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EXPLORING THE POTENTIAL OF *SENILIA SENILIS* SHELLS AS A PARTIAL REPLACEMENT FOR FINE AGGREGATE IN HOLLOW CONCRETE BLOCK PRODUCTION

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Abstract

Rising demand for sustainable construction materials has spurred research into alternatives that reduce reliance on natural aggregates. This study investigates the feasibility of using *Senilia senilis* shells as a partial substitute for fine aggregate in manufacturing hollow concrete blocks. The shells, collected from coastal areas and processed by cleaning, drying, crushing, and sieving, were incorporated into concrete mixes at replacement levels of 0%, 10%, 20%, 30%, and 40% by weight of fine aggregate, with 0% serving as the control. Laboratory tests, including assessments of physical properties, compressive strength, water absorption, and microstructural analysis, were performed on the materials and cured blocks over 28 days. The specific gravity of natural fine and *Senilia senilis* aggregates is 2.65 and 2.63, respectively. The two values obtained are within the recommended limit of 2.7 as specified by the Standard Organisation of Nigeria (SON) and ASTM C128. Compressive strength results showed that replacing 10-30% of fine aggregate with *Senilia senilis* shells produced blocks with mechanical properties meeting the minimum acceptable compressive strength of 3.5 N/mm^2, as observed at 30% replacement, in accordance with Nigerian Industrial Standard (NIS-87) and ASTM C90 standards for load-bearing applications. Also, for water absorption, the results obtained for 10-30% fine *Senilia senilis* shells are within the 15% limit specified by ASTM C90. Microstructural analysis (SEM/EDS) revealed that *Senilia senilis* shell fines, rich in $CaCO_3$, serve as effective nucleation sites for hydration products and aid in densifying the interfacial transition zone at lower replacement levels. Overall, the study highlights the potential of seashell waste as a construction material, which will reduce total dependence on natural aggregate for block production, contributing to waste management within the construction industry.

Keywords: marine waste utilization; sustainable construction materials; concrete block production; waste to wealth; *Senilia senilis* shells.

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1. Introduction

The rising demand for concrete and masonry products in the construction industry has led to the extensive exploitation of natural resources, especially fine aggregates like river sand [1]. Overreliance on natural aggregates for masonry and concrete work has greatly contributed to environmental damage, including but not limited to the loss of aquatic habitats, riverbed depletion, increased erosion, and lowered water tables [2]. Additionally, the scarcity of sand in some areas has significantly raised costs for builders and developers [2]. Consequently, industry practitioners and researchers are exploring eco-friendly, cost-effective, and sustainable alternatives to traditional construction materials that can partially or completely replace natural aggregates without sacrificing structural strength. One promising solution involves using waste and by-products from agricultural and marine sources [3, 4]. *Senilia*

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senilis shells, a type of bivalve mollusk shell commonly found in coastal regions, are often discarded as waste after consumption [5]. *Senilia senilis* is distributed along the West African Atlantic coast [5]. This means it occurs naturally in multiple West African countries along the Atlantic seaboard where suitable lagoons, estuaries, and tidal flats exist [4, 5]. Without proper disposal methods, these shells contribute to environmental pollution, produce unpleasant odors during decomposition, and take up valuable landfill space [4].

These shells are rich in calcium carbonate ($CaCO_3$) and have desirable physical and mechanical properties that could be used for construction purposes [4, 5]. Their use not only reduces environmental pollution caused by improper disposal but also helps conserve natural sand resources. Although studies on other mollusk shells, such as oyster and cockle shells, have demonstrated their potential as aggregate substitutes, there is limited scientific investigation into the suitability of *Senilia senilis* shells for block production [5–7]. Without empirical data on their performance in terms of strength, durability, and workability, their adoption in the construction industry remains uncertain. This research explores the potential of using *Senilia senilis* shells as a partial substitute for natural fine aggregate in hollow concrete block production. The study assesses the physical properties of shells, and it also assesses their influence on block density, compressive strength, and water absorption at varying replacement rates, and determines compliance with relevant masonry standards, including those of the Standards Organisation of Nigeria. The scope is limited to laboratory-scale production, controlled curing conditions, and performance evaluation up to 28 days, excluding durability and structural system analysis. By examining the potential of *Senilia senilis* shells as a partial replacement for fine aggregates, this research supports global sustainability efforts focused on waste recycling, resource efficiency, and environmental protection. The results could offer practical insights for local and international construction practices, encouraging eco-friendly alternatives while tackling waste management issues in coastal areas.

2. Materials and methods

The materials used for this study are Ordinary Portland Cement (OPC) grade 42.5 N, well-graded clean riverbed sand, cleaned and processed *Senilia senilis* shells obtained from the Seme border in Badagry, Lagos State, Nigeria. Potable water for mixing and curing is available at the laboratory used for the study. In line with relevant standards such as NIS-87 [8] and ASTM C90) [9], a laboratory study was done comparing conventional sandcrete blocks, which serve as a control, with blocks containing graded percentages of processed *Senilia senilis* shell as partial replacement of fine aggregates. The key variables of the experiment are density/unit weight, porosity, water absorption, microstructural observations, and compressive strength on days 7, 14, and 28 in line with relevant standards. The *Senilia senilis* shells were replaced in varying percentages of 0%, 10%, 20%, 30%, and 40%. The mix with 0% represents the 100% natural river sand, which is the control experiment.

2.1. Preparation and processing of Senilia senilis shells

Senilia senilis shells were collected from a coastal deposit. The organic residues of *Senilia senilis* shells were removed by washing with water to remove impurities, brushing, and oven-drying at 105 °C until constant mass to determine moisture content. Seashells were crushed and sieved to produce particle size fractions comparable to the river sand used. In order to arrive at a finer size for experimental purposes, it was washed and further crushed to a fine size of 2.5 mm. This served as a partial substitute for the fine sand of the entire experiment. It was ensured that the shells' sieve analysis produced sieve sizes to match sand fractions to enhance uniformity in the mix. The processed *Senilia senilis* shells were stored in a sealed covered container to avoid moisture changes. Natural river sand was used as the control fine aggregate.

2.2. Mix design and block production

The OPC binder-to-fine aggregate ratio is 1:6 by volume for hollow sandcrete blocks. A constant 1:6 cement-to-aggregate ratio and 0.5 water-cement ratio suitable for block production were maintained. The mixes were prepared by replacing sand with shell at the percentage proportion by mass of fine aggregate. A mechanical mixer was used to produce a homogeneous consistency, followed by compaction using a vibrating block molding machine. Hollow concrete blocks 6-inch (150 × 150 × 150 mm) were produced by partially replacing natural fine aggregate with processed shells at 0%, 10%, 20%, 30%, and 40% by weight. A compact press compacted the samples to ensure consistent compaction energy across samples in line with Nigeria Industrial Standards (NIS) [8] and ASTM C90 [9]. The samples were cured for 7, 14, and 28 days. The moisture is maintained by sprinkling water 3 times daily. Some of the block samples produced are shown in Fig. 1. Samples were subjected to a standard water curing to preserve and prepare them for further tests. Tables 1 and 2 show the mix design and samples as labelled with partial replacement of fine aggregate. The target strength is 3.5 N/mm^2 in accordance with NIS [8] and ASTM C90 [9] standards.

Table 1. Mix Design and Mix Proportions

Mix Identity	Mix Proportion (1 : 1.6)
M - 0 (Control mix)	Concrete with 100% riverbed sand as fine aggregate
M - 10	Concrete with 90% riverbed sand and 10% *Senilia senilis*
M - 20	Concrete with 80% riverbed sand and 20% *Senilia senilis*
M - 30	Concrete with 70% riverbed sand and 30% *Senilia senilis*
M - 40	Concrete with 60% riverbed sand and 40% *Senilia senilis*

Table 2. Mix Design with varying *Senilia senilis* replacement

Replacement Level	Cement (kg)	Natural Sand (kg)	*Senilia senilis* (kg)	Water (kg)
0% (Control)	300	1800	0	150
10%	300	1620	180	150
20%	300	1440	360	150
30%	300	1260	540	150
40%	300	1080	720	150

2.3. Tests and measurements

The following physical and mechanical tests were carried out on the materials used and the samples produced: water absorption of materials (*Senilia senilis* shell and fine), particle size distribution of fine aggregates, and *Senilia senilis* shell. Blocks were demoulded after 24 hours and cured under moist conditions for 28 days in line with the NIS [8] and ASTM C90 [9] Standards. Tests conducted included water absorption of hollow sancrete blocks, compressive strength test, and microstructural analysis were carried out to examine the interfacial transition zone between *Senilia senilis* shell particles and cement paste. Results were compared with the minimum requirement of the Standards Organisation of Nigeria for sandcrtete blocks. A compression testing machine (CTM) was used to crush each block as shown in Fig. 2. Each sample was fixed into the CTM, and the compressive effort was then applied at a defined rate until the material failed. The average compressive strength value was then estimated for each mix set using the material's maximum load.

Figure 1. Batched Hardened Hollow block samples with *Senilia senilis* shells

Figure 2. Compression testing machine with seashell block

3. Results and discussions

3.1. Physical properties of aggregates

The processed *Senilia senilis* shells had a specific gravity of 2.63, slightly lower than that of natural river sand (2.65), indicating similar density. The water absorption capacity obtained for fine aggregates was 1.69%, while 6.9% was obtained for *Senilia senilis* shell fine aggregates. The difference in the values obtained for the two materials indicates that seashell fine is marginally more absorptive than natural fine aggregates [10]. The higher water absorption of *Senilia senilis* shell aggregates used as a partial replacement for conventional fine aggregate implies an increase in the mixture moderate water demand as the percentage of *Senilia senilis* increases [11, 12]. Previous studies consistently report that natural river sand exhibits relatively low water absorption values (typically 0.5-2.0%), attributed to its dense silica composition and low internal porosity [13, 14]. In contrast, crushed seashell aggregates predominantly composed of calcium carbonate demonstrate higher absorption values ranging from 3-8%, depending on the processing and particle grading [15, 16]. This higher absorption has been linked to the intrinsic micro-porosity and irregular surface texture of shell particles, which increase water demand and may influence the effective water-cement ratio.

Particle size distribution plays a critical role in the packing density, strength development, and durability of hollow block production [17]. Fig. 3 shows that the cumulative particle-size distributions of the natural fine aggregate (NFA) and the *Senilia senilis* shell fine aggregate (SFA) were similar and well graded. These results support the use of SFA as a partial replacement for NFA without major departures from target gradation; however, the observed finer/coarser shift around the sieve implies a modest adjustment to fines content to maintain workability and compaction in block pressing. Well-graded river sand enhances particle packing, reduces void content, and minimizes cement demand, thereby improving compressive strength and dimensional stability ASTM C33 [18]. The natural fine aggregate exhibited a fineness modulus of 3.01, while the seashell fine aggregate recorded a slightly higher value of 3.26, indicating a modestly coarser grading [5, 15]. The small difference in FM suggests that both materials are broadly compatible for blending [19]. When *Senilia senilis* shell fines are introduced as partial replacements, the combined fineness modulus is expected to remain within the recommended range for block production (2.6–3.3), thereby ensuring adequate workability and packing density. Crushed seashell fines frequently exhibit gap grading or excessive coarseness unless properly processed and sieved [20]. Studies report that shell-derived aggregates often contain higher proportions of particles retained on the 2.36mm sieve and irregular angular shapes, which can increase void ratio and water demand [7, 11, 21]. However, excessive replacement may shift the gradation toward the coarser side, which could reduce the fines fraction and marginally affect compaction and water absorption. Optimal replacement levels are therefore advised to balance workability, strength, and durability in the produced blocks. Comparatively, while natural sand inherently satisfies grading specifications with minimal processing, seashell fines require controlled crushing and sieving to achieve a comparable particle distribution for hollow block production.

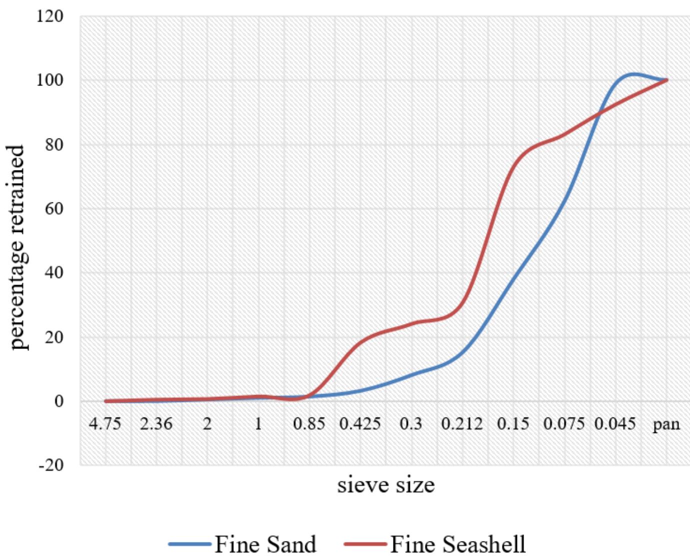

Figure 3. Particle size distribution for riverbed sand and *Senilia senilis* shell

3.2. Water Absorption of Hollow Sandcrete Block Produced

Water absorption is a key durability index for masonry units, reflecting pore connectivity and internal microstructure [17, 22]. Conventional sandcrete or concrete blocks produced with natural river sand typically exhibit relatively low absorption values due to the dense silica composition and low porosity of the aggregate [22, 23]. The blocks produced in this study with the partial replacement of natural fine aggregate by seashell fines exhibited 24-hour water absorption values ranging from 11.21 to 15.59, as shown in Fig. 4. At the 0% to 20% the water absorption , range between 11.21 to 13.72. This implies that there is relatively low porosity, aiming to have increased compressive strength. Only 40% replacement exceeds 15% recommended limits as stated in ASTM C90 [9], with 0.59% difference, and others are within the recommended limit. Findings from previous studies revealed that when seashell fines are introduced as a partial replacement for natural sand, reported absorption values generally increase with increasing replacement ratio. This trend is attributed to the intrinsic porosity and irregular surface morphology of carbonate-based shell particles, which elevate total void content and water demand [24–26]. The results obtained from this study are an indication that the partial use of seashell fines is liable to produce acceptable block units if the aggregate grading, batching moisture, compaction energy, and curing are optimized. While the value approaching 15% water absorption is an indication of increased pore connectivity and of having moisture-related durability issues. However, the values obtained from the study are in line with ASTM C90 [9] standard recommending values not exceeding 15%.

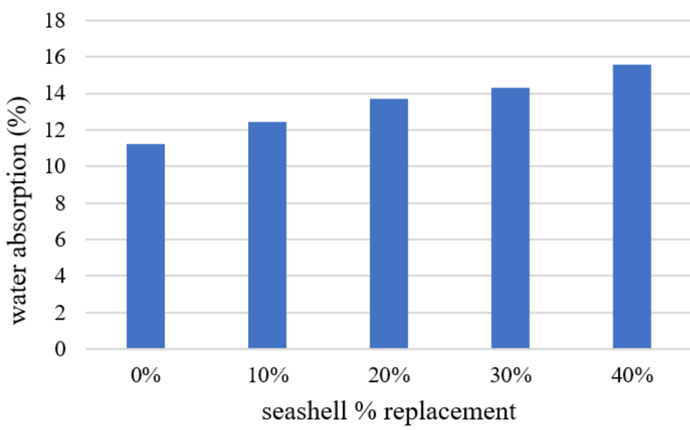

Figure 4. Water Absorption of Hollow sandcrete block produced

3.3. *Compressive strength of hollow sandcrete block*

Compressive strength is the primary mechanical index governing the structural suitability of masonry units [27]. Blocks produced with natural river sand typically exhibit stable and predictable strength development due to the dense, well-graded silica composition and low porosity of the aggregate [28, 29]. The compressive strength of hollow sandcrete blocks produced from the study decreases with an increase in seashell percentages. It should be noted that there is a steady increase with curing age, which is a reflection of the hydration progression of cement, and slightly drops as *Senilia senilis* shells increase to 40%. This reduction is commonly attributed to the lower stiffness, higher porosity, and weaker interfacial transition zone associated with calcium carbonate-based shell particles [19, 30]. It was observed from the results obtained as shown in Fig. 5 that 0%–30% seashell replacement meets the minimum requirement of 3.5 N/mm^2 at 28 days for load bearing as specified in NIS [8] and ASTM C90 [9] standard. In some cases, finely ground shell powders have demonstrated filler effects that improve particle packing and partially offset strength losses [31]. Comparatively, while natural sand provides superior mechanical performance, controlled substitution with processed seashell fines can achieve satisfactory strength performance within specified masonry standards.

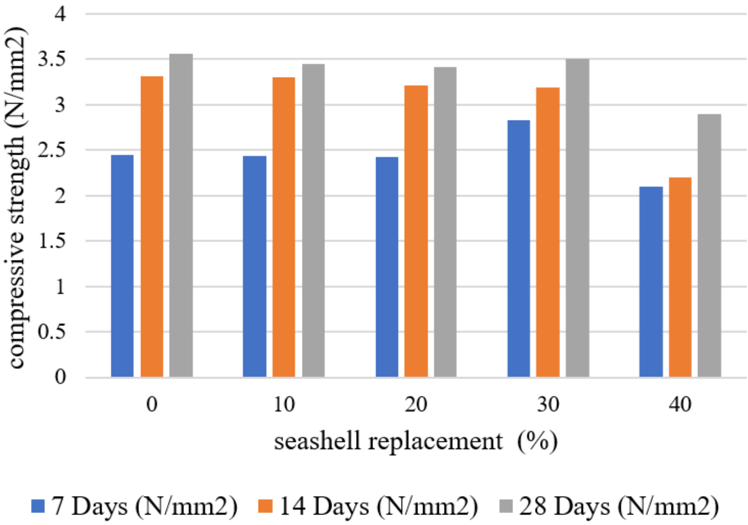

Figure 5. Compressive strength of hollow sandcrete block

3.4. Microstructural Analysis

Microstructural analysis provides fundamental insight into the mechanical and durability performance of masonry units incorporating alternative aggregates [32]. Blocks produced with natural river sand typically exhibit a relatively dense microstructure, characterized by compact hydration products and a well-bounded interfacial transition zone (ITZ) between cement paste and silica-based aggregate [33]. The angular stability and low porosity of natural sand contribute to reduced capillary voids and improved matrix continuity [34, 35]. SEM analysis of *Senilia senilis* shell fines revealed angular, irregular, and plate-like morphologies with surface grooves and micro-porous features, in contrast to the smoother texture of natural sand. When incorporated into the block matrix, these morphological features enhanced mechanical interlock with cement hydrates [33], . SEM micrographs of mixes containing 20% seashell fines, as shown in Fig. 6, showed dense C–S–H deposition around seashell particles, indicating strong bonding at the interfacial transition zone. At higher replacement levels (30% seashell as shown in Fig. 8), however, the microstructure exhibited some voids and microcracks at the aggregate–paste interface, consistent with the increased water absorption values measured, which is in line with the finding of [33]. EDS spectra of the seashell fines, as shown in Figs. 7 and 9 for 20 and 30 percentage replacement, confirmed $CaCO_3$ dominance, with strong Ca and O peaks. In blended blocks, EDS profiles revealed Ca, Si, and Al signatures, suggesting the coexistence of carbonate phases and cement hydration products. These microstructural and compositional observations explain the compressive strength improvement at moderate replacement levels and the decline at higher contents, linking the seashell's chemistry and morphology directly to block performance. The strength improvement observed in hollow concrete block incorporating *Senilia senilis* shells is closely linked to the microstructural features and chemical composition revealed by Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS). Arunachalam and Henderson [33] reported that the incorporation of seashell fines, predominantly composed of calcium carbonate, modifies the internal morphology of the composite. SEM observations reported in previous studies reveal increased micro voids and a comparatively weaker ITZ at higher shell replacement levels, attributed to the porous and irregular structure of crushed shell particles [32, 35, 36]. However, when shells are finely round and uniformly distributed, filler effects may enhance particle packing and promote denser calcium-silicate-hydrate (C-S-H) gel formation at moderate replacement levels [34]. As natural sand-based hollow blocks demonstrate inherently compact microstructures, controlled incorporation of well-processed seashell fines can achieve comparable matrix densification at low substitution levels (10-30%), whereas excessive replacement (40% and above) tends to increase pore connectivity and microcracking.

Figure 6. SEM for 20% seashell percentage replacement of natural fine aggregates

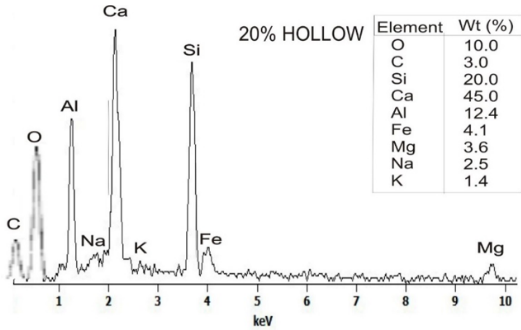

Figure 7. EDX for 20% seashell percentage replacement of natural fine aggregates

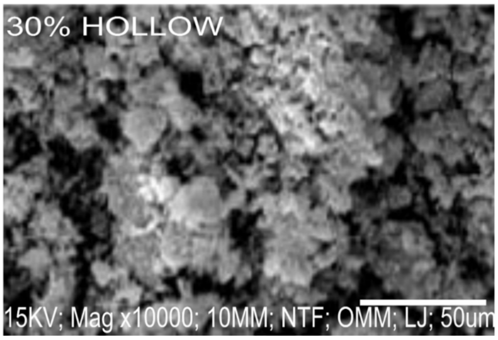

Figure 8. SEM for 30% *Senilia senilis* percentage replacement of natural fine aggregates

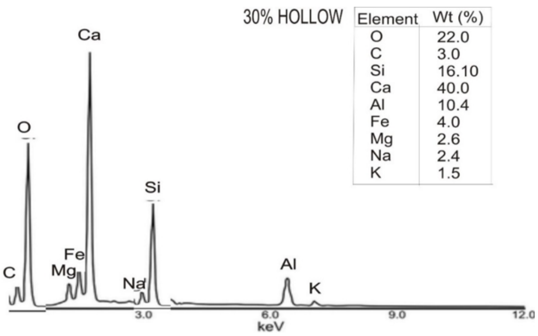

Figure 9. SEM for 30% *Senilia senilis* percentage replacement of natural fine aggregates

4. Conclusions

This study evaluated the potential of *Senilia senilis* shells as a partial replacement for fine aggregate in hollow block production, with emphasis on physical properties, mechanical performance, and microstructural characteristics. The findings indicate that the incorporation of seashell material significantly influences the physical and mechanical properties of the blocks, with performance strongly dependent on the replacement level and particle grading. While natural fine aggregate provided superior packing density, lower water absorption, and higher compressive strength, moderate substitution with well processed *Senilia senilis* fines demonstrated acceptable performance within the standard requirement for load bearing application. The results demonstrated that incorporating crushed and graded shell particles up to 30% by mass of fine aggregate produced blocks that met the minimum strength and water absorption requirements for load-bearing applications, as specified in relevant standards. However, higher replacement levels (> 40%) led to increased porosity, elevated water absorption, and reduced strength, attributable to weaker interfacial bonding and void formation. Microstructural analysis (SEM/EDX) confirmed that seashell fines, rich in $CaCO_3$, provide effective nucleation sites for hydration products and contribute to densification of the interfacial transition zone at lower replacement levels. At excessive replacement, microcracks and unfilled voids were observed, explaining the reduction in performance. Overall, seashell fines can be considered a viable supplementary fine aggregate for sustainable block production, offering both environmental benefits through waste valorization and technical potential for reducing dependence on natural sand. Optimal performance was achieved at 10–30% replacement, beyond which mechanical and durability properties begin to deteriorate.

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