



Evaluation of Mechanical Properties of High-Strength Reinforced Concrete (HSRC) Beam Containing Periwinkle Shell Ash (PSA)

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KEY WORDS

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ABSTRACT

This study evaluated the effects of Periwinkle shell ash (PSA) on high strength reinforced concrete (HSRC) beam. The periwinkle shells were obtained as an agricultural waste then ground into fine powder and charred at a control temperature (500°C). Laboratory/experimental investigations were also carried out on the PSA and its effect on high strength concrete (HSC) within 0% to 15% (at interval of 5%) replacements with cement were recorded using 64 cubes and 16 beams samples. Engineering properties such as compressive strength, water absorption test, slump test, flexural test were studied on concrete with PSA replacement from 0% to 15%. The results indicate 2.49 as specific gravity of PSA with major chemical properties constituent (SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, K₂O, Na₂O, P₂O₅, TiO₂ & LOI) responsible for pozzolanic reaction during hydration. The results of compressive strength of concrete from 0% to 5% PSA replacement revealed values of a high strength concrete (51.22N/mm²- 40.11N/mm²) while 10% to 15% PSA replacement indicated conventional concrete strength (35.78N/mm²- 34.89N/mm²). Slump test indicated that concrete slump decreased with increase in PSA percentage while rate of concrete water absorption increased as percentage of PSA increase. The flexural test revealed that as the percentage replacement of PSA increases the applied load (151,75kN, 137kN, 122kN and 99.75kN) decreases and the reduction in the percentage of applied load ranges from 9.72% to 34.27%. Based on the results obtained from compressive and flexural strength tests, 5% PSA replacement with cement should only be considered in the production of high strength concrete while 10% to 15% PSA replacement can only produce conventional concrete. Government should provide proper legislative framework for usage of PSA as alternative material in the production of concrete for construction industry.

1. INTRODUCTION

High strength concrete (HSC) has researched in various studies shows that HSC should be considered in the design of various Structural element/members due to its performance in terms of resistance to various degrees of environmental condition and high load impact load. These distinctive properties enable its use in diverse construction project applications such as concrete bridges, dams etc (Biolzi *et al.*, 1997; Kou and Poon, 2015; Lim and

Ozbakkaloglu, 2014; Majed *et al.*, 2023; Song and Hwang, 2004; Vincent and Ozbakkaloglu, 2015).

Periwinkle Shell Ash is obtained by burning periwinkle shell which is the by-product of Periwinkle. According to (Dahunsi and Bamisaiye, 2002) Periwinkle is a seashell a marine mollusc (gastropods) which growth follows a mathematically regular pattern and still retains its original form at full growth. They are common in North America and European shores and are widely distributed in their littoral drifts and sand banks. The major species available in the lagoon and mudflats of Nigeria's Niger Delta, between Calabar in the east and Badagry in the west are *Tympanostomus* species and *Pachmellania* species.

According to (Prashant and Mysore, 2020) concrete technology had changed rapidly since its discovery and usage in infrastructural projects. High strength concrete is made by carefully selecting the high-quality materials and mixture design.

According to (ACI, 1984) the definition of high strength concrete varies with time and region depending on the developments in the construction industry. ACI report 363R-84 treated concretes having strengths in excess of grade 40N/mm² as HSC.

(Jayanandana *et al.*, 1997) studies show that, cement and aggregates can adequately produce concrete with compressive strength within grade 40 - 70N/mm² with careful selection of mix proportion and use of water reducing admixtures. Water cement ratio is a great determinant to achieve high strength concrete; the studies also note that super plasticizer is necessary not only to achieve the workability but also to obtain the maximum strength by proper compaction.

(Wei Wang *et al.*, 2024) studies give further details on High Strength concrete (HSC) as a kind of specially prepared concrete, with superior performance which is mainly stems from its unique composition and fine preparation process.

(Akaninyene and Kolapo, 2020) worked on the possibility of processing and utilization of the periwinkle shell ash in order to assess its compressive strength, durability and elasticity performance when used as supplementary cementitious material in concrete production. The chemical and physical properties of PSA was also obtained by firing washed periwinkle shell in a gas furnace to temperature range of 600 °C - 800 °C, then ground and sieved with sieve size of 45µm.

2. MATERIALS AND METHODS

2.1 Materials and Equipment

In order to accomplish this research's objectives, materials such as Cement (ordinary portland cement), Coarse and Fine aggregate, Periwinkle shell and Reinforcement were carefully sourced. Minitab computer based software was used for all the laboratory results analysis.

2.1.1 Cement

Ordinary portland cement (OPC) from Lafarge (Elephant Supaset brand), was used in preparing the concrete cubes and beams for this study. The specific gravity of the cement is 3.10 with 7.5% standard consistency.

2.1.2 Aggregate

12mm. sized coarse aggregate with fine aggregate was used to prepare the concrete cubes and beams. The value of specific gravity of the fine and coarse aggregate are 2.43 and 2.76 respectively

2.1.3 Reinforcement

The 12mm. diameter bars were used as longitudinal reinforcement, while the 10mm. diameter bars were used as transverse reinforcement with the characteristic strength in the range of 507.72 – 572.65N/mm².

2.1.4 Periwinkle shell ash (PSA)

The periwinkle shell was washed thoroughly, sun dry and grind into fine powder at Oyingbo market to increase the contact surface area thereafter taken to Central Laboratory at Yaba College of Technology, for charring at a control temperature (500°C) using Muffle Furnace SX -4 - 10 and reading taken at a regular interval of 15minutes. After which the burnt ash was sieved through a 75µm sieve to get smoothness comparable to that of regular Portland cement. The obtained results are tabulated in Table 3, 4 & 5. Plate 1, 2 & 3 below shows the pictorial view from grinding of Periwinkle Shell to burning in a Furnace.



Plate 1. Periwinkle Shell



Plate 2. Grinding of Periwinkle Shell



Plate 3. Charring of Periwinkle

2.2 Experimental Procedure

Yaba College of Technology, Civil Engineering Department concrete laboratory was used for the experiment conducted on the materials including the crushing of the concrete cubes and flexural test.

2.2.1 Concrete Design Mix

Selection of mix proportions for High Strength Concrete (HSC) is generally carried out using empirical procedures based on trial mix, as universally accepted mix design methods are not available for HSC therefore, for the purpose of this research mixing ratio and water-cement ratio of $2 : \frac{1}{2} : 1$ and $\frac{0.625}{2} = 0.313$ was adopted. The Plate 4 & 5 shows the preparation and casting of the concrete cubes while Table 1 shows concrete samples mix ratio.

Table 1: Concrete Samples Mix Ratio

Materials	Cement	Periwinkle shell ash	Sand	Granite	Water/Cement ratio	
Sample A: Batching analysis (0% replacement of PSA)						
Weight (kg)	2	0	0.5	1	$\frac{0.625}{2} = 0.313$	
Sample B: Batching analysis (5% replacement of PSA)						
Weight (kg)	1.9	0.1	0.5	1		
Sample C: Batching analysis (10% replacement of PSA)						
Weight (kg)	1.8	0.2	0.5	1		
Sample D: Batching analysis (15% replacement of PSA)						
Weight (kg)	1.7	0.3	0.5	1		



Plate 4: Concrete Cubes Formwork



Plate 5: Weighing of Concrete Materials

2.2.2 Compressive Strength Test

The compressive strength test of the hardened concrete was determined after the required curing days of 7, 14, 21 and 35 days without replacement and with periwinkle shell ash replacement at 5%, 10% and 15% using the compressive testing machine (Budenberg) at the concrete laboratory of Yaba College of Technology in accordance with BS 1881: Part 116 (1983). Total numbers of cubes cast were 64 samples. Plate 6 & 7 shows the concrete cubes crushing at the laboratory while the compressive test results are tabulated in Table 6.



Plate 6: Concrete Crushing



Plate 7: Concrete Crushing

2.2.3 Water Absorption Test

This was determined according to BS 1881: Part 122: 1983. Cube specimens were taken from that cast sample and weighed to the nearest 0.001g. The samples were immersed in water for 24 hours at room temperature. Excess water on sample surface was removed before re-weighing. The percentage increase in mass during immersion was calculated to the nearest 0.01% using the following equation: $\text{Water Absorption} = \frac{\text{Weight after 24 hrs} - \text{initial weight}}{\text{initial weight}} \times \frac{100}{1}$. The results of the absorption test are tabulated in Table 8.

2.2.4 Slump Test

In accordance with BS EN 12350-2:2019, the consistency and workability of the freshly made concrete was measured before the concrete harden. Periwinkle shell ash replacement with cement was also considered to determine the effect of the replacement on the workability of concrete and the results are tabulated Table 9.

2.2.5 Flexural Strength Test

In this study, 16 samples of R.C. Beam (1000 x 250 x 150mm.) were cast to determine flexural strength of High Strength Reinforced Beam (HSRB) with and without PSA. Nominal reinforcement was used as detailed in Figure 1 shown below and placed inside prepared formwork, thereafter the beams were cast and test at 35 days. The HSRB were

divided into four groups (A, B, C and D) according to the percentage of cement replacement (0% replacement, 5% replacement, 10% replacement and 15% replacement with periwinkle shell ash). Emulsion paint was also applied on each of the beam to enhance crack visibility during the test procedure. In Plate 8 & 9 below the laboratory procedure and cracks on the beam sample are shown while flexural test results are tabulated Table 10.

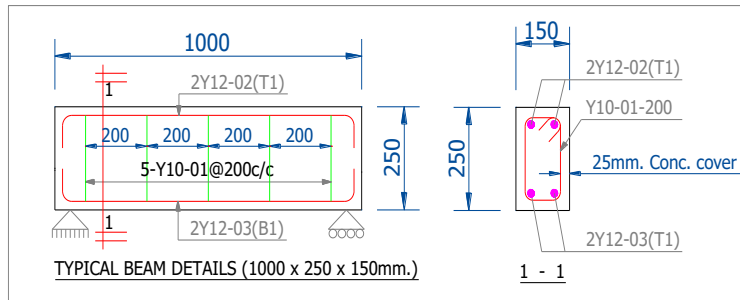


Figure 1: Typical HSRB Details



Plate 8: Flexural Test Set-up **Plate 9:** Cracks on High Strength Reinforced Concrete Beam Sample

3. RESULTS AND DISCUSSION

3.1 Periwinkle Shell Ash

From the laboratory results presented in Table 2 and the plotted graph in Figure 2 below, it indicate that change in temperature in the furnace is directly proportional to time require for the ground periwinkle shell to char into ash.

Table 2: Charring of Periwinkle Shell Ash

S/N	1	2	3	4	5	6	7	8	9	10
Time (seconds)	0.0	300	600	900	1200	1500	1800	2100	2400	2700
Temperature(⁰ C)	0.0	48	101	153	205	260	310	360	409	459

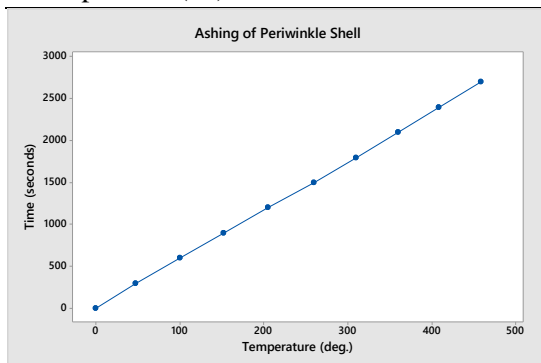


Figure 2: PSA Charring

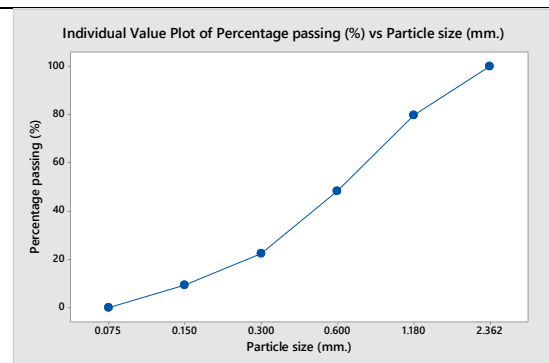


Figure 3: Particle Size Distribution for PSA

3.2 Sieve Analysis of Periwinkle Shell Ash

The sieve analysis result for periwinkle shell ash presented in Table 3 below, with the graphical representation shown above in Figure 3 indicate that 90.16% are above 75micron while 9.16% of the particles fall below 75micron.

Table 3: Sieve Analysis for Periwinkle Shell Ash the Initial Weights of Fine PSA was 500g.

Sieve size	Mass retained (g)	Total percentage mass retained (%)	Total mass passing (g)	Total percentage passing (%)
2.362mm			500.00	100.00
1.18mm	100.6	20.12	399.4	79.88
600 micron	156.8	31.36	242.6	48.52
300 micron	130.2	26.04	112.4	22.48
150 micron	65.6	13.12	46.8	9.36
75 micron	45.8	9.16	1.00	0.20

3.3 Specific Gravity of Periwinkle Shell Ash

From the laboratory test result (Le Chatelier flask method) as shown in Table 4 below, the specific gravity of periwinkle shell ash is 2.49 which signify that PSA is lighter in weight when compared to cement and this finding also fall in the same range with earlier study carried out by (Attah *et al.*, 2018) with 2.56 as the specific gravity of PSA.

Table 4: Specific Gravity Results of Periwinkle Shell Ash

Description	Sample A (g)	Sample B (g)	Specific gravity = $\frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$
Weight of glass jar (W_1)	13.5	13.5	
Weight of glass jar + sample (W_2)	25.2	24.4	
Weight of glass jar + sample + kerosene (W_3)	40.8	40.5	$\frac{2.44 + 2.53}{2} = 2.49$
Weight of glass jar + kerosene (W_4)	33.9	33.9	
Result	2.44	2.53	

3.4 Chemical Properties of Periwinkle Shell Ash

The laboratory analysis conducted on periwinkle shell ash implies that major chemical constituent (SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , MgO , K_2O , Na_2O , P_2O_5 , TiO_2 & LOI) of Ordinary Portland Cement are also present in PSA though the ratio/percentage of the chemical components varies. From tabulated Table 5 below, the value of CaO (35.62) fall within the require range that is needed for a proper hydration reaction to take place. The presence of SiO_2 (36.39) and Al_2O_3 (14.57) create chemical reaction (pozzolanic reaction) responsible for portlandite formed during cement hydration in the presence of water. Moreover according to (Ruslan *et al.*, 2021) for a material to be described as pozzolan material it must contain at least 25% silica oxide which is an attribute of cementitious composition and the variation in the chemical composition of periwinkle shell ash is influenced by calcination temperature and grinding technique.

Table 5: Chemical Properties of Periwinkle Shell aAsh

Elemental oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	TiO_2	LOI
%	36.39	14.57	6.18	35.62	0.48	0.24	0.35	0.58	0.36	7.60

3.5 Compressive Strength Test

In accordance with BS 1881: Part 116 (1983) and for the purpose of this study 64 samples of concrete cubes were cast and the results tabulated in Table 6 below shows the mean

compressive strength of concrete with various percentage of periwinkle shell ash replacement (0%, 5%, 10% & 15%) at different curing ages (7days, 14days, 21days & 35days). It was observed that as the percentage replacement of periwinkle shell ash increase the compressive strength of concrete decrease. The concrete gain significant strength as the curing ages of the concrete increase while PSA replacement with cement lead to decrease in the compressive strength of the concrete, the Table 7 above shows percentage reduction in concrete strength as the periwinkle shell ash percentage replacement increases. When compared with the previous studies the strength relationship between cement and PSA as shown in Table 6 and Figure 4 below also indicate similar trend in (Attah *et al.*, 2018) research works.

Table 6: Compressive Test Result

% Replacement	Strength @ 7days (N/mm ²)	Strength @ 14days (N/mm ²)	Strength @ 21days (N/mm ²)	Strength @ 35days (N/mm ²)
0	36.05	41.22	47.89	51.22
5	24.89	30.23	36.45	40.11
10	22.89	27.42	31.11	35.78
15	19.0	25.78	30.89	34.89

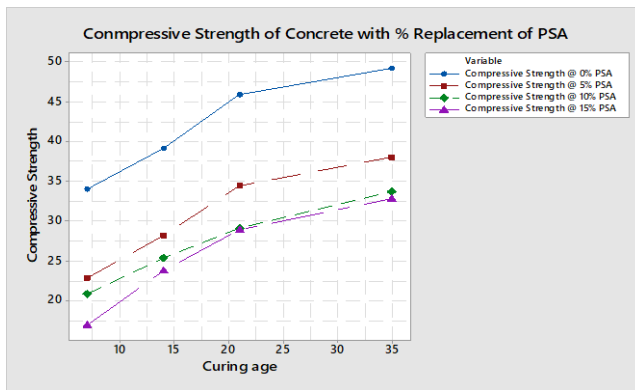


Figure 4: Compressive Strength of Concrete with % Replacement of PSA

Table 7: Compressive Strength Reduction Analysis with PSA Replacement.

% Replacement	Compressive strength at different curing age & % Strength reduction							
	Strength @ 7days (N/mm ²)	% Strength reduction	Strength @ 14days (N/mm ²)	% Strength reduction	Strength @ 21days (N/mm ²)	% Strength reduction	Strength @ 35days (N/mm ²)	% Strength reduction
0	36.05		41.22		47.89		51.22	
5	24.89	33.65	30.23	28.02	36.45	24.93	40.11	21.69
10	22.89	38.65	27.42	35.19	31.11	36.57	35.78	30.14
15	19.0	50.07	25.78	39.37	30.89	37.05	34.89	31.88

3.6 Water Absorption Results

From the results tabulated below in Table 8, it shows that increase in percentage replacement of PSA with cement also lead to increase in the rate of water absorption of the concrete cubes sample due to particles shape affecting the concrete matrix with a reduced pore structure, increase permeability require more water to achieve complete hydration.

Table 8: Water Absorption Results

Percentage replacement for periwinkle shell ash (%)	Dry weight (g)	Weight of specimen after immersion in water (g)	Percentage of water absorption (%)	Absorption ratio
0	7000	7190	2.71	1.03
5	7100	7460	5.07	1.05
10	7150	7650	6.99	1.07
15	7100	7660	7.89	1.08

3.7 Slump Test

In respect to previous literature and studies by (Olusola & Umoh, 2012) the effect of PSA on the workability of concrete as presented in Table 9 below shows similar trend which implies that concrete slump decrease with percentage increase of periwinkle shell ash. The implication is that more water will be required to maintain the same consistency as periwinkle shell ash content increases due to its fineness, particles shape and high surface area.

Table 9: Slump Test Results

Percentage replacement for periwinkle shell ash (%)	Cone Height (mm)	Measured Height (mm)	Slump (mm)	Slump percentage (%)
0	300	263	37	14.07
5	300	267	35	13.11
10	300	267	33	12.36
15	300	271	29	10.70

3.8 Flexural Strength Test

From the results tabulated in Table 10 and plotted graph in Figure 5 below, it shows that as the percentage replacement of periwinkle shell ash increased the applied load (failure load) decreased. At 5% replacement of PSA the applied load reduced by 9.72%, at 10% replacement of PSA the applied load reduced by 19.60% and at 15% replacement of PSA the applied load reduced by 34.27%.

At 5% replacement of PSA, concrete and flexural strength reduction are 21.69% & 9.72%, at 10% replacement of PSA, reduction in strength are 30.14% & 19.60% and at 15% replacement of PSA, reduction in strength are 31.88% & 34.27%. The difference between percentage reduction of compressive and flexural strength implies that introduction of steel (reinforcement) increases the resistance and behaviour of concrete under applied load, as it act as ties, which caused an increase in the compressive strength and the ability of the material to withstand bending. The obtained results when compared with similar previous studies by (Majed *et al.*, 2023) indicate that steel increase the bending strength and shear strength of concrete. The chemical adhesion, friction and mechanical interlocking between the reinforcement and the concrete matrix increase the concrete strength while increase PSA replacement affects the bonding mechanism due to late hydration process which reduces the concrete strength.

Table 10: Flexural Test Result

% Replacement of PSA	Average Ultimate Load (kN)	Flexural Strength $f_{st} = \frac{3fL}{2bd^2}$ (N/mm ²)
0	151.75	24.28
5	137.00	21.92
10	122.00	19.52
15	99.75	15.96

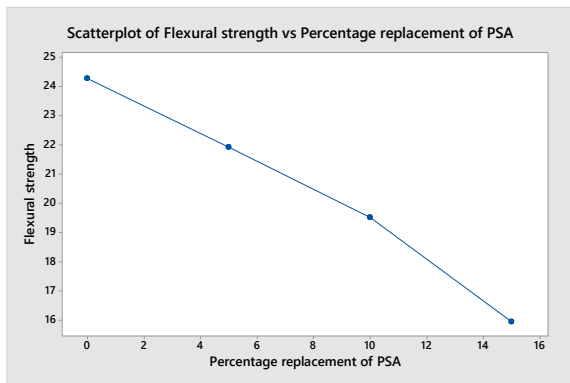


Figure 5: Flexural Strength of Concrete with % Replacement of PSA

4. CONCLUSION

The following conclusions are drawn from this study

1. 2.49 was obtained as the specific gravity of periwinkle shell ash which indicates that PSA is lighter in weight than cement. The chemical composition of PSA comprises of some major chemical constituent CaO (35.62%), SiO₂ (36.39%) and Al₂O₃ (14.57%) that are also present in cement though the ratio/percentage varies when compared together but still falls within acceptable range require for pozzolanic reactions during hydration.
2. Slump test shows that concrete slump decrease with percentage increase of periwinkle shell ash which implies that more water will be required to maintain the same level of workability with concrete without PSA due to its fineness, particles shape and high surface area of PSA.
3. The compressive strength also decrease with increase in the percentage of PSA but increase in strength was noticed as the curing age of the concrete increased nevertheless at 35days 5% replacement of PSA reduced in strength by 21.79% while at 10% and 15% replacement the compressive strength reduced by 30.14% and 31.88% respectively.
4. Bending/tensional strength of the beam reduces as the periwinkle shell ash percentage increases and regardless of the reinforcement the concrete beam shows 9.72% reduction in load resistance strength at 5% replacement of PSA with cement while at 10% and 15% replacement the tensional strength reduced by 19.60% and 34.27% respectively.
5. Based on the results obtained from compressive and flexural strength tests, 5% PSA replacement with cement should only be considered in the production of high strength concrete while 10% to 15% PSA replacement can only produce convectional concrete grade.

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