

Utilization of Oyster Shell Waste As A Fine Aggregate Substitute in Mortar and Its Effect on Workability and Strength

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Abstract:

The increasing generation of oyster shell waste and the continued demand for natural fine aggregates have created a need for sustainable approaches to waste utilization in construction materials. This study investigated the use of oyster shell waste as a partial substitute for natural fine aggregate in mortar and evaluated its effects on workability and compressive-strength development. Oyster shells sourced from fishing communities in Old Bortianor, Accra, Ghana, were washed, sun-dried, crushed and sieved for use as fine aggregate. Mortar mixtures were prepared with oyster shell replacement levels of 0%, 10%, 20%, 30% and 40% by mass, using a constant cement-to-fine-aggregate ratio of 1:3 and a water-to-cement ratio of 0.45. Workability was assessed using the slump test, while compressive strength was determined at 7, 14, 21 and 28 days using 50 mm cube specimens. The slump increased from 45 mm for the control to 50 mm at 10% replacement, after which it decreased to 42.5, 37.5 and 35 mm at 20%, 30% and 40%, respectively. Compressive strength increased with curing age for all mixtures. At 28 days, the control achieved 20.16 MPa, while the 10%, 20% and 30% replacement mixtures achieved 20.51, 20.34 and 20.13 MPa, respectively; the 40% mixture recorded 19.22 MPa. The findings demonstrate that oyster shell waste can be incorporated as a partial fine aggregate substitute while maintaining compressive strength close to the control at replacement levels up to 30% under the investigated conditions. The study provides locally derived evidence supporting oyster shell waste valorization as a potential resource for more sustainable mortar production.

Keyword: Oyster shell waste; fine aggregate replacement; mortar; workability; slump; compressive strength; sustainable construction; waste valorization.

1. INTRODUCTION

The increasing demand for construction materials has intensified the consumption of natural aggregates and placed additional pressure on finite sources of construction sand. At the same time, the continued generation of oyster shell waste from fisheries and seafood-related activities presents an environmental management challenge where disposal and reuse systems are inadequate. The conversion of such waste into construction materials provides an opportunity to reduce waste accumulation while partially replacing conventional raw materials. Oyster shells are predominantly calcium-carbonate-based materials and have therefore attracted increasing attention as potential aggregate constituents in cement-based materials.

Recent research has demonstrated that oyster-shell-derived materials can be incorporated into mortar and concrete, although their influence on engineering performance varies with particle size, replacement level, mixture proportions and processing conditions.

The use of oyster shell as a fine aggregate substitute is of particular interest because the shell particles become part of the aggregate skeleton rather than serving primarily as a cementitious binder. Consequently, particle grading, particle morphology, surface characteristics and water absorption can influence the fresh and hardened properties of the resulting mortar. Research on oyster-shell aggregate mortar has reported that the irregular and porous characteristics of shell particles may affect flowability and strength, particularly when the replacement proportion is increased. For example, Liao et al. (2022) investigated the flowability and compressive strength of mortar containing waste oyster shell powder, demonstrating the sensitivity of mortar performance to the proportion of shell material incorporated.

Workability is a critical consideration in mortar production because it governs the ease of mixing, placing and compaction and can consequently influence the development of a uniform hardened matrix. Changes in workability associated with oyster-shell substitution may result from differences between shell particles and natural sand in terms of grading, particle shape and water demand. Previous studies have reported reductions in workability as oyster-shell content increases, while the magnitude of the change has depended on particle size and mixture composition [Liao et al. (2022), Ruslan et al. (2024)]. A review of oyster-shell construction composites further identified particle granulometry and the relatively high-water absorption associated with shell materials as important factors affecting fresh-state behaviour.

Compressive strength provides an important measure for determining whether a mortar containing waste-derived fine aggregate can achieve the mechanical performance required for its intended application. Existing research has shown that partial replacement of natural sand with oyster-shell materials can produce acceptable compressive strength at selected replacement levels, whereas excessive replacement may result in strength reduction [Ruslan et al. (2024)]. Studies have attributed these variations to factors including particle packing, shell morphology, internal void formation and the quality of the interfacial region between shell particles and the cementitious matrix. The reported variation among studies indicates that replacement levels cannot be selected independently of the characteristics of the shell material and the mortar mixture in which it is incorporated.

The need for locally generated evidence is particularly relevant in Ghana, where oyster-shell waste generated within coastal communities represents a potentially available secondary material for construction. The experimental work underlying the present study involved oyster shells obtained from fishing communities in Old Bortianor, Accra, followed by washing, drying, crushing and processing for use as a fine aggregate substitute. The particle-size investigation reported a continuous distribution from 4.75 mm to the pan, with $D_{10} = 0.58\text{mm}$, $D_{30} = 0.90\text{mm}$, $D_{60} = 1.30\text{mm}$, a coefficient of uniformity of 2.24 and a coefficient of curvature of 1.07. These characteristics provide a basis for evaluating the suitability of the processed shell material as a fine aggregate substitute in mortar.

Although previous investigations have established the potential of oyster-shell materials in mortar and concrete, differences in shell processing, particle grading, replacement proportion and mixture design continue to produce varied results. Furthermore, much of the available evidence has been generated under conditions that differ from those of locally sourced and processed shell materials in Ghana. The relationship between oyster-shell replacement level, workability and compressive-strength development therefore requires further experimental evaluation under defined local material and mixture conditions. This is particularly important where the objective is not merely to maximize waste utilization, but to

identify a replacement level that provides an appropriate balance between fresh-state performance and hardened strength.

Accordingly, this study investigates the utilization of oyster shell waste as a partial substitute for natural fine aggregate in mortar and evaluates its effect on workability and compressive-strength development. Mortar mixtures containing 0, 10, 20, 30 and 40% oyster shell replacement were investigated using a 1:3 cement-to-fine-aggregate ratio and a water-to-cement ratio of 0.45. Workability was assessed using the slump test, while compressive strength was evaluated at 7, 14, 21 and 28 days using 50 mm cube specimens. The study provides experimental evidence on the performance of locally processed oyster-shell material and assesses its potential contribution to more resource-efficient construction-material production.

2. RELATED RESEARCH WORK

Oyster Shell Waste and Its Potential in Sustainable Construction

The increasing generation of shell waste from fisheries and seafood-related activities has encouraged investigation into its potential recovery as a secondary construction material. Oyster shells are principally calcium-carbonate-rich biological materials and have been investigated in a range of cement-based applications, including mortar and concrete. Bellei et al. (2023), in a review of oyster-shell construction composites, identified aggregate substitution as an important pathway for shell-waste valorization and emphasized that the engineering performance of shell-containing materials is strongly influenced by processing, particle characteristics and mixture composition.

From a construction-material perspective, the use of oyster shell as an aggregate substitute has two related implications. First, it creates a potential pathway for diverting shell waste from disposal and returning the material to the construction-material cycle. Second, it provides an opportunity to partially reduce reliance on naturally sourced aggregate materials. However, the environmental benefit cannot be assumed solely from material substitution because shell collection, cleaning, drying, crushing and other processing requirements can also contribute to resource consumption. Consequently, the technical performance and processing requirements of locally sourced shell materials need to be considered together when assessing their construction potential.

Oyster Shell as a Fine Aggregate Substitute in Mortar

The use of oyster shell as a fine aggregate differs from its use as a cement replacement because the shell primarily contributes to the aggregate skeleton of the mortar. Its influence is consequently determined by physical characteristics such as particle size, grading, shape, surface texture and water absorption, in addition to the proportion incorporated into the mixture.

Liao et al. (2022) investigated waste oyster shell powder as a replacement for river sand in mortar and evaluated workability, compressive and flexural strength, sorptivity, water permeability, chloride-ion diffusion and microstructural characteristics. Their study demonstrated that incorporating oyster shell modifies both mechanical and transport-related properties, indicating that the suitability of shell aggregate should be assessed using more than a single performance indicator. The study further illustrates the importance of replacement proportion and shell characteristics when interpreting the behaviour of oyster-shell mortar.

Ruslan et al. (2024) investigated crushed oyster shell as a partial fine aggregate replacement in mortar at replacement levels of 0%, 10%, 20%, and 30%. The study evaluated flowability, compressive strength, and water absorption, and reported that all mixtures achieved the targeted 20 MPa compressive strength

at 28 days, with values ranging from 22.87 MPa to 35.20 MPa. The study further reported that oyster shell particles exhibited higher water absorption and lower fineness modulus compared to river sand, which influenced the fresh-state behaviour of the mortar. These findings provide a direct point of comparison for the present investigation, as both studies assess oyster shell as a fine aggregate substitute using similar replacement gradients and evaluate workability and compressive strength as primary performance indicators.

Jung and Kim (2022) similarly examined mortar containing oyster shell as fine aggregate and investigated the influence of shell particle size. Their findings demonstrated that oyster-shell particle characteristics influence mortar properties and highlighted the importance of the irregular, flat and elongated morphology of shell particles when assessing their incorporation into cementitious mixtures.

Mora-Ortiz et al. (2024) investigated crushed oyster shell (COS) as a partial replacement for natural sand in masonry mortar and examined both fresh and hardened properties. The study considered replacement levels from 10% to 60% and compared mortars prepared with pre-wetted oyster shell and oyster shell at its natural moisture condition. The authors reported that increasing COS content increased the water demand of the mortar and reduced density, which was associated with the relatively high water absorption and physical characteristics of the shell particles. Their results further demonstrated that pre-wetting improved the performance of oyster-shell mortar by reducing the absorption of mixing water by the shell aggregate. The study is particularly relevant to the present investigation because it demonstrates that the performance of oyster-shell fine aggregate is strongly dependent not only on replacement level but also on the moisture condition of the aggregate.

Taken together, these studies establish that oyster shell can function as a fine aggregate substitute, but they do not support a single universally applicable replacement level. Differences in shell source, particle preparation, grading, replacement proportion and mortar composition can produce different responses. Consequently, replacement levels should be established experimentally for the particular material and mixture being investigated.

Particle Size, Grading and Morphology of Oyster Shell

Fine-aggregate grading influences the packing arrangement of particles, paste demand, void structure and fresh-state behaviour of mortar. These considerations become particularly important for oyster shell because shell particles can differ considerably from conventional sand in terms of shape and surface characteristics. Jung and Kim (2022) reported that the particle-size characteristics of oyster shell influenced the properties of mortar and identified the morphology of the shell particles as an important factor affecting particle arrangement and internal void formation.

Bellei et al. (2023) likewise identified particle granulometry as an important consideration in the use of oyster shell in cement-based construction materials. The review indicates that differences in shell particle size and processing can contribute to variations in workability and mechanical performance among reported investigations. This suggests that replacement percentage alone is insufficient for predicting the performance of oyster-shell mortar; the grading and physical characteristics of the substituted material must also be established.

The oyster-shell fine aggregate used in the present study exhibited a continuous particle-size distribution from 4.75 mm to the pan. The experimentally determined values of D_{10} , D_{30} and D_{60} were 0.58, 0.90 and 1.30 mm, respectively, while the coefficient of uniformity and coefficient of curvature were 2.24 and 1.07. These characteristics provide a material-specific basis for evaluating the behaviour of the shell aggregate in the mortar investigated in this study.

Effect of Oyster Shell Replacement on Workability

Workability is essential to mortar production because it affects mixing, placing, compaction and the ability to obtain a relatively uniform hardened matrix. The introduction of oyster shell may alter workability because its particle characteristics differ from those of natural sand. In particular, particle morphology, grading, surface texture and water absorption may influence the amount of free water available for flow. Liao et al. (2022) directly assessed the fresh-state behaviour of mortar containing waste oyster shell powder using slump-flow and slump-flow-loss measurements. Their results demonstrated that oyster-shell incorporation affects mortar workability and that the response is dependent on the characteristics and proportion of the shell material used.

Ruslan et al. (2024) similarly reported that the flowability of mortar decreased as the proportion of crushed oyster shell increased, attributing this reduction to the higher water absorption and irregular particle characteristics of the shell material relative to natural sand.

Jung and Kim (2022) also identified particle size as an important factor affecting oyster-shell mortar behaviour. Their findings indicate that finer particles can possess a greater specific surface area and therefore influence water demand differently from coarser shell particles. Bellei et al. (2023) similarly reported that particle characteristics and granulometry are important determinants of the workability of oyster-shell cementitious materials.

Mora-Ortiz et al. (2024) provided further evidence that the water demand of oyster-shell aggregate is an important factor governing the fresh-state behaviour of mortar. Their crushed oyster shell exhibited higher water absorption than the natural sand used in their investigation, and increasing the proportion of shell substitution increased the effective water-to-cement ratio of the mixtures. The authors further showed that pre-wetting the oyster shell reduced its absorption of water from the cement paste and improved the resulting mortar properties. These findings indicate that variations in oyster-shell moisture condition and absorption characteristics should be considered when interpreting changes in workability.

These findings indicate that the effect of oyster-shell replacement on workability cannot be generalized without considering the specific mortar design. In particular, changes in water-to-cement ratio, replacement basis, particle-size distribution and shell preparation can alter the measured fresh-state response. Therefore, experimental workability assessment is necessary when oyster shell obtained from a particular geographic and processing context is introduced as a fine aggregate substitute.

Effect of Oyster Shell Replacement on Compressive Strength

Compressive strength is a principal indicator of the mechanical performance of mortar and provides a basis for evaluating the feasibility of replacing conventional fine aggregate with waste-derived materials. Existing investigations have reported different strength responses to oyster-shell incorporation. The differences have been associated with replacement proportion, particle size, particle morphology, aggregate packing and the characteristics of the cementitious matrix.

Liao et al. (2022) reported that the incorporation of waste oyster shell powder as a fine aggregate affected the mechanical properties of mortar, with the magnitude of the response varying according to the quantity of shell incorporated. The study demonstrates that oyster-shell substitution can produce measurable changes in hardened-mortar performance rather than functioning simply as a neutral aggregate replacement.

Ruslan et al. (2024) reported that mortar mixtures containing up to 30% crushed oyster shell achieved 28-day compressive strengths between 22.87 MPa and 35.20 MPa, exceeding the targeted 20 MPa. This

finding demonstrates that selected replacement levels can maintain acceptable compressive strength, although the magnitude of performance depends on mixture proportions and shell characteristics.

Jung and Kim (2022) further showed that oyster-shell particle size influences mortar characteristics. Their findings provide evidence that particle-size distribution and morphology can affect the internal arrangement of shell particles and, consequently, the mechanical behaviour of the mortar.

Mora-Ortiz et al. (2024) reported that compressive strength decreased as the proportion of crushed oyster shell increased, particularly in mixtures where the shell was used without pre-wetting. The authors associated the reduction with the flat and elongated morphology of the shell particles, difficulties in bonding between the shell surface and cement paste, and the relatively high porosity and water absorption of the oyster shell. Pre-wetted oyster-shell mortar exhibited higher compressive strength than corresponding mixtures without pre-wetting, and replacement levels up to 30% in the pre-wetted mixtures reached the reference strength adopted in their investigation. These findings demonstrate that the mechanical response of oyster-shell mortar is influenced by the interaction between replacement level and the moisture and physical characteristics of the shell aggregate.

The existing literature therefore indicates that moderate oyster-shell replacement may be technically feasible under suitable mixture conditions, but increased replacement does not necessarily produce a proportional or consistent change in strength. This variability highlights the importance of evaluating strength development at multiple curing ages rather than relying only on a single-age result.

Influence of Replacement Level on Strength Development

The curing age of mortar is an important consideration when evaluating alternative aggregate materials because strength develops progressively as the cementitious matrix matures. A replacement level that produces satisfactory early-age performance may behave differently at later ages, particularly where aggregate packing, moisture availability and matrix development are affected by the substituted material. The experimental evidence reported by Liao et al. (2022) and Jung and Kim (2022) indicates that the performance of oyster-shell mortar is dependent on both material characteristics and mixture composition. Consequently, the identification of a suitable replacement level requires consideration of strength development rather than only the final strength value.

In the present study, compressive strength is evaluated at 7, 14, 21 and 28 days for mortar containing 0, 10, 20, 30 and 40% oyster-shell fine aggregate. This age-based assessment permits the effect of replacement level on the progression of strength development to be examined rather than evaluated solely from the 28-day condition.

Relationship between Workability and Strength

Workability and compressive strength are related through the ability of fresh mortar to be properly mixed, placed and compacted. Insufficient workability may hinder compaction and increase entrapped voids, whereas changes in water content used to compensate for reduced workability can influence the hardened matrix. In oyster-shell mortar, this relationship is further affected by differences in shell grading, morphology and water demand relative to natural sand.

The simultaneous evaluation of workability and strength is therefore important when identifying a suitable replacement level. Liao et al. (2022) adopted a broader performance assessment that considered both fresh and hardened properties, illustrating the value of evaluating oyster-shell mortar through multiple performance indicators. Jung and Kim (2022) likewise demonstrated that particle-size characteristics influence mortar behaviour and should be considered when interpreting differences in mechanical performance.

Accordingly, a technically appropriate replacement level should not be identified solely from the highest compressive strength. The replacement level should also provide sufficiently workable fresh mortar to permit effective mixing and compaction under the specified mixture conditions.

Research Gap

Existing research has established the potential of oyster shell as a fine aggregate substitute in mortar and other cement-based materials, but substantial variation remains in the reported effects on workability and compressive strength. This variability has been associated with differences in shell source, processing method, particle grading, morphology, replacement proportion, water-to-cement ratio, curing conditions and aggregate moisture condition. Bellei et al. (2023) identified processing and particle characteristics as important factors influencing the performance of oyster-shell construction composites, while Liao et al. (2022), Ruslan et al. (2024), and Jung and Kim (2022) demonstrated that oyster-shell content, particle characteristics and mixture composition can produce different fresh and hardened responses.

Aggregate moisture condition represents an additional factor that requires consideration. Mora-Ortiz et al. (2024) demonstrated that pre-wetting crushed oyster shell reduced its absorption of mixing water and influenced the mechanical behaviour of masonry mortar. Their findings indicate that the behaviour of oyster-shell mortar cannot be interpreted solely on the basis of replacement percentage, since the interaction between shell particles and the available mixing water can also influence workability and strength development. Consequently, results obtained using one shell material or mixture condition cannot necessarily be transferred directly to another without experimental verification.

A further limitation in the existing literature is the geographical variability of oyster-shell materials. Shell characteristics may differ according to source, processing history and particle preparation, meaning that results obtained in one region may not necessarily represent the behaviour of locally available materials elsewhere. The oyster shells used in the present study were obtained from fishing communities in Old Bortianor, Accra, Ghana, and were washed, sun-dried, crushed and sieved before incorporation as a fine aggregate substitute. The processed material exhibited a continuous particle-size distribution from 4.75 mm to the pan, with $D_{10} = 0.58$ mm, $D_{30} = 0.90$ mm, $D_{60} = 1.30$ mm, a coefficient of uniformity of 2.24 and a coefficient of curvature of 1.07. These characteristics provide a material-specific basis for evaluating its behaviour in mortar.

The present study therefore addresses the need for locally derived experimental evidence by investigating oyster shell waste as a partial substitute for natural fine aggregate in mortar under controlled mixture conditions. Replacement levels of 0, 10, 20, 30 and 40% by mass are investigated using a constant 1:3 cement-to-fine-aggregate ratio and water-to-cement ratio of 0.45. Workability is assessed using the slump test, while compressive strength is determined at 7, 14, 21 and 28 days. The study consequently evaluates the combined effect of oyster-shell replacement on fresh-state consistency and strength development and provides experimental evidence specific to locally sourced oyster shell from Ghana.

3. DATA AND METHODOLOGY

Materials

The materials used in the experimental investigation comprised cement, natural fine aggregate, oyster shell waste and water. Ordinary Portland cement was used as the binder, while natural fine aggregate served as the reference aggregate. Oyster shells were obtained from fishing communities in Old Bortianor, Accra, Ghana, and were processed for use as a partial substitute for natural fine aggregate. The use of locally

sourced oyster shells was intended to provide experimental evidence on the feasibility of converting an available waste material into a construction resource.

The oyster shells were initially washed thoroughly to remove adhering organic matter, salts and other surface impurities. The washed shells were subsequently sun-dried to reduce their moisture content before further processing. The dried shells were crushed and sieved to obtain particles suitable for incorporation as a fine aggregate substitute. The source study indicates that the processed shell material was subjected to particle-size analysis over a range extending from 4.75 mm to the pan.

Characterization of Oyster Shell Fine Aggregate

Particle-size distribution was determined for a 2,000 g sample of the processed oyster shell material. Sieve sizes of 4.75, 2.56, 1.18, 0.60 and 0.30 mm, together with a pan, were used for the grading analysis. The masses retained on the individual sieves were recorded and expressed as percentages of the total sample mass. The corresponding cumulative percentage retained and cumulative percentage passing were then determined.

The reported grading results showed that 5.8% of the material was retained on the 4.75 mm sieve, 17.75% on the 2.56 mm sieve, 17.90% on the 1.18 mm sieve, 47.15% on the 0.60 mm sieve, 9.80% on the 0.30 mm sieve and 1.60% in the pan. The characteristic particle-size parameters obtained from the grading analysis were $D_{10} = 0.58$ mm, $D_{30} = 0.90$ mm and $D_{60} = 1.30$ mm, with a coefficient of uniformity of 2.24 and a coefficient of curvature of 1.07.

The characterization approach was consistent with the broader methodology adopted in previous oyster-shell mortar investigations, in which particle size and grading were treated as important variables influencing workability and hardened properties. Jung and Kim (2022), for example, classified oyster-shell aggregate according to particle size before evaluating its influence on mortar properties. Their methodology also included characterization of aggregate density, water absorption and particle-size effects.

Mortar Mix Proportions

A control mortar and four oyster-shell-modified mortars were prepared. The cement-to-fine-aggregate ratio was maintained at 1:3, while the water-to-cement ratio was maintained at 0.45 for all mixtures. Oyster shell was introduced as a partial replacement for natural fine aggregate by mass at replacement levels of 0, 10, 20, 30 and 40%.

The mixtures were designated as Control, M10, M20, M30 and M40, corresponding to 0, 10, 20, 30 and 40% oyster-shell replacement, respectively. Except for the replacement of natural fine aggregate by the specified proportion of processed oyster shell, the mixture proportions were kept constant. This approach permitted the effect of oyster-shell replacement level on workability and compressive strength to be evaluated under a constant cement content and water-to-cement ratio.

The selection of the replacement range was informed by previous investigations in which oyster shell was incorporated as a substitute for natural sand. Liao et al. (2022) investigated replacement levels of 0, 10, 20 and 30%, while other studies have examined crushed oyster shell aggregate at comparable partial-replacement levels. The present study extended the replacement range to 40% in order to examine the response at a higher level of aggregate substitution.

Table 1. Mortar Mix Design and Oyster Shell Replacement Levels

Mix	OSP Replacement of Fine Aggregate	Natural Fine Aggregate	OSP	Cement:Fine Aggregate	Water-Cement Ratio
	(%)	(%)	(%)		
Control	0	100	0	1:3	0.45
M10	10	90	10	1:3	0.45
M20	20	80	20	1:3	0.45
M30	30	70	30	1:3	0.45
M40	40	60	40	1:3	0.45

Mixing and Preparation of Specimens

The required quantities of cement, natural fine aggregate and processed oyster shell were measured according to the predetermined mix proportions. The dry constituents were thoroughly combined to achieve a uniform distribution of the oyster-shell particles within the fine-aggregate fraction. The required quantity of water corresponding to the water-to-cement ratio of 0.45 was then introduced and mixing was continued until a visually uniform mortar was obtained.

Fresh mortar from each mixture was used for the workability assessment. Following the workability test, the mortar was placed into cube moulds having dimensions of 50 mm × 50 mm × 50 mm. The moulds were filled and compacted to reduce entrapped air and to obtain adequately consolidated specimens. The specimen surfaces were levelled after filling, and the moulded samples were allowed to set before removal from the moulds.

A total of 20 mortar-cube specimens were prepared, comprising five mixture proportions and four curing ages. One specimen was assigned to each mixture at each curing age.

Workability Test

The workability of the fresh mortar mixtures was evaluated using a conventional slump-cone procedure as a comparative measure of consistency among the mixtures. The test was conducted immediately after mixing to determine the vertical deformation of the fresh mortar and thereby provide a comparative measure of consistency among the different replacement levels.

For each mixture, the slump cone was positioned on a firm, level and non-absorbent surface and filled with the freshly prepared mortar. The mortar was compacted during filling, after which the excess material was struck off at the top of the cone. The cone was then lifted vertically, and the reduction in height between the mould and the slumped mortar was measured in millimetres. The measured value was recorded as the slump of the corresponding mixture.

The use of a fresh-state workability measurement was considered necessary because previous studies have shown that oyster-shell incorporation can alter mortar flowability. Liao et al. (2022) reported a progressive reduction in slump flow as oyster-shell replacement increased, which was associated with the characteristics and water demand of the shell particles. Because their study employed slump flow rather than conventional slump, direct numerical comparison between the two datasets is not appropriate; comparison is therefore made primarily in terms of the observed trend.

Curing of Mortar Specimens

After demoulding, the mortar cubes were subjected to water curing. Specimens were maintained under cu

ring conditions until the designated testing ages of 7, 14, 21 and 28 days. The curing period was controlled according to the planned testing schedule so that the development of compressive strength with increasing age could be evaluated.

The selection of multiple curing ages enabled both early-age and later-age strength development to be assessed. This approach is comparable with previous oyster-shell mortar research, although the specific testing ages have varied among studies. Liao et al. (2022), for example, evaluated compressive strength at several curing ages extending to 90 days, while Jung and Kim (2022) investigated mortar properties using controlled experimental conditions and strength testing based on standardized cement-mortar procedures.

Compressive Strength Test

Compressive strength was determined at 7, 14, 21 and 28 days using the 50 mm × 50 mm × 50 mm mortar cubes. At each testing age, the specimens were removed from curing and prepared for testing. The specimen dimensions were confirmed before being centrally positioned between the compression platens of the testing machine.

Load was applied progressively until failure occurred, and the maximum load sustained by the specimen was recorded. The compressive strength was calculated from the maximum applied load divided by the loaded cross-sectional area, according to:

$$f_c = \frac{P}{A} \text{ Equation 1}$$

where:

f_c = compressive strength (N/mm²),

P = maximum load at failure (N), and

A = loaded cross-sectional area (mm²).

The resulting strength values were recorded for each replacement level and curing age and subsequently compared to establish the influence of oyster-shell substitution on strength development.

Experimental Design and Data Analysis

The experimental programme consisted of five oyster-shell replacement levels: 0, 10, 20, 30 and 40%, with compressive strength determined at four curing ages: 7, 14, 21 and 28 days. Workability was assessed for each mixture using the measured slump value.

The effect of oyster-shell replacement was assessed by comparing each modified mixture with the control mortar. Changes in compressive strength with replacement level and curing age were examined using absolute values and percentage differences relative to the control. The relationship between workability and strength was also considered to determine whether reductions in fresh-state consistency were associated with changes in hardened performance.

Particular attention was given to identifying the replacement range within which compressive strength was maintained relative to the control mixture while changes in workability remained within the measured experimental range. The experimental findings were subsequently compared with published results from oyster-shell mortar studies to determine areas of agreement and difference and to consider the possible influence of particle grading, replacement basis, mixture proportions and processing conditions. Previous studies have demonstrated that these factors can substantially influence the behaviour of oyster-shell-containing mortar.

4. RESULTS AND DISCUSSION

Workability of Oyster Shell-Modified Mortar

The workability results obtained from the slump test are presented in Table 1. The control mortar recorded a slump of 45 mm. With the incorporation of 10% oyster shell (M10), the slump increased slightly to 50 mm. Further increases in oyster-shell replacement resulted in a progressive reduction in slump, with values of 42.5, 37.5 and 35 mm recorded for M20, M30 and M40, respectively.

Table 2. Slump values of mortar containing oyster shell as fine aggregate substitute

Mix	OSP replacement	Slump
	(%)	(mm)
Control	0	45.0
M10	10	50.0
M20	20	42.5
M30	30	37.5
M40	40	35.0

The results indicate that the influence of oyster-shell substitution on workability was not completely linear. A small increase in slump was observed at 10% replacement, followed by a clear reduction as the replacement level increased beyond 10%. Relative to the control, the slump increased by approximately 11.1% at 10% replacement, whereas reductions of approximately 5.6, 16.7 and 22.2% were recorded at 20, 30 and 40% replacement, respectively.

The reduction in workability at higher replacement levels is consistent with observations reported in previous studies. Liao et al. (2022) investigated waste oyster shell powder as a partial replacement for river sand in mortar and reported a progressive decrease in slump flow with increasing oyster-shell content. Their investigation attributed the change in fresh-state behaviour to characteristics of the oyster-shell particles and their interaction with the mortar system. Similarly, studies on crushed shell materials used as fine-aggregate replacements have reported reduced workability as shell content increases. A study on crushed cockle shell, which is a related marine-shell aggregate, found that slump decreased as the proportion of shell replacement increased.

The reduction in slump observed at the higher replacement levels is also consistent with the findings of Mora-Ortiz et al. (2024), who reported that increasing crushed oyster-shell substitution altered the fresh-state behaviour of masonry mortar. Their investigation showed that oyster shell had a higher water absorption than natural sand and that increasing shell content increased the effective water-to-cement ratio in mixtures where the shell was not pre-wetted. Pre-wetting reduced the absorption of mixing water by the shell and improved the resulting mortar properties.

The general agreement between these studies and the present investigation suggests that shell incorporation can increase the demand for the available mixing water and alter particle packing within the mortar. The processed oyster shell used in the present investigation contained particles ranging from 4.75 mm to the pan, with a substantial proportion retained at 0.60 mm. Such differences in particle distribution and particle geometry may influence the amount of water required to achieve a given consistency. Jung and Kim (2022) specifically demonstrated that oyster-shell particle characteristics and particle size affect mortar behaviour and noted that the flat and elongated form of oyster-shell particles can reduce workability and contribute to differences in internal pore formation.

The slight increase in slump at 10% replacement may therefore be associated with the relatively small quantity of shell introduced at this level and possible changes in particle packing. However, because no measurements of shell-specific water absorption, particle shape or rheological properties were undertaken in the present study, the observed increase cannot be assigned to a single mechanism with certainty. As the replacement level increased to 20–40%, the reduction in slump became more pronounced, indicating that the influence of the shell particles became increasingly significant in the fresh mortar.

An important methodological distinction should be noted when comparing the present findings with Liao et al. (2022). Their study measured slump flow, whereas the present investigation used a conventional slump measurement; therefore, the numerical values cannot be directly compared. The comparison is instead based on the direction of the observed change with increasing oyster-shell content.

Overall, the workability results demonstrate that increasing oyster-shell substitution beyond 10% was associated with progressively lower slump under the fixed mixture conditions adopted in this investigation. This finding is important because reductions in workability can influence mixing, placement and compaction and may consequently affect the development of the hardened mortar matrix.

Compressive Strength Development

The compressive-strength results obtained at 7, 14, 21 and 28 days are presented in Table 3.

Table 3. Compressive strength of oyster-shell modified mortar

Mix	OSP replacement	7 days	14 days	21 days	28 days
	(%)	(MPa)	(MPa)	(MPa)	(MPa)
Control	0	15.35	16.80	18.01	20.16
M10	10	15.48	17.21	19.19	20.51
M20	20	14.38	16.97	18.67	20.34
M30	30	13.76	16.17	17.59	20.13
M40	40	13.23	15.70	15.80	19.22

Seven-Day Strength

At 7 days, the control mortar attained a compressive strength of 15.35 MPa, while M10 recorded the highest value of 15.48 MPa. Strength subsequently decreased with increasing replacement, with M20, M30 and M40 recording 14.38, 13.76 and 13.23 MPa, respectively.

Relative to the control, the 10% mixture produced a marginal increase of approximately 0.85%, whereas reductions of 6.32, 10.36 and 13.81% were recorded for M20, M30 and M40, respectively. The progressive decline at the higher replacement levels indicates that early-age strength was increasingly affected as more natural fine aggregate was replaced.

The early-age trend is broadly consistent with research showing that higher proportions of oyster-shell aggregate can reduce mechanical performance when the replacement level becomes excessive. Studies on oyster-shell and other shell-based fine aggregates have associated strength reduction at higher incorporation levels with changes in aggregate packing, increased voids and differences in particle morphology. Jung and Kim (2022), for example, reported that oyster-shell particle characteristics influence the internal pore structure and mechanical behaviour of mortar.

At 10% replacement, however, the present result did not show an early-age strength penalty. This is consistent with the broader findings of Liao et al. (2022), who reported that moderate oyster-shell replacement could be incorporated into mortar without necessarily causing a reduction in compressive strength.

Fourteen-Day Strength

At 14 days, the control mortar recorded 16.80 MPa, while M10 achieved the highest strength of 17.21 MPa. M20 recorded 16.97 MPa, followed by M30 at 16.17 MPa and M40 at 15.70 MPa.

Compared with the control, M10 and M20 produced increases of approximately 2.44% and 1.01%, respectively. In contrast, M30 and M40 showed reductions of approximately 3.75% and 6.55%. The results therefore indicate that the incorporation of oyster shell at low replacement levels was capable of maintaining or slightly improving intermediate-age strength, whereas higher replacement levels resulted in progressively lower values.

The persistence of relatively good performance at 10% replacement is noteworthy because shell aggregate does not act in the same manner as a cementitious replacement. Its contribution is more appropriately considered in terms of particle packing, aggregate skeleton characteristics and interaction with the cement paste. Previous oyster-shell studies have also shown that the effect of shell incorporation depends strongly on particle size and mixture composition.

Twenty-One-Day Strength

The 21-day results followed a similar pattern. The control produced 18.01 MPa, while M10 achieved 19.19 MPa, representing an increase of approximately 6.55% over the control. M20 recorded 18.67 MPa, approximately 3.66% higher than the control, while M30 and M40 recorded 17.59 and 15.80 MPa, corresponding to reductions of approximately 2.33% and 12.27%, respectively.

The marked difference between M10 and M40 at this age indicates that replacement level had a stronger influence on intermediate-age strength than on the final 28-day result. The relatively high performance of M10 and M20 may be related to favourable packing of the shell particles within the fine-aggregate skeleton at moderate replacement levels. In contrast, the lower strength obtained at 40% replacement may reflect less favourable packing and a greater likelihood of discontinuities or voids in the hardened matrix. This interpretation is consistent with the conclusions of studies examining oyster-shell particle size and mortar microstructure, where particle characteristics were shown to influence pore distribution and strength development. Fine oyster-shell particles have, under some conditions, been associated with improved packing and higher mechanical performance compared with coarser shell particles.

Twenty-Eight-Day Strength

At 28 days, the control mortar achieved 20.16 MPa. M10 recorded the highest compressive strength of 20.51 MPa, followed by M20 at 20.34 MPa, M30 at 20.13 MPa, and M40 at 19.22 MPa.

The 28-day results are particularly important because they indicate that 10–30% oyster-shell replacement was capable of maintaining a compressive strength very close to that of the control mortar under the conditions investigated. M10 exceeded the control by approximately 1.74%, while M20 exceeded it by approximately 0.89%. M30 was approximately 0.15% lower than the control, whereas M40 was approximately 4.66% lower.

The slight improvement observed at 10% is consistent with the general finding in previous oyster-shell research that moderate replacement can maintain or enhance compressive strength. Liao et al. (2022) reported that oyster-shell-containing mortar could achieve improved mechanical performance at selected

replacement levels, while Jung and Kim (2022) demonstrated that oyster-shell particle size strongly influences mortar strength and porosity.

However, the replacement level associated with the highest strength in the present study differs from that reported by some earlier investigations. This difference should not be interpreted as a contradiction because the experimental conditions were not identical. Liao et al. (2022) used volumetric replacement, a different mortar formulation and slump-flow testing, whereas the present study employed mass-based replacement with a 1:3 cement-to-fine-aggregate ratio and a water-to-cement ratio of 0.45. Furthermore, the oyster-shell particle-size distribution adopted in the present investigation extended from 4.75 mm to the pan, whereas other investigations deliberately classified shells into specific particle-size fractions.

The reduction in strength at 40% replacement indicates that increasing shell content beyond the lower and intermediate replacement levels did not continue to provide a beneficial effect. This observation agrees with the general behaviour reported for shell-based aggregate systems, where excessive substitution can become detrimental because of changes in packing, particle morphology and the quality of the aggregate-paste interface. Similar reductions at higher substitution levels have also been reported for other marine-shell fine aggregates.

Effect of Curing Age on Strength Development

All mortar mixtures exhibited an overall increase in compressive strength with increasing curing age, although the magnitude of development differed among replacement levels. The control increased from 15.35 MPa at 7 days to 20.16 MPa at 28 days, while M10 increased from 15.48 to 20.51 MPa. M20 increased from 14.38 to 20.34 MPa, M30 from 13.76 to 20.13 MPa, and M40 from 13.23 to 19.22 MPa.

The results demonstrate that continued curing was associated with progressive strength development in both the control and oyster-shell-modified mortars. The general increase in strength with curing age is consistent with the development of the cementitious matrix as hydration progresses. More importantly, the results show that the influence of oyster-shell replacement was age-dependent. At 7 days, the reduction associated with higher replacement levels was more pronounced, whereas by 28 days the differences between the control, M10, M20 and M30 mixtures had become comparatively small.

This pattern is relevant when interpreting the performance of oyster-shell aggregate mortar. The results suggest that moderate shell replacement did not prevent continued strength development, while the highest replacement level remained below the control at all testing ages. Previous investigations have similarly examined strength development over multiple curing periods and reported that oyster-shell particle size and replacement conditions influence both early-age and later-age mechanical behaviour.

Relationship between Workability and Compressive Strength

The combined workability and strength results indicate that the relationship between fresh-state consistency and hardened strength was not strictly linear. The highest slump, 50 mm, was obtained at 10% replacement, which also produced the highest 28-day compressive strength of 20.51 MPa. However, the progressive reduction in slump from 20 to 40% was not accompanied by a proportionally equivalent reduction in 28-day strength. M20, M30 and the control all produced values close to 20 MPa despite their different slump values.

This observation suggests that workability alone did not determine the final compressive strength of the mortar. Rather, strength development was likely influenced by the combined effects of particle packing, aggregate characteristics, compaction and the cementitious matrix. The importance of particle characteristics is supported by Jung and Kim (2022), who demonstrated that oyster-shell particle size influences mortar workability, porosity and mechanical properties.

The results also demonstrate why replacement level should be evaluated using both fresh and hardened properties. At 10% replacement, the mixture exhibited the highest measured slump and the highest 28-day compressive strength. At 40%, the lowest slump was accompanied by the lowest 28-day strength. Nevertheless, the differences between M20, M30 and the control at 28 days were relatively small, demonstrating that a reduction in slump does not necessarily result in an equivalent proportional reduction in final compressive strength.

Comparison with Previous Research

The overall findings of the present study are broadly consistent with previous research showing that oyster-shell incorporation affects mortar workability and mechanical performance, but that the magnitude and direction of the effect depend on replacement level and material characteristics. Liao et al. (2022) reported decreasing workability with increasing waste oyster-shell replacement while demonstrating that moderate replacement could maintain favourable mechanical properties. Jung and Kim (2022) further demonstrated that oyster-shell particle size is an important determinant of mortar behaviour, particularly because shell geometry and particle characteristics can influence pore formation and workability. Research on oyster-shell particle size has likewise shown that finer shell particles can produce different strength and workability responses from coarser particles, confirming that replacement percentage alone is insufficient to explain the performance of oyster-shell mortar.

The present results therefore add a locally derived dataset based on oyster shell sourced from Old Bortianor, Accra, Ghana, using mass-based replacement levels up to 40% and a fixed 1:3 cement-to-fine-aggregate ratio with a water-to-cement ratio of 0.45. The results show that the response of the mortar to oyster-shell substitution was dependent on replacement level, with low-level replacement producing comparable or slightly improved strength and higher replacement producing greater reductions in workability and, at 40%, a measurable reduction in 28-day compressive strength.

It is important to acknowledge that direct numerical comparison between the present study and Ruslan et al. (2024) should be made with caution due to differences in mixture design. Ruslan et al. (2024) adopted a water-to-cement ratio of 0.67, whereas the present study maintained a water-to-cement ratio of 0.45. This difference in water content influences the porosity and strength development of the cementitious matrix. Consequently, the higher 28-day compressive strengths reported by Ruslan et al. (2024) ranging from 22.87 MPa to 35.20 MPa compared to the present study's range of 19.22 MPa to 20.51 MPa, can be partly attributed to differences in mixture proportioning rather than to oyster shell performance alone. The comparison is therefore made primarily in terms of the observed trends in workability and strength development, which were broadly consistent between the two studies.

Taken together, the findings indicate that oyster shell can function as a partial fine-aggregate substitute in mortar without necessarily causing a substantial loss of 28-day compressive strength at low-to-moderate replacement levels. However, the observed performance is material- and mixture-specific, and direct transfer of an optimum replacement level from another study would not be justified because the processing conditions, particle grading, replacement basis and mortar composition differ among investigations.

5. Conclusion

This study investigated the utilization of oyster shell waste as a partial substitute for natural fine aggregate in mortar and evaluated its effects on workability and compressive-strength development. Mortar mixtures containing 0%, 10%, 20%, 30% and 40% oyster shell replacement were produced using a constant 1:3

cement-to-fine-aggregate ratio and a water-to-cement ratio of 0.45. Based on the experimental results, the following conclusions were drawn.

The incorporation of oyster shell influenced the workability of the mortar. The control mixture recorded a slump of 45 mm, while the 10% replacement mixture recorded the highest slump of 50 mm. Thereafter, slump decreased progressively to 42.5, 37.5 and 35 mm at 20%, 30% and 40% replacement, respectively. Thus, low-level oyster shell incorporation did not reduce the measured slump, whereas higher replacement levels were associated with reduced workability. The observed trend is consistent with previous studies that have reported changes in mortar workability with increasing oyster-shell content.

Compressive strength increased with curing age for all mixtures. At 28 days, the control achieved 20.16 MPa, while M10, M20 and M30 achieved 20.51, 20.34 and 20.13 MPa, respectively. M40 recorded 19.22 MPa. Therefore, replacement levels from 10% to 30% maintained 28-day compressive strengths very close to that of the control, whereas 40% replacement resulted in a more noticeable reduction. Among the investigated mixtures, the 10% replacement level produced the highest compressive strength at all four curing ages and also recorded the highest slump.

The combined results indicate that the effects of oyster shell replacement on workability and strength were dependent on the level of substitution. Although slump generally decreased at higher replacement levels, the reduction in workability did not correspond directly to an equivalent reduction in 28-day compressive strength. This indicates that hardened strength was influenced by more than fresh-state consistency alone and was likely related to the interaction of aggregate characteristics, particle packing and the cementitious matrix. These interpretations remain specific to the materials and mixture proportions investigated.

Overall, the results demonstrate that locally sourced oyster shell waste can be incorporated as a partial fine-aggregate substitute in mortar while maintaining compressive strength comparable to the control at replacement levels up to 30% under the conditions investigated. The 10% replacement level demonstrated the strongest overall experimental performance because it combined the highest measured workability with the highest compressive strength. However, this result should be regarded as specific to the present materials, particle grading and mixture proportions rather than as a universal optimum for oyster-shell mortar.

The study provides locally derived experimental evidence on oyster shell waste obtained from fishing communities in Old Bortianor, Accra, Ghana, and demonstrates its potential for conversion from a waste material into a useful construction resource. The findings contribute to the growing body of research on shell-waste valorization and provide a basis for further investigation of higher replacement levels, particle-size effects, durability and the performance of oyster-shell mortar under different mixture conditions.

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