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Compressive Strength and Water Absorption Performance of Papercrete Solid Block

Awodiji, C. T. G. and Asaba, A. R.
[1,2]*Department of Civil Engineering, University of Port-Harcourt, Rivers State, Nigeria*
Corresponding Author: chioma.awodiji@uniport.edu.ng

ABSTRACT : *The over-reliance on concrete for construction poses major environmental challenges, due to the large-scale extraction of sand and the carbon-intensive production of cement. These activities significantly leads to resource depletion, ecological imbalance, and climate change. This study seeks to mitigate these challenges by investigating the compressive strength and water absorption performance of papercrete solid blocks (PCSB) produced by partially replacing sand with wastepaper pulp and adding 10% rice husk ash (RHA) as an additive. A water–cement ratio of 0.6 and control mix of 1:6 (cement:sand) were used, with paper pulp replacing sand at 0%, 10%, 20%, 30%, and 40% respectively. Blocks of size 150 × 225 × 450 mm were cast and cured for 28 and 56 days respectively before subjected to compressive and water absorption tests accordingly. The slump test showed reduced workability with increasing paper pulp, recording 1.5 mm at 10% and 0 mm for higher replacements. Compressive strength at 28 days decreased from 3.18 N/mm² for the control to 2.16, 1.88, 1.67, and 1.57 N/mm² for 10%, 20%, 30%, and 40% paper pulp, respectively. After 56 days, the 10% mix improved to 2.68 N/mm², showing good fibre–matrix bonding. Water absorption reduced from 5.92% in the control specimen to 2.71% in the 10% mix, confirming enhanced durability due to the pozzolanic action of RHA. In conclusion, the 10% paper pulp + 10% RHA provided the best balance of strength and durability. However, this mix is recommended for non-load-bearing and sustainable walling units.*

KEYWORDS: *Paper pulp, rice husk ash, walling units, non-load bearing.*

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I. INTRODUCTION

The demand for sustainable and environmentally friendly construction materials has become increasingly urgent in the face of global climate change, rapid urbanization, and depletion of natural resources. The construction industry, which is one of the largest consumers of raw materials globally, is also a significant contributor to environmental degradation and greenhouse gas emissions. Traditional materials such as conventional concrete and fired clay bricks, though widely used for their strength and durability, have high environmental footprints due to their production processes [1]. The production of cement and clay bricks is carbon-intensive, consuming vast amounts of energy and releasing large quantities of carbon dioxide (CO_2), a major greenhouse gas [2]. Consequently, there is an urgent global call for innovative and sustainable alternatives that can minimize the ecological impacts of conventional building materials.

Concrete, one of the most widely used construction materials, owes its popularity to its versatility, strength, and adaptability [3]. However, its production has come under scrutiny for its environmental cost. The manufacture of cement—the main binder in concrete—accounts for approximately 8% of global CO_2 emissions [4]. Additionally, the extraction of fine and coarse aggregates, such as sand and gravel, has led to extensive environmental damage, including riverbed depletion, deforestation, and loss of aquatic habitats [5]. The transportation of these heavy materials also contributes to increased energy consumption and carbon emissions. These challenges collectively underscore the unsustainable nature of conventional construction materials and highlight the pressing need to develop eco-friendly, cost-effective, and resource-efficient alternatives. The growing accumulation of paper waste worldwide poses both environmental and management challenges. Millions of tons of wastepaper are generated annually from offices, packaging industries, newspapers, and educational institutions, with only a fraction being recycled. Most of this waste ends up in landfills or is incinerated, contributing to pollution and greenhouse gas emissions.

In response to these environmental and resource challenges, researchers and industry professionals have intensified efforts toward developing sustainable materials that incorporate waste products. Waste recycling and reuse in construction not only reduces the volume of waste that ends up in landfills but also conserve natural resources and mitigate environmental pollution. Among the emerging innovations in this field is papercrete, a lightweight composite material produced by mixing wastepaper pulp with a binder such as cement and water, often supplemented with fine aggregates like sand or other additives to improve its performance [6].

Papercrete offers a unique dual advantage: it provides a sustainable solution for managing wastepaper, which constitutes a significant portion of municipal solid waste, and simultaneously reduces the dependence on virgin materials used in traditional concrete production. Transforming wastepaper into a construction material such as papercrete thus represents a practical and sustainable waste-to-wealth strategy. Furthermore, because papercrete utilizes materials that are readily available and inexpensive, it presents a cost-effective option for affordable housing, particularly in developing countries where access to conventional building materials is often limited by high costs.

Papercrete is a composite building material composed primarily of recycled paper pulp, cement, water, and in some cases, sand or lime. It serves as an eco-friendly alternative to traditional construction materials by utilizing waste products and reducing reliance on virgin natural resources [6]. Its fibrous structure contributes to its lightweight nature and thermal insulation capabilities, making it suitable for non-load-bearing and sustainable construction applications [7]. Paper pulp is derived from wastepaper products that are processed and blended with cement and water to form a slurry. Additives may include natural or synthetic fibers, as well as pozzolanic materials such as lime and fly ash, which enhance bonding, reduce porosity, and improve the mechanical and durability performance of the final product [8-9].

Papercrete blocks are typically characterized by low density due to the high volume of entrapped air and cellulose fibers from paper pulp. Their density ranges between 600–1200 kg/m³, significantly lower than conventional concrete [10]. This lightweight nature makes it easier to transport and handle, especially in low-rise construction. Thermal insulation is another notable property. The fibrous texture of paper pulp creates a porous matrix that traps air and slows down heat transfer. This contributes to energy efficiency in buildings by reducing reliance on mechanical heating and cooling systems [7]. In terms of acoustic properties, the open-cell structure of papercrete offers sound absorption capabilities, making it suitable for use in noise-sensitive environments such as classrooms or residential areas. These features collectively position papercrete as a sustainable, multifunctional construction material [11]. Despite these advantages, the adoption of papercrete in mainstream construction remains limited due to certain performance-related concerns. Therefore, investigating the compressive strength and durability performance of papercrete solid blocks is essential to establishing their reliability as sustainable alternatives to conventional building materials thereby helping to reduce environmental impact and promote circular construction practices.

II. LITERATURE REVIEW

Nkwanta et al. [12], reviewed multiple papercrete studies to examine the sources of variability in outcomes. Mix ratios like 1:2:3, 1:1:2, and 1:0:4 was common, with compressive strengths ranging from 1.0 to 3.5 MPa. The review highlighted how changes in wastepaper type, cement grade, and inconsistent curing regimes affect test results. The authors emphasized the need for standardization in experimental procedures to ensure repeatability and reliability in research and practice. Rahul and Prabha [9], responded to the problem of sand scarcity by replacing sand with fly ash in papercrete. They developed a 1:0.7:1.5 (cement: fly ash: paper pulp) mix that was water-cured for 28 days and reached a compressive strength of 2.7 MPa. Their research demonstrated that fly ash not only reduces costs but also minimizes shrinkage, making it suitable for non-load-bearing walls in low-income housing. Onwualu et al. [13], experimentally validated a 1:2.25:1.75 mix (cement: sand: paper pulp), which met minimum structural requirements for partition walls. After 28-day water curing, the blocks achieved compressive strengths exceeding 3.0 MPa. Their findings confirmed that properly proportioned papercrete, even without additives, can be a sustainable and compliant alternative for non-load-bearing structures.

Ogunlade et al. [14] experimented with several ratios ranging from 1:4:1 to 1:3:1. Their best-performing mix, 1:3:1 (cement: sand: paper pulp), achieved a compressive strength of 3.5 MPa after 28-day water curing. The inclusion of more sand in the mix improved structural cohesion and significantly lowered water absorption. This study recommended the 1:3:1 formulation for partitioning in residential structures where strength and moisture resistance are needed. Ede and Yusuf [15], focused on affordability and chemical compatibility of papercrete. Their 1:0:2.6 mix, containing 10% lime, reached a compressive strength of 2.4 MPa after 28-day water curing.

The mix was easy to produce and used widely available materials, making it ideal for affordable housing projects. The addition of lime also helped reduce shrinkage and improved material stability. Obasi et al. [16], investigated the effect of curing on strength development in a 1:2:2 mix. They found that compressive strength significantly increased with longer curing durations, reaching 3.2 MPa after 28 days. Their results reinforced the importance of sufficient hydration and curing for enhancing both strength and durability of papercrete blocks.

III. MATERIALS AND METHODS

3.1 Materials

The major materials used in this study include Portland Cement (Dangote 42.5R), fine aggregate (river sand), paper pulp, Rice Husk Ash (RHA), and potable water. All materials were sourced locally to ensure sustainability and cost-effectiveness.

3.1.1 Portland Cement

Dangote Portland Cement (Grade 42.5R) was used as the primary binder in this study. It conforms to the requirements of Nigerian Industrial Standard [17] equivalent to [18]. Portland cement provides strength and binding property in papercrete blocks, ensuring proper adhesion between paper fibers and aggregates. Its rapid strength development makes it suitable for achieving significant compressive strength at both 28 and 56 days of curing. Portland cement brand used is shown in Fig. 1.

3.1.2 River Sand

Clean, well-graded river sand obtained from locally sourced vendor in Port Harcourt was used as the fine aggregate. The sand was sieved through a 4.75 mm sieve to remove impurities and ensure uniform grading. Sand serves as the filler and structural component that enhances the density and load-bearing capacity of papercrete blocks. According to [19], the sand was classified as a zone 4 aggregate (fine grading) having coefficient of curvature (Cc) and coefficient of uniformity (Cu) values of 1.27 and 2.42 respectively with an average bulk density of 1471.49kg/m^3. Fig. 2 illustrates the river sand used.

3.1.3 Paper Pulp

The paper pulp used in this study was produced manually from waste newspaper materials. The cut pieces of paper were soaked in clean water for 24 hours to soften the fibers. After soaking, the softened papers were mechanically shredded and blended into a uniform pulp using a hand mixer. The pulp was gently pressed by hand to remove excess water and achieve a consistent, workable texture. The prepared paper pulp was subjected to chemical composition testing according to [20 – 21]. The paper pulp exhibited high cellulose content of 46.94% and moderate lignin of 3.48%. Fig, 3 presents the paper pulp produced for the investigation.

3.1.4 Rice Husk Ash

Rice husk was sourced from Rukpoku in Port-Harcourt. The rice husk ash was produced by the controlled burning of rice husk at moderate temperature of about 650^{0}C and sieved through a 75 µm sieve to obtain fine ash. The ash was also subjected to chemical composition test according to [20- 21]. The rice husk ash (RHA) contained CaO content of 31.8%, SiO_2 of 13.78%, and Al_2O_3 of 1.54% respectively. This result suggests some degree of pozzolanic potential. Rice husk ash used for the study is shown in Fig 4.

3.1.5 Water

Potable tap water, from Choba campus of the University of Port-Harcourt, conforming to [22] was used for all mixing and curing operations. Water is essential for the hydration of cement and the workability of the mix. A water-cement ratio of 0.6 was adopted for the mix, which ensured adequate consistency and proper bonding between the cement paste and paper fibers.

Fig. 1. Portland cement

Fig. 2. River sand

Fig. 3. Paper Pulp

Fig. 4. Rice Husk Ash

3.2 Methods

3.2.1 Sample Preparation

The papercrete mix was proportioned at a 1:6 ratio of cement to sand, with a water–cement ratio of 0.6. The measured quantities of cement, sand, and RHA were thoroughly mixed in dry condition until a uniform color was obtained. The prepared paper pulp was gradually added to the dry mix, followed by water, and the components were mixed manually until a uniform blend was achieved. The mixture was placed into steel molds of size 150 × 225 × 450 mm and compacted manually to remove entrapped air. The papercrete blocks were demolded immediately after casting to maintain the integrity of the mix and prevent surface cracking. The samples were cured by sprinkling clean water daily, a process carried out for 28 and 56 days to ensure proper hydration and strength development. After curing, samples were air-dried and labeled for subsequent testing for compressive strength and water absorption properties. Table 1 depicts the mix proportions by mass adopted for the study.

Table 1. Mix proportion for one volume of block mold

Mix I.D	% Paper Pulp	Cement (kg)	RHA (kg)	Sand (kg)	Paper Pulp (kg)	Water (Liter)
A	0%	3.28	0.33	21.87	0.00	1.97
B	10%	3.28	0.33	19.68	1.03	1.97
C	20%	3.28	0.33	17.50	2.05	1.97
D	30%	3.28	0.33	15.31	3.08	1.97
E	40%	3.28	0.33	13.12	4.10	1.97

3.2.2 Slump test of papercrete

A standard slump cone of size 300mm x 200mm x 100mm was placed on a flat, clean steel plate and held firmly in position. The cone was filled with freshly mixed papercrete in three equal layers. Each layer was tamped 25 times with a 16mm standard steel rod to ensure uniform compaction and remove entrapped air. After filling, the top surface was levelled using the tamping rod. The cone was carefully lifted vertically without any lateral or downward pressure to allow the papercrete to subside freely. The difference in height between the top of the cone (H_1) and the top of the slumped papercrete (H_2) was measured using a ruler and recorded as the slump value. The observed slump was used to evaluate the consistency, cohesiveness, and ease of compaction of the papercrete mix. This test was carried out in accordance with [23].

3.2.3 Bulk Density test

In this test the bulk density of the hardened papercrete blocks, which indicates the mass of the material per unit volume, including the air voids within the structure, was measured according to equation 1. The average bulk density of all tested blocks was determined to represent the overall density of the papercrete material.

$$\rho = M/V \tag{1}$$

where:
ρ = bulk density (kg/m³); M = mass of papercrete block (kg); V = volume of block (m³)

3.2.4 Water absorption test

The water absorption capacity of the papercrete blocks, which indicates the amount of water absorbed as a percentage of the dry weight of the sample, was assessed in accordance with [24]. Percentage water absorbed was calculated using equation 2.

$$\text{Water Absorption } (\%) = [(W_{wet} - W_{dry}) / W_{dry}] \times 100 \tag{2}$$

where: W_{dry} = dry weight of block (kg); W_{wet} = wet weight of block after 24-hour immersion (kg)

3.2.5 Compressive strength test

The compressive strength test was conducted, according to [25], on the 28 and 56 days cured papercrete block. This test helps to measure the ability of the material to withstand axial loads without failure. Equation 3 was used to determine the value of compressive strength given the maximum load at failure.

$$f_c = P / A \tag{3}$$

where:
f_c = compressive strength (N/mm²); P = maximum load at failure (N); A = cross-sectional area of specimen (mm²)

IV. RESULTS AND DISCUSSION

4.1 Slump of papercrete

Table 2 presents the slump values for the different mixes of papercrete produced for the study.

Table 2. Slump of papercrete

Mix I.D	A	B	C	D	E
% Paper Pulp	0%	10%	20%	30%	40%
Slump (mm)	1.8	1.5	0	0	0

It can be observed that the addition of 10% paper pulp in the mix reduced the slump by 16.67%. Above 10% inclusion, the mixture had no slump making it very suitable for block molding,

4.2 Bulk density of papercrete

Fig. 5 shows the magnitude of bulk density of the papercrete blocks produced. Overview, the bulk density of the blocks reduced as the content of paper pulp increased in the mix. Highest reading of 1899.676kg/m^3 was observed at 0% paper pulp content while lowest value of 1549.257kg/m^3 was seen at 40% pulp content. This finding corroborates the results of [26], who reported that papercrete's reduced density offers advantages for non-load-bearing construction. A slight improvement of about 3.66% was recorded between 10% and 20% paper pulp content.

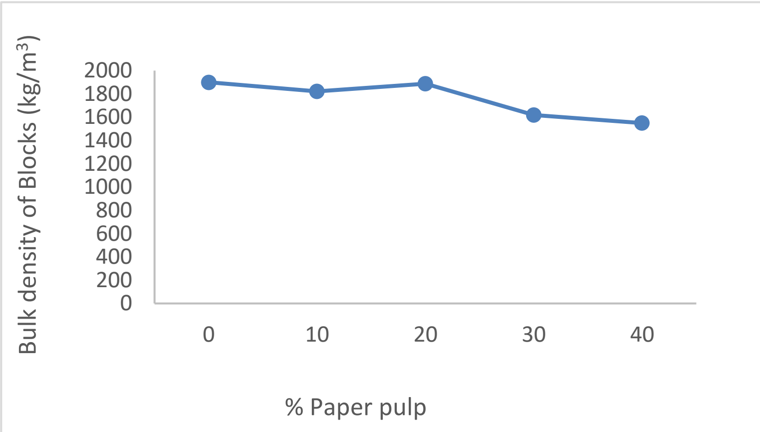

Fig. 5. Bulk density of papercrete (kg/m^3) vs % paper pulp content

4.3 Water absorption of papercrete blocks

Readings of water absorption of papercrete mixes are depicted in Fig. 6.

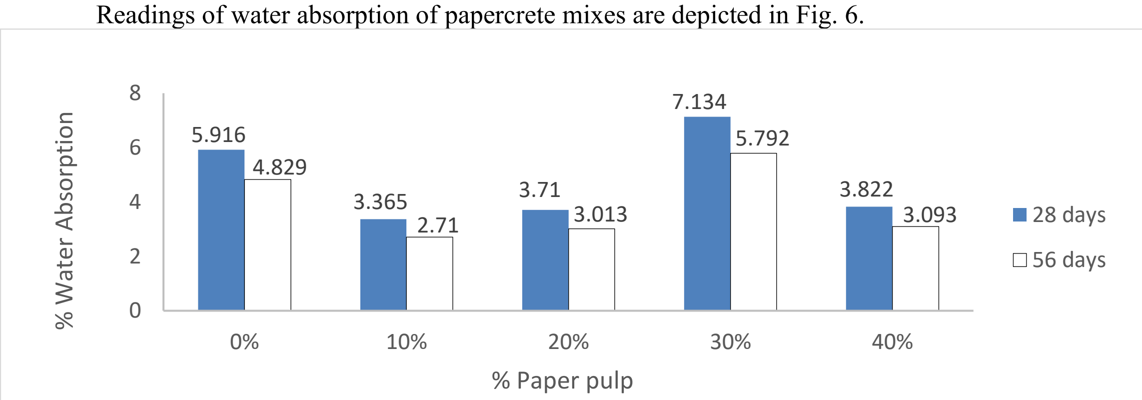

Fig. 6. % Water Absorption vs. % paper pulp content

Best water absorption of 3.365% and 2.71% at 28 and 56 days respectively were observed at 10% pulp content. These values were 43.12% and 43.88% less than those of the control accordingly. Maximum values were seen at 30% inclusion having values of 7.134% and 5.792% on 28 and 56 days correspondingly. These readings were 20.59% and 19.94% higher than the control values respectively.

Addition of paper pulp in the mix improved water absorption at 10%, 20%, and 40%. However, there was a surge at 30% pulp content (This could be due to experimental error). This result generally aligns with the finding of [27] that higher amount of paper pulp rises the content of cellulose fiber that takes up pore spaces and thus reduces water intake. Moderate paper inclusion between 10% to 20% improved compactness due to better water retention during curing, reducing early-age cracks and absorption rates. All values obtained were less than the acceptable maximum absorption value of 10% according to [28].

4.4 Compressive strength of papercrete

Fig. 7 shows the relationship between compressive strength and paper pulp content.

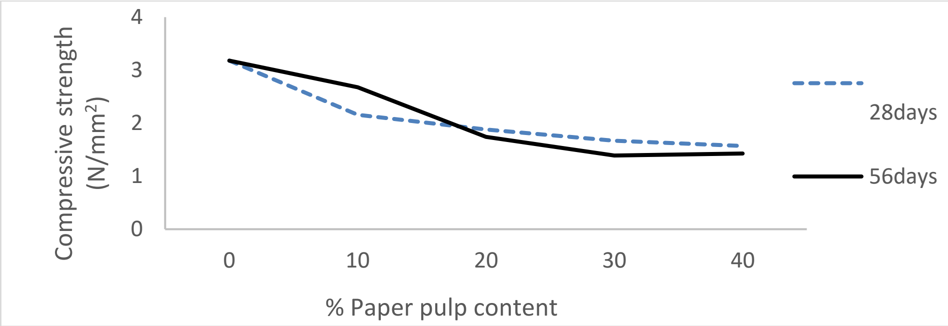

Fig. 7. Compressive strength (N/mm^2) vs. % paper pulp content

The compressive strength decreased with increasing paper pulp content, especially beyond 10%. The 0% mix at 3.18 N/mm² had the highest strength, while the 40% mix at 1.57 N/mm² had the lowest value. This trend agrees with findings by [29]. They reported that best replacement of cement with paper pulp content is between 5% and 10% but best at 10%. This was because particles of wet cement were found in the matrix at replacement levels greater than 10%.

At 56 days, papercrete experienced better strength between 0 to 10% pulp content than at 28days. The slight strength improvement at 10% pulp content of 2.68 N/mm² indicates hydration and good fiber–matrix interaction at lower pulp levels. In conclusion, the 10% papercrete mix presented a balance between strength, durability, and density. Beyond this level, excess fibers disrupted the cementitious bonding network aligning with the findings by [30], who reported that papercrete blocks with 10%–15% paper content achieved optimal performance, while higher proportions led to reduced strength and excessive water uptake.

V. CONCLUSION

This study investigated the effect of incorporating wastepaper pulp into papercrete solid blocks, focusing on compressive strength, water absorption, and overall suitability as an alternative building material. The results showed that adding paper pulp reduced block density, making them lighter and more workable, while higher paper content led to decreased compressive strength due to increased porosity and weaker binder–aggregate bonding. Optimum performance was achieved at 10% paper pulp replacement, with a compressive strength of 2.68 N/mm² at 56 days, a bulk density of 1821.06 kg/m³, and a water absorption rate of 2.71%. Beyond 20% replacement, strength declined and water absorption increased.

These findings demonstrate that papercrete blocks can effectively achieve the study objective of providing lightweight, durable, and environmentally friendly units suitable for non-load bearing and partition walls, offering a sustainable alternative to conventional blocks while promoting waste reduction.

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