

Performance Evaluation of Lightweight Papercrete Blocks Produced Using Waste Paper

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Abstract

This study investigates the suitability of waste paper pulp as a partial replacement for fine aggregates in mortar production, with the aim of developing lightweight, sustainable, and functional papercrete blocks. Waste paper was incorporated into mortar mixes at replacement levels of 0–100%, and the resulting blocks were tested for density, water absorption, compressive strength, fire resistance, and acoustic insulation following ASTM and BS EN standards. Results revealed that density decreased progressively from 2032.2 kg/m³ (PS-00) to 657.0 kg/m³ (PP-100), classifying mixes from PP-20 to PP-100 as lightweight blocks suitable for non-load-bearing applications. Water absorption increased significantly from 6.3% to 59.8%, with only the control sample meeting NIS/BS requirements ($\leq 12\%$). Compressive strength reduced from 3.8 N/mm² to 0.36 N/mm², indicating that mixes with up to 10–20% paper content are structurally viable, while higher percentages are suitable for acoustic or decorative panels. Fire resistance decreased from 45 to 5 minutes with increasing paper content, whereas acoustic performance improved from 30 dB to 46 dB due to increased porosity. The study concludes that waste paper enhances sustainability and acoustic performance but compromises strength and fire resistance at higher percentages; therefore, the optimum mix falls within 10–20% paper replacement for lightweight, non-load-bearing construction applications.

I. INTRODUCTION

Sandcrete blocks remain the most widely used walling material in Nigeria, accounting for more than 90% of building wall systems [1]. Defined by the Nigerian Industrial Standard [2] and British Standard [3], sandcrete consists primarily of cement, sand, and water and is

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***Related declarations are provided in the final section of this article.*

Manufactured in both solid and hollow units for masonry construction. Although these blocks are popular due to availability and ease of production, their relatively high density increases the dead load of buildings, requiring larger structural members and increasing construction costs. Furthermore, reliance on sand an increasingly scarce and non-renewable resource raises environmental concerns related to depletion, erosion, and ecological disturbance [4], [9] and [10].

In response to the demand for sustainable and lighter masonry materials, research attention has shifted toward alternative composites such as papercrete, a material produced by combining Portland cement with waste paper pulp, sand, and water. Papercrete utilizes waste paper as a partial or full replacement for fine aggregates, thereby reducing block weight and transforming paper waste into a construction resource [5]. The incorporation of paper fibers introduces air voids within the cement matrix, resulting in significantly lower density and improved workability compared to conventional sandcrete [6] and [10]. Lightweight building units reduce the imposed load on foundations and columns, offering structural and economic benefits, particularly in low-rise and non-load-bearing construction.

Despite increasing interest, the widespread adoption of papercrete in the Nigerian construction sector remains limited due to uncertainty regarding performance criteria such as compressive strength, water absorption, fire resistance, and acoustic insulation properties critical for compliance with [2] and [7] standards. The practical viability of papercrete depends not only on whether strength and durability remain adequate at different waste paper replacement levels but also on whether the material offers added functional advantages, such as thermal and sound insulation, that justify its use over sandcrete [8] and [10]. Therefore, scientific evaluation of the mechanical and physical behaviour of papercrete is essential to determining its suitability for real-world applications.

This study evaluates the performance of lightweight papercrete blocks produced using waste newspaper and office paper, focusing on density, water absorption, compressive strength, acoustic insulation, and fire resistance. The objectives are to determine the suitability of waste paper in mortar mix for block production, assess changes in fresh and hardened block properties due to waste paper incorporation, develop an optimum mix proportion, and evaluate the potential of waste paper pulp as a sustainable block material. By providing empirical data and performance benchmarks, this research contributes to sustainable construction knowledge in

Nigeria, promotes recycling of solid waste, and demonstrates how waste paper can serve as an innovative alternative to sandcrete in lightweight and non-load-bearing applications.

I. Paper as a Potential Composite Material



Plate I: Prepared Paper Waste

Plate II: Weighing of Paper Pulp for Batching and Mixing

Recent advances in sustainable construction have highlighted waste paper as a promising composite material due to its cellulose fiber content, low density, and porosity, enabling the development of lightweight and eco-efficient building components. Several studies have explored paper as reinforcement in cementitious composites, demonstrating improved workability, reduced density, and enhanced acoustic performance [21, 27]. Paper fibers act as micro-reinforcement, reducing crack propagation and improving bonding with cement matrices [23, 25]. Research by [6] and [9] showed that ground or chemically modified waste paper increases the fiber–matrix interfacial adhesion, enhancing mechanical and durability performance. Beyond blocks, paper-based composites have been successfully developed into fiber-reinforced panels, ceiling boards, insulation boards, and interior acoustic partitions, benefitting from their sound-absorbing properties and low thermal conductivity [16, 27]. These applications support the global shift toward renewable materials and carbon-reducing technologies in construction, aligning with [5], who emphasize that using recycled materials reduces construction-related carbon emissions.

Despite its benefits, paper as a composite material introduces challenges, including increased water absorption, reduced compressive strength, and susceptibility to biological degradation [8],[28]; and [24]. However, research shows that modification techniques such as incorporating pozzolanic additives (rice husk ash, fly ash, silica fumes) or adding fire retardants can

significantly improve dimensional stability, moisture resistance, and fire performance [11], [32] and [18]. For example, [31] and [10] confirmed that alkaline-treated cellulose fibers improve the structural integrity and load transfer capability of fiber-based composites. In non-structural applications such as interior partitions, acoustic panels, false ceilings, thermal insulation boards, and lightweight decorative units, papercrete and paper-based composites outperform traditional sandcrete blocks in terms of lower density and better acoustic attenuation [20], [30], [15] and [19]. Thus, literature shows a growing agreement that incorporating waste paper into composites is not only technically feasible but also aligns with sustainability and circular-economy goals, reducing landfill loads and promoting green material innovation in the construction industry.



Plate III: Mixing of Aggregates



Plate IV: Produced Block for Curing

II. Materials and Methods

Research Design

An experimental research design was adopted to evaluate the influence of waste paper pulp as a partial replacement for fine aggregate in mortar for papercrete block production. The independent variable was the percentage of paper pulp (0–100%), while the dependent variables were density, water absorption, compressive strength, fire resistance, and acoustic insulation. Seven mix formulations were produced (PS-00, PP-10, PP-20, PP-30, PP-40, PP-50, PP-100), keeping the cement-to-aggregate ratio constant at 1:4 and replacing sand volumetrically with paper pulp at 0–100%.

Materials

Ordinary Portland cement (OPC 42.5N), conforming to NIS 444-1 [11], was used as binder. Clean river sand, sieved through 2.36 mm aperture to comply with BS EN 12620 [12], served as

fine aggregate. Waste paper consisted of post-consumer non-glossy office paper and newspaper free from contaminants. Potable water meeting BS EN 1008 [13] requirements was used for pulping and mixing. Equipment included a mechanical concrete mixer, digital weighing scale (0.01 g precision), vibrating block-molding machine, drying oven, and a 2000 kN Universal Testing Machine (UTM).

Mix Design and Sample Preparation

Mix design was performed using the British volumetric method, maintaining a cement-to-aggregate ratio of 1:4 while varying the paper content. Water-cement ratios were adjusted (0.55–0.70) to achieve workable consistency based on preliminary trials. Paper pulp was prepared by shredding waste paper, soaking for 24 hours, and pulping mechanically until uniform. Cement and sand were dry-mixed for 3 minutes before adding pulp, followed by gradual water addition and mixing for 5–7 minutes until homogeneous. The fresh mix was placed into a vibrating hollow-block mold (225 × 225 × 450 mm) and compacted. Blocks were demolded after 24 hours and air-cured for 28 days, with wetting twice daily during the first 7 days (see plate I –VI).



Plate V: Fire Resistance test on a Sample Using

Plate VI: Compressive Strength Test UTM

Test Procedures

Density

Density was determined according to [14]. After curing, samples were oven-dried at 105 ± 5 °C to constant mass (W_d), and volume (V) was computed from measured dimensions using a Vernier caliper. Density (ρ) was calculated using Equation (1) [15, 16]:

$$\text{Density} \left(\frac{\text{kg}}{\text{m}^3} \right) = \frac{W_{dry}}{V} \quad (1)$$

Water Absorption

Water absorption followed [17]. Oven-dried samples were immersed in water for 24 hours, wiped, and weighed to obtain saturated mass (W_s). Water absorption (WA) was calculated using Equation (2):

$$\text{Water Absorption (\%)} = \frac{W_{sat} - W_{dry}}{W_{dry}} \times 100 \quad (2)$$

Compressive Strength

Compressive strength was determined based on [18]. Cube specimens (100 mm) were positioned centrally in the UTM and loaded at a controlled rate until failure. Strength was calculated using Equation (3):

$$\text{Compressive Strength} \left(\frac{N}{mm^2} \right) = \frac{F}{A} \quad (3)$$

Fire Resistance

Fire performance was evaluated using [19]. Specimens were exposed to a controlled heat curve until structural failure (fire integrity time). Residual mass was calculated per Equation (4), similar to [16]:

$$\text{Residual Mass (\%)} = \frac{W_{after\ fire}}{W_{before\ fire}} \times 100 \quad (4)$$

Acoustic Insulation

Acoustic insulation was measured according to [20]. A steady sound source was projected at one side of the block while a sound meter recorded sound pressure on both sides. The sound reduction index (Rw) was computed using Equation (5) (Asroni et al., 2019):

$$Rw(dB) = L_1 - L_2 \quad (5)$$

Data Analysis

All experimental readings were performed in triplicate and averaged. Results were analyzed using Microsoft Excel 2013 for descriptive statistics and were compared against international standards and findings from previous studies [15, 16].

III. Results

Table 2 present the results of bulk density, water absorption and Compressive strength. The results show that increasing waste paper content causes a continuous reduction in density from 2032.2 kg/m³ (PS-00) to 657.0 kg/m³ (PP-100) (see Figure 1), shifting the material from normal-weight to lightweight classification due to the low specific gravity of cellulose fibers and void formation within the matrix, consistent with [9, 10, 15] and [16]. Water absorption increased from 6.3% to 59.8% as paper content increased (see Figure 2), because cellulose fibers are porous and hydrophilic [21, 22]; however, only PS-00 and PP-10 met the ≤12% absorption limit specified in [2, 7].

Table 1: Mix Design for Papercrete Blocks

Mix	p (agg vol)	V _s (m ³)	V _p (m ³)	Cement (kg)	Sand (kg)	Paper pulp (kg)	Water (kg ≈ L)	w/c
PS-00	0	0.8	0	630	2120	0	472.5	0.75
PP-10	0.1	0.72	0.08	630	1908	52	346.5	0.55
PP-20	0.2	0.64	0.16	630	1696	104	378	0.6
PP-30	0.3	0.56	0.24	630	1484	156	409.5	0.65
PP-40	0.4	0.48	0.32	630	1272	208	422.1	0.67
PP-50	0.5	0.4	0.4	630	1060	260	428.4	0.68
PP-100	1	0	0.8	630	0	520	441	0.7

Compressive strength declined from 3.8 N/mm² to 0.36 N/mm² as paper increased, due to disrupted cement hydration and increased pore volume (see Figure 3), supporting findings by [15] and [16], who recommend limiting paper content to 10–20% for non-load-bearing applications. The result of the fire resistance as presented in Table 3, Figures 4 and 5 dropped from 45 minutes to 5 minutes as paper content increased, with only PS-00 and PP-10 satisfying the minimum 30-minute fire rating generally required for internal partitions; the decline results from the combustibility of cellulose fibers, similar to observations by [16].

Conversely, the results of acoustic performance presented in Table 4 and Figure 6 improved with increasing paper content as the Sound Reduction Index (R_w) increased from 30 dB to 46 dB due to increased porosity and sound dissipation, aligning with the enhanced acoustic effects reported

for lightweight fibrous composites by [6], [8] and [16]. Overall, while higher waste paper content enhances sustainability and acoustic insulation, excessive substitution reduces moisture resistance, strength, and fire performance.

Table 2: Density, Water Absorption and Compressive Strength of Papercrete Blocks

Mix ID	Density (kg/m ³)	Water Absorption (%)	Compressive Strength (N/mm ²)
PS-00	2032.2	6.3	3.83
PP-10	1734.9	10.7	2.25
PP-20	1396.3	22.4	1.52
PP-30	1095.5	32.0	0.81
PP-40	944.9	41.3	0.64
PP-50	834.1	49.7	0.51
PP-100	657.0	59.8	0.36

Table 3: Fire Resistance Properties of Papercrete Blocks

Mix ID	Fire Integrity (min)	Residual Mass (%)	Physical Observation after Test
PS-00	45	98	Minor surface cracking; intact structure
PP-10	28	92	Surface charring; good cohesion retained
PP-20	18	80	Moderate charring and material loss
PP-30	12	70	Noticeable charring and softening
PP-40	9	65	Heavy charring; partial deformation
PP-50	7	60	Severe surface burning; brittle residue
PP-100	5	55	Complete charring; structural collapse

Table 4: Acoustic Insulation Performance of Papercrete Blocks

Mix ID	Estimated Sound Reduction Index (R _w , dB)	Acoustic Observation

Mix ID	Estimated Sound Reduction Index (Rw, dB)	Acoustic Observation
PS-00	30	Typical dense concrete sound barrier
PP-10	36	Improved sound attenuation due to micro-voids
PP-20	40	Enhanced sound damping from increased porosity
PP-30	42	High acoustic absorption from fibrous matrix
PP-40	44	Excellent noise reduction; porous structure
PP-50	45	Very good sound insulation and low sound reflection
PP-100	46	Exceptional acoustic absorption; high porosity

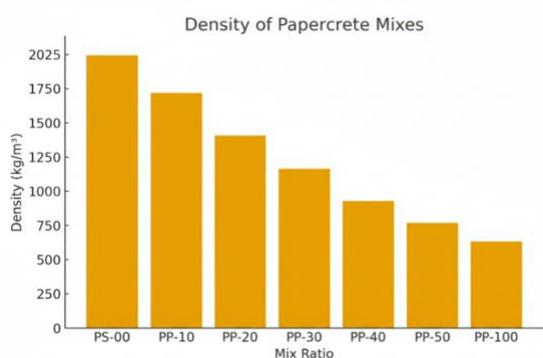


Figure 1: Density of Papercrete Blocks

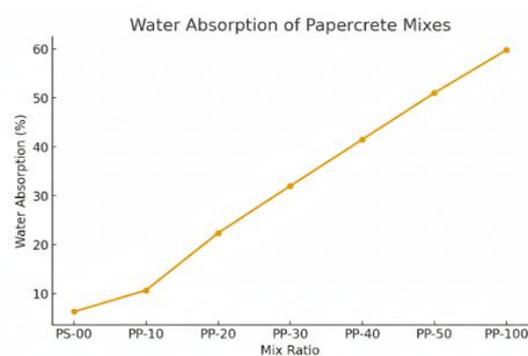


Figure 2: Water Absorption Rate

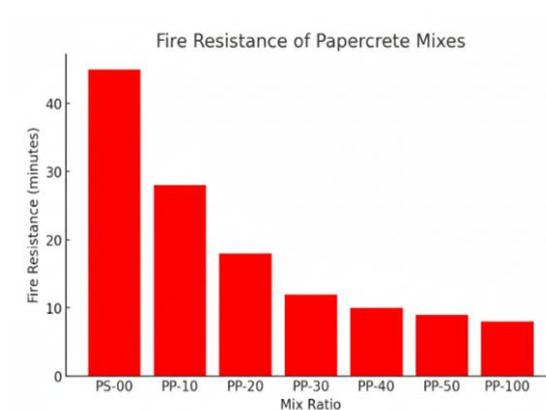
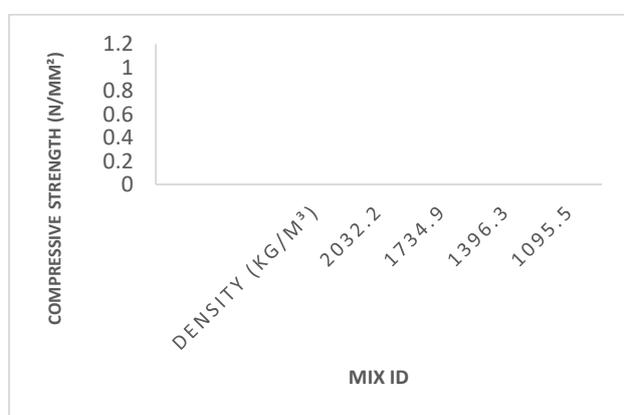


Figure 3: Compressive Strength against Mix Ratio

Figure 4: Fire Resistance Test Result

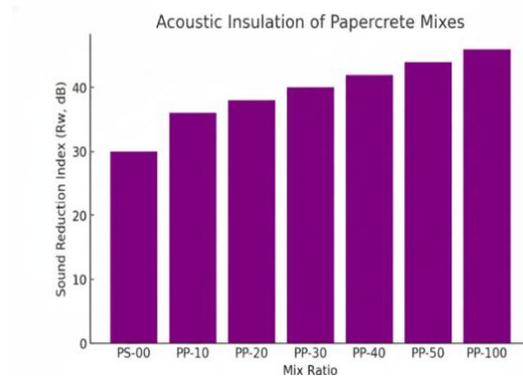
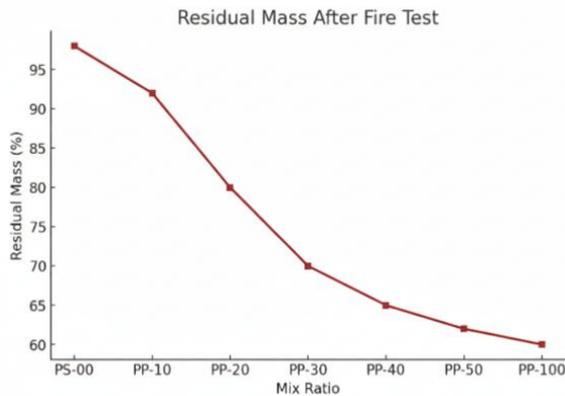


Figure 5: Residual Mass against Mix Ratio Results

Figure 6: Acoustic Insulation

IV. CONCLUSION

The study concludes that waste paper can be successfully incorporated into mortar to produce lightweight papercrete blocks, with increasing paper content reducing density and enhancing acoustic insulation but also increasing water absorption and reducing compressive strength and fire resistance. The optimum performance was achieved at 10–20% waste paper replacement, where blocks retained acceptable strength and moisture characteristics while remaining lightweight and structurally sound for non-load-bearing applications. Higher replacement levels ($\geq 30\%$) are only suitable for acoustic panels, partitions, and decorative uses due to reduced structural performance. To enhance durability and fire performance in mixes with high paper content, the use of surface treatments such as waterproof coatings and fire retardants is recommended, and pozzolanic additives (e.g., silica fume or rice husk ash) should be explored to improve fiber–matrix bonding. Overall, the use of waste paper in block production is strongly recommended as a sustainable and eco-friendly approach that reduces environmental waste, promotes recycling, and supports green construction practices.

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