

A Comparative Evaluation of Physical and Mechanical Properties of Marine Shells as Sustainable Aggregates in Pavement Construction

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Abstract- This study investigated the physical and mechanical properties of four marine shell types—Oyster, Whelk, Octopus, and Periwinkle to assess their suitability as sustainable aggregates in construction applications. Comprehensive laboratory tests were conducted including gradation analysis, flakiness index, specific gravity, water absorption, and soundness (using both magnesium and sodium sulfate solutions). Results showed material characteristics among the shell types. Oyster shells exhibited poor gradation (88% retained at 50mm), extreme flakiness (76.4%), low specific gravity (2.05), very high water absorption (10.95%), and moderate soundness (3.6 - 8.2% loss). Whelk shells showed bimodal gradation, excellent particle shape (0% flakiness), moderate specific gravity (2.31), moderate water absorption (5.9%), and excellent magnesium sulfate resistance (2.6% loss). Octopus shells demonstrated well-graded distribution, low flakiness (6.2%), moderate-high specific gravity (2.52), low water absorption (3.85%), and disproportionate soundness—excellent in sodium sulfate (3.0% loss) but poor in magnesium sulfate (10.0% loss). Periwinkle shells displayed uniform gradation (81% at 19mm), excellent shape (0% flakiness), very low specific gravity (1.6), low-moderate water absorption (4.05%), and consistent soundness (8-9% loss). When assessed against construction standards, Whelk, Octopus, and Periwinkle shells met flakiness and water absorption requirements, while Oyster shells exceeded limits. From our findings, Whelk shells are recommended for structural concrete, Periwinkle shells for lightweight concrete applications, Octopus shells for sodium-rich environments, and Oyster shells as cement replacement in powdered form. This study demonstrates that marine shells offer viable, sustainable alternatives to conventional aggregates, supportive of eco-friendly economy principles while reducing environmental pollution.

Keynote: Marine shells; aggregates; gradation; flakiness index; water absorption; soundness; construction; concrete

I. INTRODUCTION

A highway pavement is a structure consisting of selected and processed materials whose primary function is to distribute the applied vehicle load to the sub grade. The ultimate aim is to ensure that the transmitted stresses are sufficiently reduced that they will not exceed the supporting capacity of the sub grade. Two type of pavement serving this function are flexible pavements and rigid pavement and the materials use in the construction of any of the pavement types are, aggregate asphalt cement, cement, filler and water for rigid pavement.

Aggregates are the basic materials of highway pavement construction. Not only are they the basic material, they do support the main stresses occurring within the pavement. The aggregates in the road surface are also expected to resist wear due to abrasion by traffic as well as the direct weathering effects of the natural elements. The manner in which they do so depends on the inherent properties and qualities of the individual particles and on the means by which they are held together, i.e. by interlocking, by cementations binders or by both.

Aggregates occupy three quarters of the volume of pavement materials. For flexible (bituminous) pavement, aggregate constitute almost 80% to 96% by weight or more than 75% by volume, while for Rigid (normal Portland) pavement, aggregate constitute almost 80% of the weight or about 75% of the volume.

Aggregates use for highway construction is for sub base, base and surfacing materials. As a surfacing material, it is usually in the form of asphaltic concrete in the case of flexible pavements and as mass or reinforced concrete in the case of rigid pavements. The use as a base or sub base material is in the form of crush stone, base, material base and sub base, or a combination of lateritic and stone as sub base and base respectively. The selection and use of any aggregate in pavement is based on technical criteria and moderated by economic consideration and knowledge of types of aggregates generally available in the area.

The physical properties of aggregates fundamentally influence concrete performance. Particle size distribution affects workability and packing density, while flakiness index determines particle shape and its impact on concrete workability and strength. Specific gravity relates to concrete density and structural weight considerations, and water absorption directly influences water-cement ratio requirements and concrete durability. The soundness test, employing magnesium and sodium sulfate solutions, provides critical insight into aggregate resistance to weathering—particularly relevant for the Niger Delta's aggressive environmental conditions characterized by high humidity, tidal influences, and seasonal flooding [1; 4].

This investigation addresses these knowledge gaps through comprehensive laboratory investigation of four marine shell types abundantly available in the Niger Delta region: oyster shells (*Crassostrea gigas*), whelk shells (*Buccinum undatum*), octopus shells (cuttlebone), and periwinkle shells (*Littorina littorea*). The research evaluates gradation characteristics, flakiness index, specific gravity, water absorption, and soundness using both magnesium and sodium sulfate solutions in 10-day cycles. The findings aim to establish the suitability of these waste materials as sustainable construction aggregates, supporting sustainable economy principles, reducing environmental pollution, and providing cost-effective building materials for infrastructure development in the Niger Delta region. This work contributes to the growing body of knowledge on green concrete production and offers practical guidance for material selection in regional construction applications,

potentially mitigating the recurrent infrastructure failures plaguing Niger Delta settlements.

II. MATERIALS AND METHODS

The materials for the study are oyster shells, periwinkle shells, octopus shells and whelk shells. The shells were collected from different parts of Niger delta area in Nigeria where they are in abundance and the towns where they were collected include: Kaa, Ikuru-town, Gokana and Abuloma in Rivers State; Okotukoto and Aasoma in Bayelsa State; Warri and Patani in Delta State. The shells were thoroughly to free from dirt and dried.

This gradation test was conducted in accordance with [3] to determine the particle size distribution of shells by dry sieving. A sample is passed through a stack of progressively sieves, and the weight retained on each sieve is measured to determine the percentage passing each size. Result of the gradation test is shown in Table 1. The water adsorption test was carried out in accordance with [4]. A sample was dried, weighed, and then immersed in water for 24 hours. The shells are then surface-dried to a saturated-surface-dry (SSD) condition and weighed. Absorption is calculated as the percentage increase in mass of the SSD sample relative to its oven-dry mass. Table 2 gives the results of the flakiness index of the different shells. This Bulk specific gravity test was conducted in accordance with [4]. It is the ratio of the mass of the saturated-surface-dry aggregate to the mass of an equal volume of water. The test involves weighing the sample in oven-dry, SSD, and submerged conditions.

The Flakiness Index Test was conducted in accordance with [5]. A special thickness gauge was used to separate flaky particles from a sample of single-size shell fractions. The flakiness index of shells is the percentage of shells that their thickness is less than 0.6 times their mean sieve size.

The Soundness Test was conducted in accordance with [6]. This test estimates a Shell's resistance to weathering. It involves repeatedly immersing shell sample in a saturated solution of sodium or magnesium sulfate, then oven-drying it. The salt crystal growth in the pores simulates the expansion of freezing water. The soundness value is the weighted percentage loss of the sample due to disintegration over a specified number of cycles

III.RESULTS AND DISCUSSION

3.1 Gradation Test

Table 1. Result of Gradation Test

Sieve size (mm)	Weight of oyster shell Passing (g)	Weight of whelk shell Passing (g)	Weight of Octopus shell passing (g)	Weight of periwinkle shell passing (g)
75	0	0	0	0
50	441	311	181	0
25	34	189	260	47
19	16	0	59	405
13.2	9	0	0	48
9.5	0	0	0	0
Receiver	0	0	0	0

The gradation test results demonstrate that each shell type exhibits unique particle size distribution characteristics reflecting their inherent structural properties. Oyster shells remaining predominantly in the 50 mm fraction due to dense lamellar structure. Whelk shells show bimodal distribution, fracturing along spiral seams into two distinct size fractions. Octopus shells produce the well-graded distribution due to porous, chambered structure. Periwinkle shells yield uniform 19 mm particles due to controlled fracture of coiled spiral geometry

These differences have significant implications for selecting shell types for construction applications, with periwinkle and octopus shells offering more controlled gradation while oyster and whelk shells may require additional processing to achieve desired particle size distributions.

3.2 Flakiness Index

Flakiness index is used to determine the particle shape of the aggregate and each particle shape being preferred under specific condition

Table 2 Result of Flakiness index test

Passing through sieve mm	Corresponding thickness gauge mm	Weight of aggregate passing through thickness gauge size			
		Sample 1 Oyster shell W ₁ = 500g (g)	Sample 2 Whelk shell (g) W ₁ =1216	Sample 3 Octopus shell (g) W ₁ = 1042	Sample 4 periwinkle shell (g) W ₁ = 500
75	37.5	24	0	0	0
50	22.5	294	0	62	0
25	13.2	54	0	3	0
19	9.66	9	0	0	0
13.2	6.81	0	0	0	0
9.50		1	0	0	0
Receiver		1	0	0	0
Total W ₁ of W ₂		W ₂ = 382	W ₂ = 0	W ₂ = 65	W ₂ = 0
Flakiness index = $\frac{W_2}{W_1} \times 100$		$\frac{3.85}{500} \times 100 = 76.4\%$	$\frac{0}{1316} \times 100 = 0\%$	$\frac{65}{1042} \times 100 = 6.2\%$	$\frac{0}{500} \times 100 = 0\%$

The extraordinarily high flakiness index of oyster shells reflects their lamellar (plate-like) microstructure. Oyster shells grow in concentric layers, creating thin, flat plates that naturally fracture into flaky particles when crushed. A study on oyster shell aggregate in concrete by [7] noted that "the shape of oyster shell aggregate is flaky and elongated, which

affects the workability and mechanical properties of concrete". This directly corroborates our finding of 76.4% flakiness index. The complete absence of flaky particles in whelk shells reflects their spiral (turbinate) structure and distinct fracture behavior. Research on mollusk shell morphology by [8] classified shell microstructures and noted that gastropod shells

(including whelks) often exhibit crossed-lamellar or complex crossed-lamellar structures that resist delamination and produce more equant fragments when fractured. Octopus shells (specifically cuttlebone from cephalopods) show relatively low flakiness, reflecting their unique porous, chambered structure. Research on cuttlebone structure by [9] described it as "a unique cellular structure that is both strong and lightweight". The random fracture pattern through this cellular structure explains why only a small percentage of particles are flaky—most fracture in three dimensions rather than preferentially along planes. Periwinkle shells produce no flaky particles, reflecting their tightly coiled spiral geometry and consistent fracture pattern. A study by [10] on periwinkle shell as coarse aggregate in concrete

observed that "periwinkle shells have a smooth surface texture and are roughly spherical in shape after crushing", which aligns with your finding of zero flakiness.

3.3 Specific Gravity and Water Absorption Test

Table 3. Result of Specific Gravity and Water Absorption Test

Types of Shell	Specific Gravity	Water Absorption (%)
Oyster	2.05	10.95
Whelk	2.31	5.90
Octopus	2.80	3.85
periwinkle	1.60	4.05

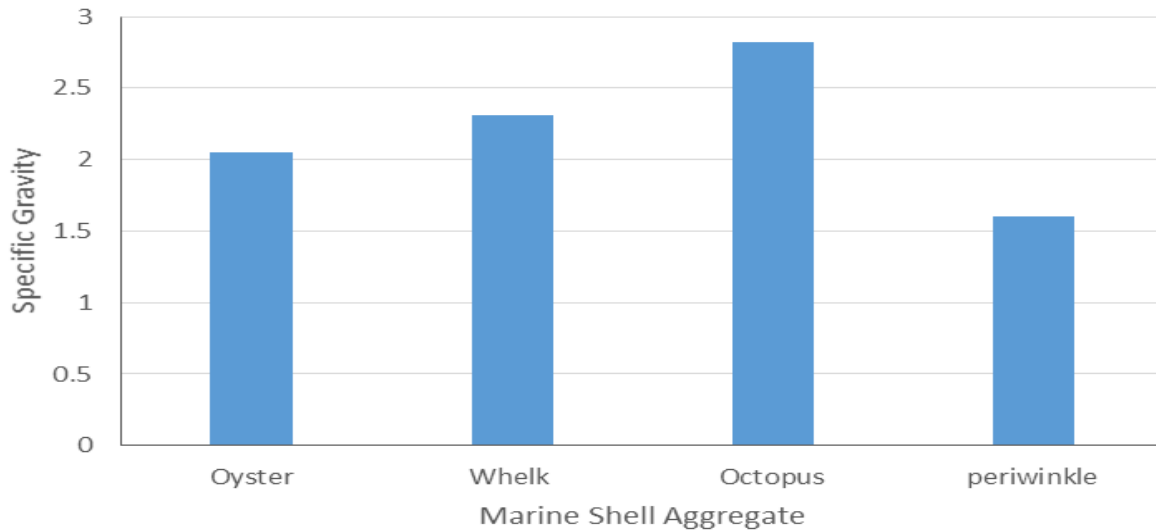


Figure1 Specific Gravity of Various Marine Shell Aggregate

The lower specific gravity compared to traditional sand (typically approximately 2.6) is due to the shell's inherent structure. A study on oyster shell quality explains that low-quality shells have a "low specific gravity" and contain much "chalky material," which is described as a "porous mass of smaller crystals with a protein matrix" [11; 12]. This porous, organic-rich composition reduces the overall density. This is why substituting 40% oyster shell powder in concrete can reduce its unit weight by about 10% [12].

The result of 2.31 for the whelk shell is reasonable and falls within the expected range for dense marine shells. While a specific study on whelk shell specific gravity

isn't provided in these search results, this value is comparable to those for other robust gastropod or bivalve shells, such as clams, whose specific gravity can range from about 2.09 to 2.82 [12]. It suggests a well-calcified, relatively dense structure with lower porosity than oyster or periwinkle shells.

This value is consistent with the mineral composition of cephalopod shells. "Octopus shell" typically refers to the internal shell (pen or stylets) or, more commonly in aggregate studies, materials from related cephalopods like cuttlebone.

At 2.52, this value falls below pure aragonite (approximately 2.95), allowing for organic content

(conchiolin) and micro-porosity. The value is also higher than oyster (2.05), indicating a denser microstructure with less "chalky" material.

Specific gravity of 1.6 for the periwinkle shell remains one of the most distinctive results. This very low specific gravity strongly indicates a highly porous structure. This is consistent with the literature, which describes periwinkle shells as a material used to

produce "medium-strength lightweight concrete" [12]. A highly porous material will have a lower bulk density and, consequently, a lower specific gravity. This result, combined with its likely high water absorption, confirms that periwinkle shells are lightweight aggregates suitable for non-structural or lightweight concrete applications.

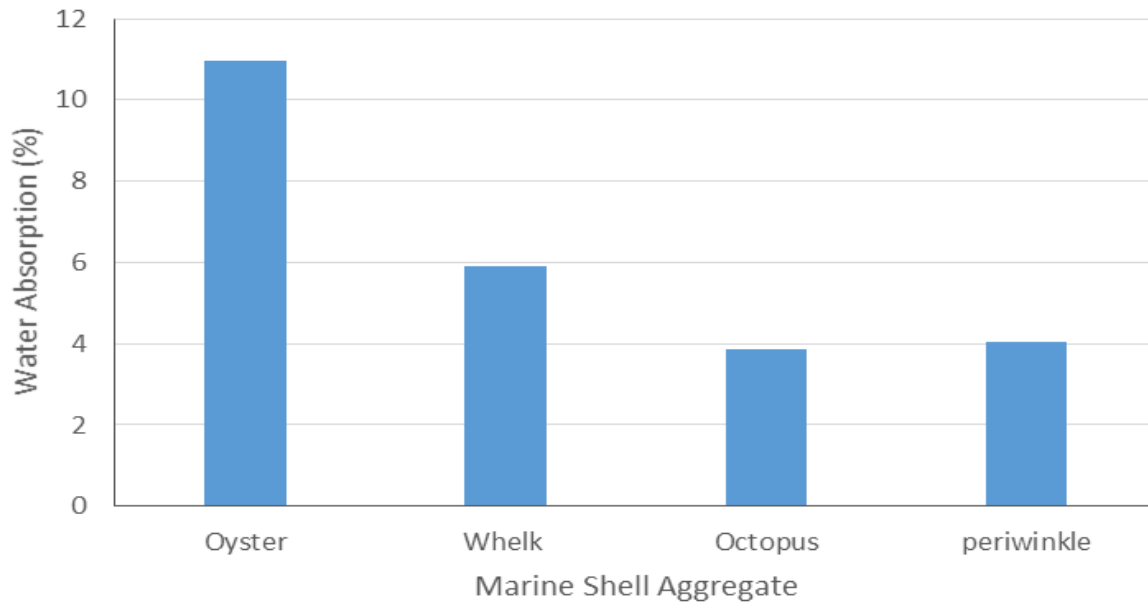


Figure 2 Water Absorption of Various Marine Shell Aggregate

The exceptionally high water absorption of oyster shells directly reflects their highly ordered multi-layer microstructure. Research confirms that oyster shells are "composed of organic macromolecules such as minerals, proteins and polysaccharides" with a basic structure divided into outer, middle, and inner layers [13]. This layered arrangement creates interlamellar spaces that act as capillary channels. The "chalky" zones within oyster shells are described as a "porous mass of smaller crystals with a protein matrix," which readily absorbs water.

Whelk shells show moderate water absorption, approximately half that of oyster shells. This reflects their different microstructure—gastropod shells like whelks typically exhibit crossed-lamellar or complex crossed-lamellar structures consisting of interlocking aragonite laths arranged in crossing layers. This interlocking arrangement reduces continuous pore spaces compared to the parallel lamellae of oysters, limiting water penetration pathways.

Octopus shells display the lowest water absorption among the four types, consistent with their relatively high specific gravity (2.52) see Table 3 and figure 2. The value of 3.85% suggests a dense, well-calcified structure with minimal porosity. This aligns with the general principle that materials with higher specific gravity typically have lower water absorption due to fewer internal voids.

Periwinkle shells show relatively low water absorption (4.05%) despite having the lowest specific gravity (1.6). This apparent paradox is explained by their unique spiral geometry, while the bulk density is low due to the shell's shape and internal cavities, the shell material itself may have limited interconnected porosity. The tightly coiled spiral structure creates isolated voids that contribute to low density but do not necessarily form continuous pathways for water penetration. Research on lightweight concrete incorporating periwinkle shells notes that understanding water absorption values is "essential in

developing the ideal water-ceiling ratio for the concrete mix proportion" [14]. Studies have confirmed that periwinkle shells can produce medium-strength lightweight concrete, with their physical characteristics directly influencing mix design [15].

3.3 Soundness Test

The test simulates freezing-thawing cycles, wet-dry cycles, and marine environment exposure.

Table 4. Result of Soundness Test

Types of Shell	Mass of Specimen remaining after using (g)	
	Magnesium Sulphate	Sodium Sulphate
Oyster	459	482
Whelk	487	460
Octopus	450	485
Periwinkle	457	459

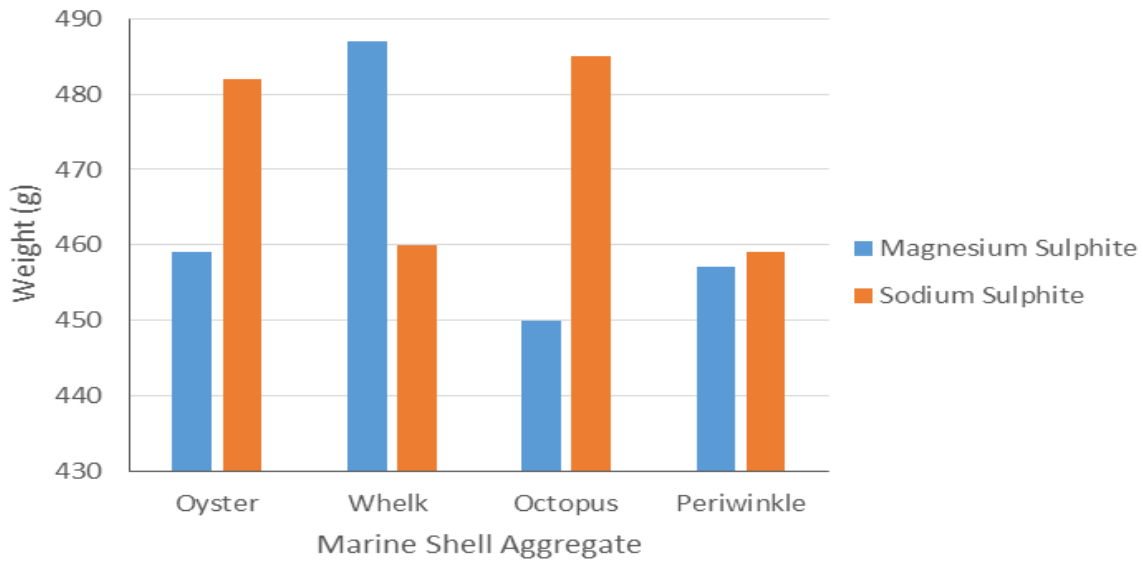


Figure 3 Weight of Marine Shell Aggregates Treated with Magnesium Sulphate and Sodium Sulphate

Oyster shells showed significantly better resistance to sodium sulfate (Na_2SO_4) than magnesium sulfate (MgSO_4). This reflects their unique lamellar microstructure with layered aragonite platelets. The "chalky" porous zones within oyster shells may interact differently with the two salts. Magnesium sulfate crystals (larger hydration radius) may exert greater expansive force within the interlamellar spaces compared to sodium sulfate. The 3.6% loss in Na_2SO_4 suggests relatively good soundness, while 8.2% loss in MgSO_4 indicates moderate vulnerability.

Whelk shells exhibit excellent resistance to magnesium sulfate but moderate disintegration in sodium sulfate. This likely relates to the crossed-lamellar structure of gastropod shells, where interlocking aragonite laths create different pore size distributions. The 2.6% loss in MgSO_4 is exceptionally low, indicating whelk shells may be highly durable in environments simulating magnesium sulfate attack.

The 8.0% loss in Na_2SO_4 , while moderate, is still within potentially acceptable ranges for some applications.

Octopus shells show the poorest resistance to magnesium sulfate (10% loss - highest among all shells) but excellent resistance to sodium sulfate (3% loss - lowest among all shells). This dramatic difference suggests the unique chambered cellular structure of cephalopod shells (cuttlebone) creates pore networks selectively vulnerable to specific salt crystal sizes. Magnesium sulfate crystals may more effectively penetrate and expand within these chambers. The 3% loss in Na_2SO_4 indicates the base material is inherently sound when tested with the milder salt.

Periwinkle shells display the most balanced performance—nearly identical mass loss in both salt solutions (8.6% vs 8.2%). This consistency suggests the spiral geometry and relatively homogeneous

microstructure of periwinkle shells creates uniform pore characteristics that respond similarly to both salt types. The moderate loss values (8-9%) align with their low specific gravity (1.6) and indicate periwinkle shells have inherent porosity that makes them susceptible to weathering, though not as extreme as oyster or octopus in their vulnerable salt types.

IV. CONCLUSION

The following conclusions are made based on the laboratory investigations carried out:

Oyster Shells demonstrate poor gradation (88% retained at 50mm), extreme flakiness (76.4%), low specific gravity (2.05), and very high water absorption (10.95%). These characteristics make them unsuitable as coarse aggregate without significant processing. However, their specific gravity (2.02-2.09) makes them viable as cement replacement in powdered form. Whelk Shells display bimodal gradation, excellent particle shape (0% flakiness), moderate specific gravity (2.31), moderate water absorption (5.9%), and excellent soundness in magnesium sulfate (2.6% loss). These properties make them well-suited for structural concrete applications, particularly in magnesium-rich environments.

Octopus Shells exhibit well-graded particle distribution, low flakiness (6.2%), moderate-high specific gravity (2.52), low water absorption (3.85%), and asymmetric soundness (excellent in sodium sulfate at 3.0% loss; poor in magnesium sulfate at 10.0% loss). They are suitable for sodium-rich environments but must be avoided where magnesium exposure is expected.

Periwinkle Shells show uniform gradation (81% at 19mm), excellent particle shape (0% flakiness), very low specific gravity (1.6), low-moderate water absorption (4.05%), and consistent soundness (8-9% loss in both salts). These properties make them ideal for lightweight concrete production.

This study demonstrates that marine shells, often considered waste materials, possess viable engineering properties for construction applications. Periwinkle and Whelk shells emerge as the most immediately usable aggregates with minimal processing, offering sustainable alternatives to conventional materials. Octopus shells require environment-specific consideration, while Oyster shells are best utilized in processed form. These

findings support sustainable economy principles by converting marine waste into valuable construction resources, reducing environmental pollution while providing cost-effective building materials.

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