



Modeling and Cost Prediction of the structural behavior of Granite-Periwinkle Shell (G-PWS) concrete for sustainable development

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Abstract

The study covered the modeling and cost prediction of the structural behavior of granite-periwinkle shell (G-PWS) concrete using polynomial regression model. A total of 72 concrete cubes of 150mm x 150mm x 150mm were produced manually using a concrete mix of 1:2:4 and 0.6 w/c ratio to determine the compressive strength of concrete at 7, 14 and 28 days. Periwinkle shell (PWS) was used to partially replace granite varying between 0-28percent at 4percent interval. The slump test results showed that the workability of the fresh concrete decreases as the percentage replacement of granite with PWS increased. Polynomial regression models were developed for predicting the compressive strengths of G-PWS concrete for the various curing ages using these polynomial regression equations; $Y7 = 18.9108 - 0.0271x - 0.0049x^2$; $Y14 = 23.6575 - 0.3252x + 0.0020x^2$; $Y28 = 26.9575 - 0.5501x + 0.0066x^2$ The coefficient of determination R^2 at 7days, 14days and 28 days were 0.9172, 0.8805 and 0.9555 respectively indicating the model adequacy and reliability as there was a strong relationship between the experimental results and the model predicted results.. The material cost analysis results at 12 percent replacement of granite with periwinkle shell gave a saving cost of 5.76% per cubic meter of (G-PWS) concrete with compressive strength of 21.31 N/mm² that can be used for C 20 N/mm². The study recommended that the predictive model formulated can be used effectively to minimize environmental impact and overall cost of concrete production in riverine areas and coastal regions of Nigeria.

KEYWORDS: periwinkle shells (PWS), compressive strength, modeling, (G-PWS) concrete, slump

1. INTRODUCTION

The needs for affordable housing pose a serious challenge in Nigeria's coastal regions due to population growth, rapid urbanization, high cost of building materials and high rate of inflation (Mbadike & Osadebe, 2014; Sonege et. al, 2016; Ruslan et al., 2021). These coastal regions and riverine communities especially in Bayelsa state such Nembe Basambiri in Nembe local government area, Okpoma and Tuwo in Brass local government area , Ipoi and Ekewe in southern Iyaw local government area, Kayama in Kolo-kuma Opokuma local government area and Swali in Yenagoa local government area are characterized by unique environmental conditions and limited resources used as coarse aggregates for concrete production. According to Ettu et al (2013), these coarse aggregate materials (granitic chippings) are often sourced from distant quarries outside the coastal regions and hauled at high cost to various construction sites for concrete production in these riverine communities. In order to reduce the high cost of building materials and

environmental impacts to enhance affording housing, the need to utilize locally available material within these areas is essential for sustainable development. Periwinkle shells, abundant along Nigeria's coastal shores, seen as agricultural waste materials offer an innovative solution that researchers can explore to partially replace granite in concrete production (Egamana & Sule, 2016; Omisande & Onugba, 2020; Ugwu & Egwuagu, 2022; Erhiferhi & Budu; 2023). In recent years, several studies have investigated the mechanical properties of concrete incorporating periwinkle shells as partial replacement for granite in concrete production (Akijje et. al, 2022; Usman et al, 2020; Timothy et al, 2016; Sulaiman & Olatunde, 2019; Oluwasola & Olufemi, 2021; Ajayi et. al, 2017). However, cost implications involved in the use of periwinkle shells as partial replacement of granite has not been extensively explored by most researchers. Also, most clients within these riverine area due to high cost of transporting granite materials tend to use the periwinkle shells as alternative replacement without considering the structural behavior of the concrete. This paper aims to develop a predictive model for granite- periwinkle shells (GPWS) concrete that will be sustainable and cost effective for affordable housing tailored to the needs of coastal regions and riverine communities in Nigeria using polynomial regression.

2. MATERIAL AND METHODS

2.1 Materials

The materials used for this work include cement, sand, granite, water and periwinkle shell.

Cement: Superset Ordinary Portland Cement (OPC) that meets the requirements of NIS 444-1: 2018 CEM B-L 42.5R. was used for this work.

Sand: Unwana river sharp sand clean and free from deleterious materials sourced from Afikpo, Ebonyi State was used for the work. See Fig. 1c

Granite: The coarse aggregates used was crushed granite of maximum size 20mm sourced from ConRock, Amasiri, Afikpo, Ebonyi State. See Fig. 1b.

Water: Portable water was used in this work and meets the requirements of NIS 554:2007.

Periwinkle Shell: It was obtained along Nembe Basambiri river bank in Nembe local government area of Bayelsa state and transported to the laboratory, washed to remove impurities and sun dried to remove the water in the sample. See Fig. 1a.



Fig. 1a: Periwinkle shell



Fig. 1b: Granite



Fig. 1c: Sand

2.2 Experimental Method

A total of seventy-two (72) 150mm x 150mm x 150mm concrete cubes were produced manually using a standard mix 1:2:4 and 0.6 w/c ratio with the concrete materials batched by weight to obtain target strength of 25 N/mm². The periwinkle shell was used to partially replace granite at 4 percent interval varying between 0-28 percent. Slump test was conducted on all the samples to determine the workability of the fresh concrete for different percentage replacements. Cube test were conducted at different periwinkle shell replacements for 7, 14 and 28 days respectively to determine the average compressive strength values.



Fig. 2a: mixing of G-PWS concrete



Fig. 2b: casting of concrete cubes

2.2.1 Mathematical Modelling of G-PWS Concrete

A polynomial regression model using two variables namely; compressive strengths as dependent variable and percentage replacement of granite with periwinkle shell as independent variable was adopted for predicting the compressive strength of concrete as expressed in equation 1 :

$$Y = \beta_0 + \beta_1 x + \beta_2 x^2 \quad (1)$$

Where y is the compressive strength in (N/mm²), x is the percentage replacement (%), β_0 , β_1 and β_2 are regression constants.

The stats,blue polynomial regression calculator was used to determine the polynomial constants β_0 , β_1 , β_2 respectively. The Coefficient of Determination R^2 was used to obtain the accuracy and reliability of the developed models. The compressive strengths at various curing ages of 7, 14 and 28 days were predicted using the models developed as shown in equations 2 to 4:

$$Y_7 = 18.9108 - 0.0271x - 0.0049x^2 \quad (2)$$

$$Y_{14} = 23.6575 - 0.3252x + 0.0020x^2 \quad (3)$$

$$Y_{28} = 26.9575 - 0.5501x + 0.0066x^2 \quad (4).$$

3. RESULTS AND DISCUSSION

3.1 Slump Test Result

Table 1: Slump Test Result

Periwinkle Shell (%)	0	4	8	12	16	20	24	28
Slump (mm)	40	33	26	18	11	5	-	-

**Fig. 3: Slump Test**

Table 1 showed the slump test results obtained for the fresh (G-PWS) concrete varying from 0-28 percent periwinkle shell replacement. The result revealed that the workability of the G-PWS concrete decreased as the percentage of PWS used as partial replacement of granite increased indicating low workability as the PWS tends to absorb the water.

3.2 Compressive Strength Results

The experimental and model results of the compressive strength of concrete with partial replacement of granite with PWS varying between 0-28% and its correlation were presented in Table 2 and Fig.s 5-10. The concrete compressive strength model results were gotten from equations 3-6 by using percentage content of PS as coarse aggregate and the concrete strength. The accuracy and reliability of the model formulated were obtained using the coefficient of determination R² values for 7days, 14days and 28days curing age. The R² values ranging between 0.8805 - 0.9555 indicated that there was a strong relationship between the laboratory results and the model predicted results. These results were similar to the R² values obtained in the done by Ugwu & Egwuagu (2022).

**Fig. 4a: crushing of concrete cube****Fig. 4b: Crushed cubes samples**

Table 2: compressive strength results for experimental and model tests

Periwinkle Shell % Replacement	Compressive Strength Results (N/mm ²)					
	7 days		14 days		28 days	
	lab	model	lab	model	lab	model
0	19.41	18.91	24.37	23.68	27.19	26.96
4	18.22	18.72	22.15	22.38	25.04	24.86
8	18.17	18.38	20.38	21.18	22.78	22.98
12	17.48	17.88	19.33	20.04	20.35	21.31
16	17.41	17.22	18.96	18.97	19.68	19.85
20	17.33	16.41	18.81	17.95	19.24	18.6
24	15.11	15.44	18.52	17	18.85	17.56
28	14.07	14.31	14.72	16.12	15.67	16.73

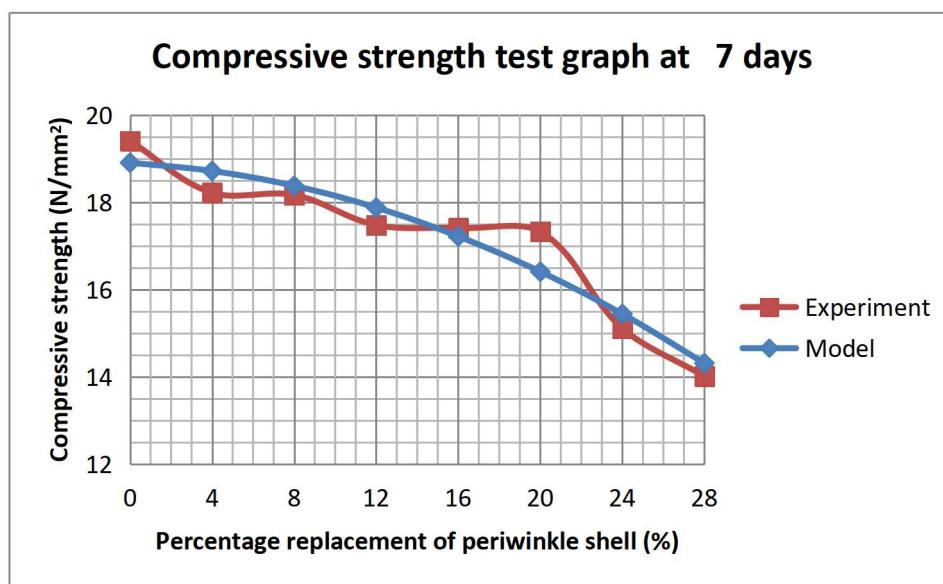


Fig. 5: 7 days compressive strength result for experimental and model tests

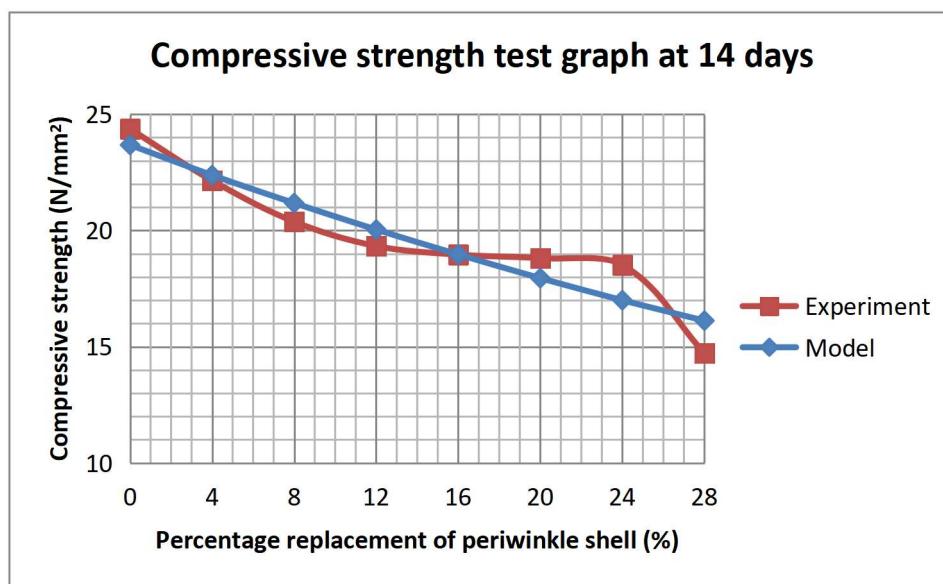


Fig. 6: 14 days compressive strength result for experimental and model tests

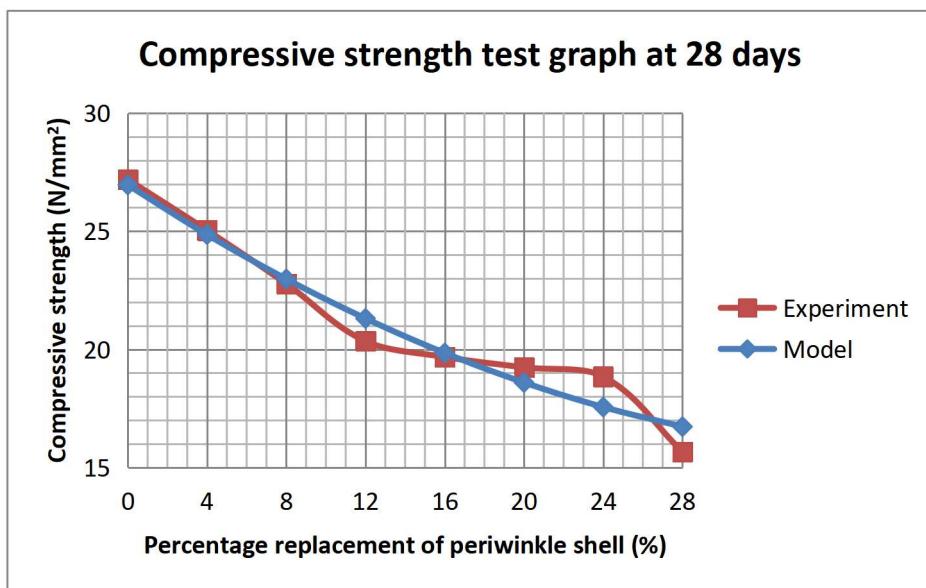
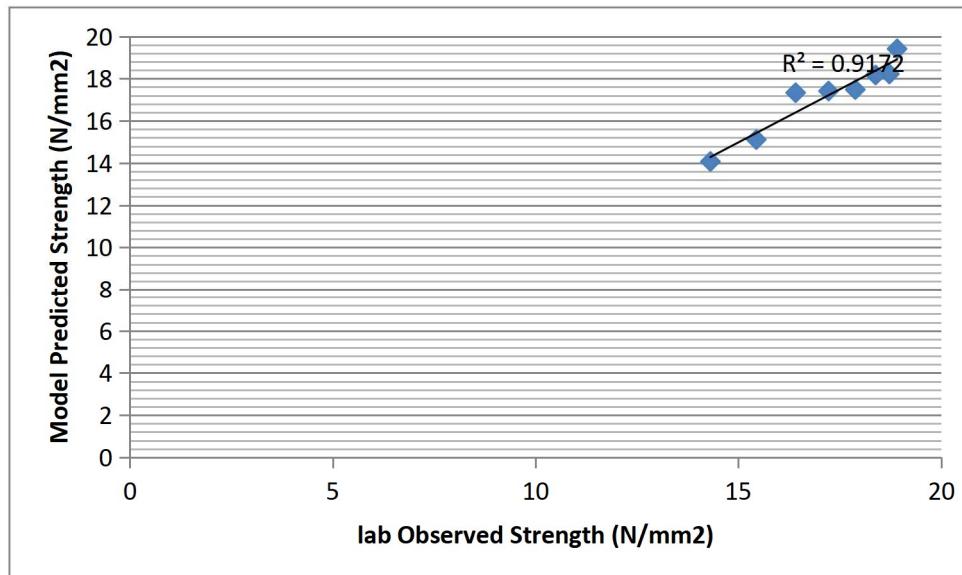
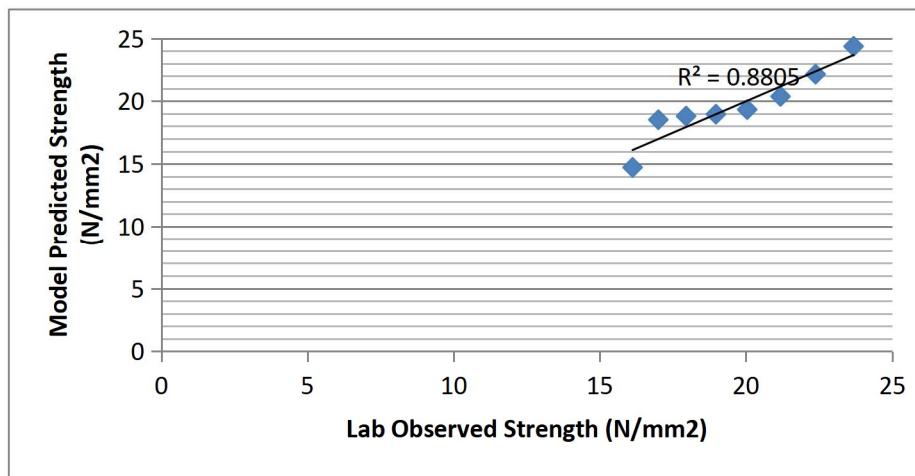
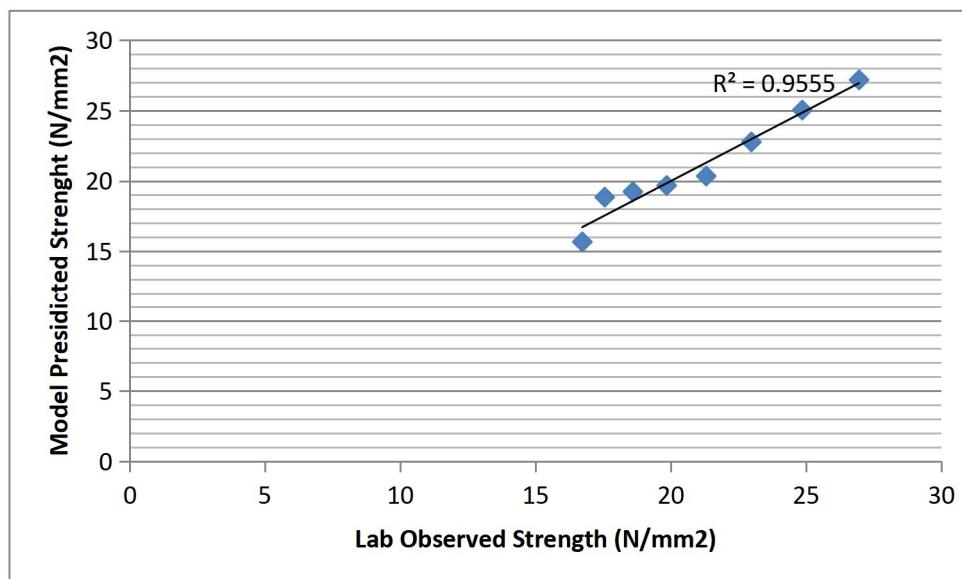


Fig. 7: 28 days compressive strength result for experimental and model tests

Fig. 8: Coefficient of determination R^2 at 7 days compressive strengthFig. 9: Coefficient of determination R^2 at 14 days compressive strength

Fig. 10: Coefficient of determination R^2 at 28 days compressive strength

3.3 Cost Analysis

Tables 3-4 present the cost analysis of 1:2:4 concrete mix and 0.6 w/c ratio using 12 percent periwinkle shell replacement of granite for 1m³ concrete based on the model results were compared with the control sample (0% PWS replacement) to determine the saving material cost of G-PWS concrete.

3.4 Material estimates for 1m³ concrete assuming a void ratio of 40%

Cement: 1/7 x 1.4 = 0.2m³

Mass of cement: 0.2m³ x 1442 kg/m³ = 288.4kg

But 1 bag of cement =50kg

Mass of cement= 288.4kg/50kg =5.768; approximately 6 bags

Sand: 2/7 x 1.4 = 0.4m³

Granite: 4/7 x 1.4 = 0.8m³

12% of 0.8m³ granite replaced by periwinkle shell:

Periwinkle shell: 0.12 x 0.8 = 0.096 m³

Granite; 0.8 – 0.096 = 0.704 m³

Water: 0.6 x 288.4 kg = 173kg =173 litres

Material costs for 1m³ in Nembe Basambiri, Nembe local government area of Bayelsa state

One bag of cement ₦10000

One tipper of sand (3.82 m³) ₦80000

One tipper of granite (3.82 m³) ₦420000

One tipper of periwinkle shell ₦60000

Table 3: Material cost for 0% periwinkle shell replacement for 1m³ concrete

Material	Quantity	Unit cost	Total cost
Cement	6 bags	₦10000/bag	₦60000
Sand	0.4 m ³	₦20942.41/m ³	₦8376.96
Granite	0.8 m ³	₦109947.64/m ³	₦87958.11
Periwinkle shell	0 m ³	₦0/m ³	₦0
water	173 litres	₦5/litre	₦865
Grand Total			₦157200.07

Table 4: Material cost for 12% periwinkle shell replacement for 1m³ concrete

Material	Quantity	Unit cost	Total cost
Cement	6 bags	₦10000/bag	₦60000
Sand	0.4 m ³	₦20942.41/m ³	₦8376.96
Granite	0.704 m ³	₦109947.64/m ³	₦77403.14
Periwinkle shell	0.096 m ³	₦15706.81/m ³	₦1507.85
water	173 litres	₦5/litre	₦865
Grand Total			₦148152.95



$$\text{Saving cost} = \frac{(157200.07 - 148152.95)}{157200.07} \times 100\% = 5.76\%$$

The 5.76% indicated that an average saving cost of ₦9054.72 per cubic meter of concrete for 12 percent partial replacement of granite with periwinkle shell.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The following conclusions were made for this study;

- i. The study revealed that the polynomial regression equation $Y_{28} = 26.9575 - 0.5501x + 0.0066x^2$ gave an optimum compressive strength of 21.31 N/mm² for a 1:2:4 concrete mix and 0.6 w/c ratio using 12 percent periwinkle shell as partial replacement of granite.
- ii. There was a strong relationship between the laboratory results and model predicted results as the coefficient of determination R^2 at 28 days equals to 0.9555 indicating the accuracy and reliability of the model.
- iii. The paper showed that the material saving cost at 12 percent partial replacement of granite with periwinkle shell was 5.76 percent, approximately ₦9052.72 per meter cube of concrete.

4.2 Recommendation

The following recommendations were made based on the outcome of the study.

- i. The polynomial regression model formulated can be used to produce grade C 20 concrete adequate for reinforced concrete works using 12 percent replacement of granite with periwinkle shell,
- ii. Effective utilization of GPWS concrete can be used to minimize environmental impacts by recycling PWS as coarse material as well as reducing the overall cost of concrete production.

Conflicts of Interest

The authors declare that they have no conflicts of interest

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