Experimental Investigation of Water Absorption Behaviour of Coconut Shell Aggregate Concrete

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ABSTRACT

The increasing demand for sustainable construction materials has stimulated interest in the utilization of agricultural waste as alternative concrete constituents. This study investigated the water absorption characteristics of concrete produced with coconut shell as a partial replacement for conventional coarse aggregate by volume. Four concrete mixtures containing 0%, 10%, 20%, and 30% coconut shell replacement were evaluated. A total of twenty (24) concrete cube specimens measuring 100 mm × 100 mm × 100 mm were cast, with eight specimens allocated to the total water absorption test, eight for absorption capacity and the remaining eight to the capillary water absorption test, giving two replicate specimens for each mixture in each test. Capillary water absorption test was determined in accordance with ASTM C1585 while the total water absorption test was evaluated using modified full-immersion procedure adapted from the weighing protocol of ASTM C1585, in which concrete cubes were completely submerged in water and weighed after 1,3,5,15 and 30 minutes, and after 1, 4, 24, and 48 hours to monitor water uptake. The absorption capacity was determined in accordance with ASTM C642. The results showed that both the absorption capacity, total and capillary water absorption increased with increasing coconut shell content due to the higher porosity and water absorption capacity of coconut shell compared with conventional granite aggregate. Statistical evaluation using two-way analysis of variance (ANOVA) revealed that both coconut shell replacement level and exposure time had statistically significant effects ($p < 0.05$) on the water absorption behavior of the concrete. Despite the increase in water absorption, the measured values remained within acceptable ranges reported for structural lightweight concrete. The findings indicate that coconut shell can be used as a sustainable partial replacement for coarse aggregate while maintaining acceptable durability characteristics, particularly at moderate replacement levels.

Keywords: *Coconut shell concrete; Total water absorption; Capillary water absorption; Sustainable concrete; ASTM C642; ASTM C1585; ANOVA*

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INTRODUCTION

Concrete remains the most widely used construction material because of its high compressive strength, versatility, and ability to withstand a broad range of environmental conditions. Nevertheless, the durability of reinforced concrete structures continues to be threatened by deterioration processes initiated through the ingress of water and aggressive ions. Water transport mechanisms, including permeability, diffusion, and capillary absorption, play fundamental roles in determining the long-term durability of concrete because they govern the penetration of moisture, chlorides, sulphates, and other deleterious substances into the cement matrix (Javier et al., 2011; Mohammadi, 2013). Consequently, water absorption has become one of the most reliable durability indicators because it reflects pore connectivity, permeability characteristics, and the quality of the interfacial transition zone (ITZ), which collectively influence the service life of concrete structures.

Growing environmental concerns associated with the excessive extraction of natural aggregates and the high carbon emissions generated during concrete production have stimulated global interest in sustainable construction materials. Agricultural wastes have increasingly been recognized as viable alternatives capable of reducing environmental pollution while conserving natural resources. Among these materials, coconut shell has attracted considerable attention because of its low density, high toughness, wide availability, and potential application as a lightweight coarse aggregate. The utilization of coconut-derived materials contributes to circular economy principles by transforming agricultural waste into value-added construction materials while reducing disposal challenges (Javadi Pordesari et al., 2025; Mutnbak, 2026). Recent investigations have significantly expanded the understanding of coconut-based concrete systems. Huang et al. (2026) demonstrated that incorporating coconut shell ash and coir fibre improves the sustainability of concrete and provided microstructural evidence showing that the interfacial transition zone largely controls the mechanical and durability performance of coconut-derived concrete. Their study revealed that while coconut shell ash may reduce compressive strength because of increased porosity, appropriate fibre reinforcement can compensate for strength loss through crack-bridging mechanisms. Similarly, Mutnbak (2026), in a comprehensive review of 98 published studies, concluded that the engineering performance of coconut shell concrete depends primarily on aggregate conditioning, pore connectivity, curing conditions, and matrix refinement rather than simply on compressive strength. The review further emphasized that durability should be evaluated based on transport properties such as water absorption and permeability under functional performance requirements.

Several recent experimental studies have focused on optimizing the engineering properties of coconut-based concrete using modern analytical techniques. Okeke et al. (2025) successfully applied artificial neural network modelling to optimise concrete blocks incorporating coconut shell and coconut shell ash, demonstrating that appropriate replacement levels can reduce density while maintaining satisfactory compressive strength. Marcos and Rodirguez (2025) similarly reported that partial replacement using coconut shell ash and coconut husk ash improved both compressive strength and water absorption performance of concrete blocks, while statistical optimization identified optimum replacement levels for sustainable production. Likewise, Sales et al. (2026) showed that replacing conventional materials with 10% coconut husk ash and crushed coconut shell produced lightweight concrete blocks with satisfactory mechanical strength, thermal performance, and acceptable water absorption characteristics. These studies collectively demonstrate that coconut-derived materials possess considerable potential for sustainable concrete production when properly proportioned.

Research has also highlighted the importance of fibre reinforcement and optimization in controlling moisture transport within cementitious materials. Alenezi et al. (2025) demonstrated that untreated coconut fibres significantly reduced water absorption through improved fibre–matrix bonding and densification of the interfacial transition zone, while excessive fibre contents adversely affected workability because of fibre agglomeration. Similarly, Firmawan et al. (2026) employed factorial experimental design and analysis of variance (ANOVA) to optimize coconut fibre and expanded polystyrene compositions, reporting that controlled fibre incorporation improved compressive strength while maintaining acceptable lightweight characteristics. These findings indicate that pore refinement, fibre dispersion, and interface quality are critical factors influencing both mechanical performance and moisture transport behaviour.

Although substantial progress has been achieved in developing coconut shell concrete, important knowledge gaps remain. Most previous investigations have concentrated on compressive strength, flexural behaviour, thermal conductivity, optimization techniques, fibre reinforcement, or microstructural characterization, whereas comparatively fewer studies have comprehensively evaluated the capillary water absorption behaviour of coconut shell aggregate concrete produced using locally available Nigerian materials. Furthermore, existing investigations often assess either total water absorption or mechanical performance independently, with limited attention given to simultaneously evaluating capillary absorption, total water absorption, and moisture absorption capacity as complementary indicators of durability. Consequently, there remains insufficient experimental evidence for engineers seeking to determine the optimum coconut shell replacement level that provides acceptable lightweight performance without compromising long-term durability.

Problem Statement

The increasing demand for sustainable construction materials has accelerated the use of agricultural wastes such as coconut shell as substitutes for conventional aggregates. However, because coconut shell possesses significantly higher porosity and water absorption than natural coarse aggregates, uncertainty remains regarding its influence on moisture transport and the long-term durability of concrete. Although recent studies have demonstrated encouraging improvements in strength optimization, fibre reinforcement, and sustainability, comprehensive investigations into the water absorption behaviour of coconut shell lightweight concrete remain limited, particularly under locally available Nigerian materials and environmental conditions. This knowledge gap restricts the wider engineering application of coconut shell concrete in structures exposed to prolonged moisture and aggressive service environments.

Research Gap

A critical review of recent literature indicates that while significant advances have been made regarding the mechanical behaviour, optimisation, and sustainability of coconut shell concrete (Javadi Pordesari et al., 2025; Okeke et al., 2025; Huang et al., 2026; Mutnbak, 2026), limited studies have systematically investigated capillary water absorption, total water absorption, and moisture absorption capacity simultaneously using conventional coarse aggregate replacement under standard laboratory conditions. Furthermore, there remains inadequate experimental information relating water absorption behaviour to practical durability assessment for coconut shell lightweight concrete produced from locally sourced Nigerian materials.

Novelty of the Study

Unlike previous studies that primarily focused on compressive strength optimisation, fibre reinforcement, machine learning prediction, or microstructural characterisation, the present study provides an integrated experimental assessment of capillary water absorption, total water absorption, and moisture absorption capacity of coconut shell lightweight concrete at different replacement levels using locally available materials. The study therefore contributes practical durability information for the design and application of sustainable lightweight concrete in tropical environments.

Aim and Objectives

The aim of this study is to evaluate the water absorption properties of coconut shell lightweight concrete produced through partial replacement of conventional coarse aggregate with coconut shell aggregate.

The specific objectives are to:

1. evaluate the effect of coconut shell aggregate replacement on capillary water absorption;
2. determine the total water absorption characteristics of coconut shell concrete after 28 days of curing;
3. assess the moisture absorption capacity of coconut shell lightweight concrete at different replacement levels; and
4. determine the suitability of coconut shell aggregate for producing durable and sustainable lightweight concrete suitable for engineering applications.

The findings of this study are expected to contribute to the development of environmentally sustainable construction materials by providing experimental evidence that supports the utilization of coconut shell as an alternative lightweight aggregate while improving understanding of the durability implications associated with water absorption. The outcomes will assist engineers, material scientists, and policymakers in developing sustainable concrete mixtures that balance lightweight performance, durability, and resource conservation.

MATERIALS AND METHODS

Materials

BUA Sokoto brand Ordinary Portland Cement, grade 42.5N, conforming to BS standards, was used as the binder. Fine and coarse aggregates were obtained from a local quarry in Nama, Sokoto, with a maximum coarse aggregate size of 20 mm. Coconut shell aggregate, sourced as waste from Gawon Nama, Sokoto, was manually crushed to approximately uniform size. Potable water free from deleterious materials was used for mixing and curing. All materials were locally sourced and free from hard lumps or impurities.

Proportion of Concrete Mix

The mix proportion which was obtained from the trial mix of water/cement ratio for the experiments was (1:2.5:3.5) by weight with a water/cement ratio of 0.5%. In this research only 10%, 20% and 30% of the volume of coarse aggregate was replaced by equivalent volume of coconut shell aggregate and then the control (0%). The mixing was manually done in the laboratory and the curing of concrete cubes was by total submerging inside water in a curing tank. The material mix proportion is as shown in (Table 1).

Capillary water absorption

Sorptivity test was carried out for the 4 different concrete mixes according to ASTM C1585. Concrete specimens of 100mm^3 were casted from the mix. For the curing age of 28 days, two specimens were prepared and after 24 hours they were remolded and placed in water for curing under the same condition as those cubes for compression test until the required testing days. The samples were dried in an oven at 85^{0}C for 72 hours, the specimens were kept at regular intervals removed and then left to cool at normal room temperature in the laboratory before the water absorption test commenced. The capillary water absorption test was conducted by placing one face of each sample just in contact with water on supports in a capillary tray and water was gradually added until the level rose above the contact surface, as the concrete specimen absorbed water and increase in mass the water absorbed was measured by weighing each sample at prescribed time intervals of 1, 3, 5, 15, 30min, 1, 4, 24, 48hours, and

Table 1: Concrete mix proportion for the experiment

Ref.	Water/ cement ratio	Water (kg)	Cement (kg)	Fine Aggregate. (kg)	Coarse Aggregate. (kg)	Coconut shell Aggregate (CSA) Replacement by (volume).		
						8.05kg	16.10kg	24.15kg
Values	0.5	11.5	23	57.5	80.5	10%CSA	20%CSA	30%CSA

Table 2: Physical properties of coarse aggregates

Properties	Results	Standards
Specific Gravity of aggregates		BS 812-2: 1995
Coarse aggregates	2.65	
Fine aggregates	2.63	
	1.44	
Coconut shell aggregates		
Bulk density of aggregates (kg/m^3)		BS 812-2: 1995
Coarse aggregates	1509	
Fine aggregates	1777	
	531	
Coconut shell aggregate		
Flakiness Index (%)		BS 812-105.1: 1989
Coarse aggregate	19.33	
	87.13	
Coconut shell aggregate		
Elongation Index (%)		BS 812-105.2: 1990
Coarse aggregate	21.50	
	27.62	
Coconut shell aggregate		
Water absorption (%)		BS 812-2: 1995
Coarse aggregate	0.91	
Coconut shell aggregate	29	

the average of each of set of sample mass was computed. Total mass of water absorbed at each time was obtained by subtracting the dry weight from the wet. The capillary water absorption was computed by the ration of mass gained to the area of the specimen in contact with water in (g/mm^2) which was plotted against the square root of time, the area of concrete in contact with water is 100mm x 100mm = 10,000mm^2. Capillary water absorption coefficient is the slope of linear variation of absorbed water per unit area plotted against square root of time for the experiment.

Total water absorption

The experimental process is the same as that of capillary absorption except that; in this case, the total water absorption test was evaluated using modified full-immersion procedure adapted from the weighing protocol of ASTM C1585 the cubes are totally submerged in water inside a container (Table 2). The level of water above the face of concrete in the container is kept at nearly 50 mm. Increase in sample mass as water absorbed was measured by weighing each sample at prescribed time intervals of 1, 3, 5, 15, 30 min, 1, 4, 24, and 48, to monitor water uptake and the average of each set of two sample mass was computed. Total mass of water absorbed at each time was obtained by subtracting the dry weight from the wet.

RESULTS AND DISCUSSION

Improved capillary absorption after 28 days of curing

The capillary absorption results presented in (Figure 1) demonstrate that water absorption increased progressively with increasing coconut shell aggregate (CSA) replacement levels throughout the 48-hour testing period. The control concrete (0% CSA) recorded the lowest capillary water absorption of 0.0031 g/mm², whereas mixtures containing 10%, 20%, and 30% CSA exhibited higher values of 0.0036 g/mm², 0.0043 g/mm², and 0.0050 g/mm², respectively. This progressive increase indicates that replacing conventional coarse aggregate with coconut shell aggregate enhances the capillary suction capacity of concrete, primarily because coconut shell possesses a naturally porous microstructure and higher intrinsic water absorption than crushed granite. Consequently, increasing the volume of coconut shell aggregate increases pore connectivity and facilitates greater moisture transport through the hardened concrete matrix.

The regression analysis further demonstrated excellent correlations between capillary water absorption and the square root of time, with R^2 values of 0.9740, 0.9753, 0.9848, and 0.9895 for 0%, 10%, 20%, and 30% CSA, respectively. These high coefficients of determination indicate that the capillary absorption process closely

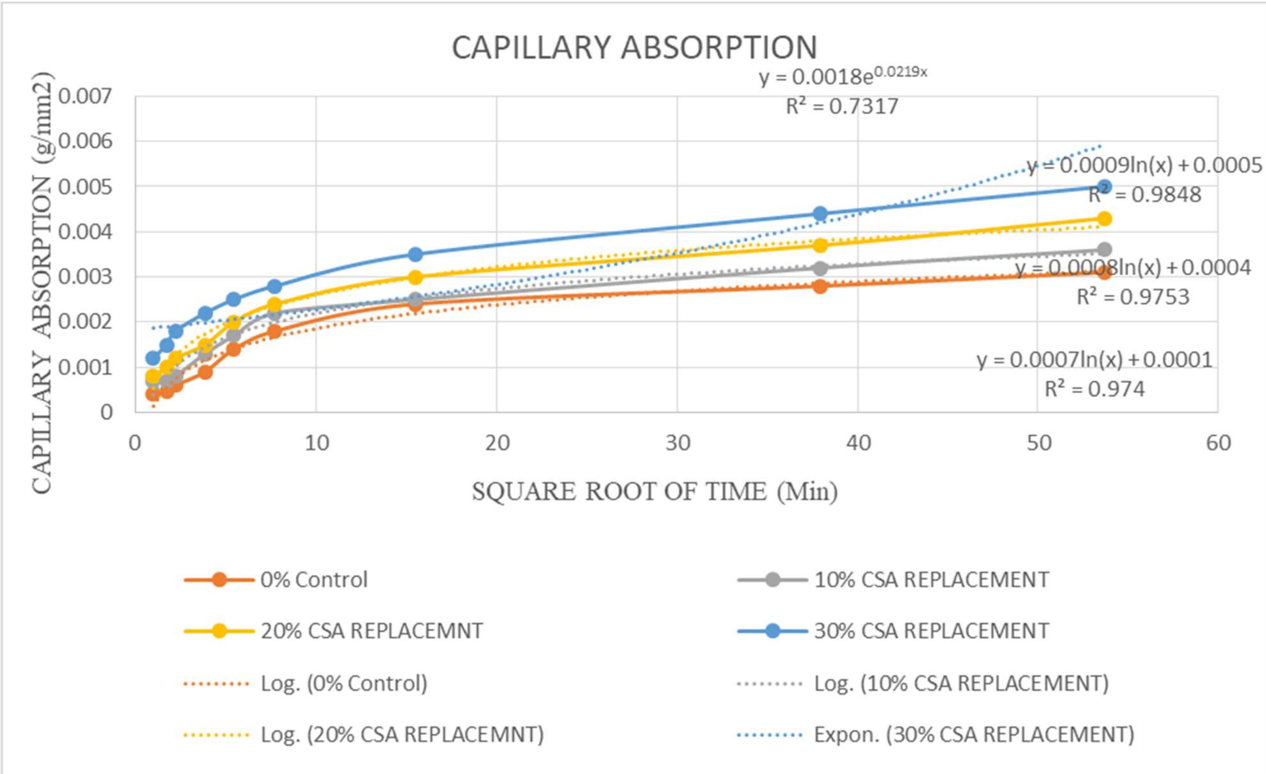

Figure 1: Capillary Absorption vs √t

follows the sorptivity principles described in ASTM C1585, confirming that water movement through the specimens was predominantly governed by capillary suction. The steep slopes observed during the initial stages of absorption indicate rapid filling of accessible capillary pores, after which the rate gradually decreased as the concrete approached moisture equilibrium. This behaviour is consistent with the established mechanism of unsaturated water transport in cementitious materials.

The observed increase in capillary absorption agrees with the findings of Javadi Pordesari et al. (2025), who reported that increasing coconut shell aggregate replacement from 10% to 30% generally increases water absorption because of the porous nature of coconut shell aggregates and their higher pore connectivity compared with conventional coarse aggregates significantly increased sorptivity due to higher pore connectivity and changes within the interfacial transition zone (ITZ). They attributed this behaviour to the combined effects of paste volume, aggregate porosity, and the quality of the aggregate cement interface, all of which control moisture movement through concrete. The present study therefore validates earlier findings while providing additional experimental evidence that locally sourced coconut shell aggregate exhibits similar moisture transport characteristics under Nigerian conditions.

The present findings are also consistent with the comprehensive review by Javadi Pordesari et al. (2025), who reported that coconut shell aggregate possesses a relatively low specific gravity (1.03–1.56) and a highly porous internal structure compared with conventional aggregates. Their review concluded that although coconut shell aggregate offers substantial environmental and economic benefits for lightweight concrete production, increasing replacement levels generally increase water absorption because of the porous nature of the aggregate and the higher permeability of the resulting concrete. The authors further recommended limiting replacement levels to approximately 20–50%, depending on the desired balance between lightweight performance and durability. The progressive increase in capillary absorption observed in the present study therefore supports these conclusions regarding the durability implications of higher coconut shell contents.

Similarly, the results corroborate the observations of Mutnbak (2026), who reviewed ninety-eight published studies and concluded that the durability of coconut shell concrete is primarily governed by pore connectivity, aggregate conditioning, curing quality, and the characteristics of the interfacial transition zone rather than compressive strength alone. Mutnbak emphasized that transport properties such as sorptivity, permeability, and water absorption should be considered critical indicators of long-term durability because they determine the ingress of moisture and aggressive ions into the concrete matrix. The increasing capillary absorption recorded in the present study confirms the importance of evaluating durability beyond mechanical strength when assessing coconut shell concrete. The present results also agree with the microstructural observations reported by Huang et al. (2026). Their investigation showed that incorporating coconut shell ash without adequate pore refinement increased porosity and weakened the interfacial transition zone, resulting in reduced resistance to moisture penetration. However, they demonstrated that incorporating coir fibres partially compensated for this effect through crack-bridging mechanisms that improved fibre–matrix interaction and reduced crack propagation. Although fibres were not incorporated in the present investigation, the increasing capillary absorption with higher coconut shell aggregate replacement suggests that future studies should investigate fibre reinforcement or supplementary cementitious materials as potential approaches for reducing moisture transport and improving durability.

In contrast, the lower water absorption reported by Alenezi et al. (2025) differs from the findings of the present study. They observed that incorporating 1.0% untreated coconut fibres reduced water absorption to 8.38% because fibre reinforcement improved fibre–matrix bonding, refined the interfacial transition zone, and reduced connected pore networks, as confirmed by scanning electron microscopy. The difference between their results and those obtained in the present study can be explained by differences in the constituent materials and mechanisms. While the present study replaced dense coarse aggregate with porous coconut shell aggregate, Alenezi et al. enhanced the cement matrix using discrete coconut fibres that improved crack resistance and reduced permeability. This comparison highlights that coconut-derived materials can either increase or decrease water absorption depending on whether they function as lightweight aggregates or reinforcing fibres.

Comparable observations were reported by Marcos and Rodirguez (2025), who demonstrated that partial replacement using coconut husk ash and coconut shell ash maintained acceptable water absorption while improving compressive strength when optimum replacement levels of approximately 10% were adopted. Their statistical optimisation indicated that moderate replacement levels refined the cementitious matrix through pozzolanic reactions, thereby limiting excessive pore connectivity. Likewise, Sales et al. (2026) found that concrete hollow blocks incorporating 10% coconut husk ash and crushed coconut shell achieved an appropriate balance between compressive strength, thermal performance, and water absorption, whereas higher replacement levels adversely affected mechanical performance because of increased porosity. These findings suggest that moderate incorporation of coconut-derived supplementary materials may effectively offset the higher water absorption associated with coconut shell aggregate.

The excellent logarithmic relationships obtained in the present study further agree with the predictive modelling approach reported by Okeke et al. (2025), who successfully applied exponential regression analysis to characterize the engineering performance of coconut shell concrete. Their study demonstrated that mathematical modelling provides a reliable approach for predicting concrete behaviour under varying replacement levels and identified optimum material proportions capable of balancing sustainability with structural performance. Likewise, the strong regression coefficients obtained in the present investigation demonstrate that capillary absorption behaviour can be accurately modelled as a function of exposure time, providing useful predictive information for durability assessment and service-life evaluation.

Recent work by Yu et al. (2026) also provides valuable insight into the moisture transport mechanisms observed in the present study. They reported that modifying coconut fibres with superabsorbent polymers significantly improved fibre dispersion, refined pore structure, reduced total porosity, and enhanced internal curing, resulting in higher compressive strength and lower drying shrinkage. Their microstructural analysis confirmed that controlling pore connectivity is fundamental to improving durability. Although the present study focused solely on untreated coconut shell aggregate, the findings suggest that combining coconut shell aggregate with internal curing technologies or fibre modification could reduce capillary absorption while preserving the sustainability benefits of coconut-derived concrete.

The present study demonstrates that increasing coconut shell aggregate replacement significantly increases capillary water absorption because of the higher porosity and moisture affinity of coconut shell compared with conventional coarse aggregate. Nevertheless, the results confirm that coconut shell aggregate remains a promising sustainable lightweight aggregate when replacement levels are carefully controlled. The findings also indicate that future optimization strategies incorporating supplementary cementitious materials, fibre reinforcement, or pore-refining additives may improve durability while retaining the environmental advantages associated with agricultural waste utilization. Consequently, this study contributes valuable experimental evidence supporting the development of durable, sustainable, and lightweight concrete for tropical construction environments while complementing recent advances reported in the contemporary literature (2025–2026).

Statistical analysis of capillary water absorption

A two-factor ANOVA without replication was performed to

Table 3: Two-factor ANOVA without replication for capillary water absorption.

Source of variation	SS	df	MS	F	p-value	F crit
Immersion time	4.34E-05	8	5.43E-06	214.8286	2.04 x E-20	2.355081
Coconut shell replacement	7.56E-06	3	2.52E-06	99.78495	1.09 x E-13	3.008787
Error	6.06E-07	24	2.53E-08	-	-	
Total	5.16-05	35				

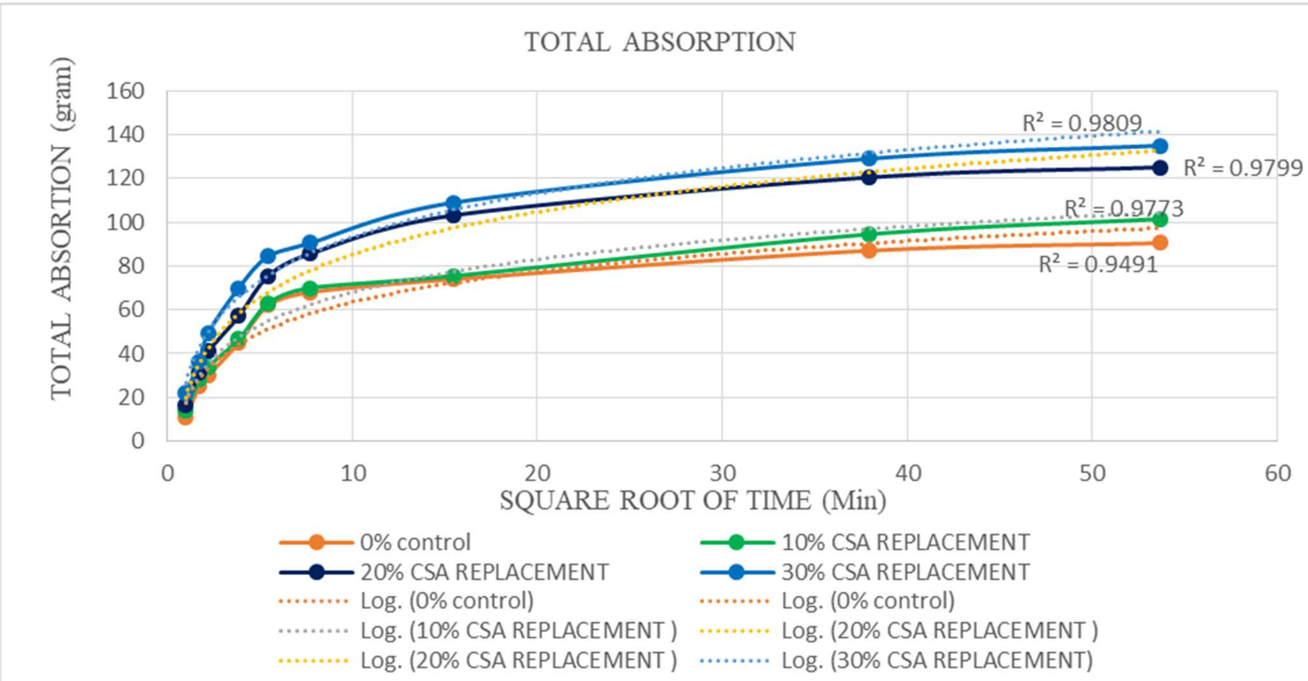

Figure 2: Total water Absorption vs √t

evaluate the effects of exposure time and coconut shell replacement level on capillary water absorption (Table 3). The analysis revealed that exposure time had a highly significant effect on capillary water absorption (F = 214.83, p = 2.04 × 10^{-20}), indicating that water uptake increased significantly as the exposure duration increased from 1 minute to 48 hours. Similarly, coconut shell replacement level significantly affected capillary water absorption (F = 99.78, p = 1.09 × 10^{-13}), demonstrating that increasing the proportion of coconut shell aggregate resulted in significantly higher capillary water absorption. The higher absorption observed at greater replacement levels is attributed to the porous structure and higher intrinsic water absorption of coconut shell aggregate, which increases the connectivity of pores within the concrete matrix and facilitates capillary transport of water. Although capillary water absorption increased with coconut shell content, this does not necessarily mean the concrete is unsuitable. Many studies conclude that coconut shell concrete can still be suitable for structural or lightweight applications when: the replacement level is optimized (often around 10–20%, depending on the mix design), the mix is properly designed, and durability is enhanced using supplementary cementitious materials or other admixtures.

Total absorption

The results of total water absorption for all the concrete specimens are shown in (Figure 2) it also shows that the water content increases as percentage of coconut shell increases and also increases with time of suction, the average weight of water absorbed for the two specimens of the control concrete is 90.5 grams after 48hrs while specimens with 10%, 20% and 30% coconut shell aggregate replacement have a weight of water absorbed as 101.5 grams, 125.1 grams and 135 grams respectively. The outcome of this findings is in accordance with that of (mukhtar 2017; Trokon 2018; and Azuma et al., 2018). The modeled relationship from excel, between the total water Absorbed and square root of time in the figure shows a strong logarithmic relationship with regression value of 0.9491, 0.9773, 0.9799 and 0.9809 for 0%, 10%, 20% and

30% respectively.

Total water absorption

Figure 2 illustrates the variation of total water absorption of concrete containing 0%, 10%, 20%, and 30% coconut shell aggregate (CSA) replacement with immersion time. It is evident that total water absorption increased with increasing immersion time for all concrete mixtures. The rate of water absorption was rapid during the initial stages of immersion before gradually decreasing as the concrete approached saturation. This trend is characteristic of cement-based materials, where the readily accessible capillary pores are filled first, followed by a slower rate of water penetration as the pore network becomes saturated. The control concrete (0% CSA) consistently exhibited the lowest total water absorption throughout the testing period, whereas the mixtures containing coconut shell aggregate recorded progressively higher absorption values as the replacement level increased. At the end of the test period, the 30% CSA mixture showed the highest total water absorption, followed by the 20% and 10% mixtures. This behaviour indicates that increasing the percentage of coconut shell aggregate increases the water absorption capacity of concrete. The higher absorption is primarily attributed to the porous cellular structure, rough surface texture, and higher intrinsic water absorption of coconut shell aggregate compared with conventional crushed granite, resulting in greater pore connectivity within the concrete matrix.

The observed are also results are consistent with recent studies. Boakye et al. (2025) reported that incorporating coconut shell aggregate improves the sustainability of concrete but also increases its porosity and affects durability-related properties as the replacement level increases. Similarly, the recent review by Mutnbak (2026) concluded that coconut shell concrete generally exhibits higher water absorption than conventional concrete because of the porous nature of the aggregate, although the extent depends on the replacement percentage and mix design.

The gradual reduction in the rate of absorption after the initial period observed in the present study indicates that the available capillary pores progressively became saturated with water, thereby reducing further water ingress. A similar absorption pattern has been reported in durability studies of coconut shell concrete, where water absorption increases rapidly at the early stages of immersion before stabilizing as saturation is approached.
Although higher water absorption is generally associated with increased permeability and reduced durability, the results suggest that lower replacement levels, particularly 10%, still exhibited relatively moderate absorption compared with the 20% and 30% mixtures. This implies that partial replacement of conventional coarse aggregate with coconut shell aggregate can produce environmentally sustainable lightweight concrete with acceptable durability when appropriate mix proportions and curing practices are adopted.

Statistical analysis of total water absorption

The two-way ANOVA confirmed that immersion time and coconut shell replacement significantly affected the total water absorption of the concrete specimens (Table 4). The highly significant effect of immersion time ($F = 113.48$, $p < 0.001$) indicates continuous water uptake as exposure duration increased, while the significant effect of coconut shell replacement ($F = 31.93$, $p < 0.001$) shows that increasing the proportion of coconut shell aggregate increased the water absorption of the concrete. This behavior is attributed to the higher porosity and water affinity of coconut shell compared with conventional crushed stone, which facilitates greater water penetration during immersion. These findings agree with previous studies on coconut shell concrete, which reported increasing water absorption with increasing coconut shell content due to the porous microstructure of the aggregate.

Water absorption capacity (moisture content)

The results of the water absorption test are shown in (Figure 3). The highest water absorption was achieved at 30% coconut shell aggregate replacement (6.09%), followed by concrete containing 20% CSA (5.77%) and 10% CSA (5.58%), the control concrete (0%) has the lowest water absorption of (4.15%). The same with the study by Anandh and Gunasekaran (2019) where they observed a higher water absorption by coconut shell concrete of 11.32% after 28 days of curing. Mhaya et al., (2022) reported that the water absorption of coconut shell concrete increased between 5% and 6.7% when the replacement of sand with coconut shell increased from 0% to 60%. But Gunasekaran et al., (2017) reported that coconut shell concrete water absorption and permeable pore voids decreases as the age of curing increases under full water, intermittent and air-dry curing condition. This shows that the use of coconut shell aggregate in concrete increases the water retaining capacity of concrete, and this will reduce the durability properties of the concrete material, as the coconut shell aggregate has the highest water absorption capacity than the normal aggregate.

The control concrete (0% CSA) exhibited the lowest total water absorption throughout the test period, indicating a denser microstructure with fewer interconnected pores. In contrast, concretes containing coconut shell aggregate showed progressively higher water absorption as the replacement level increased. The 10% CSA mixture recorded only a moderate increase compared with the control, while the 20% and 30% CSA mixtures exhibited the highest absorption values. At the end of the test period (approximately 54 hours), the total water absorption reached about 90, 100, 125, and 135 for the 0%, 10%, 20%, and 30% replacement levels, respectively.

Table 4. Two-factor ANOVA without replication for Total water absorption

Source of variation	SS	df	MS	F	p-value	F crit
Immersion time	37716.31	8	4714.538	113.48	3.60 x E-17	2.335081
Coconut shell replacement	3978.994	3	1326.331	31.93	1.52 x E-8	3.008787
Error	997.0403	24	41.54335	-	-	
Total	42692.34	35				

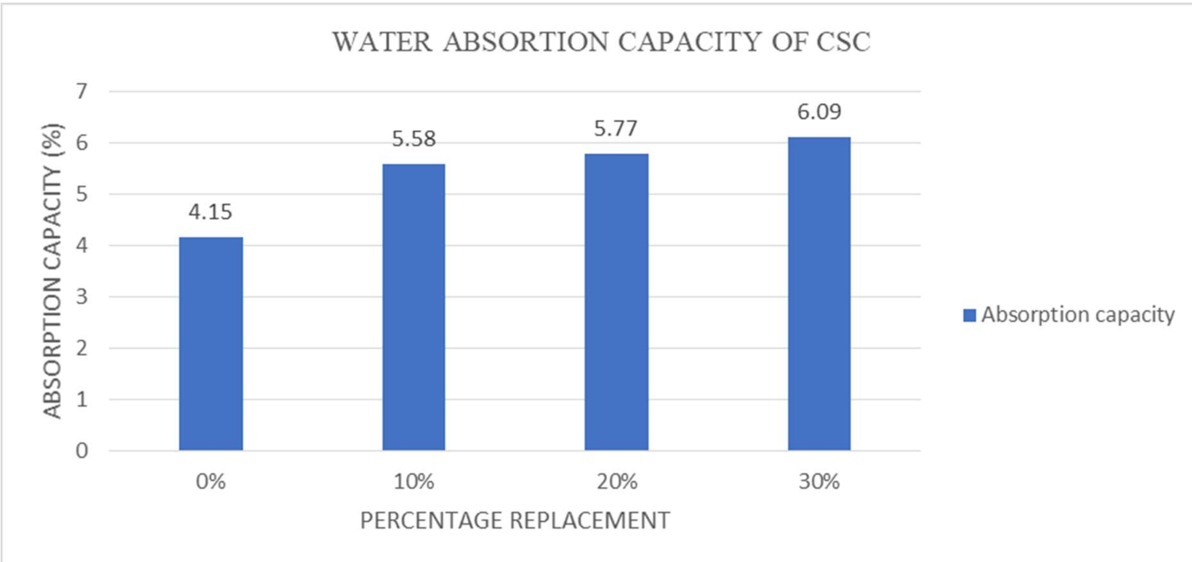

Figure 3: Water absorption vs coconut shell percent (%)

The higher water absorption observed in coconut shell concrete can be attributed to the porous cellular structure and high-water absorption capacity of coconut shell aggregate. As the percentage of CSA increased, the volume of permeable pores within the concrete also increased, allowing more water to penetrate the concrete matrix. This agrees with recent findings by Mhaya et al (2022) Sekar & Kandasamy (2019) Gunasekaran et al (2015) and kanajia & jain (2017) who reported that incorporating coconut shell aggregate increases the porosity and water absorption

Conclusion

This study evaluated the influence of coconut shell as a partial replacement of conventional coarse aggregate on the water absorption characteristics of concrete. The results demonstrated that increasing the coconut shell replacement level from 0% to 30% (by volume) significantly increased the absorption capacity, capillary water absorption, and total water absorption of the concrete. The 48-hour absorption capacity increased from 4.15% for the control mixture to 5.58%, 5.77%, and 6.09% for the 10%, 20%, and 30% replacement levels, respectively. Likewise, the 48-hour capillary water absorption increased from 0.0031 g/mm² to 0.0036 g/mm², 0.0043 g/mm², and 0.0050 g/mm², while the corresponding total water absorption increased from 90.5 g to 101.5 g, 125.1 g, and 135.0 g, respectively. Statistical analysis using two-way ANOVA confirmed that both immersion time and coconut shell replacement level had statistically significant effects on water absorption characteristics ($p < 0.05$). The observed increase in water absorption with increasing coconut shell content is attributed to the higher porosity and water absorption capacity of coconut shell aggregates compared with conventional crushed stone. Although coconut shell concrete exhibited higher water absorption than the control concrete, the measured values remained within the range reported for lightweight aggregate concrete in the literature, indicating its potential for structural and sustainable construction applications where appropriate durability considerations are incorporated into the mix design. Future studies should investigate the long-term durability of coconut shell concrete under different environmental exposure conditions and evaluate strategies for reducing its permeability while maintaining its sustainability benefits.

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