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Analysis of the Impact of Superplasticizer on the Compressive Strength of Periwinkle Shell Concrete

Adeleke A. O[1]., Alake .O[1], Ekundayo O.O[1], Ojo B.S[1], Farayibi .O.O [2].
[1]*Department of Building, Federal University of Technology, Akure, Ondo State, Nigeria.*
[2]*Department of Building, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria.*

---***ABSTRACT***---

This research project investigates the compressive strength characteristics of superplasticized concrete incorporating periwinkle shell (PS) as partial replacements for granite coarse aggregate. The study aims to assess the influence of superplasticizer content and curing age on the compressive strength development of the novel concrete mixtures. Comparative analysis with plain concrete (control specimen) reveals that superplasticized concrete with periwinkle shell partial replacement exhibits a slower strength development.

Results indicate that the compressive strength of superplasticized PS concrete attains its maximum strength (22.07 kN/mm²) at 21 days with a 15% partial replacement and
0.5% superplasticizer content. The findings suggest that optimal strength development for PS partial replacement performs best at higher percentages (15%).

Concerning the workability of fresh concrete, PS partial replacement exhibits a consistent increase in slump values with higher percentages of replacement and superplasticizer content, peaking at 55mm at 15% partial replacement and 1.5% superplasticizer content.

This study contributes valuable insights into the optimization of compressive strength and workability of superplasticized concrete with PS partial replacements, offering a sustainable and resource-efficient alternative to conventional concrete mixtures.

Keywords: ***Superplasticizer, Periwinkle shell, Concrete, Compressive Strength, Fresh properties.***

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I. INTRODUCTION

The need for housing in Nigeria keeps increasing as a resultant effect of the country's rapid population growth, [18]. According to Statista, Nigeria's population as of 2023 was estimated to be around 227 million. This has also been projected to rise to 400 million by 2050 according to the United Nation estimates. Housing is one of the basic needs of human and this comes at a high price beyond the affordability of the common citizen. Housing cost has over the years remain a matter of urgent attention in scaling down its cost while looking for innovative ways to utilize the existing wastes and other local materials.

In the provision of housing and physical infrastructure in Nigeria and worldwide, concrete has been the most important and widely used construction material. Concrete may be defined as a building material obtained by mixing cement, aggregate, water, and chemical admixtures in suitable proportions and then cured to a hard mass [12]. The aggregates bind with the cement and harden to form a stone-like material. [14] (2014) describes concrete as composite material consisting of cement (binding agent); aggregates (fine and coarse) which are relatively inert in nature; water (matrix mix) and sometimes admixture to regulate the properties of concrete. Concrete as a composite material is produced on demand and once formed, the component parts cannot be retrieved easily. The major constituents of concrete are produced industrially and are therefore energy intensive. Portland cement despite being manufactured from a very extensive thermal process accounts for about the least volume and mass in concrete mix. Coarse aggregate usually has the largest chunk of the concrete mass and volume, [10].

Traditionally, granite is used as coarse aggregate in the production of concrete. According to [10] (2010), the volume of concrete is made up of about 70% - 80% coarse aggregate which means that granite is very important in determining the weight and volumetric composition of concrete. The increasing need for concrete materials triggers the mining of stone, one of the constituent materials of concrete as coarse aggregate, on a large scale which causes a decrease in the number of natural resources available for concrete production. Granite, the traditional coarse aggregates, is extracted from natural stone which is blasted, crushed and graded to size for use. This process of granite production involves large amounts of energy and heavy machinery and thus constitutes a great threat and damage to the environment. An example of the environmental damage due to the use of natural resources is the destruction of rock hills.

With the growing environmental concern and the need for eco-friendly building materials in line with the sustainability and climate action goal of the United Nations towards the achievement of a sustainable building and reducing the carbon dioxide emissions, there is therefore the need to consider the use of renewable alternatives in place of the traditional aggregate component of concrete.

There are many types of concrete prepared by rationing the proportions of the main ingredients, the proportions materials used or by replacing the cement material with other binding agents. The finished product can be tailored to its application with varying strength, density, or chemical and thermal resistance properties. The mix design depends on the type of structure being built, how the concrete will be prepared and delivered, and how it will be placed to form this structure. [15] (2011), opined that inclusion of waste elements to concrete will not only enhance its sustainability but also help to minimize the rate of consumption of the non-renewable natural resources in the environment thus enabling the production of environmentally friendly concrete. Therefore, the use of renewable alternatives in form of suitable agricultural and seafood processing wastes such as palm kernel shell, periwinkle shell, rice husk, saw dust etc. as coarse aggregates, used wholly or partially, will go a long way in recycling materials that would have otherwise been wasted and constitutes environmental damage and pollution to the detriment of the safety and health of the teaming populace.

Research on the use of varying shells is ongoing to get a better composition of the ingredients in the production of quality and improved concrete. According to [17] (2021), one of the ways to use shells is to substitute them as replacement, wholly or partially, for coarse aggregate in the production of concrete. The study further stated that shells of agricultural by-products or seafood processing wastes can be used as a substitute for coarse aggregate in the production of environmentally friendly concrete. Environmentally friendly concrete is the concrete produced with environmentally friendly materials such as periwinkle shells (PS). According to [1] (2009), periwinkle shells are found majorly at riverine areas and in an uncontrolled disposal which do constitutes nuisance to the health condition of the immediate environment.

[7] (2018), reported that periwinkle shells (PS) are waste products obtained from periwinkles that are small greenish-blue marine snails with spiral conical shell and round aperture. The study further reported that these shell wastes do contribute environmental nuisance in terms of unpleasant odour and appearance in open-dump site mostly in the Niger Delta of Nigeria. It also stated that the periwinkle shells (PS) are now being considered as coarse aggregate in the production of lightweight concrete be it partially or wholly for building structures. [8] (2013), asserted that periwinkle shells were used wholly and partially as replacement of gravel in concrete production for the purposes of waste reduction and decrease in the use of coarse aggregate

[16] (2022), describes superplasticizer (SP) as an admixture for concrete that is added to reduce the water content in a mixture or to slow the setting rate of concrete while retaining the flowing properties of a concrete mixture. Its use will have positive effects on the properties of concrete both in the fresh and hardened states. It is also used to retard the setting of fresh mix concrete by slowing down early-age hydration reaction. [11] (2009) reported that superplasticizers are high range water reducers which can produce high-strength concrete with low permeability. They further stated that a cement factory in Sindh has recently launched Superplasticized Cement (SPC) that contains the required amount of superplasticizers. They submitted that the results of the SPC have indicated that structural concrete produced with SPC gives higher compressive strength than that of the ordinary Portland cement (OPC) at all the curing ages, also enabling 10% saving in cement content consumption. They further claimed that structural concrete made with superplasticized cement could attain higher strength within a shorter period, with corresponding increase in the workability. According to [2] (2022), the use of superplasticizer could be of merit in concrete production where workability, ease of compaction and high-quality strength is required when hardened.

Several works ([2], [17], [1], [8] and so on) have reported upon their experimental studies on the use of periwinkle shells as substitute to coarse aggregate and superplasticizer in the production of hybrid concrete. However, many are still being conducted to determine the percentage of shells as well as the addition of appropriate superplasticizer additives in the making of high-performance concrete. This study therefore aimed at determining the possible suitable amounts of both periwinkle shells (PS) and superplasticizer (SP) that could give highest value of compressive strength regarding certain mixtures in concrete production. The research will also be aiming at recommending environmentally friendly and locally available materials as substitute to coarse aggregates in the production of low-cost light weight concrete for use in building and construction works. The research will be limited to assessing the compressive strength characteristics of superplasticized concrete with PS as partial replacement for coarse aggregate.

2.1 Materials and Methods
2.2 Materials
2.2.1 Cement
The cement used for the experiment was Ordinary Portland Cement (OPC) of grade 42.5 which was sourced from Akure metropolis, Ondo State, Nigeria.

2.2.2 Aggregates
The aggregates used for the experimentation were purchased and sourced from Akure, Ondo State. The aggregates include fine aggregate and coarse aggregate.

2.2.3 Fine Aggregate
The fine aggregate used for the experiment was sharp sand obtained from a local river shore. The particle size distribution of the sharp sand used was determined later in the course of the study.

2.2.4 Coarse Aggregate
The coarse aggregate used was gravel from granite rock. The particle size distribution was determined later in the course of the study.

2.2.5 Substitute aggregates
The materials used as partial replacement for coarse aggregate was periwinkle shell (PS). It was obtained from a sea food market in Bayelsa state. The shells were washed and dried before use. The particle size distribution of the shells was determined and discussed in the course of the study.

2.2.6 Superplasticizer
The superplasticizer used for the experiments was MasterRheobuild 858C which is a polymer base on styrene acrylic. The additive was in liquid form with a characteristic dark colour and manufactured in accordance with EN 934-2 Table 3.2 (Specific requirements for high range water reducing/super plasticizing admixtures) and ASTM C-494 Type F (Water Reducing, High Range) and Type G (Water Reducing, High Range and Retarding).

2.2.7 Water
The water that was used for the production of concrete and for curing of the concrete during experimentation was potable water obtained from the Building Workshop, Federal University of Technology, Akure, Ondo State, Nigeria.

3.1 Testing of Materials
The tests that were carried out on the sand, granite, and periwinkle shell are the sieve analysis test, specific gravity test and moisture content test in order to determine their physical properties.

3.2 Production of Concrete
A concrete mix consists of components combined to create concrete, including cement, aggregates (such as crushed stone, sand, and gravel), water, and often additional ingredients like admixtures or additives. In this study, periwinkle shell (PS) was used to partially replace coarse aggregate at replacement levels of 0%, 5%, 10%, 15%, and 20% by weight, with concrete cubes containing 0% PS serving as the control. Superplasticizer was added at 0.5%, 1%, and 1.5% of the cement mass to the mixes with different PS replacement percentages. A total of 240 concrete cubes, each measuring 100 mm on each side, were cast using cube molds across 20 different batches.

3.3 Test of compressive strength
After assembling the cube molds, the compressive strength test was performed following BS EN 12390-4:2002. The interior surfaces of the molds were lubricated with engine oil to facilitate the removal of the hardened concrete cubes. Concrete was placed in the 100 mm x 100 mm x 100 mm molds in three layers, each layer receiving 25 blows to ensure proper compaction. The mix used 100% granite for coarse aggregate, with periwinkle shell substituted at 0%, 5%, 10%, 15%, and 20% by weight, and the mix ratio was 1:2:4. Superplasticizer was added at 0.5%, 1%, and 1.5% of the cement mass.

The concrete cubes were demolded after 24 hours and cured in a water tank maintained at 20 °C. They were left in the tank until the specified curing periods of 7, 14, 21, and 28 days were completed. After curing, the cubes were weighed and tested for compressive strength, with the cast faces placed in contact with the compression machine's plate. The load was applied at a constant stress rate of 0.02–0.4 N/mm^2, and the crushing strength was recorded to the nearest 0.05 N/mm^2. The test setup is illustrated in Figure 1.

Figure 1: Testing Machine Compressive Strength Set up

IV. RESULTS AND DISCUSSION

4.1 Natural moisture content of fine aggregate

The average natural moisture content of the three (3) samples of fine aggregate (sharp sand) was ≈ **0.6%.** The moisture content of the fine aggregate is a measure of the amount of water/moisture in the sample used. The moisture natural content of fine aggregates has great effects on the physical and mechanical properties of the concrete such as workability, strength and durability, water/cement ratio, and shrinkage. The average moisture content for the 3 samples of fine aggregate tested was obtained to be 0.57% which falls within the typical expected value of moisture content for fine aggregates

Table 1: Result of Natural Moisture Content Test of Fine Aggregate.

Weights/Moisture Content	SAMPLE A	SAMPLE B	SAMPLE C
Container (g), W1	32.5	46.8	38.3
Container + Wet Sample (g), W2	103.2	121.8	105.9
Container + Dry Sample (g), W3	102.7	121.5	105.5
Wet Sample (g), W2-W1	70.7	75	67.6
Moisture (g), W2-W3	0.5	0.3	0.4
Moisture Content (%) (W2-W3)/(W2-W1)	0.71	0.40	0.59
Average, % (MC)		**0.57**	

Moisture content for sample A $=\frac{0.5}{70.7} \times 100 = 0.71\%$

Moisture content for sample B $= \frac{0.3}{75} \times 100 = 0.40\%$

Moisture content for sample C $= \frac{0.4}{67.6} \times 100 = 0.59\%$

Average Moisture Content $= \frac{0.71+0.40+0.59}{3} = \mathbf{0.57\%}$

4.2 Specific Gravity of Fine Aggregate

The specific gravity of fine aggregate is a measure of the density of the aggregate as compared to the density of water. The specific density of fine aggregate has effects on the workability, strength, durability, unit weight and volume stability of the concrete. Table 2 indicated that the specific gravity of the fine aggregate was found to be **2.6** which falls within the typical range of fine aggregates suitable for concrete (2.5-2.9)

Table 2: Specific Gravity of Fine Aggregate (Sharp Sand)

Mass/Specific Gravity	Sample
Empty glass, W_1	78.4g
Glass + sample, W_2	139.4g
Glass + sample + water, W_3	406.9g
Glass + water, W_4	369.4g
Specific Gravity	2.60

Specific gravity = $\frac{W2-W1}{(W4-W1)+(W3-W2)}$

4.3 Sieve analysis result for Periwinkle shell

The particle size distribution curve of the substitute coarse aggregate used (periwinkle shell) was plotted as shown in figure 2. The fineness modulus was obtained to be **6.27** which indicates that the periwinkle shell used is graded as coarse.

Weight of the can – 69.6g
Weight of the sample - 200g
Weight of the can + sample - 269.6g
Sample Mass = 200g
Weight of sample retained = Weight of sample + sample retained - Weight of sieve

Percentage weight retained = $\frac{Weight\ retained}{Total\ weight\ retained} \times 100$

Percentage passing = Total weight retained (%) - Corresponding value of cumulative (%)

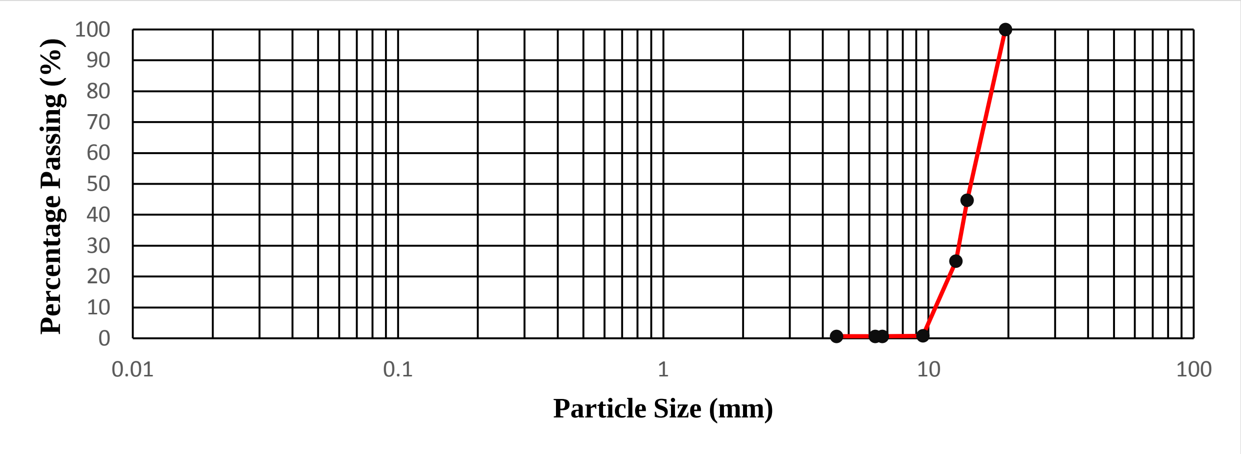

Figure 2: Grading Curve for Periwinkle Shell

4.4 Sieve analysis for coarse aggregate (granite)

The particle size distribution curve of the coarse aggregate (gravel) was plotted as shown in figure 3. The fineness modulus was obtained to be **6.80** which indicates that the coarse aggregate used is graded as coarse.

Weight of the can – 69.9g
Weight of the sample - 200g
Weight of the can + sample - 269.9g
Sample Mass = 200g
Weight of sample retained = Weight of sample + sample retained - Weight of sieve

Percentage weight retained = $\frac{Weight\ retained}{Total\ weight\ retained} \times 100$

Percentage passing = Total weight retained (%) - Corresponding value of cumulative (%)

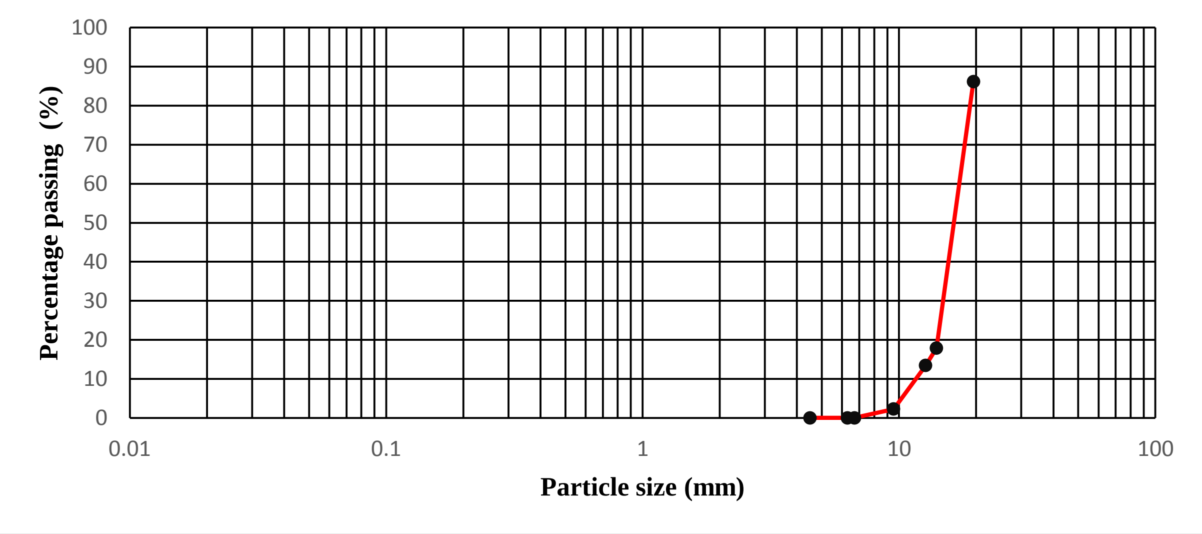

Figure 3: Grading Curve for Coarse Aggregate (Granite)

4.5 Sieve analysis for fine aggregate

The particle size distribution curve of the fine aggregate (sand) was plotted as shown in figure 4 The fineness modulus was obtained to be **4.37** which indicates that the fine aggregate used is graded as moderately fine. Reading the D10 and D60 values from figures allowed for the determination of the coefficient of uniformity for each sample type. The coefficient of uniformity CU was determined to be **0.87** which falls within the range of well-graded aggregates

Weight of the can - 99.9g
Weight of the sample - 200g
Weight of the can + sample - 299.9g
Weight of the can + dry sample - 257.5g
Weight of the sample = 257.5g - 99.9g = 157.6g
Sample Mass = 157.6g

Weight of sample retained = Weight of sample + sample retained - Weight of sieve

Percentage weight retained = $\frac{Weight\ retained}{Total\ weight\ retained} \times 100$

Percentage passing = Total weight retained (%) - Corresponding value of cumulative (%)

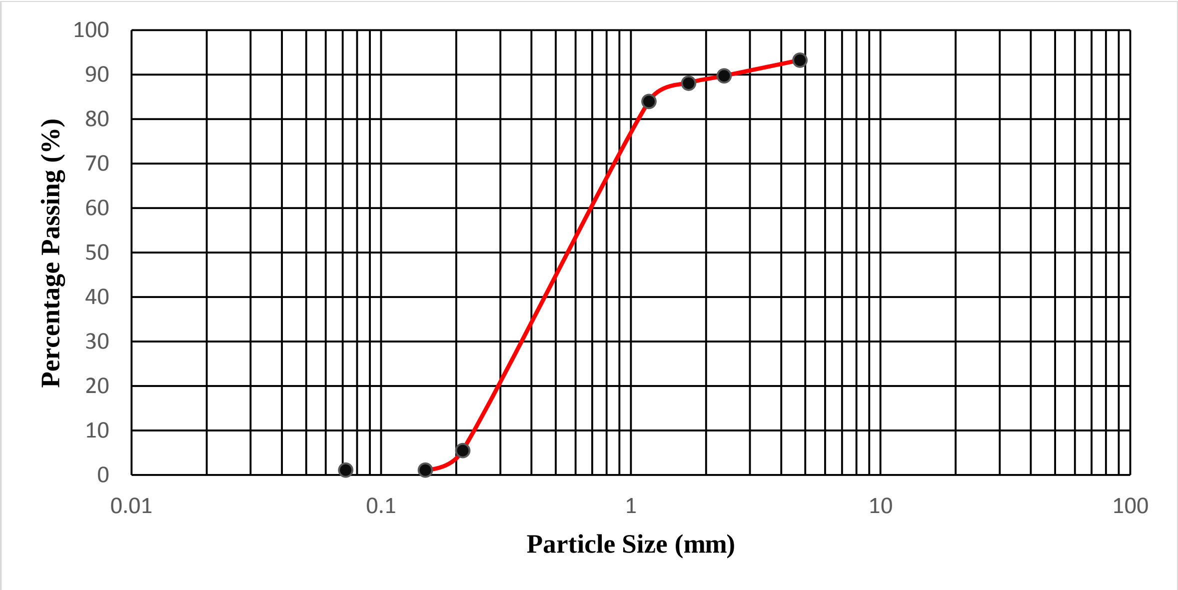

Figure 4: Grading Curve for Fine Aggregate

Fineness Modulus (FM) = $\frac{\text{cummulative percentage retained on standard seive}}{100}$

$$= \frac{6.73+10,22+11,93+11,93+15.99+94.54+98.98+98.98+100}{100} \qquad = \mathbf{4.37}$$

The formula gives the coefficient of uniformity:

For Sharp Sand, $C_U = \frac{D60}{D10} = \frac{0.88}{0.27} = \mathbf{3.26}$

$C_c = \frac{(D30)2}{D60 \times D10} = \frac{(0.51)2}{0.88 \times 0.27} = \mathbf{0.87}$

4.6 Weights and Densities of Specimen.

The average weights and densities of concrete specimen cast for control, and Periwinkle Shell are presented in Figure 5 and Figure 6 respectively.

Figure 5 shows the densities of control specimen cast. The highest density of 2700 kg/m^3 was observed for plain concrete specimen while the lowest density was observed to be 2450 kg/m^3 for 1% superplasticized concrete

Figure 6 shows the densities for specimen with Periwinkle Shell partial replacement and it was also observed that the densities generally decreased with an increase in percentage preplacement as the peak value was observed to be 2320 kg/m^3 at 5% partial replacement and 2260 kg/m^3 at 20% partial replacement.

Figure 5: Densities of Control Specimens

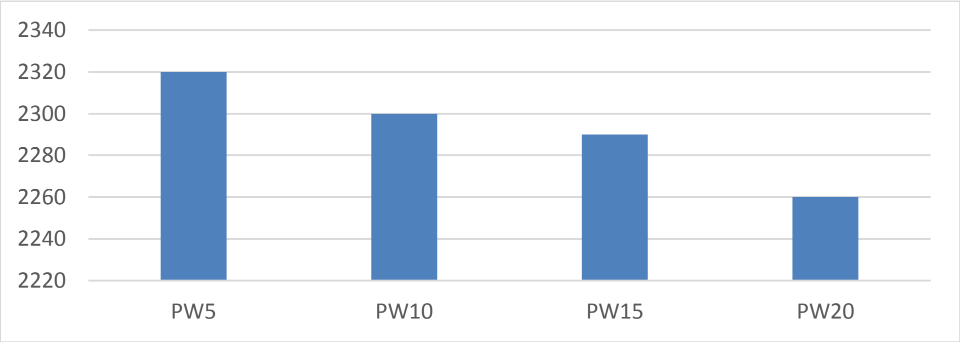

Figure 6: Densities of Specimen with Periwinkle Shell

4.7 Compressive Strength

The compressive strength values of the control specimens for plain concrete are presented in Table 3

Table 3: Compressive Strengths of Control Specimens

Specimen/Curing Age	7 days Strength (N/mm^2)	14 days Strength (N/mm^2)	21 days Strength (N/mm^2)	28 days Strength (N/mm^2)
C1	13.73	15.18	22.51	26.97
C_A	6.76	9.70	21.78	17.12
C_B	12.31	21.25	24.75	21.25
C_C	19.06	20.28	21.89	25.13

Figure 7 shows the effect of curing age on the compressive strength characteristics of superplasticized concrete with periwinkle shell partial replacement for coarse aggregate. A slight rise in the compressive strength was observed with curing age. Furthermore, it depicts that the peak strength of 26.97 kN/mm^2 was achieved by the

control specimen at 28 days curing age. Also, it was observed that 15% was optimum partial replacement for coarse aggregate with a peak value of 22.07kN/mm^2 at 21 days curing age and 0.5% superplasticizer content.
Figure 8 also depicts the effects of percentage replacement of periwinkle shell on the compressive strength characteristics of superplasticized concrete. The optimum percentage replacement was observed to be 15% with the peak value being 22.07 kN/mm^2 at 21days curing age and 0.5% superplasticizer content.
Figures 9 show the effect of superplasticizer content on the compressive strength characteristics of concrete with partial replacement with periwinkle shell. It was observed that the compressive strength generally peaked at 0.5% superplasticizer content.

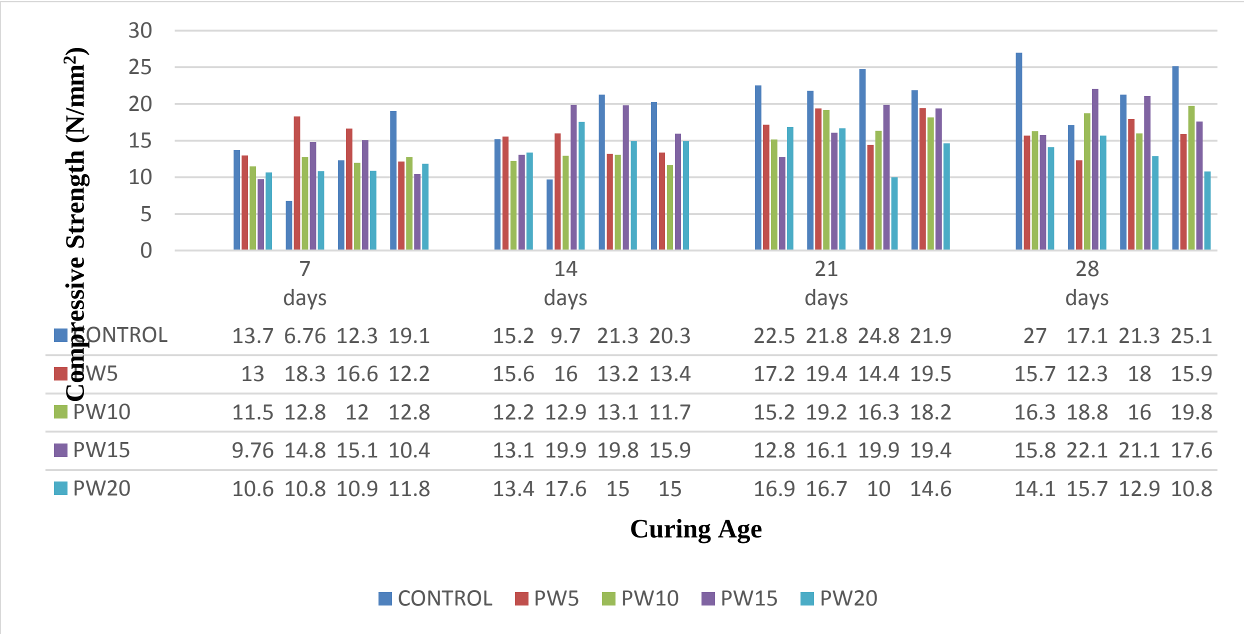

Figure 7: Effect of Curing Age on the Compressive Strength Characteristics of Superplasticized Concrete with Periwinkle Shell Partial Replacement

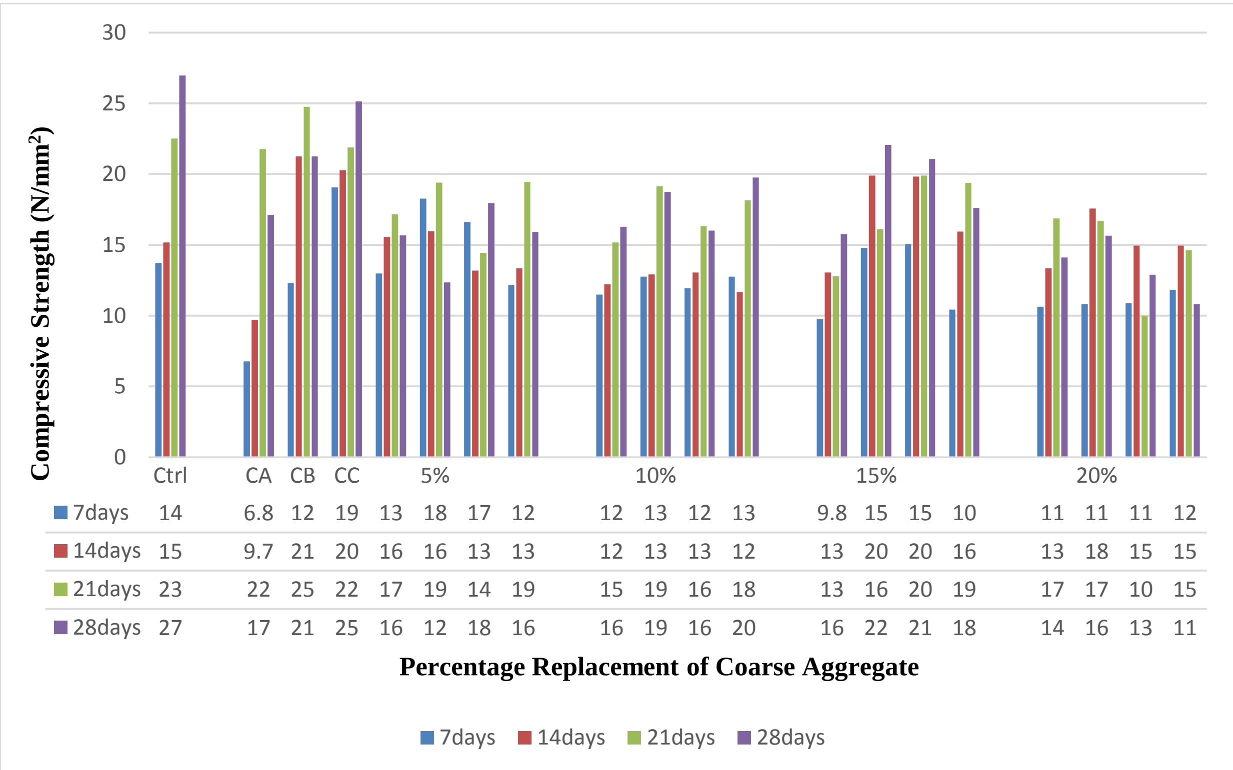

Figure 8: Effect of Percentage Replacement on the Compressive Strength Characteristics with PS

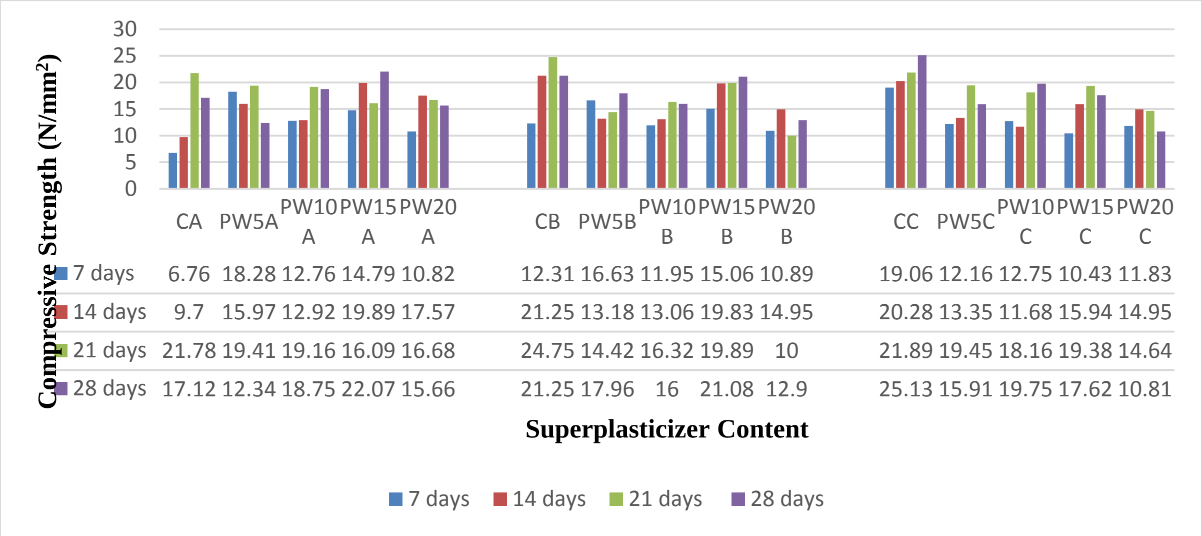

Fig. 9: Effect of Superplasticizer Content on the Compressive Strength Characteristics with PS

5.1 Conclusion

The research examined the effect of incorporating periwinkle shell as a partial replacement for granite coarse aggregate in superplasticized concrete. The results showed that periwinkle shell replacements led to slower strength development compared to plain concrete. However, superplasticized periwinkle shell concrete achieved its peak strength of 22.07 kN/mm² at 21 days of curing with 0.5% superplasticizer content and 15% periwinkle shell replacement, indicating optimal strength at higher replacement percentages.

Additionally, strength development improved with increasing superplasticizer content. Workability analysis revealed higher slump values with greater replacement and superplasticizer content, reaching a maximum of 55 mm. The density decreased with increased replacement, with a value of 2260 kg/m³ at 20% replacement. In conclusion, the study suggests that periwinkle shells show potential as partial substitutes for granite coarse aggregate in superplasticized concrete. However, their impact on strength development, workability, and density varied, and further research is needed to optimize their durability and suitability for specific concrete applications.

5.2 Recommendation

It is recommended that, to fully harness the potential of periwinkle shell (PS) in concrete, its use should be standardized. Comprehensive research into the tensile strength of periwinkle shell is also essential to support its application in reinforced periwinkle shell concrete for structural construction. The production of lightweight concrete using periwinkle shell can benefit both rural farming communities with periwinkle shell mills and the broader construction industry. Further research is needed to address various aspects related to periwinkle shell utilization.

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