Proceeding of ICMR 8(1), 156-169

Effects of Snail Shell Waste on Compressive Strength of Concrete with Partial Cement and Fine Aggregate Replacement

Bunyamin Bunyamin[1*], Heru Pramanda[1], Rafiqa Muhnita Yusputri[2], Wan Berkat Damai Gea[1]

[1]Faculty of Engineering, Universitas Iskandar Muda, Aceh, Indonesia
[2]Faculty of Engineering, Universitas Syiah Kuala, Aceh, Indonesia

*Corresponding Author: bunyamin@unida-aceh.ac.id

Abstract. *The concrete industry is under increasing pressure to reduce cement consumption and natural aggregate exploitation to enhance environmental sustainability. In Leupung District, Aceh Besar Regency, Indonesia, the consumption of black snail as a traditional local food, rooted in coastal community local wisdom, generates significant shell waste that remains largely underutilized. While previous studies have extensively examined other biogenic wastes, the use of snail shell waste (SSW) as a partial replacement for cement and fine aggregate has received limited attention. This study proposes an innovative integration of local wisdom with modern concrete technology by employing SSW as a dual substitution material. The objective was to evaluate the compressive strength performance of concrete incorporating snail shell waste at replacement levels of 0%, 5%, 10%, and 15%, targeting a design strength of 17 MPa. Compressive strength tests were conducted in accordance with ASTM and ACI standards. The results showed compressive strengths of 21.98 MPa for the control mix and 19.23 MPa, 17.86 MPa, and 17.53 MPa for the 5%, 10%, and 15% mixtures, respectively. Regression analysis revealed a strong negative linear relationship ($y = -0.2948x + 21.361$; $R^2 = 0.8808$) between replacement level and compressive strength. Although strength decreased with increasing substitution, all mixtures met the target concrete strength, indicating that SSW derived from local wisdom practices is suitable for application in non-structural concrete and contributes to sustainable waste utilization.*

Keywords: *cement, compressive strength, concrete, fine aggregate, snail shell.*

1. Introduction

The concrete industry remains highly dependent on the use of Portland cement (Yang & Wang, 2025) and natural aggregates as its primary constituents (Zhu et al., 2024). his dependency significantly contributes to the depletion of non-renewable natural resources and the escalation of carbon dioxide (CO_2) emissions (Jang et al., 2025; yarra et al., 2025). Cement production is widely recognized as one of the major sources of CO_2 emissions in the construction sector, while large-scale extraction of fine and coarse aggregates poses serious environmental risks, including ecosystem degradation, coastal damage, and deterioration of environmental quality (Guo et al., 2024; Li et al., 2023; N. Li et al., 2022). These challenges have driven extensive research efforts aimed at enhancing concrete performance while simultaneously reducing its environmental footprint, particularly through the utilization of waste materials as partial substitutes in concrete mixtures (Bunyamin & Mukhlis, 2020). The incorporation of waste materials not only reduces reliance on conventional raw materials but also aligns with the principles of circular economy and sustainable construction (Ruth Bola Oliveira et al., 2023).

In coastal regions of Indonesia, particularly in Leupung District, Aceh Besar Regency, the consumption of black snails as a traditional food rooted in local cultural practices generates a considerable amount of Snail Shell Waste (SSW). To date, this waste has not been optimally utilized and is generally disposed of without proper treatment, leading to potential environmental problems such as visual pollution, unpleasant odors, and sanitation issues in coastal areas (Alla & Asadi, 2022). On the other hand, SSW is known to contain a high proportion of calcium carbonate, which theoretically exhibits properties similar to limestone and therefore has potential as an alternative material in concrete, either as a partial replacement for cement or fine aggregate (Alhassan et al., 2023). Nevertheless, the utilization of SSW derived from local traditional practices has not yet been systematically and scientifically integrated into the development of concrete technology.

Based on these considerations, the present study aims to investigate the potential of SSW obtained from Leupung District, Aceh Besar, as a partial substitute for cement and fine aggregate in concrete. The primary objective of this research is to evaluate the effect of varying SSW substitution levels of 0%, 5%, 10%, and 15% on the compressive strength performance of concrete with a target strength of 17 MPa. Compressive strength testing was conducted in accordance with ASTM (American Society of Testing and Materials) and ACI (American Concrete Institute) standards to ensure scientific comparability and reproducibility of the results. In addition, this study seeks to assess the feasibility of utilizing SSW as an environmentally friendly alternative material suitable for non-structural concrete applications.

Although numerous previous studies have examined the use of biogenic waste materials in concrete, most have focused on marine seashell waste (Zhu et al., 2024), oyster shells (Hu et al., 2025), or eggshells (Imani et al., 2025), either as supplementary materials or partial cement replacements. Research that specifically explores SSW generated from local traditional consumption practices and its simultaneous use as a partial replacement for both cement and fine aggregate remains very limited in the scientific literature, particularly in the context of low- to medium-strength concrete. Furthermore, the integration of local wisdom, coastal waste management, and sustainable concrete material development has not been comprehensively investigated, thereby highlighting a clear research gap.

The novelty of this study lies in its integrative approach that combines the local wisdom of coastal communities in Aceh with material innovation in concrete technology. This research represents one of the earliest systematic studies utilizing SSW from Leupung as a dual substitution material, serving simultaneously as a partial replacement for cement and fine aggregate in concrete. Moreover, this study presents an analysis of the linear relationship between SSW substitution levels and concrete compressive strength, providing new insights into the technical limitations and practical applicability of this waste material in non-structural concrete. This approach not only enriches the body of knowledge on biogenic waste-based concrete but also offers a contextualized perspective for developing sustainable construction materials tailored to local conditions.

The findings of this study are expected to demonstrate that, although compressive strength decreases with increasing SSW substitution levels, all concrete mixtures still meet the specified target strength. Accordingly, SSW derived from local practices has the potential to be utilized as a viable alternative material for non-structural concrete applications. More broadly, this research is anticipated to contribute to coastal waste reduction, conservation of natural resources, and the advancement of sustainable construction practices that support environmentally responsible development in Indonesia and other coastal regions.

2. Method

This study was designed as a laboratory-based experimental investigation to evaluate the effect of Snail Shell Waste (SSW) substitution on the properties of concrete, with particular emphasis on compressive strength and unit weight. The primary materials used in this research consisted of Type I Portland cement, fine aggregate, coarse aggregate, water, and SSW sourced from Leupung District, Aceh Besar Regency, Indonesia. The fine aggregate comprised fine sand with a maximum particle size of 4.76 mm and coarse sand with a maximum particle size of 9.52 mm, while the coarse aggregate consisted of crushed gravel with a maximum size of 25.4 mm. These aggregate sizes were selected in accordance with standard aggregate classification recommendations for normal-weight concrete.

Acquisition of SSW

SSW was collected from Leupung District, Aceh Besar Regency, Indonesia, a coastal area where black snails are commonly consumed as a traditional local food. This consumption activity generates a substantial amount of shell waste, which to date has not been optimally utilized and is generally disposed of directly into the surrounding environment (Adepitan et al., 2025). The snail shells were manually collected from snail processing and selling sites, after which they were carefully sorted to ensure that only intact shells free from non-biogenic contaminants were used as research materials. The selection of this waste source was based not only on material availability but also on considerations of local wisdom, which form the foundation of the sustainability-oriented approach adopted in this study.

Processing of SSW

The processing of Snail Shell Waste (SSW) was carried out through several sequential stages to obtain shell ash suitable for use as a substitution material in concrete. The initial stage involved washing the shells with clean water to remove residual organic matter, mud, and other surface contaminants adhering to the shells (Bunyamin et al., 2025). Subsequently, the cleaned shells were dried in a laboratory oven at a temperature of approximately 105 ± 5 °C until a constant dry condition was achieved.

The dried shells were then mechanically crushed using a Los Angeles Abrasion machine to obtain smaller particle sizes. The crushed material was subsequently separated through a sieving process. The SSW fraction passing the No. 4 sieve (4.76 mm) was designated as SSW powder and utilized as a partial replacement for fine aggregate in the concrete mixture. This fraction was intended to function as a filler and granular material, contributing to void filling within the concrete matrix.

Meanwhile, the SSW fraction intended for partial cement replacement underwent further processing through calcination. The finely sieved shell material was calcined at a temperature of 500 °C in a laboratory furnace for a specified duration to obtain treated SSW (Bunyamin et al., 2022). his calcination process was performed to enhance the reactivity of the material by eliminating residual organic compounds and inducing partial decomposition of calcium carbonate ($CaCO_3$) into calcium oxide (CaO), which exhibits higher chemical activity and potential contribution to cement hydration reactions (Jang et al., 2025).

After calcination, the SSW was allowed to cool naturally at room temperature to prevent mineralogical alterations caused by rapid coolin (Ujwal et al., 2024). The cooled ash was then reground if particle agglomeration was observed, followed by sieving through a No. 200 sieve to obtain a highly fine and homogeneous particle size distribution (Bunyamin et al., 2024). The processed SSW was stored in airtight containers to prevent rehydration and carbonation prior to its use as a partial cement replacement material in concrete production. A schematic illustration of the SSW processing procedure is presented in Figure 1.

Figure 1. SSW Processing Procedure

Through these processing stages, SSW can be optimally utilized as an environmentally friendly alternative material, serving as a partial replacement for both cement and fine aggregate. This utilization contributes to reducing the consumption of conventional construction materials while supporting the principles of sustainable construction.

Examination of Physical Properties of Aggregates

Prior to their use in concrete production, both fine and coarse aggregates were tested for their physical properties to ensure compliance with the requirements for concrete materials. Bulk density tests were conducted to determine the mass of aggregate per unit volume under loose and compacted conditions, serving as a basis for calculating aggregate quantities in concrete mix design. Specific gravity and water absorption tests were performed to evaluate the porosity characteristics and water absorption capacity of the aggregates, which significantly influence the effective water–cement ratio in concrete.

In addition, aggregate gradation was analyzed through sieve analysis to ensure that the particle size distribution fell within the recommended grading limits. Proper gradation is expected to enhance concrete density, reduce internal voids, and result in improved mechanical performance. All physical property tests of the aggregates were conducted in accordance with the relevant ASTM standards.

Concrete Mix Design

The concrete mix design was developed based on standard concrete mix proportioning methods to achieve a target compressive strength of 17 MPa (Bunyamin et al., 2021; Permatasari et al., 2024). The concrete mixtures were prepared with SSW substitution levels of 0%, 5%, 10%, and 15% as a partial replacement for cement, while snail shell powder was simultaneously used to replace fine aggregate at the same percentages. The water–cement (W/C) ratio was maintained constant across all mixture variations to ensure that any observed differences in concrete properties were primarily attributed to variations in the substitution level of the materials. Each mix composition was calculated based on the mass of materials per unit volume of concrete, allowing the test results to be analyzed quantitatively and consistently.

Preparation and Curing of Concrete Cylindrical Specimens

Concrete specimens were prepared in the form of standard cylindrical samples with dimensions in accordance with compressive strength testing requirements. The mixing process was carried out using a concrete mixer until a homogeneous mixture was obtained, after which the fresh concrete was poured into cylindrical molds in several layers and compacted using a tamping rod to minimize entrapped air and internal voids (Bunyamin et al., 2023). The workability of the fresh concrete was verified through a slump test, with the target slump maintained within the range of 75–100 mm. The water–cement (W/C) ratio was kept constant for all concrete mixtures to ensure consistency while achieving the specified slump range. After casting, the specimens were left in the molds for 24 hours under laboratory ambient conditions. Subsequently, the specimens were demolded and cured by immersion in a curing tank filled with clean water at a controlled temperature until the designated testing age. This curing process was intended to promote optimal cement hydration, ensuring that the measured compressive strength accurately represents the actual performance of the concrete materials. Details regarding the number and distribution of test specimens are presented in Table 1.

Tabel 1. Number and Types of Test Specimens

No	Concrete Type	Amount of Sample	SSW Treated Level (%)	SSW Powder Level (%)	High Slump Value Planned
1	NC	5	0.00	0.00	75 - 100 mm
2	SSWC-5	5	5.00	5.00	
3	SSWC-10	5	10.00	10.00	
4	SSWC-15	5	15.00	15.00	

Testing of Concrete Unit Weight and Compressive Strength

Concrete unit weight testing was conducted at the age of 28 days to determine the density of the concrete after the curing process. The cylindrical specimens were removed from the curing tank and dried to achieve a saturated surface-dry (SSD) condition. Subsequently, the specimens were weighed to obtain the mass of the hardened concrete. The concrete volume was calculated based on the geometric dimensions of the cylindrical specimens. The unit weight of concrete was then determined as the ratio of mass to volume, which was used to evaluate the level of concrete compactness resulting from the incorporation of SSW.

Compressive strength testing was performed at the age of 28 days using a compression testing machine in accordance with ASTM and ACI standards. The cylindrical specimens were centrally positioned on the testing machine, and axial compressive load was applied gradually until failure occurred. The maximum load recorded was used to calculate the compressive strength of the concrete as the ratio of the maximum load to the cross-sectional area of the concrete cylinder. The results of this test were employed to assess the effect of SSW substitution on the mechanical performance of the concrete.

Data Analysis

The data obtained from the unit weight and compressive strength tests were analyzed quantitatively to evaluate the effect of varying SSW substitution levels on concrete performance. Regression analysis was employed to determine the mathematical relationship between the percentage of SSW substitution and concrete compressive strength, as well as to identify trends indicating a reduction or enhancement in the mechanical properties of the concrete. In addition, the experimental results were conceptually compared with findings from previous studies to assess the consistency and scientific contribution of this research to the development of sustainable concrete.

The use of regression analysis was intended to quantify the significance of each substitution level in contributing to variations in concrete response and to identify the most efficient substitution range for maintaining concrete performance while maximizing waste utilization. This analytical approach also aligns with best practices in sustainable concrete research reported in recent literature, including studies on snail shell and other shell waste substitutions, which have demonstrated significant effects on the mechanical characteristics of concrete within specific replacement ranges (e.g., 5–15%).

3. Results and Discussions

In this study, all tests were conducted experimentally in the laboratory and consisted of physical and mechanical evaluations. The physical tests included the assessment of aggregate properties (fine sand, coarse sand, and gravel) as well as concrete physical properties, namely slump value and unit weight. Meanwhile, the mechanical testing was performed on cylindrical concrete specimens through compressive strength testing.

Results of Aggregate Physical Properties Testing

The examination of aggregate physical properties was conducted as preliminary data for concrete mix design. The physical properties of aggregates evaluated in this study included bulk density, specific gravity, water absorption, and fineness modulus. These parameters were subsequently analyzed for compliance with relevant ASTM standard requirements to assess the suitability of the aggregates for use in concrete mixtures. The detailed results are presented in Table 2.

Tabel 2. Results of Aggregate Physical Properties Testing

No.	Type of Aggregate	Bulk Density (Kg/l)	Specific Gravity	Absorption (%)	Fineness Modulus (FM)
1	Fine Sand	1.697	2.75	1.61	2.34
2	Coarse Sand	1.848	2.74	1.63	2.92
3	Coarse Aggregate	1.736	2.83	1.93	6.83

Based on the results of aggregate physical properties testing presented in Table 2, it can be concluded that all aggregates used in this study satisfy the technical requirements recommended by ASTM standards and are therefore suitable for use as concrete constituent materials (Surahyo, 2019). The bulk density values of fine sand, coarse sand, and coarse aggregate were 1.697 kg/L, 1.848 kg/L, and 1.736 kg/L, respectively, all exceeding the minimum requirement of 1.400 kg/L specified by ASTM. These results indicate that the aggregates possess adequate density and are neither excessively lightweight nor overly porous, enabling them to contribute effectively to the overall density and structural stability of the concrete.

The specific gravity values in the saturated surface-dry (SSD) condition also demonstrate compliance with ASTM criteria. Fine sand and coarse sand exhibited specific gravity values of 2.75 and 2.74, respectively, which fall within the recommended range for fine aggregates, while the coarse aggregate showed a specific gravity of 2.83, remaining within the acceptable limits for gravel. The relatively high specific gravity values suggest that the aggregates are composed of dense materials with low internal porosity, which is beneficial for achieving higher compressive strength and improved durability of concrete.

The water absorption test results further indicate satisfactory aggregate quality. Fine sand and coarse sand recorded absorption values of 1.61% and 1.63%, respectively, which are within the ASTM allowable range of 0–2%. The coarse aggregate exhibited a slightly higher absorption value of 1.93%, approaching the upper recommended limit but still considered acceptable. This result suggests that the aggregates do not contain excessive open pores and are unlikely to absorb significant amounts of mixing water, thereby minimizing adverse effects on the effective water–cement ratio of the concrete mixture.

In terms of gradation, the fineness modulus (FM) values of fine sand and coarse sand were 2.34 and 2.92, respectively, both within the ASTM-recommended range of 2.3–3.1. This indicates a well-graded particle size distribution that supports good workability and effective compaction of fresh concrete. Meanwhile, the coarse aggregate exhibited an FM value of 6.83, which falls within the acceptable range of 5.50–8.00, confirming that the gravel size is appropriate for structural concrete applications and capable of forming a stable load-bearing skeleton within the concrete matrix.

Results of Concrete Mix Design

In this study, the concrete mix was designed to achieve a target compressive strength of 17 MPa with a water–cement ratio (W/C) of 0.62. The results of the mix design for 1 m³ of concrete are presented in Table 3. Meanwhile, the detailed mix proportions incorporating SSW at replacement levels ranging from 0% to 15% for the preparation of 20 cylindrical concrete specimens with dimensions of 150 mm × 300 mm are summarized in Table 4.

Tabel 3. The Results of the Concrete Mix Design for 1 m3

No.	Mix Design for 1 m³ of concrete	Material Weight (kg)
1	Water	193.00
2	Cement	288.06
3	Coarse Aggregate	1201.31
4	Coarse Sand	184.72
5	Fine Sand	512.91
	Total	**2380.00**

Table 3 presents the results of the normal concrete mix design for a volume of 1 m³, which was used as the control mixture without SSW substitution. A water content of 193.00 kg/m³ was specified to ensure adequate workability of the mixture, while a cement content of 288.06 kg/m³ was provided to supply a sufficient amount of paste to bond the aggregates and support the development of compressive strength at the target age. Coarse aggregate was used in the largest proportion, amounting to 1201.31 kg/m³, serving as the primary structural framework of the concrete and playing a crucial role in its stability and strength. Fine aggregates, consisting of coarse sand (184.72 kg/m³) and fine sand (512.91 kg/m³), were proportioned to achieve an optimal gradation, enhance mixture density, and reduce internal voids within the concrete. The total mixture weight of 2380 kg/m³ indicates that the produced concrete can be classified as normal-weight concrete. These results are consistent with previous studies reporting that normal-weight concrete typically exhibits a unit weight ranging from 2200 to 2500 kg/m³ (Djaelani et al., 2022).

Tabel 4. The Results of the Concrete Mix Design for Variations in SSW

Concrete Type	Material Weight (kg)								
	Cement	Replacement level (%)	SSW treated	Fine Sand	Replacement level (%)	SSW powder	Coarse sand	Coarse Aggregate	Water
NC	9.47	0.00	0.00	11.29	0.00	0.00	9.39	36.54	5.89
SSWC-5	9.00	5.00	0.47	10.72	5.00	0.56	9.39	36.54	5.89
SSWC-10	8.52	10.00	0.95	10.16	10.00	1.13	9.39	36.54	5.89
SSWC-15	8.05	15.00	1.42	9.59	15.00	1.69	9.39	36.54	5.89

Table 4 presents the concrete mix proportions incorporating SSW substitution levels ranging from 0% to 15% for the preparation of 20 cylindrical concrete specimens with dimensions of 15 cm × 30 cm. All mixtures were designed to achieve a target compressive strength of 17 MPa while maintaining a constant water–cement ratio (W/C) of 0.62. The normal concrete mixture (NC) was used as the reference, in which the total cement and fine sand requirements were entirely supplied by conventional materials without the incorporation of SSW, following proportions equivalent to the previously designed 1 m³ normal concrete mix.

In the SSWC-5 mixture, SSW was introduced as a partial replacement of cement and fine sand at a level of 5%, which was subsequently increased to 10% in SSWC-10 and 15% in SSWC-15. The increasing SSW content resulted in a proportional reduction in the quantities of cement and natural fine sand compared to the normal concrete mixture, while the contents of coarse aggregate, coarse sand, and mixing water were kept constant. This approach was adopted to ensure that any observed changes in concrete performance could be primarily attributed to the influence of SSW rather than variations in the water–cement ratio or aggregate proportions. Previous studies have similarly reported that maintaining constant water–cement and aggregate ratios is essential when investigating the effects of seashell-based materials, so that performance variations can be directly linked to the substitution material itself (Zhu et al., 2024).

Compared with the normal concrete mixture designed for 1 m³, the SSW-containing mixtures exhibit modifications in both the binder system and the fine fraction of the concrete. Treated SSW potentially acts as a calcium-rich filler that influences the microstructure of the cement paste, while SSW powder contributes to alterations in the gradation of fine aggregates. By keeping the primary mix parameters constant, this experimental design provides a rational and measurable basis for evaluating the effects of SSW substitution levels up to 15% on the performance of normal-strength concrete in a systematic and scientifically controlled manner.

Results of Slump Test

The slump test was performed after the concrete mixtures were thoroughly mixed to achieve a homogeneous consistency. The results of the slump test are presented in Table 5.

Tabel 5. The Results of the Slump Test for Concrete Mixtures Incorporating SSW

No	Concrete Type	SSW treated (%)	SSW powder (%)	Slump value (mm)	Workability (± Water Quantity)	High Slump Value Planned
1	NC	0.00	0.00	97.50	±0.00%	75 - 100 mm
2	SSWC-5	5.00	5.00	97.50	±0.00%	
3	SSWC-10	10.00	10.00	97.50	-5.00%	
4	SSWC-15	15.00	15.00	80.00	-7.00%	

The results presented in Table 5 indicate a decreasing trend in slump values and water demand for concrete mixtures incorporating SSW as a partial substitute for cement and fine aggregate. At substitution levels up to 10%, the slump value remained relatively stable at approximately 97.5 mm, accompanied by a 5% reduction in water demand. However, at a substitution level of 15%, a more pronounced decrease in slump was observed, reaching 80 mm, with a 7% reduction in water demand required to maintain workability within the target range of 75–100 mm. This behavior suggests that SSW exhibits a lower water absorption capacity compared to conventional cement and natural fine aggregate. Consequently, concrete mixtures containing SSW require a lower water–cement ratio to achieve comparable workability. Such a reduction in water demand may potentially enhance the strength and durability of concrete, provided that the mixture proportions are appropriately optimized. The observation that seashell-based materials can reduce water demand while maintaining adequate workability is consistent with findings from previous studies, which report that calcined seashell materials often possess finer particle morphology and lower porosity, thereby limiting water absorption within the cement paste system. (Hasan et al., 2023).

Results of Concrete Unit Weight Test

The concrete unit weight test was conducted by measuring the dimensions and mass of the cylindrical concrete specimens and was performed immediately prior to the compressive strength test. The results of the concrete unit weight measurements are presented in Figure 2.

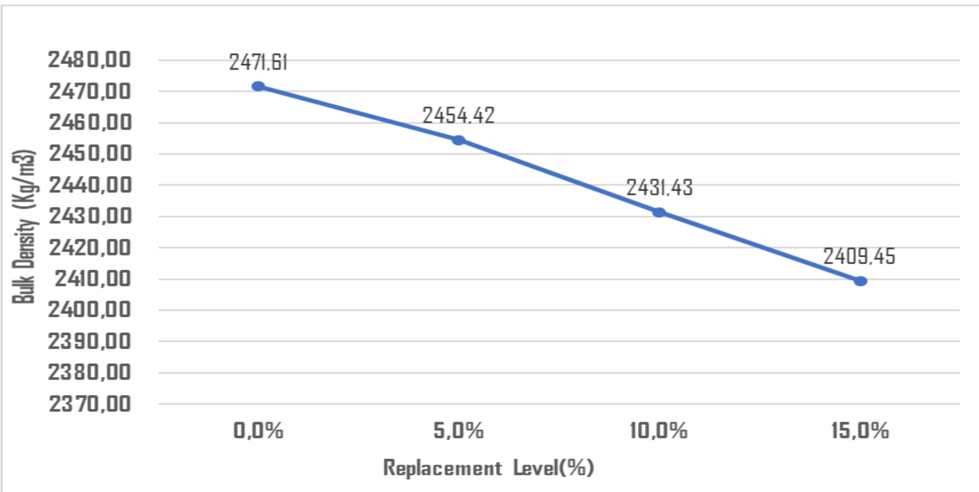


Figure 2. Results of Concrete Unit Weight Test

Based on Figure 2, the control concrete (Normal Concrete, NC) exhibits the highest unit weight of 2471.61 kg/m³. In contrast, concrete mixtures incorporating SSW show a gradual reduction in density with increasing substitution levels, recording values of 2454.42 kg/m³ for SSWC-5, 2431.43 kg/m³ for SSWC-10, and reaching the lowest value of 2409.45 kg/m³ for SSWC-15. This reduction in unit weight is consistent with the fundamental principle that partial replacement of conventional dense materials (cement and fine aggregate) with biogenic waste materials such as treated SSW and SSW powder, which possess lower specific gravity, tends to produce concrete with reduced density.

The observed decrease in unit weight resulting from the incorporation of biogenic substitute materials has also been widely reported in previous studies. Earlier research indicated that increasing the proportion of oyster shell ash in concrete mixtures may lead to a higher amount of entrapped air, primarily due to the irregular morphology of shell ash particles, which ultimately contributes to a reduction in concrete unit weight (Varhen et al., 2017). Other studies have reported similar findings, noting that materials such as seashells, coconut shells, and biochar generally exhibit lower specific gravity compared to natural mineral aggregates or Portland cement. Consequently, substituting part of the concrete mass with these lighter materials inherently reduces the overall unit weight of concrete (Netinger Grubeša et al., 2025). Comparable conclusions have also been reported in related investigations (Itam et al., 2022).

Therefore, the unit weight data obtained in this study demonstrate a logical trend that is consistent with relevant literature, namely that higher substitution levels of shell-based waste materials in concrete result in a progressive reduction in concrete density. Nevertheless, low substitution levels are still capable of maintaining unit weight characteristics relatively close to those of the control concrete, indicating the potential feasibility of SSW incorporation for normal-density concrete applications.

Results of Compressive Strength Test

In this study, the compressive strength test of concrete was conducted when the specimens reached the age of 28 days. The results of the compressive strength test are presented in Figure 3.

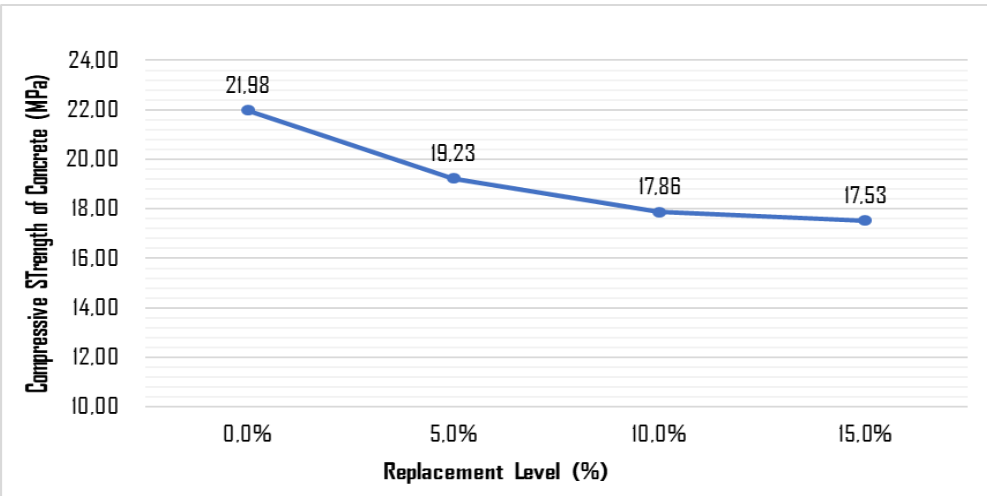


Figure 3. Results of Compressive Strength Test

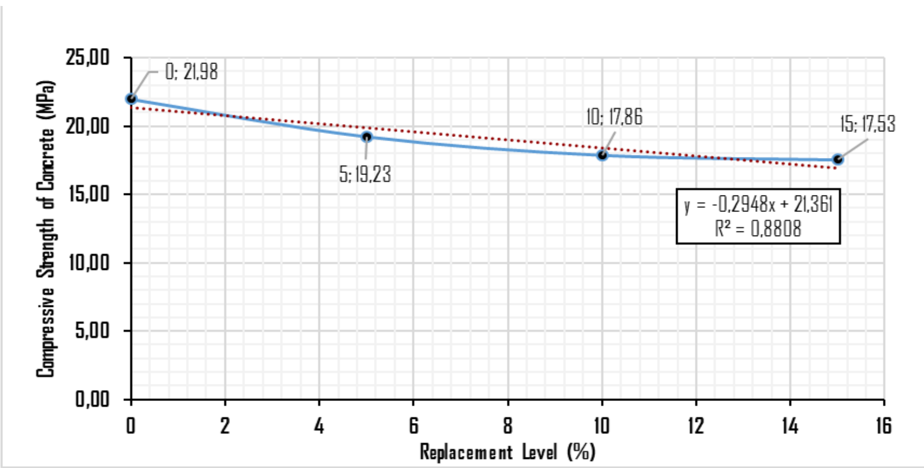
Figure 3 presents the 28-day compressive strength results of concrete incorporating SSW at substitution levels ranging from 0% to 15%. The control concrete without substitution (NC) exhibited the highest compressive strength of 21.98 MPa. In contrast, concrete mixtures containing SSW showed a progressive reduction in compressive strength with increasing substitution levels, recording values of 19.23 MPa for SSWC-5, 17.86 MPa for SSWC-10, and 17.53 MPa for SSWC-15, with the lowest strength observed at the 15% substitution level. Overall, although compressive strength decreased as the proportion of SSW increased, all mixtures satisfied the target design strength of 17 MPa specified in this study.

The reduction in compressive strength is consistent with numerous previous studies reporting that partial replacement of cement or fine aggregate with biogenic waste materials, such as shell powder, tends to gradually reduce concrete strength, particularly at medium to high substitution levels. This behavior can be attributed to differences in density and hydration capability between the substitute materials and Portland cement, as well as to an increase in micro-porosity within the cement paste, which contributes to crack propagation and reduced continuity of the interfacial bond between aggregates and the cement matrix (Sangeetha et al., 2022). Other studies have similarly shown that high levels of cement replacement with shell-based powders can result in a noticeable reduction in 28-day compressive strength due to limited hydration reactions and an increased volume of internal pores within the concrete matrix (Abbas & Thapa, 2025).

Nevertheless, several previous investigations have reported that low to moderate substitution levels (e.g., 5–10%) do not necessarily lead to a significant reduction in compressive strength and may, under certain conditions, maintain or even enhance strength when the waste material is properly processed and optimized. Controlled processing of seashell materials has been shown to improve concrete strength performance at 28 days compared to control concrete (Tayeh et al., 2020). Similar conclusions have also been reported by other researchers (Naqi et al., 2020).

Results of Concrete Compressive Strength Regression Analysis

Based on the average compressive strength data obtained from each substitution group, a regression analysis was performed to describe the relationship between the substitution level (x) and the corresponding characteristic compressive strength (y). The resulting regression curve is presented in Figure 4.



Gambar 4. The Regression and Correlation Results of Concrete Compressive Strength

The graph illustrates the relationship between 28-day compressive strength and increasing substitution levels of cement by SSW, ranging from 0% to 15%. The regression equation, y = -0.2948x + 21.361 with R^2 = 0.8808, confirms a strong negative linear trend, indicating that approximately 88.08% of the variation in compressive strength can be attributed to changes in SSW content. The highest compressive strength was observed in normal concrete (0% SSWC) at approximately 21.36 MPa, while the lowest predicted value at 15% substitution was around 16.94 MPa. The actual measured strength at 8% SSWC (10.77 MPa) deviates below the predicted value, suggesting a potential critical point in the mixture where the influence of SSW on strength becomes more pronounced.

4. Conclusions

1. All concrete mixtures incorporating snail shell waste satisfied the required aggregate properties and workability criteria, with slump values remaining within the specified range.
2. Increasing snail shell waste replacement levels resulted in reduced compressive strength and unit weight; however, mixtures containing up to 15% replacement still met the target concrete strength of 17 MPa, supporting their application in non-structural concrete.
3. A strong linear correlation between snail shell waste content and compressive strength was confirmed by regression analysis (R^2 = 0.8808), indicating a significant influence of substitution level on concrete performance.

5. References

Abbas, A. A., & Thapa, S. J. (2025). Experimental Investigation of Low-Carbon Concrete Using Biochar as Partial Cement Replacement. *Sustainability (Switzerland)*, *17*(23), 82. https://doi.org/10.3390/su172310744

Adepitan, O. L., Alabi, O. O., Gbadeyan, O. J., Deenadayalu, N., & Jayeola, A. T. (2025). Investigation into the development and utilization of snail shell biomaterials: a systematic review. *Discover Materials*, *5*(1), 1–18. https://doi.org/10.1007/s43939-025-00218-6

Alhassan, A., Aboshio, A., & Uche, O. A. (2023). Rice Husk and Snail Shell Ash As Partial Replacement of Ordinary Portland Cement in Concrete – a Review. *Nigerian Journal of Technology*, *42*(4), 425–436. https://doi.org/10.4314/njt.v42i4.2

Alla, S., & Asadi, S. S. (2022). Experimental investigation and microstructural behavior of un-calcined and calcined snail shell powder cement mortar. *Journal of Building Pathology and Rehabilitation*, *7*(1), 42. https://doi.org/10.1007/s41024-022-00183-0

Bunyamin, B., Hady, M., Munirwan, R. P., & Putra Jaya, R. (2024). Cymbopogon nardus Leaf Ash as an Alternative Material for Enhancing Concrete Strength. *Advances in Civil Engineering*, *2024*, 1–15. https://doi.org/10.1155/2024/4997651

Bunyamin, B., Kurniasari, F. D., Munirwan, R. P., & Putra Jaya, R. (2022). Effect of Coral Aggregates of Blended Cement Concrete Subjected to Different Water Immersion Condition. *Advances in Civil Engineering*, *2022*. https://doi.org/10.1155/2022/2919167

Bunyamin, B., & Mukhlis, A. (2020). Utilization of Oyster Shells as a Substitute Part of Cement and Fine Aggregate in the Compressive Strength of Concrete. *Aceh International Journal of Science and Technology*, *9*(3), 150–156.

https://doi.org/10.13170/aijst.9.3.17761

Bunyamin, B., Munirwan, R. P., Ridha, M., & Hendrifa, N. (2021). Utilization of wood processing dust as a substitute for a part of cement in concrete. *IOP Conference Series: Materials Science and Engineering*, *1087*(1), 012004. https://doi.org/10.1088/1757-899x/1087/1/012004

Bunyamin, B., Saidi, T., Sugiarto, S., & Hasan, M. (2025). Calcination Analysis of CaCO. *Structural Durability \& Health Monitoring*, *19*(5), 1089–1109. https://doi.org/10.32604/sdhm.2025.066887

Bunyamin, Pramanda, H., Hendrifa, N., & Afdhal. (2023). Limbah Cangkang Telur Sebagai Inovasi Material Pengganti Agregat Halus Beton. *Jurnal Manajemen Teknologi & Teknik Sipil*, *6*(1), 17–30. https://doi.org/10.30737/jurmateks.v6i1.4583

Djaelani, M., Judiono, J., Darmawan, D., & Amri, M. W. (2022). Study of Concrete: Quality and Economic. *Bulletin of Science, Technology and Society*, *1*(1), 1–3. https://inti.ejournalmeta.com/index.php/inti/article/view/1

Guo, Y., Luo, L., Liu, T., Hao, L., Li, Y., Liu, P., & Zhu, T. (2024). A review of low-carbon technologies and projects for the global cement industry. *Journal of Environmental Sciences (China)*, *136*, 682–697. https://doi.org/10.1016/j.jes.2023.01.021

Hasan, K., Karim, A., Islam, M. T., Ali, M. Bin, Rahman, M. T., Rahman, M. M., & Yahaya, F. M. (2023). A review of the mechanical properties and durability of concrete containing recycled seashells as a partial cement replacement. *Journal of Material Cycles and Waste Management*, *25*(6), 3192–3216. https://doi.org/10.1007/s10163-023-01795-5

Hu, S. L., Mo, L. Z., & Zhang, P. J. (2025). Study on the Development of an Oyster Shell-Based Clarifier for Enhancing Sugar Industry Processes. *Sugar Tech*, *27*(2), 328–339. https://doi.org/10.1007/s12355-024-01505-x

Imani, R., Nasmirayanti, R., Suandi, R., & Oktavani, D. L. (2025). The Improvement of Self-Compacting Concrete Strength with ESP-Glass Powder as a Substitute for Concrete Admixture. *International Journal of Engineering Technology and Natural Sciences*, *7*(1), 87–94. https://doi.org/10.46923/ijets.v7i1.479

Itam, Z., Johar, A. D., Syamsir, A., Zainoodin, M., Fadzil, S. M. M. S. A., & Beddu, S. (2022). Utilization of coconut shell as a supplementary cementitious material in concrete. *Materials Today: Proceedings*, *66*, 2818–2823.

Jang, K., Ikram, M., Lee, D., Myung, J., Oh, S., Kim, S. H., Choi, W. Y., & Park, J. (2025). Sustainable conversion of oyster shell waste into high-purity calcium carbonate via CO2 mineralization. *Journal of Environmental Chemical Engineering*, *13*(1), 115099. https://doi.org/10.1016/j.jece.2024.115099

Li, L., Liu, Q., Dao, V., & Wu, M. (2023). Dimensional change of cement paste subjected to carbonation in CO2 sequestration and utilization context: A critical review on the mechanisms. *Journal of CO2 Utilization*, *70*, 102444–102457. https://doi.org/10.1016/j.jcou.2023.102444

N. Li, L. Mo, & C. Unluer. (2022). Emerging CO2 utilization technologies for construction materials: A review. *Journal of CO2 Utilization*, *65*, 1–2. https://www.sciencedirect.com/science/article/pii/S2212982022003560

Naqi, A., Siddique, S., Kim, H. K., & Jang, J. G. (2020). Examining the potential of calcined oyster shell waste as additive in high volume slag cement. *Construction and Building Materials*, *230*, 116973.

https://doi.org/10.1016/j.conbuildmat.2019.116973

Netinger Grubeša, I., Šamec, D., Juradin, S., & Hadzima-Nyarko, M. (2025). Utilizing Agro-Waste as Aggregate in Cement Composites: A Comprehensive Review of Properties, Global Trends, and Applications. *Materials*, *18*(10), 2195. https://doi.org/10.3390/ma18102195

Permatasari, N., Bunyamin, B., Hady, M., Hafiz, D. A., Lathifah, N., & Auliyah, M. H. (2024). Utilization of Rice Field Conch Shells as a partial substitution of Cement and Fine Aggregate for Split Tensile Strength of Concrete. *E3S Web of Conferences*, *476*, 1018. https://doi.org/10.1051/e3sconf/202447601018

Ruth Bola Oliveira, D., Leite, G., Possan, E., & Marques Filho, J. (2023). Concrete powder waste as a substitution for Portland cement for environment-friendly cement production. *Construction and Building Materials*, *397*, 132382. https://doi.org/10.1016/j.conbuildmat.2023.132382

Sangeetha, P., Shanmugapriya, M., Santhosh Saravanan, K., Prabhakaran, P., & Shashankar, V. (2022). Mechanical properties of concrete with seashell waste as partial replacement of cement and aggregate. *Materials Today: Proceedings*, *61*, 320–326. https://doi.org/10.1016/j.matpr.2021.09.501

Surahyo, A. (2019). Physical Properties of Concrete. In *Concrete Construction* (pp. 61–88). Springer. https://doi.org/10.1007/978-3-030-10510-5_3

Tayeh, B. A., Hasaniyah, M. W., Zeyad, A. M., Awad, M. M., Alaskar, A., Mohamed, A. M., & Alyousef, R. (2020). Durability and mechanical properties of seashell partially-replaced cement. *Journal of Building Engineering*, *31*, 101328. https://doi.org/10.1016/j.jobe.2020.101328

Ujwal, M. S., Rudresh, A. N., Sathya, T. P., Shiva Kumar, G., Vinay, A., Sridhar, H. N., & Ramaraju, H. K. (2024). Optimizing the properties of seashell ash powder based concrete using Response Surface Methodology. *Asian Journal of Civil Engineering*, *25*(8), 6021–6036. https://doi.org/10.1007/s42107-024-01160-3

Varhen, C., Carrillo, S., & Ruiz, G. (2017). Experimental investigation of Peruvian scallop used as fine aggregate in concrete. *Construction and Building Materials*, *136*, 533–540. https://doi.org/10.1016/j.conbuildmat.2017.01.067

Yang, B., & Wang, X. Y. (2025). Analysis of Hydration Strength and CO2 Emissions of Cement–Quartz Powder Binary Blends Considering the Effects of Water/Binder Ratios and Quartz Contents. *Applied Sciences (Switzerland)*, *15*(4). https://doi.org/10.3390/app15041923

yarra, A., Nakkeeran, G., Roy, D., & Alaneme, G. U. (2025). Evaluation of SCBA-replaced cement for carbon credits and reduction in CO2 emissions. *Discover Applied Sciences*, *7*(2), 114. https://doi.org/10.1007/s42452-025-06487-3

Zhu, Y., Chen, D., Yu, X., Liu, R., & Liao, Y. (2024). Properties of Cementitious Materials Utilizing Seashells as Aggregate or Cement: Prospects and Challenges. *Materials*, *17*(5), 1222. https://doi.org/10.3390/ma17051222