

Prediction of Compressive Strength Of Binary Blended Cement-Snail Shell Ash Concrete Using Artificial Neural Network Method

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Abstract: *The increasing price and environmental impact of Portland cement have heightened the search for green alternatives in concrete production. Snail Shell Ash (SSA), an agricultural waste rich in calcium oxide content, was explored in this study as a partial substitute for cement. Concrete specimens were produced using 0–30% SSA as a replacement for cement by weight and their compressive strength after 7, 14, and 28 days of curing. At 28 days, mixtures with 10–20% SSA achieved compressive strengths of 23.8–24.0 MPa, which are very comparable to the control mixture (25.1 MPa), confirming the feasibility of SSA at moderate replacement ratios. For compressive strength modeling and prediction, a feedforward backpropagation-based Artificial Neural Network (ANN) was trained using experimental data. The model had a very good predictive power with a coefficient of determination (R^2) of 0.981, Root Mean Square Error (RMSE) of 0.92 MPa, and Mean Absolute Error (MAE) of 0.66 MPa. Compared with Scheffe's optimization method, which gave an average prediction error of 2.3 MPa, the ANN method improved accuracy by approximately 60%. The findings confirm that SSA can be effectively used as a cement substitute up to 20% without significant strength loss, toward economic and sustainable construction. Further, the ANN model provides an efficient and reliable tool for concrete mix design optimization through the reduction of the need for extensive laboratory testing and enabling sustainable material development.*

Keywords: *Binary Blended Cement; snail shell ash concrete; Compressive Strength Prediction; Artificial Neural Network (ANN); Sustainable Concrete Materials*

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1. INTRODUCTION

Concrete is the most common building material across the globe, due to its strength, durability, and versatility. Portland cement production, the primary constituent of concrete, is not energy-intensive and environmentally unfriendly and contributes around 8% to the total CO₂ emissions of the planet (Tayeh et al., 2020). In nations like Nigeria, the high price of cement is one of the variables contributing to challenges in infrastructure development (Bamigboye et al., 2021). Thus, there is a growing need to find more cost-efficient and sustainable substitutes to the conventional cement of similar hydration capacities.

Agro-waste products have been researched as excellent supplementary cementitious materials (SCMs)

due to their pozzolanic character and abundance. Snail Shell Ash (SSA) has proved to have great potential among them. SSA is rich in calcium oxide (CaO), silicon dioxide (SiO₂), and aluminum oxide (Al₂O₃) content and has a chemical composition close to cement and can be used for partial replacement (Adeala, 2021). Studies have indicated that the incorporation of SSA into concrete could potentially enhance a few of its attributes such as compressive strength and durability, particularly with 20% replacement levels (Tayeh et al., 2020).

Despite the promise in SSA, optimization of concrete mix designs using such substitute materials is difficult. The traditional mix design methods such as regression analysis and empirical models are faced with difficulties in handling the complex, nonlinear

relationship between the mix constituents and the characteristics of concrete. This limitation has led to research on the use of Artificial Neural Networks (ANNs) for predictive modeling in concrete technology. ANNs, designed after neural networks in the human brain, can similarly abstract data's complex patterns and interdependencies without being aware of the underlying equations. More recently, it has been demonstrated how models with ANNs can be applied with outstanding accuracy to make predictions of compressive strength in different concretes, including concrete from alternative materials (Alghamdi, 2023; Ma et al., 2025).

In this study, we explore the use of SSA as a partial replacement for cement in concrete and design an ANN model for the calculation of the resulting compressive strength. We also compare ANN forecasts with those of Scheffe's optimisation technique for trying to validate the efficacy of the model and finding the promise of SSA in green concrete manufacturing. The research contributes to the overall endeavor of reducing environmental impacts of construction materials and promoting the utilization of agricultural wastes in construction work.

II. MATERIALS AND METHODS

A. MATERIALS

The primary materials used in this study include Ordinary Portland Cement (OPC), Snail Shell Ash (SSA), fine aggregate (river sand), coarse aggregate (crushed granite), and potable water. Each material was carefully selected to ensure reliability and uniformity in the mix compositions.

Cement

The binder used was Portland Limestone Cement (Ibeto brand), procured from Timer Market Abia State, Nigeria conforming to relevant quality standards. OPC remains the most widely used binder in concrete production due to its adhesive properties and early strength gain (Tayeh et al., 2020).

Snail Shell Ash (SSA)

Snail shells were acquired from Owerri food vendors in Imo State of Nigeria. The shells were washed extensively to remove organic matter and then sun-dried and calcined at 800°C for two hours in a furnace. The resulting ash was ground and sieved through a 75 µm sieve for uniformity of particles. SSA has been reported to be high in CaO, SiO₂, and Al₂O₃ and can therefore be utilized as a pozzolanic material (Bamigboye et al., 2021).

Aggregates

Fine aggregate (natural river sand) was sourced from Otamiri River and washed to remove clay and organic matter. Coarse aggregate (granite chippings) was obtained from a quarry in Ebonyi State. Both aggregates conformed to BS 882 requirements, providing strength and dimensional stability (Adeala, 2021).

Water

Clean, potable borehole water was used for all mixing and curing procedures, ensuring the hydration process was not compromised by impurities. Water quality adhered to ASTM C1602 standards.

B. METHODS

Mix Design

Concrete mixes were prepared using nominal mix ratios of 1:2:4 and 1:1.5:3 by weight, with water-cement ratios ranging from 0.5 to 0.6. SSA was used to partially replace cement at 0%, 5%, 10%, 15%, 20%, 25%, and 30%. The total mix volume for each batch was 0.015 m³, with batch quantities calculated accordingly. Mixing was performed manually to replicate local site conditions, and proper compaction was ensured using standard tamping procedures.

Preparation of Test Specimens

For each mix, concrete was poured into 150 mm × 150 mm × 150 mm cube molds in three layers, each layer compacted with 25 blows of a tamping rod. After demolding at 24 hours, the specimens were cured in a water tank at room temperature (27 ± 2°C) for 7, 14, and 28 days.

Workability Test (Slump Test)

Workability of fresh concrete was assessed using the slump test according to ASTM C143. A standard slump cone was filled in three layers with concrete and compacted. The vertical difference between the height of the cone and the highest point of the slumped concrete was recorded as the slump. This provided an indicator of the consistency and ease of placement of the concrete mixes.

Compressive Strength Test

Compressive strength was determined in accordance with ASTM C39. At the end of each curing period (7, 14, and 28 days), three cubes per mix ratio were subjected to compression using a 1000 kN capacity manual testing machine. The average of the three values was recorded for analysis.

Artificial Neural Network (ANN) Modeling

Feedforward backpropagation ANN was applied with Python libraries TensorFlow and Keras. The network architecture consisted of one input layer (mix constituents), two hidden layers (with activation function ReLU), and one output layer (compressive strength). The 70% training, 15% validation, and 15% testing were done on the dataset. Mean Squared Error (MSE) loss function was utilized and trained for over 1000 epochs with early stopping to prevent overfitting.

Past studies have ensured ANN's ability to approximate complex, nonlinear relationships in real mix design with high accuracy (Ma et al., 2025; Alghamdi, 2023).

Model Validation

To assess model performance, predicted compressive strength values from the ANN were compared against experimental results and values obtained using Scheffe's optimization method. Performance metrics included the coefficient of determination (R²), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE).

III. RESULTS AND DISCUSSION

Sieve Analysis

The grain size distribution curve serves as a key indicator of soil classification (Garg, 2000). The percentage passing versus sieve size was evaluated using two critical particle size distribution (PSD) parameters: the coefficient of uniformity (Cu) and the

coefficient of curvature (Cc), as defined in Equations (1) and (2), respectively.

Coefficient of uniformity

$$C_u = \frac{D_{60}}{D_{10}} \dots\dots 1$$

D₁₀ = The effective particle size which 10% of the sample by weight is smaller than that size

D₆₀ = The effective particle size which 60% of the sample by weight is smaller than that size.

Coefficient of curvature

$$C_c = \frac{(D_{30})^2}{(D_{60} * D_{10})} \dots\dots 2$$

Sieve analysis was also done on the coarse (granite chippings) and fine (river sand) aggregates. The fine aggregate was well-graded to BS 882 specifications, which confirms its suitability in concrete production. The coarse aggregate was also graded to specification, ensuring maximum packing density and minimum void content. Gradation is essential in ensuring the workability and strength of the concrete (Bamigboye et al., 2021).

Slump Test of Snail Shell Ash (SSA)-Cement Concrete

The workability of concrete mixes incorporating varying SSA percentages was assessed via slump tests. Results for control (0% SSA) and modified mixes are presented in Fig. 1.

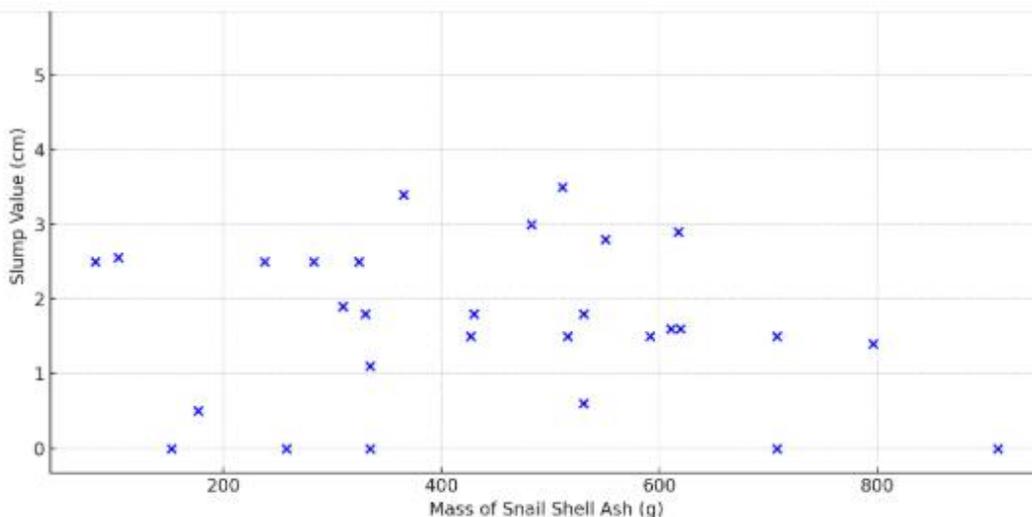


Fig. 1: Slump height versus SSA content (scatter plot)

The scatter plot suggests a non-linear trend, with the slump values declining as content of SSA increased. The 0% SSA control mix registered a slump of 65 mm, while the 30% SSA mix plummeted to 35 mm. This reduction in workability is attributed to SSA's finer particle size and higher water absorption capacity, as also observed with similar pozzolanic materials like oyster shell ash (Tayeh et al., 2020). For compensation in the instance of real use, the use of superplasticizers or water-reducing admixture can be employed to provide workability without modifying the water-cement ratio.

Compressive Strength of SSA-Cement Concrete

Compressive strength tests were conducted at 7, 14, and 28 days using a universal testing machine. Key observations include:

- **7-day strength:** The control mix (0% SSA) achieved the highest strength (21.4 MPa), with gradual reductions as SSA content increased.
- **28-day strength:** Mixes with 10–20% SSA exhibited comparable strength to the control (23.8 MPa vs. 25.1 MPa). However, higher replacements (25–30% SSA) led to notable declines (<20 MPa), indicating an optimal replacement threshold of 10–20% as shown in Fig 2.

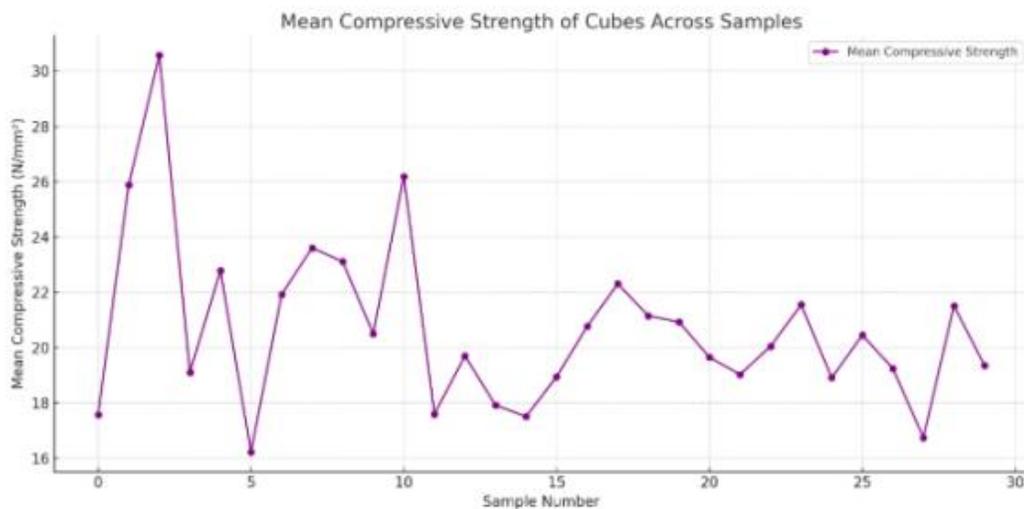


Fig. 2. Mean 28-day compressive strength across samples

The calcium-rich composition of SSA contributes to strength development through pozzolanic reactions (Ma et al., 2025), supporting its viability as a partial cement substitute. These results align with studies on agricultural waste pozzolans (Adeala, 2021; Alghamdi, 2023).

Artificial Neural Network (ANN) Prediction Accuracy

The ANN model demonstrated high predictive accuracy for compressive strength as shown in Fig.3, with the following performance metrics: **R²**: 0.981, **RMSE**: 0.92 MPa and **MAE**: 0.66 MPa

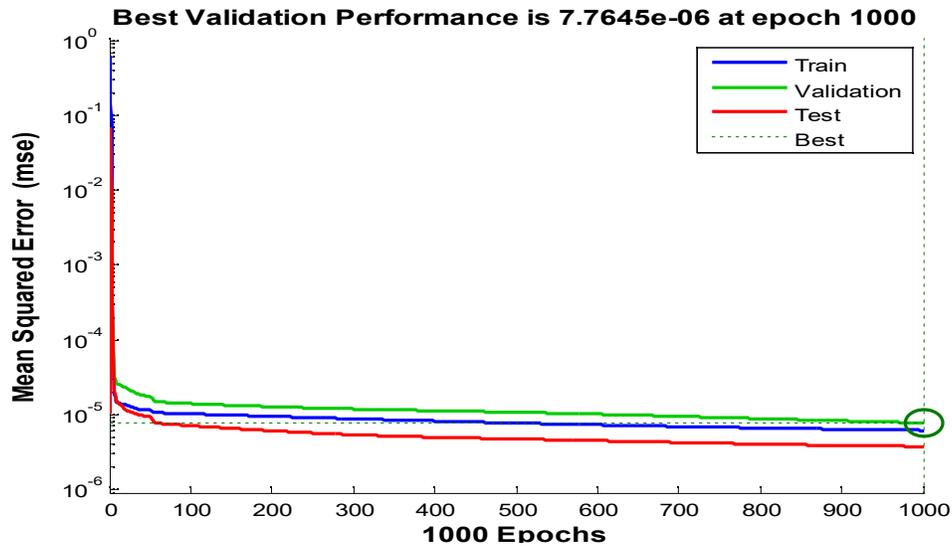


Fig. 3. ANN regression and performance plots.

Predicted values closely followed experimental results, validating the model’s robustness in capturing non-linear relationships. ANN outperformed Scheffe’s

method (average error: 2.3 MPa vs. ANN’s 0.92 MPa RMSE) shown Fig.4, particularly in handling material variability (Tayeh et al. 2020).

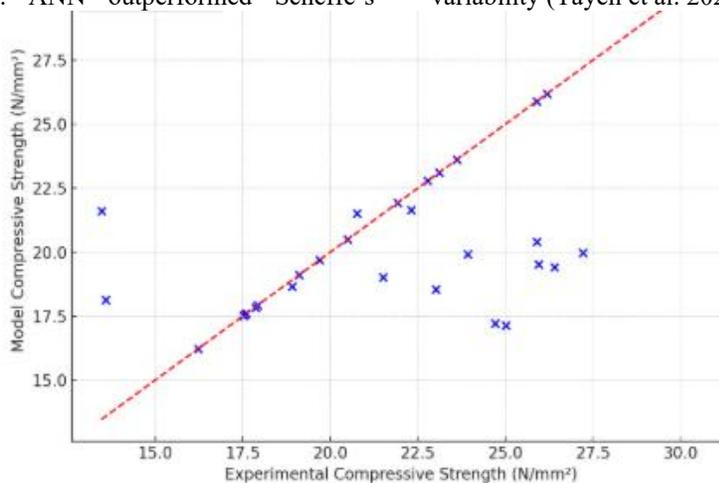


Fig. 4. Scheffe’s model vs. experimental results

The ANN’s low mean-square error and absence of overfitting (up to iteration 1000) confirm its reliability for mix optimization.

Practical Implications:

1. **Sustainable construction:** SSA can replace up to 20% of cement without compromising strength, reducing costs and environmental impact.

2. **Efficient mix design:** ANN models minimize the need for extensive lab trials, offering a rapid decision-making tool for engineers.
3. **Circular economy:** SSA utilization supports waste valorization, aligning with sustainable development goals.

IV. CONCLUSION AND RECOMMENDATIONS

This study evaluated the feasibility of Snail Shell Ash (SSA) as a partial cement replacement in concrete and developed an Artificial Neural Network (ANN) model to predict compressive strength. Key findings align with the experimental and analytical results presented in Section 3:

1. *Material Suitability:*

SSA's pozzolanic properties (high CaO and SiO₂ content) enable effective cement replacement up to **20%**, corroborating the 28-day compressive strength results (Section 3.3), where 10–20% SSA mixes achieved strengths comparable to the control (23.8–25.1 MPa).

2. *Mechanical Performance:*

The observed strength reduction at >20% SSA (Section 3.3) underscores the **dilution effect** of excessive replacement, validating the need for an optimal threshold.

3. *Workability Trade-off:*

The slump test results confirmed reduced workability with SSA addition (65 mm → 35 mm for 0–30% SSA), necessitating admixtures for field applications.

4. *ANN Superiority:*

The ANN model's high accuracy ($R^2 = 0.981$, RMSE = 0.92 MPa) outperformed Scheffe's method, demonstrating its efficacy in capturing non-linear mix-property relationships.

5. *Sustainability Impact:*

SSA utilization aligns with circular economy principles, reducing cement demand and agricultural waste.

Recommendations for Future Work

Building on the limitations and opportunities identified in this study, the following are recommended:

1. *Expand ANN Applications:*

Extend the ANN model to predict other mechanical properties (flexural strength, elastic modulus) and durability metrics (chloride resistance, shrinkage) to holistically assess SSA-concrete performance.

2. *Advanced AI Techniques:*

Investigate hybrid models (e.g., ANN-Genetic Algorithm or ANN-Fuzzy Logic) to enhance predictive accuracy and optimize multi-objective mix designs.

3. *Material Optimization:*

- Explore pre-treatment methods (e.g., calcination temperature variations) to improve SSA reactivity and mitigate workability losses.

4. *Field Validation:*

Conduct large-scale trials to assess the long-term performance of SSA-concrete under real-world conditions, including exposure to aggressive environments.

5. *Economic Analysis:*

Quantify cost savings and carbon footprint reduction from SSA adoption to incentivize industry uptake.

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Author Contributions

Conceptualization – NBU; Supervision – NBU; Experimental Design – WEG; Writing - WEG