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The Behaviour of Concrete Made with Nanosized Periwinkle Shell Ash as Partial Replacement of Cement Under Varying Curing Conditions with Emphasis on Its Compressive Strength

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ABSTRACT

The need to optimize the outcome of concrete casting, to curb excessive shrinkage and cracking in concrete, promotes the attention on concrete curing as durability, and strength, especially compressive strength of concrete depends largely on it. In this paper, the compressive strength of concrete containing nanosized periwinkle shell ash (NPSA) as a partial replacement of cement, was investigated using different curing techniques. The study applied three methods of curing: sprinkling, immersion and plastic wrapping. A concrete mix ratio of 1:1.5:3 and a water-cement ratio of 0.6 was employed to produce a total of 144 concrete cubes, with 48 cubes used for each of the curing methods. Curing periods of 14, 28, 56 and 90 days were considered with NPSA replacements at 5%, 10%, 15% and 20%. At 15% cement replacement with NPSA, immersion, sprinkling and plastic wrapping method produced optimum compressive of strengths of 24.76N/mm^2, 23.28N/mm^2, 21.25N/mm^2; 31.54N/mm^2, 29.24N/mm^2, 27.85N/mm^2; 37.44N/mm^2, 34.12N/mm^2, 31.53N/mm^2; and 43.73N/mm^2, 40.27N/mm^2, 37.16N/mm^2, at 14, 28, 56 and 90 days respectively. Immersion and sprinkling methods produced concrete with greater compressive strengths due to adequate moisture and vapour pressure sustained for continued cement hydration. The reduction in strength encountered in the plastic sheeting technique was due to early blockage of the pores by sufficient calcium silicate hydrate which stopped the cement hydration. The compressive strength of the concrete increases with age in all the curing methods with immersion curing producing the highest strength at all ages. The adoption of immersion curing is reliable for the optimization of concrete strength. However, sprinkling can be applied in case of water dearth

1. Introduction

Curing provides adequate moisture and favourable temperature in the initial stage of concrete to enhance its continuous hydration [1]. Cement hydration is accelerated and the concrete gains strength early at high temperatures, but the strength development at the early age becomes undesirable at temperatures less than 20^{o}C [2]. To boost abrasion resistance, resistance to freezing, thawing and dicers, durability and designed strength, concrete curing is imperative [3, 4]. Varying curing techniques are often adopted for curing concrete mix and this include; sprinkling, air-curing, ponding and wet-covering [5-7]. These methods depend on the state of the climate and the nature of work [8] and they have effects on the compressive strength of the hardened concrete.

The environmental impact of agricultural practices cannot be overlooked even though food is essential across the globe. According to USEPA [9], 20% of greenhouse-gas emission originate from agricultural-waste, and residents in developing countries, are more severely affected by impoverished waste management, compared to those in developed nations. Attention is drawn to effective, efficient and sustainable techniques of handling agricultural solid wastes. Utilization of these agro-waste in concrete production enhances waste management and aids in reducing cost as well as overreliance on concrete constituents such as cement [10].

Periwinkle shells are agricultural wastes with small greenish-blue marine snails with spiral conical shell and round-aperture, whose fleshy portion are processed and consumed while the hard shells are stockpiled in open sites which constitute a menace to the environment [11-14]. These shells can be adopted for construction purposes [15-17] to extricate pollution effect.

Currently, nanotechnology is being employed in many engineering applications with fast-growing attention in the construction industry. Incorporation of nanomaterials in concrete significantly improves its properties and promotes the reduction of CO_2 emission due to the decrease in cement content [18]. The use of nanomaterials enhances durability, air-quality improvement, self-sensing and weight reduction [19, 20]. Nanotechnology involves customizing the behaviour and performance of matter at the nanoscale, which is between 1 and 100 nanometres [21]. The application of nano silica, nano alumina, nano clay and nano kaolin are seen often in construction works [22]. However, the idea of nanosization is scare and this gap is worth filling through this study.

Attah *et al.*, [23] employed curing by complete immersion in water and in sulphuric acid (H_2SO4) solutions The authors concluded that concrete containing periwinkle shell ash had relative-low compressive strength when immersed in sulphuric acid solution and that the ash replacement did not alleviate the impact of chemical attack spawned by H_2SO4 on concrete. Etim *et al.,* [24] demonstrated the effect of periwinkle ash-cement concrete on compressive strength, when soaked in crude oil polluted water. The authors made no consideration for nanosization of the ash. Other techniques for curing such as sprinkling and plastic wrapping were not applied.
Although Nwa-David *et al.,* [25, 26] adopted the concept of nanosization, periwinkle ash was not used in their study, neither was other curing techniques employed.

Periwinkle shell ash (PSA) was incorporated in cement by Ekanem et al., [27] to produce lateritic blocks of high compressive and abrasive strength. The authors observed that the abrasive coefficient reduces as the percentage replacement increases and the strength of the blocks increased with increased curing age. Nanosized ash was not applied and their study was limited to one method of curing.

Adewuyi and Adegoke [28] used PSA as partial replacement of granite to investigate the compressive strength of concrete. The least 28-day cube strength values of 21N/mm^2 and 15 N/mm^2 expected for concrete mixes 1:2:4 and 1:3:6 was achieved by the authors with 35.4% and 42.5% periwinkle shells inclusion respectively. However, partial replacement of cement with this ash was not addressed. Nanosization of ash and the use of more curing techniques were not accounted for.

Olorunmeye *et al.,* [29] examined the water permeability and sorptivity behaviour of concrete containing PSA. The authors subjected the concrete to interrupted and uninterrupted curing conditions and recommended 10% PSA as the optimum replacement level. Compressive strength and nanosization was not taken into consideration. The curing techniques outlined in this study was not addressed by the authors.

Osadebe's regression approach was used by Egamana and Sule [30] to develop a mathematical model for prediction of compressive strength of concrete whose granite was partially replaced with periwinkle shell. Although a program based on the formulated model was written by the authors, they did not capture cement replacement, ash production, nanosization and curing methods.
In this study, three different curing techniques were employed to ascertain the compressive strength of concrete containing nanosized periwinkle shell ash as partial replacement of cement. The distinctiveness of this study lies in the type of supplementary cementitious material employed, the concept of nanosization for supplementary cementitious material, percentage replacement, curing techniques and curing periods.

2. Materials and Methods

2.1 Materials

The materials adopted in this study are locally available and they are portland cement, nanosized periwinkle shell ash, drinkable water, fine and coarse aggregates. These materials are discussed below.

2.1.1 Portland cement

The *BUA* brand of Portland Cement that is in accordance with the specification of BS 12 [31] was used. The BUA cement is a CEM II type of cement with strength grade 42.5 R and specific gravity of 3.02. It was procured from the community market in Ikwuano LGA, Abia State.

2.1.2 Nanosized Periwinkle Shell Ash

The periwinkle shells were fetched from dump-sites at Oboro and Oloko in Ikwuano L.G.A in Abia State. The periwinkle was removed from the shells and the shells were calcined in a kiln at a temperature of 750^{o}C in 60 minutes in a control combustion set-up to avert befouling. The torrefied material was collected and sieved scrupulously with a nano-sieve of size 150 nm, to yield fine nanosized ash.

2.1.3 Aggregates.

The coarse aggregate and fine aggregates employed in the study are locally available. The coarse aggregates were of angular-shape. The maximum size of the granite used for this work was 20mm diameter, which conformed to the requirements of BS 882 [32]. Fine aggregates were sieved through 10mm British Standard test sieve to eliminate cobbles to satisfy the requirements of [32].

2.1.4 Water

The water used for the experiment during mixing and curing operation was fit for drinking and it conformed to the stipulations in BS 3140 [33]. The water was obtained from the borehole at the concrete laboratory, civil engineering department, Michael Okpara University of Agriculture, Umudike.

2.2 Methods

The concrete used for this study was prepared using mix ratio 1:1.5:3 with water-cement ratio of 0.6 while batching of materials was done by mass using 5%, 10%, 15% and 20 % replacement of cement with periwinkle shell ash. 5% replacement interval was adopted in order to capture significant variation in the compressive strength of the concrete. A replicate of 3 (150 mm × 150 mm × 150 mm) cubes were cast for each replacement and for each curing period making a total of 144 cubes.

The concrete constituents were thoroughly and uniformly mixed before the addition of water. The homogenized mixture was poured into 150 mm ×150 mm × 150 mm metal moulds; in three layers and compacted with the tamping rod 25 stroke per layer and the top finish with the trowel and label accurately conforming to BS 1881 [34]. The tops of the cubes were marked after a while for identification purpose. The concrete was de-moulded after 24 hours.

The concrete specimens were cured under three types of curing until the day of testing. These were immersion, sprinkling and wrapping with plastic sheeting. In immersion method, the specimens were weighed and immersed in a tank containing portable borehole water. In sprinkling method, the specimens were also weighed and kept moist by sprinkling water on the specimens 2 times daily (morning and evening) until the date of testing. In plastic sheeting, the specimens were weighed and wrapped in flexible plastic sheets until the testing date. At least two layers of wrapping were used to prevent moisture movement from concrete surface. The curing temperature was maintained at 30^{o}C in all the curing methods.

The length of curing dates considered was 14,28, 56 and 90 days respectively. Considering the effect of external weather variation and projects like airport runways where long curing age are feasible, curing beyond the conventional 28days was taken into account. The compressive strength of the test cubes was determined by crushing the cubes under the compression machine. A total of 48 cubes were crushed for each of the curing technique.

3. Results and Discussion

3.1 Properties of Concrete Constituents

The physical properties of nanosized periwinkle shell ash (NPSA) calcined at 750˚C were presented in Table 1. A specific gravity of 1.76 was recorded which indicates that the heat application on the periwinkle shell has impact on the fineness of ash produced.

Nanosized periwinkle shell ash (NPSA) is categorized as class C pozzolan. Its oxide composition was captured in Table 2. The nanosized ash met the requirement of ASTM C618 [35] for loss of ignition (LOI) which stipulates a value of not more than 10%, with recorded value of 4.27. The combined acidic oxides (SiO_3+ Al_2O_3 + Fe_2O_3), at 750 ˚C met the requirement of ASTMC618-2008 for class C pozzolan with a value of 60.56%.

The river sand has coefficient of uniformity and coefficient of curvature values of 2.68 and 0.97 respectively obtained from Table 3. The coarse aggregate has coefficient of uniformity and coefficient of curvature values of 1.84 and 1.06 respectively obtained from Table 4. The coefficient of curvature for both aggregates were confirmed to be close to 1 which indicates that the samples were well-graded, while the coefficient of uniformity of less than or equal to 4, which confirms that they were uniformly-graded. Hence, these constituent materials are suitable for concrete production.

Table 1: Physical Properties of NPSA

Physical Attributes	**NPSA**
Specific gravity	1.76
Bulk density compacted (kg/m^3)	1250
Bulk density loosed (kg/m^3)	940
Colour	Grey
Water content	1.2

Table 2: Chemical Properties of NPSA calcined at 750 ^oC

Oxides	% composition NPSA	Cement
SiO_2	38.62	18.22
Al_2O_3	16.84	5.11
Fe_2O_3	5.10	2.74
Mn_2O_3	0.01	0.02
CaO	31.24	60.14
SO_3	2.12	3.31
K_2O	1.23	2.06
Na_2O	0.57	0.88
LOI	4.27	7.52

Table 3: Particle size distribution of Imo river sand

Sieve size (mm)	**Mass of sand passing (g)**	**Mass of sand retained (g)**	**% passing**
4.75	950	0	100
2.36	924.5	25.50	97.32
1.18	878.69	45.81	92.50
0.850	800.05	78.64	84.22
0.6	517.27	282.78	54.45
0.425	368.28	148.99	38.77
0.3	97.74	270.54	10.29
0.212	27.97	69.77	2.95
0.15	11.73	16.24	1.24
0.075	2.83	8.90	0.30
Pan	0	2.83	0
Total		950	

Table 4: Particle size distribution of granite chippings

Sieve size (mm)	**Mass of granite passing (g)**	**Mass of granite retained (g)**	**% passing**
31.5	3200	0	100
22.4	3118.78	81.22	97.46
19	2675.83	442.95	83.62
16	1697.87	977.96	53.06
12.5	803.72	894.15	25.12
9.5	354.21	449.51	11.07
6.3	57.41	296.80	1.79
04.75	14.74	42.67	0.46
Pan	0	14.74	0
Total		3200	

3.2. Slump Test

The results of the workability test carried out on the fresh concrete with different percentages of NPSA as cement replacement are presented in Table 5. The values obtained from the slump test correspond to the designed slump range of 10 – 30mm. The results also show that the slump increased with an increase in NPSA content, which is traceable to increased surface area emanating from nanosization.

Table 5: Workability result of NPSA-OPC blended concrete

% NPSA	Slump (mm)
0	28.5
5	20.8
10	22.6
15	24.7
20	26.2

3.3. Compressive Strength Test

Tables 6-9 presented the results of compressive strengths at different curing days, while Figures 1-3 is the graphical representation for the variation of compressive strengths with the percentage replacement of NPSA using different curing methods. The compressive strength of the concrete increases with age for all the curing methods, with the immersion method having the highest values. Sprinkling method produced strength close to immersion curing. The high strength development of these two curing techniques were attributed to the presence of adequate moisture and vapour-pressure which were maintained to sustain cement hydration. Curing by plastic sheeting produced the least compressive strength at all ages.

NPSA inclusion in concrete mix was very effective in increasing the compressive strength of concrete, due to the presence of silica (SiO_2) and alumina (Al_2O_3) in NCPA content being larger than those of OPC as captured in Table 2. Also, strength development is traceable to the formation of strengthening gel (C-S-H) and bond (C-A-H) occurring from the reaction of NPSA's silica and alumina elements with the hydrating agents of OPC [26].

At 15 % NPSA replacement, C-S-H formation was most effective resulting to higher strength-gain and the optimum strength was achieved for all the curing age and curing methods. For immersion method, the maximum strengths were recorded as 24.76 N/mm^2, 31.54 N/mm^2, 37.44 N/mm^2, and 43.73 N/mm^2 at 14, 28, 56 and 90 curing days respectively. For sprinkling, the maximum strengths were recorded as 23.28 N/mm^2, 29.24 N/mm^2, 34.12 N/mm^2, and 40.27 N/mm^2 while for plastic sheeting, the highest strengths were 21.25 N/mm^2, 27.85 N/mm^2, 31.53 N/mm^2 and 37.16 N/mm^2 at 14, 28, 56 and 90 curing days respectively.

Table 6: Results of Compressive Strength at 14days

% NPSA	Compressive Strength (N/mm^2)		
	Immersion	Sprinkling	Plastic Sheeting
0	26.40	23.56	22.34
5	22.36	21.29	19.27
10	23.10	22.71	20.11
15	24.76	23.28	21.25
20	24.34	22.87	20.86

Table 7: Results of Compressive Strength at 28days

% NPSA	Compressive Strength (N/mm^2)		
	Immersion	Sprinkling	Plastic Sheeting
0	32.57	30.22	28.94
5	27.16	25.43	22.64
10	29.07	27.78	26.93
15	31.54	39.24	27.85
20	30.66	28.32	26.42

Table 8: Results of Compressive Strength at 56days

% NPSA	Compressive Strength (N/mm^2)		
	Immersion	Sprinkling	Plastic Sheeting
0	38.12	35.00	31.45
5	31.32	29.17	28.22
10	34.36	31.29	29.16
15	37.44	34.12	31.53
20	37.10	33.54	30.87

Table 9: Results of Compressive Strength at 90days

% NPSA	Compressive Strength (N/mm^2)		
	Immersion	Sprinkling	Plastic Sheeting
0	40.62	40.34	38.56
5	38.76	36.38	31.84
10	41.10	38.61	34.82
15	43.73	40.27	37.16
20	42.66	39.44	36.69

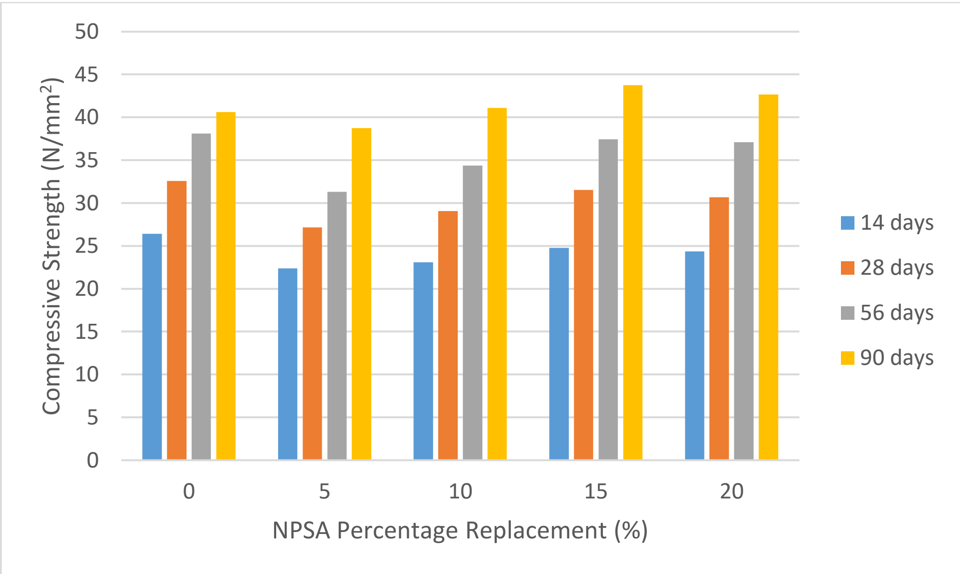

Figure 1. Variation of Compressive Strength and NPSA Percentage Replacement for Immersion Curing Method

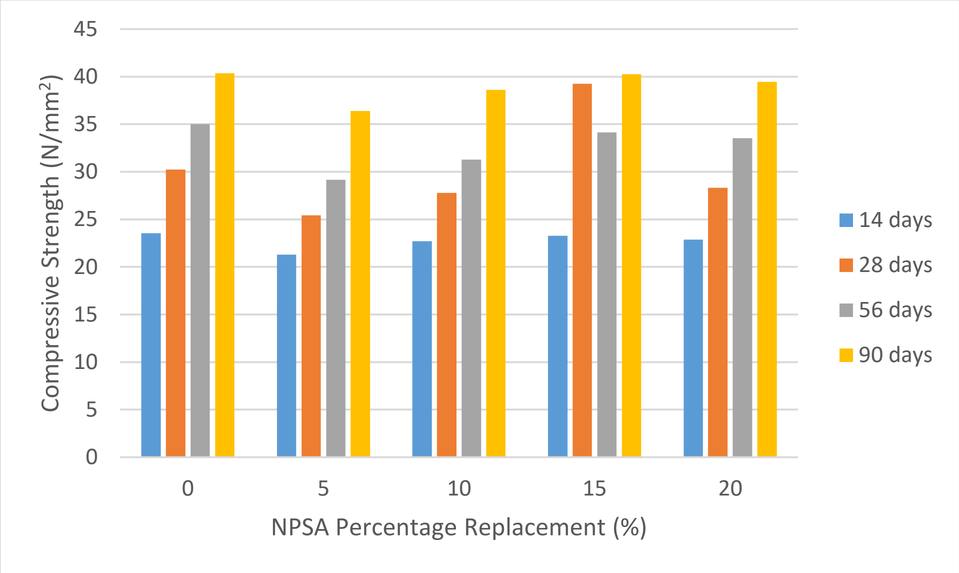

Figure 2. Variation of Compressive Strength and NPSA Percentage Replacement for Sprinkling Curing Method

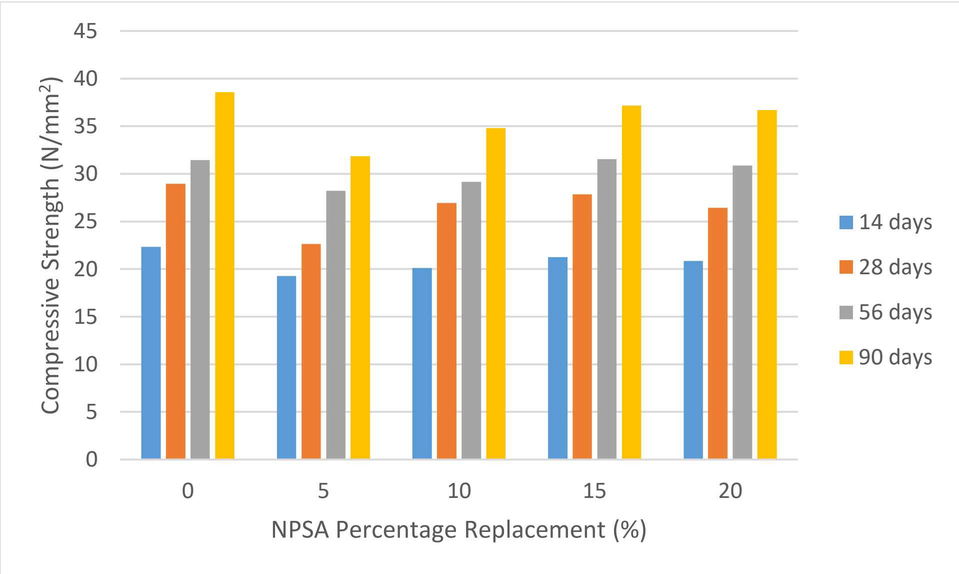

Figure 3. Variation of Compressive Strength and NPSA Percentage Replacement for Plastic Sheeting Method

4. Conclusion

Based on the experimental outcome of the study, the following conclusions were drawn;

i. Curing by immersion was observed to the most effective curing method as the greatest compressive strengths were obtained from it. Cement hydration reaction was enhanced as well as the hardened property of the concrete, because there was no loss of moisture.

ii. Method of curing determines the degree of moisture movement and the strength property of the concrete. Moisture movement occurred much in plastic sheeting method which led to strength reduction.

iii. Concrete containing up to 15% nanosized periwinkle shell ash inclusion are suitable for construction works.

iv. Nanosization improved the workability and characteristic strength of the concrete.

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