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Water absorption properties of Hollow Concrete Blocks incorporating Wood Sawdust as a partial replacement for Sand

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Abstract

This study investigated the water absorption properties of hollow concrete blocks incorporating wood sawdust as a partial replacement for sand at levels of 0%, 5%, 10%, and 15% across four mix ratios (cement: sand: water): 1:2:0.3, 1:1.5:0.4, 1:1:0.5, and 1:0.5:0.7. Blocks were produced using standard molds (150 × 225 × 450 mm) and cured for 28 days. Water absorption was measured after 24-hour and 48-hour immersion following modified ASTM C140 and BS 1881 protocols. Results showed significant variations ($p < 0.05$) with replacement levels and mix ratios. After 24 hours, absorption ranged from 0.60 ± 0.20% (1:2:0.3 mix at 5%) to 14.00 ± 1.40% (1:2:0.3 mix at 15%), with the 1:1:0.5 mix exhibiting the lowest overall values (1.10–6.20%). After 48 hours, absorption increased, ranging from 0.70 ± 0.50% (1:1.5:0.4 mix at 15%) to 24.60 ± 2.60% (1:2:0.3 mix at 15%), with most mixes at 5% replacement staying below 4%. ANOVA and Duncan's Multiple Range Test confirmed that low sawdust levels (≤5%) generally reduced absorption due to improved matrix densification, while higher levels increased porosity. Findings suggest optimal sawdust incorporation at 5–10% for sustainable, durable blocks in low-moisture applications, balancing waste valorization with performance.

Keywords: Wood sawdust, hollow concrete blocks, water absorption, sand replacement, sustainable construction, mix ratio.

Introduction

Wood sawdust, a major byproduct of timber processing, has become an environmental and waste management concern, especially within fast-growing urban centers such as Port Harcourt, Nigeria[1]. Sawmills like the Iloabuchi Sawmill, situated within a landscape dominated by mangrove and freshwater swamp forests, generate significant volumes of sawdust residues due to the high demand for timber and wood products. The tropical climatic conditions of the area, distinguished by rainfall levels above 2,500 mm per year and elevated humidity levels averaging 85%, exacerbates environmental challenges, including surface water contamination, soil degradation, and air quality deterioration[2,3]. The improper disposal or open burning of sawdust further intensifies pollution, contributing to greenhouse gas emissions and localized health risks.

Sustainable waste management practices are increasingly essential, and recycling sawdust into construction materials has emerged as a promising strategy to reduce environmental burdens while promoting resource efficiency[4-6]. The utilization of sawdust as a partial replacement for sand in cement-based composites not only addresses waste valorization but also reduces dependence on natural sand-a finite resource facing escalating demand[7,8]. Numerous studies have reported the potential of sawdust to produce lightweight, thermally insulating, and cost-effective building materials[9-11]. However, its high lignocellulosic content and porous structure raise concerns about increased water absorption and reduced mechanical strength, particularly in humid tropical environments where moisture exposure is constant[12-15].

Understanding water absorption behavior is critical because excessive moisture uptake compromises the structural integrity, durability, and service life of concrete masonry units. Elevated water absorption may accelerate deterioration mechanisms such as freeze–thaw damage, efflorescence, and microbial growth, ultimately limiting the use of sawdust-based hollow blocks in load-bearing or exterior applications[16-18]. These limitations underscore the importance of developing optimized mix designs that balance sustainability with performance.

This study investigates the influence of varying wood sawdust replacement levels (0–15%) on the water absorption characteristics of hollow concrete blocks across multiple mix ratios. Sawdust was locally sourced from sawmills in Port Harcourt, while block production and testing adhered to ASTM and British Standards (BS) guidelines to ensure methodological rigor.

The findings provide insights into the microstructural interactions between sawdust particles and cementitious matrices, with the goal of identifying formulations that minimize water absorption while promoting environmentally responsible construction practices.

By bridging material science and waste recycling, this research contributes to advancing sustainable building technologies suited to tropical and coastal regions.

Material and Methods

Study Area: Wood sawdust for this study was sourced from the Iloabuchi Sawmill Industry, a key timber processing hub at Mile 2, Diobu, Port Harcourt, Rivers State, Nigeria which lies at Latitude 4°47′19.58″ E, Longitude 6°59′22.21″ N[19]. The sawmill was established in 1989 on a 1.5-hectare site, this sawmill, part of the Iloabuchi Timber Market, processes logs from mangrove and freshwater swamp forests, transported mainly by water. It produces sawn timber for Port Harcourt's construction sector through band and circular sawing, re-sawing, and planning, supporting local artisans and industries[3]. The sawmill generates significant wood residues, including sawdust, posing waste management challenges and prompting calls for recycling and valorization[20,21]. Environmental concerns include noise pollution and water contamination in the Mile 1–3 Diobu corridor[22,23]. Located in a sub-equatorial climate, Port Harcourt experiences high humidity (85%), an average temperature of 28°C, and heavy rainfall (>2,500 mm annually) peaking from June to October, with alluvial soils shaped by seasonal flooding[32]. The Iloabuchi Sawmill remains vital to the local economy but faces ongoing environmental and occupational challenges[24].

Wood sawdust, obtained as a byproduct from local sawmills, was used in this study. To ensure uniformity, the sawdust underwent sieving to remove oversized particles and unwanted debris. Ordinary Portland Cement (OPC), in accordance with ASTM C150 specifications, was employed as the primary binder, while natural river sand, meeting ASTM C33 specifications for fine aggregates, was used as the control material. Potable water, free from impurities, was employed for mixing, while maintaining strict control of the water–cement ratio to optimize both workability and mechanical performance.

The mix proportions for the hollow blocks were determined based on previous studies and preliminary trials[25]. The control mix comprised cement, sand, and water, whereas experimental mixes incorporated varying percentages of wood sawdust as a partial replacement for sand, as shown in Table-1.

Hollow blocks were produced using steel molds measuring 150 × 225 × 450 mm (Figure-2 and 3), in accordance with ASTM C90standards for load-bearing concrete masonry units. The dry components were thoroughly blended before the gradual addition of water, and the mixture was placed into molds, compacted using a mechanical vibrator to remove air voids, and demolded after 24 hours. The blocks were cured by immersion in a water tank for 28 days to promote complete hydration, a key determinant of strength and long-term durability[26].

Table-1: Mix Design of Hollow Concrete Blocks.

Mix Ratio	% Replacement	Cement (kg)	Sand (kg)	Sawdust (kg)	Water (kg)
1:2:0.3	0%	50	100	0	15
	5%	50	95	5	15
	10%	50	90	10	15
	15%	50	85	15	15
1:1.5:0.4	0%	50	75	0	20
	5%	50	71.25	3.75	20
	10%	50	67.5	7.5	20
	15%	50	63.75	11.25	20
1:1:0.5	0%	50	50	0	25
	5%	50	47.5	2.5	25
	10%	50	45	5	25
	15%	50	42.5	7.5	25
1:0.5:0.7	0%	50	25	0	35
	5%	50	23.75	1.25	35
	10%	50	22.5	2.5	35
	15%	50	21.25	3.75	35

Determination of Water Absorption (24 Hours): Water absorption of the hollow concrete blocks after 24 hours was determined according to ASTM C140 and BS EN 772 standards, with slight modifications. Three representative specimens from each mix ratio and percentage replacement level were oven-dried at 105±5°C to a constant mass (M_1 , kg) and allowed to cool to room temperature in a desiccator. The dried specimens were completely submerged in clean water at 27±2°C for 24 hours. After immersion, they were removed, gently wiped with a damp cloth to remove surface water, and weighed to obtain the saturated mass (M_2 , kg). The 24-hour water absorption (%) was calculated as:

$$WA = \frac{M_2 - M_1}{M_1}\ x\ 100\% \quad (1)$$

where: M_1 is oven-dry mass of specimen (kg), M_2 saturated mass of specimen after 24 h immersion (kg).

Each test was performed in triplicate for every mix ratio and replacement level, and the mean ± standard deviation was computed.

Determination of Water Absorption (48 h): For the 48-hour water absorption test, a similar procedure was followed. Specimens dried and cooled as described above were immersed in water at 27±2°C for 48 hours. After immersion, specimens were carefully removed, surface water was wiped off, and the saturated mass (M_3 , g) was measured. The 48-hour water absorption (%) was calculated as:

$$WA = \frac{M_3 - M_1}{M_3}\ x\ 100\% \quad (2)$$

where: M_1 is oven-dry mass of specimen (kg), M_3 saturated mass of specimen after 48 h immersion (kg).

Experimental Design and Statistical Analysis: The experiment followed a Completely Randomized Design (CRD) comprising four mix ratios of sand, sawdust, and water, each replicated three times. Data generated from the tests were analyzed using the Statistical Package for the Social Sciences (SPSS, Version 20). Analysis of variance (ANOVA) was performed at a 5% significance level ($p < 0.05$) to identify differences among treatments, and where significant effects were observed, Duncan's Multiple Range Test (DMRT) was applied to separate the means of the measured properties of the sawdust-based hollow blocks.

Results and Discussion

Water Absorption After 24 Hours: The percentage water absorption of hollow blocks after 24 hours of water submersion is presented in Table-2. Results are expressed as mean values ± standard deviation for each mix ratio and replacement level. Statistical comparisons were performed using analysis of variance (ANOVA), and treatment means were separated with Duncan's Multiple Range Test (DMRT) at $p < 0.05$. Superscript letters indicate significant differences among treatments within each mix ratio.

After 24 hours of immersion, water absorption varied significantly across mix ratios and replacement levels. In the 1:2:0.3 mix, water absorption was highest at 15% replacement (14.00%) and lowest at 5% replacement (0.60%). The 1:1.5:0.4 mix showed a peak at 10% replacement (7.30%), while the 1:1:0.5 mix exhibited a progressive increase, reaching 6.20% at 15% replacement. The 1:0.5:0.7 mix displayed relatively stable values, with 3.60% as the highest absorption and no significant difference between 10% and 15% replacement levels. These results indicate that increased replacement material generally elevates water absorption, with notable variation between mixes.

The 24-hour water absorption performance of the hollow blocks provides critical insight into the influence of wood sawdust as a partial sand replacement. Across the various mix ratios (cement: fine aggregate: water), distinct trends emerge, underscoring the influence of mix composition and replacement level on porosity and water retention capacity.

In line with previous research, sawdust generally leads to increased water absorption in cement-based composites due to its porous structure and moisture-retaining (hygroscopic) properties; for instance, sandcrete blocks with 10% to 50% volumetric sawdust replacement exhibited a rise in water absorption from approximately 9.7% to 21.7%[27]. Similarly, an increase from 11.43% at 0% replacement to 23.72% at 20% sawdust inclusion was observed in Portland cement bricks[28]. However, the present study shows that at lower replacement levels, particularly 5%, some mixes achieve remarkably low water absorption (≤1%), well below typical ranges cited in the literature. This anomaly suggests that the specific mix designs, compaction techniques, and particle gradation employed may contribute to enhanced matrix densification, thereby mitigating sawdust's inherent water-absorbing tendencies.

Water absorption is a critical indicator of durability, as higher absorption often correlates with increased porosity and vulnerability to degradation mechanisms such as freeze–thaw cycles, moisture ingress, and efflorescence[29]. In this context, the extremely low absorption values recorded at 5% replacement in mixes such as 1:2:0.3 and 1:1:0.5 indicate their potential for producing durable, lightweight blocks suitable for interior or low-humidity environments.

Conversely, higher replacement levels exhibit more variable and, in some cases, excessive absorption rates. For instance, in the 1:2:0.3 mix, water absorption declined from 3.30% at 0% to 0.60% at 5% replacement ($p < 0.05$), suggesting that a small amount of sawdust may enhance particle packing or matrix cohesiveness. This observation aligns with findings that low levels of organic fillers can promote a denser microstructure. However, water absorption surged to 14.00% at 15% replacement, indicating a critical threshold beyond which the porous nature of sawdust dominates and compromises resistance to moisture penetration[30,31]. This trend is consistent with findings that higher organic content increases capillary pores and void connectivity, leading to heightened water absorption[32].

The behavior of the 1:1.5:0.4 mix was more complex. Here, water absorption increased steadily from 3.30% at 0% to 7.30% at 10% replacement, then decreased significantly to 2.10% at 15%. This non-linear trend suggests a dynamic interaction between the fine and coarse components of the mix. The initial rise in absorption could be attributed to increased porosity from the replacement of denser sand with lighter, more porous sawdust. However, the unexpected reduction at 15% may reflect a point of packing optimization, where sawdust effectively fills voids, thereby reducing permeability[33]. This highlights the potential for fine-tuning replacement levels to optimize both structural and durability properties.

In the 1:1:0.5 mix, water absorption remained low at 1.10% and 1.20% for 0% and 5% replacement levels, respectively, but rose to 6.20% at 15%. The low initial values suggest strong matrix cohesion and limited pore connectivity, likely due to a well-balanced cement-to-sand ratio and the presence of minimal organic filler. Low levels of organic additives can enhance internal bonding and reduce void formation[34]. However, the sharp increase at 15% suggests that excessive sawdust disrupts this balance, creating micro structural discontinuities that facilitate water ingress.

A contrasting trend was observed in the 1:0.5:0.7 mix, where the highest water absorption occurred at 0% replacement (3.60%), followed by reduced values at 5% to 15% replacements, stabilizing between 2.50% and 2.80%. This suggests that, in this particular mix, sawdust may be contributing positively to pore structure stabilization. Similar findings have been reported, where specific organic fillers reduced water absorption by enhancing the homogeneity of pore networks[15]. In this case, the relatively high initial water content in the mix (0.7) might facilitate better hydration and particle interaction, allowing sawdust to play a void-filling role.

The influence of mix ratios on water absorption performance is clear. The 1:1:0.5 mix demonstrated the lowest absorption across the board, particularly at low replacement levels, indicating that a balanced cement and aggregate ratio promotes matrix densification and reduces capillarity. On the other hand, the 1:2:0.3 mix showed the most dramatic increase at higher sawdust content, suggesting that leaner cement mixes are more susceptible to porosity under increased organic filler loads. Interestingly, the 1:0.5:0.7 mix, despite having the highest proportion of sawdust, maintained relatively stable absorption values, pointing to a unique synergy between high cement content and fine organic fillers in regulating porosity.

From a practical standpoint, water absorption results reinforce the need to calibrate sawdust content according to intended application. Low water absorption (e.g., ≤2%) is desirable for non-load-bearing walls in interior spaces or dry climates, where moisture exposure is minimal. In this context, the 1:1:0.5 mix at 5% replacement appears highly promising. In contrast, blocks with high absorption (e.g., 14% in 1:2:0.3 at 15%) may be unsuitable for exterior or moisture-prone applications without additional surface treatments such as water-repellent coatings or sealants. Beyond performance considerations, the inclusion of sawdust supports sustainable construction practices by reducing reliance on natural sand and repurposing wood waste. Nevertheless, this sustainability gain must be balanced against the potential loss of structural and durability properties at higher replacement levels. In line with previous research[35], this study suggests that sawdust replacement levels between 5% and 10% provide an optimal balance, offering environmental benefits while maintaining acceptable performance thresholds.

Water Absorption after 48 Hours: Prolonged immersion (48 hours) further emphasized differences in water uptake. The 1:2:0.3 mix recorded a marked increase at 15% replacement (24.60 ± 2.60%), compared to 1.70 ± 0.30% and 4.90 ± 0.70% at 5% and 10% replacement levels, respectively. The 1:1.5:0.4 mix peaked at 10% replacement (11.30 ± 1.30%), whereas 15% replacement (0.70 ± 0.50%) unexpectedly showed lower absorption, possibly reflecting variations in compaction or internal structure. Gradual increases were observed in the 1:1:0.5 mix (ranging from 3.70 ± 0.60% to 9.20 ± 0.90%) and in the 1:0.5:0.7 mix (3.80 ± 0.60% to 5.87 ± 0.65%).

The water absorption characteristics of hollow blocks after 48 hours of submersion, with wood sawdust used as a partial replacement for sand, reveal significant variations across different mix ratios and replacement levels. These differences, which are statistically significant at $p < 0.05$, underscore the combined influence of sawdust content and mix design on the moisture uptake and pore structure of the blocks. In the 1:2:0.3 mix, water absorption was relatively moderate at 0% replacement ($4.40 \pm 0.60\%$), dropped sharply at 5% ($1.70 \pm 0.30\%$), and then increased markedly at 10% ($4.90 \pm 0.70\%$), reaching a peak of $24.60 \pm 2.60\%$ at 15%. This pattern suggests that low percentages of sawdust may enhance matrix densification by filling interstitial voids, while higher levels introduce excessive porosity and capillary channels, leading to elevated water absorption. These findings are consistent with previous studies highlighting the porous and hydrophilic nature of lignocellulosic materials, which tend to increase water absorption at higher inclusion levels[18,36].

In the 1:1.5:0.4 mix, a different trend was observed. Water absorption increased from $5.00 \pm 0.70\%$ at 0% replacement to a peak of $11.30 \pm 1.30\%$ at 10%, then decreased unexpectedly to $0.70 \pm 0.50\%$ at 15%. This non-linear behavior may be due to better compaction or more effective paste encapsulation at higher sawdust content in this particular mix design, which includes a higher cement proportion and water content. Such outcomes have been documented in studies emphasizing the role of mix water ratio and curing in influencing the distribution and bonding of sawdust within the cement matrix[18].

A more progressive increase in water absorption with rising sawdust content was observed in the 1:1:0.5 mix, ranging from 4.00 ± 0.60% at 0% to 9.20 ± 0.90% at 15%. This trend aligns with literature noting that as sawdust content increases, so does the overall porosity of the matrix, resulting in greater susceptibility to moisture ingress[37,28,36]. Similarly, the 1:0.5:0.7 mix showed a moderate range of absorption values from 3.80 ± 0.60% (5%) to 5.87 ± 0.65% (15%), likely moderated by the higher water content in the mix. This may facilitate better paste flow and particle dispersion, leading to improved sawdust encapsulation and thus mitigating the expected increase in water absorption[38].

When the 48-hour absorption values are compared with those obtained after 24 hours of submersion, an overall increase is observed, particularly at higher replacement levels. This is a characteristic behavior of porous composite materials, where water absorption continues over time until saturation is approached. For instance, the 1:2:0.3 mix at 15% sawdust saw an increase from 14.00% at 24 hours to 24.60% at 48 hours. However, mixes like 1:0.5:0.7 at 5% sawdust showed limited change over the extended period, indicating lower capillary suction and potentially more stable performance under long-term moisture exposure. These observations emphasize the importance of evaluating block performance not only under short-term but also under prolonged exposure conditions, especially for applications in humid or water-prone environments[28,36].

Water absorption is a critical determinant of concrete block durability. Both ASTM C90 and BS 6073 set maximum absorption limits of 10–15% for structural and load-bearing applications. The present results indicate that blocks containing 5% sawdust, particularly in the 1:2:0.3 and 1:0.5:0.7 mixes, remained well below these thresholds after 48 hours, supporting their potential for use in durable construction. In contrast, blocks with 10–15% sawdust, especially in lower water-cement ratio mixes, exceeded these thresholds significantly, thereby limiting their applicability to non-load-bearing or interior structural uses unless additional treatment or material modification is undertaken[37,39,18].

The mechanisms behind these trends are closely tied to the microstructural interactions between cement paste and sawdust particles. At low replacement levels, sawdust may contribute to densifying the matrix by acting as a fine filler, reducing pore volume and water pathways. As replacement increases, however, the amount of organic matter with high internal porosity increases, promoting water retention and capillary absorption. Additionally, the inherent hydrophilic nature of wood fibers exacerbates water uptake. These effects are particularly evident in mixes with low water content, where poor paste dispersion may fail to fully coat the sawdust, while mixes with higher water content may benefit from improved workability and particle encapsulation, mitigating the adverse effects to some extent[38,36].

Overall, the data confirm that moderate incorporation of sawdust, particularly at or below 5%, can improve the water absorption performance of hollow blocks without compromising durability. However, higher replacement levels, especially at or above 10%, result in significant increases in water absorption, potentially diminishing the material’s suitability for use in moisture-sensitive or load-bearing applications. These findings align with broader literature recommendations advocating for low-percentage sawdust inclusion to balance sustainability with structural integrity and long-term durability[37,39,28,18,36].

Table-2: Mean Percentage Water Absorption of Hollow Blocks after 24Hours and 48 Hours Submersion (%) with Varying Mix Ratios and Percentage Replacement (%).

Hours	Mix Ratio	0	5	10	15
24	1:2:0.3	3.30 ± 0.50^{b}	0.60 ± 0.20^{c}	2.40 ± 0.40^{b}	14.00 ± 1.40^{a}
	1:1.5:0.4	3.30 ± 0.50^{b}	4.10 ± 0.60^{b}	7.30 ± 0.90^{a}	2.10 ± 0.40^{c}
	1:1:0.5	1.10 ± 0.40^{c}	1.20 ± 0.40^{c}	4.40 ± 0.60^{b}	6.20 ± 0.70^{a}
	1:0.5:0.7	3.60 ± 0.50^{a}	1.90 ± 0.50^{b}	2.80 ± 0.50^{ab}	2.50 ± 0.50^{b}
48	1:2:0.3	4.40 ± 0.60^{b}	1.70 ± 0.30^{c}	4.90 ± 0.70^{b}	24.60 ± 2.60^{a}
	1:1.5:0.4	5.00 ± 0.70^{b}	6.40 ± 0.80^{b}	11.30 ± 1.30^{a}	0.70 ± 0.50^{c}
	1:1:0.5	4.00 ± 0.60^{c}	3.70 ± 0.60^{c}	5.70 ± 0.70^{b}	9.20 ± 0.90^{a}
	1:0.5:0.7	4.17 ± 0.55^{bc}	3.80 ± 0.60^{c}	5.20 ± 0.60^{ab}	5.87 ± 0.65^{a}

Data are expressed as Mean ± Standard Deviation. Different superscript letters (a, b, c) within the same row indicate significant differences ($p < 0.05$) as determined by Duncan’s Multiple Range Test (DMRT).

Conclusion

The incorporation of wood sawdust as a partial sand replacement in hollow concrete blocks significantly influences water absorption, with low levels (5%) often enhancing matrix densification and reducing uptake, while higher levels (10–15%) increase porosity and moisture retention. Across mix ratios, the 1:1:0.5 formulation demonstrated superior performance, maintaining absorption below 6.20% after 24 hours and 9.20% after 48 hours at 15% replacement, well within ASTM C90 limits for many applications. In contrast, leaner mixes like 1:2:0.3 exhibited dramatic increases at higher sawdust content, reaching up to 24.60% after 48 hours, highlighting thresholds beyond which durability is compromised. These findings underscore the potential for sawdust valorization in sustainable construction, particularly at 5–10% replacement for lightweight, low-absorption blocks suitable for interior or dry-climate uses. Future research should explore complementary treatments, such as sealants or chemical additives, to extend applicability in humid regions, ultimately supporting waste reduction and resource efficiency in timber-dependent economies like Nigeria's.

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