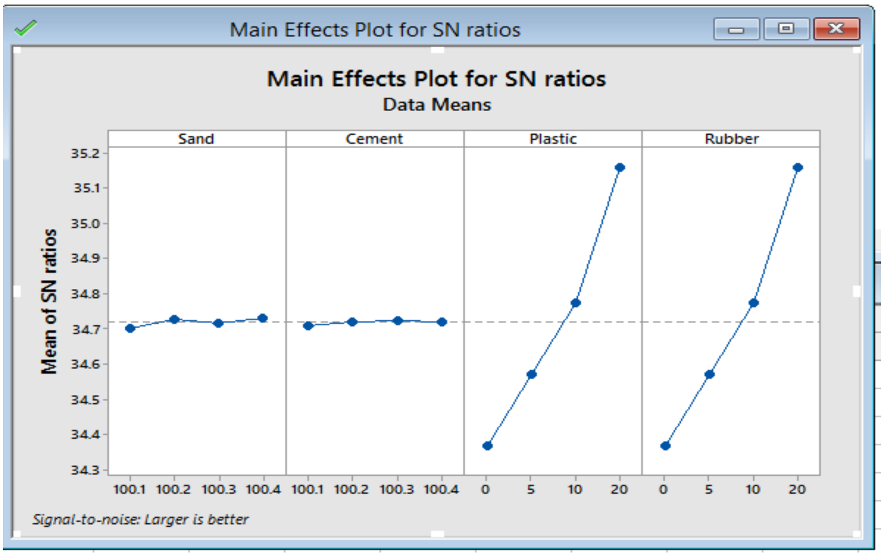

Figure 2: DOE Result

The optimal mix (7.5% plastic, 7.5% rubber) presents a compromise, offering a compressive strength of 1.85 MPa and a water absorption of 9.12%. While this strength is unsuitable for load-bearing walls, its significantly improved water resistance makes it viable for various non-structural applications in marine and water-prone environments. These include: Revetment blocks for shoreline protection against erosion, drainage liners and channel blocks, non-load bearing partition walls in coastal buildings, paving blocks for walkways and jetties and landscaping and garden edging blocks.

To enhance the strength for more demanding applications, future work should investigate surface treatments of the waste materials (e.g., acid etching) or the incorporation of pozzolanic additives like fly ash to improve the cementitious matrix's bonding and density.

4. CONCLUSION

Based on the experimental evaluation of rubber-plastic solid sandcrete blocks under marine water exposure, the following conclusions are drawn:

i. The incorporation of PET plastic and crumb rubber significantly improves the water resistance of sandcrete blocks. A mix with 20% of each waste material reduced water absorption by 32% compared to the control.
ii. The inclusion of these waste materials leads to a significant reduction in compressive strength. All mixes with waste content failed to meet the Nigerian Industrial Standard for load-bearing blocks (3.45 MPa).

Recommendations

It is recommended that, this can be used for revetment blocks for shoreline protection against erosion, drainage liners and channel blocks, non-load bearing partition walls in coastal buildings, paving blocks for walkways and jetties and landscaping and garden edging blocks.

NOMENCLATURE

%	Percentage
kN	Kilo-Newton

Abbreviations

Wsat	Saturated Weight
Wdry	Dry Weight
ASTM	American Standard Testing Machine
DOE	Design of Experiment

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