Evaluating the performance of oyster shells as sustainable coarse aggregate in concrete grade 25 (C25) production.

Gabriel Kwame Sipi Takyi[1,2], *John Kwame Tawiah*[3], *Laudina Gloria Mends*[3], *Emmanuel Adu-Afari*[3], *Charles Vicku*[4], *Maxwell Selase Akple*[2], *Franklin Liggie-Kudono*[3]

[1]*Mechanical Engineering Department, Ho Technical University. P.O. Box 217, Ho, Ghana.*

[2]*School of Engineering and Sciences, Technologico de Monterrey, Monterrey, N.L., Mexico*

[3]*Civil Engineering Department, Ho Technical University. P.O. Box 217, Ho, Ghana.*

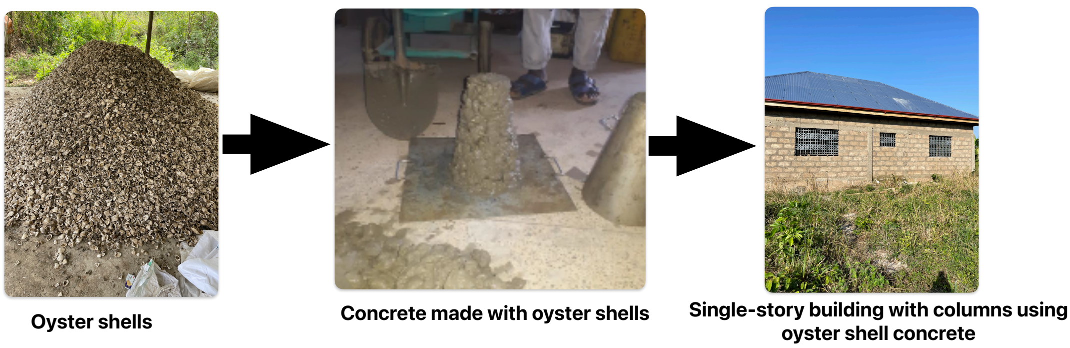
[4]*Industrial Art Department, Ho Technical University. P.O. Box 217, Ho, Ghana.*

Corresponding author: Gabriel K S Takyi (gkstakyi@htu.edu.gh)

Abstract

This study assesses concrete using crushed granite (CC) and oyster shells (OS) as aggregates. Grading analysis confirmed well-graded distributions, with sand's fineness modulus (2.52) meeting British Standard (BS 812-103.1). OS concrete exhibited a higher water-cement ratio (0.67 vs. 0.55 design) due to greater water absorption (1.8% vs. 0.4% for CC). However, it was still within the BS 8500:1 limit. Crushed granite achieved a 70 mm slump, while OS recorded zero. This is attributed to its semi-elliptical shape, reducing grout availability. Both materials met the aggregate impact value (AIV), Los Angeles Abrasion value (LAAV), and specific gravity standards. At 28 days, compressive strength was 25.7 MPa for CC and 17.3 MPa for OS. The oyster shell failed to meet the 25 MPa design strength even after 36 days of curing. This could be attributed to the geometry and water-cement ratio limiting its performance, and optimization of the concrete is required.

Graphical Abstract



Introduction

The construction sector's rapid urbanization and economic growth have significantly increased the demand for concrete. Concrete is the most widely used building material due to its affordability, durability, fire resistance, and ability to withstand harsh conditions [1, 2]. Over 10 billion tons are produced annually, and it is extensively used in residential and commercial buildings, roads, and marine constructions. Concrete is made by mixing cement, water, and aggregates such as basalt, granite, and limestone [3].

However, the depletion of natural aggregates caused by this high demand has increased concrete production costs [2].

To address this challenge, alternative materials like agricultural waste have been explored for concrete production, including snails, periwinkle, rice husk, sawdust, and oyster shells (OS) [4-6]. Studies by Eo and Yi [7] found that replacing 50% of fine aggregates with OS yields concrete with acceptable absorption rates.

Similarly, Adewuyi et al. [8] demonstrated that mollusk shell aggregates ensure durable concrete under specific conditions, such as calcination at 300°C, and resist sulfate-induced compressive strength reduction. These findings highlight the potential of agricultural waste in sustainable and cost-effective concrete production.

In Ghana's Volta region, oysters, locally called 'Adode,' are abundant and the shells are discarded as waste after consumption [9, 10]. Historical deposits of shells also exist, buried near the lake due to past overflows, some as deep as 2 meters. These shells, containing 97.2% calcium carbonate, along with gypsum and trace materials [2, 7, 11], are used for water purification, agriculture, and as construction materials. Artisans have adopted OS as a low-cost alternative to coarse aggregates like granite, although without adherence to standards or durability considerations.

Given the need for sustainable practices, this research aims to evaluate the strength, workability, and compressive properties of OS-based concrete to guide artisans. While OS offers potential cost savings and waste management benefits, limited research exists on its performance as a coarse aggregate. This study focuses on assessing its suitability, including grading analysis, water-cement ratio, workability, and compressive strength. The results will inform the feasibility of OS as coarse aggregate in concrete production, support sustainable waste management, and potentially expand its applications in non-structural or lower-strength concrete. Further research may also explore chemical admixtures or alternative OS processing methods to improve its concrete performance.

Materials and Methods

Study Area

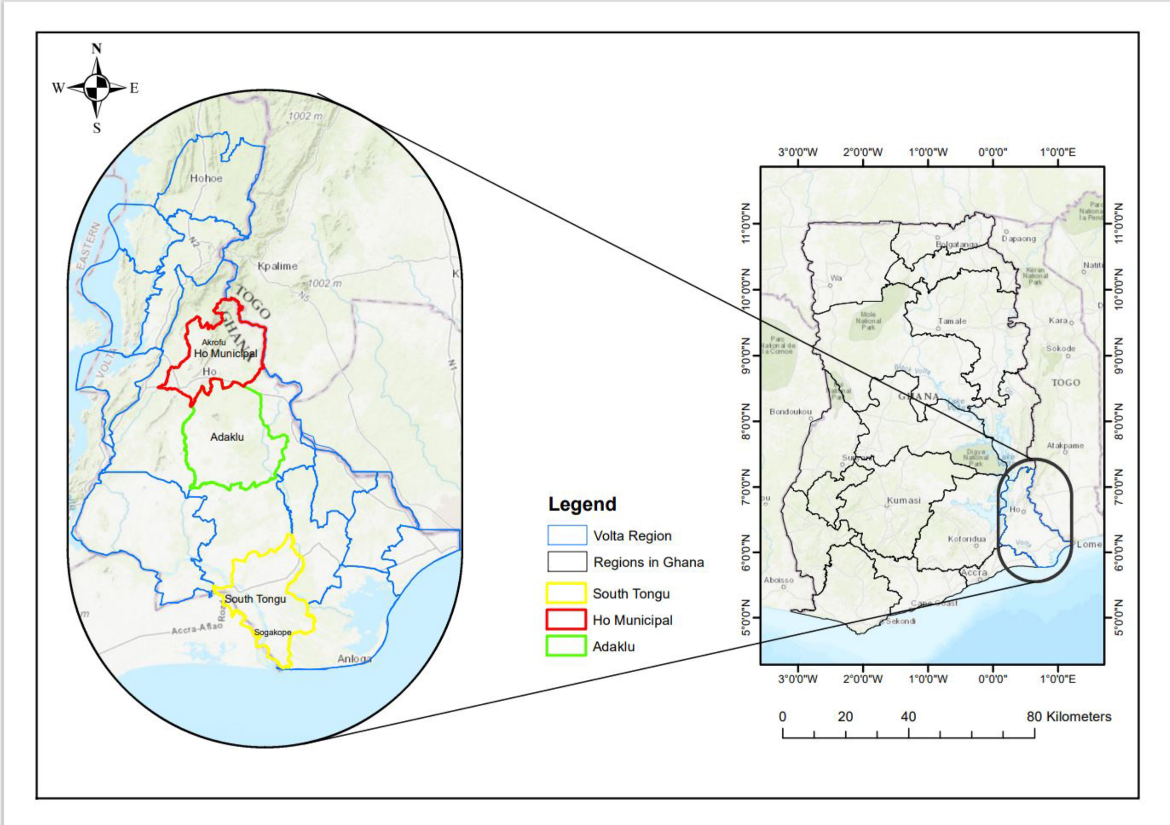


Fig. 1 Location of the three districts in Ghana where artisans fully replace coarse aggregate with oyster shells in concrete production.

This research replicates the practice of producing concrete for residential buildings in the districts shown in Fig. 1, which has been the practice of the local artisans for many years.

Communities along the Volta Lake have oyster shells buried in the soils due to an overflow of the lake since these towns are low-lying. The aggregates for this study were from three different towns which are Sogakope, Adaklu, and Akrofu.

The findings from this research will be used as a guide to educate these artisans on safe and sustainable concrete production.

Materials and methods

Cement

An ordinary Portland cement called Dangote cement brand (OPC 32.5R), which conforms to the NIS 444-1 standard [12] was used for the experiment.

Aggregates

The aggregates used in this study were oyster shells (OS), granites and pit sand. Oyster shells (OS) from Sogakope, coarse aggregate (granites, CC) from Adaklu quarry, and fine aggregate (pit sand) from Akrofu. The towns Sogakope, Adaklu, and Akroful are all located in the Volta region of Ghana, West Africa.

The physical, geometric, and chemical properties of the constituent materials were established by standardized testing methods and procedures.

The tests conform to the Ghana Standard Specification for Road and Bridges 2007 (GSSRB, 2007) is similar to the British standard 812 (BS 812).

The following physical properties were explored: particle size distribution (grading), flakiness and elongation index, Los Angeles Abrasion, bulk and specific gravity test, Loose and Rodded density test, silt test on the sand, and fineness modulus of sand.

Mixing water and admixture

Portable tap water (that is normally free from oil, organic matter, and alkalis) from Ghana Water Company Limited (GWCL) was used for the laboratory batching/trial mix process.

No admixture was used in the production of the concrete. This experiment was conducted at the Ghana Highway Authority Materials Laboratory in the Volta region of Ghana, West Africa.

Mix design details and Concrete mixtures.

In this experiment, the oyster shells were used to fully replace the coarse aggregate (granites), as is the practice in the study area. However, a control experiment was used where crushed granites (CC) were also used as a full replacement for the coarse aggregate.

The physical and geometrical properties' results aided the mix design process. The British Research Establishment (BRE) second edition manual was used to derive all parameters in the mix design. The main design parameters are outlined in Table 1**.**

A total of twenty-four (24) concrete cubes were produced using a standard mold dimension of 150 mm X 150 mm X 150 mm for curing and testing. Out of the twenty-four (24) concrete cubes, twelve (12) were produced with the OS while the remaining were produced with the CC as a control.

The curing and testing were done seven (7), fourteen (14), twenty-eight (28), and thirty-six (36) days after they were produced. Three (3) cubes each from the OS cubes and CC cubes were crushed on each of the days specified (7^{th}, 14^{th} , 28^{th} and 36^{th} day) and their compressive strengths were recorded in megapascal (MPa). The average for each of these three (3) cubes was recorded and the results are presented in Fig. 3.

Table 1 presents the mix design results and how the mixing ratio was achieved. The Characteristic strength specified for 28 days old is presented in the table and the value is 25 N/mm^2. The cubes were crushed using a compression testing machine of 2000 kN capacity at the end of each curing ages.

The design mix ratio for the C25 concrete class made of both crushed rock cobbles and Oyster shells is 1: 2: 3.5 by masses which is 2: 4. :7 head pans.

Table 1 Mix design parameters

Name of parameter	Designed Value	Adjusted design value adopted in the CC in trial mix	Design values using OS in trial mix
Characteristic strength specified for 28 days old	25 N/mm^2	25 N/mm^2	25 N/mm^2
Margin (assumed standard deviation of 8: 1.64*3 = 5)	7 N/mm^2	5 N/mm^2	5N/mm^2
Target mean strength	32 N/mm^2	30 N/mm^2	30 N/mm^2
Cement types used	Gd 32.5R Dangote	Gd 32.5R Dangote	Gd 32.5R Dangote
Aggregate type	Granite-crushed		
Fine aggregate type	Medium Pit sand-Uncrushed	Uncrushed	Uncrushed
Water/Cement ratio	0.55	0.58	0.67
Target Slump	30 – 60 mm	30-60mm	30-60m
Maximum aggregate size	20mm	20mm	20mm
Free-water = 210kg/m^3	210 kg/m^3	225 kg/m^3	210 adj to 258 kg/m^3
Cement content	382 kg/m^3	385 kg/m^3	385 kg/m^3
Relative density of combined aggregates (SSD	2800 kg/m^3	2800kg/m^3	2700kg/m^3
Concrete density	2470 kg/m^3	2470kg/m^3	2100kg/m^3
Total aggregate content (2470-382- 210)	1878 ≅ 1880 kg/m^3		1505/1805
Fine aggregate passing 600µm	47%		
Proportion of fine aggregate (adjusted)	38%	40%	40%
Fine aggregate Content (Pit sand) (188*0.38)	714 ≅ 720 kg/m^3	765 kg/m^3	605 adj 765 kg /m^3
Coarse aggregates 1880-714	1166 ≅ 1170 kg/m^3	1330 kg/m^3	900 adj to 1330 kg/m^3
Design Mix Ratio	1 :1.9: 3.04	1 :2 :3.5	1: 2 :3.5

Results and discussion

Grading analysis

The sieve analysis results of the sand, granites, and oyster shells in Fig. 1 **a** and **b** showed that the sand, OS, and CC had a well-graded particle size distribution, with many of the particles within the lower and upper limits.

The results indicated that the sand had a fine to medium particle size distribution, with a fineness modulus of 2.52, which is within the acceptable range for concrete production. The fineness modulus was conducted following BS 812-103.1 [13].

ACI Education Bulletin [14] reported that fineness modulus is most commonly computed for fine aggregates and the value ranges from 2.3 to 3.1.

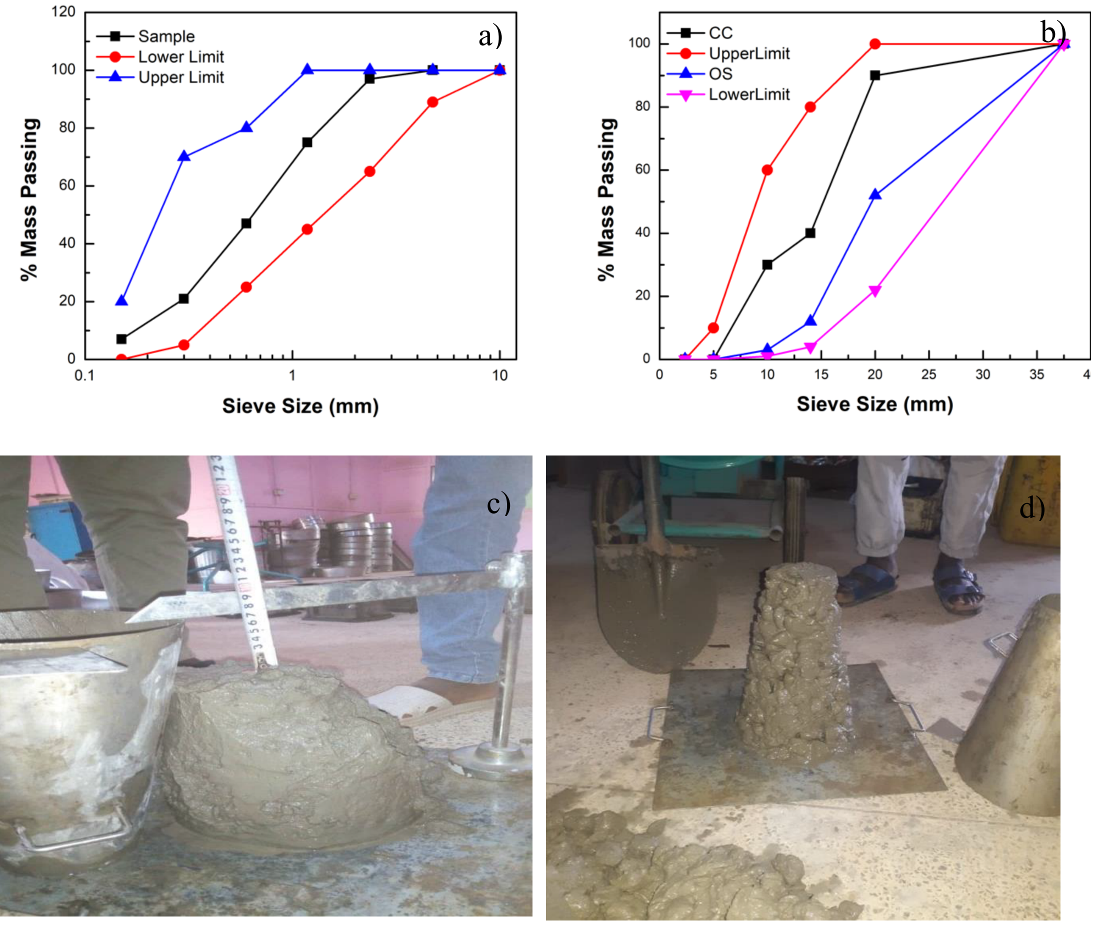


Fig. 2 **a** grading of fine aggregate (sand), **b** grading of coarse aggregate (CC and OS), **c** slump measurement of CC, **d** slump measurement of OS

Water-cement ratio

The designed water-cement ratio for both mixes is 0.55; however, actual Water Cement ratios obtained for the control design (CC) concrete and Oyster shells concrete are 0.58 and 0.67 respectively as shown in Fig. 3a. The OS recorded a higher water absorption of 1.8% than the CC which recorded a water absorption of 0.4% compared to the design value from the mix design. These values are all in the acceptable range specified by BS 8500:1 [15]. The minimum quantity specified by BS 8500:1 is 0.35, however, it could be increased to make the concrete workable.

Slump and workability.

The slump test was carried out to determine the workability of fresh concrete and the test was done in accordance with ASTM C192/C192M specification [16]. The design slump from the mix design is between

30-60mm. However, the true slump measured for granites concrete is 70 mm whereas the Oyster shells concrete recorded zero slump despite the increases in water content as shown in Fig. 2 c and d.

Aggregate Impact Value and Los Angeles Abrasion Test

Aggregate impact value (AIV) gives a measure of the resistance of an aggregate to an unexpected shock or impact [17], while Los Angeles Abrasion Value (LAAV) is the resistance to degradation of aggregates using the Los Angeles testing machine [18]. The AIV and LAAV of the coarse aggregates are and the tests were done in accordance with BS 812-112 [17] and ASTM C131/C131M [18].

The AIV and LAAV results meet the requirement of 30% maximum value specified by BS 812-112 and ASTM C131/C131M respectively for the aggregate to be used in concrete. However, BS 812-112 [17] reported that if the AIV of an aggregate is above 30%, the result should be treated with caution.

Specific gravity test

The specific gravity of the aggregates were conducted in accordance with BS 812-112 [17] and the ACI Education Bulletin [14]. The specific gravities obtained for the oyster shells and granites are 2.6 and 2.8 respectively.

These are within the acceptable range. The range of specific gravity of aggregates as specified by ACI Education Bulletin [14] is from 2.30 to 2.90.

Density Test

The mean densities of the concrete cubes made with OS and CC after 28 days of curing (hydration period) are 2100 kg/m^3 and 2470 kg/m^3 respectively and these are presented in Table 1. The density test conforms to BS EN 12390-7 [19] and BS 812-112 [17]. All concrete cubes produced falls within the range of 2000 kg/m^3 to 2600 kg/m^3 as specified by BS EN 206-1 [20] for regular concretes.

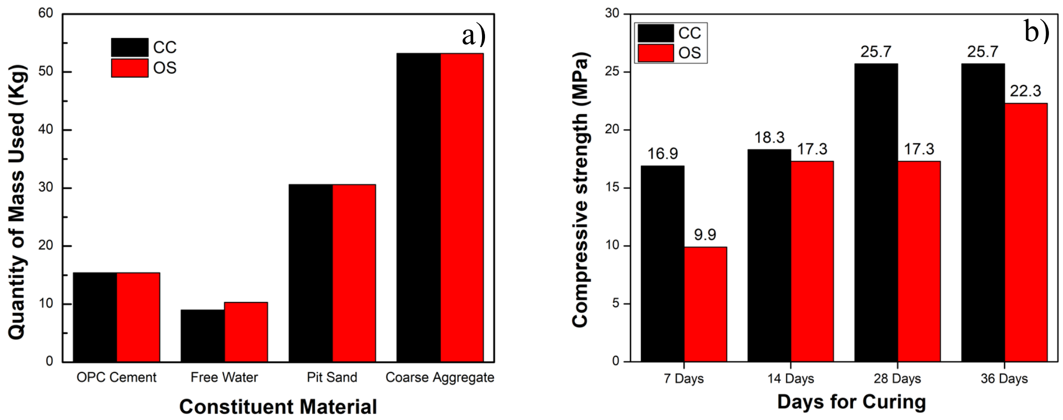


Fig. 3 **a** quantity of mass used for concrete production, **b** average compressive strength of the concretes produced.

Compressive strength

The compressive test on the OS and CC was done in accordance with BS EN 12390-3 [21].

The crushed granite concrete recorded average compressive strengths of 16.9, 18.3, 25.7, and 25.7 MPa for 7, 14, 28, and 36 days respectively whereas the Oyster shells concrete recorded Average cubes compressive strengths of 9.9,17.3, 17.3 and 22.3 MPa respectively for 7, 14, 28 and 36 days respectively. The oyster shell concrete failed to meet the design characteristic strength of 25MPa after 28 days of curing for regular concrete. However, it got close to the value (22.3 MPa) after 36 days. This is shown in Fig. 1.

The Low strength recorded by the oyster shells concrete after the 28-day curing period could be accounted for by the higher water-cement ratio of the mix which necessitated making the mix workable after its recorded zero slumps.

The geometry of the Oyster shells (rounded semi-elipse shapes) reduced the amount of grout (cement &sand paste) available for the workability of the concrete mix and bonding of the oyster shell aggregates. This was because a third of the grout that would have been available for the fluidity (workability) of the mix was stacked in the shells.

Conclusion and Recommendations

In this present work, the concrete standard grade 25 (C25) was used to produce concrete by substituting fully the coarse aggregate with oyster shells.

The analysis reveals that sand, crushed granite, and oyster shells are well-graded for concrete production, but oyster shells exhibit lower percent mass passing and compressive strength compared to crushed granite. The actual water-cement ratios exceeded the designed ratio of 0.55, particularly for oyster shell concrete, which likely contributed to its lower compressive strength.

Workability tests showed crushed granite concrete had higher slump and workability than oyster shell concrete, which recorded zero slump despite increased water content. This reduced workability is attributed to the rounded semi-elliptical shape of oyster shells, which limits grout availability for bonding.

Compressive strength tests confirmed that crushed granite concrete met the design strength of 25 MPa (average 25.7 MPa at 28 days and 36 days), whereas oyster shell concrete failed, achieving only 17.3 MPa and 22.3 MPa on 28 and 36 days respectively. The reduced strength of oyster shell concrete is linked to its higher water-cement ratio, lower percent mass passing, and poor workability.

Crushed granite is recommended for concrete production, targeting 25 MPa strength. Measures like admixtures for improved workability or reduced shell content are necessary if oyster shells are used. The team is currently exploring various admixtures and other concrete processing techniques that could improve the OS compressive strength to 25 MPa target strength.

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Author contribution: All the authors contributed equally to the project.

Data availability: The data generated during the current study are available from the corresponding author upon reasonable request.

Declaration

Conflict of interest: The authors declare no conflict of interest.

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