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EFFECTS OF PERIWINKLE SHELL ASH ON WATER PERMEABILITY AND SORPTIVITY CHARACTERISTICS OF CONCRETE UNDER DIFFERENT CURING CONDITIONS

Professor Olorunmeye Fredrick Job[1], Yahaya Umar Barambu[2] and Amma Awari Ishaya[3]
[1,3] Department of Building, University of Jos, Nigeria.
[2]Graduate Student,Department of Building, University of Jos, Nigeria.

Abstract—This study investigates the water permeability and sorptivity characteristics of periwinkle shell blended concrete under interrupted and uninterrupted curing conditions. The periwinkle shell ash was mixed in concrete at various percentages replacement of 0 %(control), 10%, 20%, 30% and 40% by weight of cement. Concrete beams, cubes and cylindrical samples were produced using the partial replacement levels and cured for 7, 28, 56 and 90 days under interrupted and uninterrupted conditions. The water permeability and sorptivity of periwinkle shell ash shows lower values at 10% replacement of PSA by weight of cement in concrete. The study concludes that blended concrete with 10% PSA was the optimum replacement level by weight of cement in concrete to produce durable concrete structures under interrupted and uninterrupted conditions.

Keywords— Permeability, Periwinkle Shell Ash, Sorptivity, Concrete Partial Replacement, Curing Conditions

I. INTRODUCTION

Ordinary Portland Cement (OPC) is one of the most consumed materials after water. The annual global production of Portland cement concrete as reported by [1] is about 11 billion metric tonnes. It is an energy intensive material and is also liable for carbon dioxide (CO_2) gas emission and other hazardous gasses such as carbon dioxide, ammonia and nitric oxide and nitrogen oxide into the atmosphere, which contributes to global warming. For instance, it has been reported that over 90% of carbon emissions from the concrete industry are attributable to Portland cement clinker production in cement kilns, and that approximately 1 tonne of CO_2 is generated for making 1 tonne of clinker [2].

Over the years, researchers have investigated into the use of by-industrial wastes and other wastes as components that could be blended with cement clinker without compromising the quality of the cement produced, or partially replaced the cement during batching in concrete production. This approach does lead to development of sustainable infrastructure that is cost effective, environmentally friendly and durable. Research had shown that small amounts of inert fillers have always been acceptable as cement replacements, what more if the fillers have the pozzolanic properties, in which it will not only impart technical advantages to the resulting concrete but also enable larger quantities of cement replacement to be achieved. There are many advantages in using pozzolans in concrete which include, improved workability at low replacement levels and with pozzolans of low carbon content, reduced bleeding and segregation, low heat of hydration, lower creep and shrinkage, high resistance to chemical attack (due to lower permeability and less calcium hydroxide available for reaction), and low diffusion rate of chloride ions resulting in a higher resistance to corrosion of steel in concrete [3].

The commonly used pozzolans have been fly ash, silica fume, metakaolin, and blast furnace slag. In continuing quest for more cost - efficient and environmentally acceptable materials, recently, there has been a growing interest in the use of agricultural wastes as pozzolans. Some of the pozzolans of agricultural origin include sawdust ash [4] and [5], rice husk ash [6], corn cob ash [7] and [8], palm oil fuel ash [9] and periwinkle shell ash [10], [11], [12] and [13] and also groundnut husk ash [14].

Periwinkle has been described by Badmus, Audu, & Anyata [10] as small marine snails with spiral-cone, shaped shells having a round opening and dull interior. The major species reported by Beredugo [15] to be available in the lagoon and mudflats of Nigeria's Niger Delta, between Calabar in the east and Badagry in the west, are *Tympanostomus*and *Pachmellania species*. Periwinkle shell is a waste product generated from the consumption of a small greenish-blue marine snail (periwinkle), housed in a 'V' shaped spiral shell, found in many coastal communities within Nigeria and word-wide is a very strong, hard and brittle material [16]. The common periwinkle (*Littorinalittorea*) is one of the most abundant marine gastropods in the North Atlantic, but *Tympanotonusfuscatus* is commonly found in the estuaries and mangrove swamp forest of the South - South region of Nigeria [10]. Massive periwinkle harvesting has been reported from some communities in this region of Nigeria [17], [18], [19] and [20].

Periwinkle shell ash (PSA) is obtained from the burning of periwinkle shells which is a by-product of periwinkle at a temperature of 800^oC [21]. Periwinkle is one of the seashell foods that are mostly found in waters of the Niger delta region of Nigeria. The shells are usually thrown away after removing the edible periwinkle. The PSA in binary blended system in concrete have been reported to enhance concrete strength and durability with replacement level up to 10% [22], [21] and [23].

Permeability is the most important aspect of concrete durability. To be durable, concrete must be relatively impervious [24]. In general, lower permeability means greater durability [25]. Permeability of concrete is governed by many factors such as the amount of cementitious material, water content, aggregate grading, consolidation, and curing. As an example through its pozzolanic properties, fly ash chemically reacts with $Ca(OH)_2$ and water to produce C-S-H gel [26]. The $Ca(OH)_2$ is consumed in the pozzolanic reaction and is converted into a water-insoluble hydration product [25].

Based on limited experimental investigation concerning the water absorption and sorptivity of concrete as observed by [27] by regarding the resistance of partially replaced fly ash for M25 and M40 grade concrete indicated that the water absorption and sorptivity of fly ash concrete shows lower water absorption and sorptivity at 10% replacement with fly ash for M25 and M40 grade concrete. For 90 days strength, the percentage decrease in water absorption was found to be 1.59% for M25 and 0.67% for M40 and sorptivity was found to be 2.32 mm/min$^{0.5}$ for M25 and 1.74 mm/min$^{0.5}$ for M40 with respect to reference mix. The water absorption and sorptivity of fly ash concrete shows higher water absorption and sorptivity than traditional concrete. This study is therefore aimed at studying the effects of periwinkle shell ash on permeability and sorptivity characteristics of concrete under different curing conditions.

II. MATERIALS AND METHODS

2.1 Materials

The Ashaka brand of ordinary Portland cement conforming to relevant specifications was used. Natural river bed quartzite sand from a river within Bauchi metropolis of Nigeria with specific gravity of 2.6, water absorption 0.29%, bulk density of 1610kg/m3 and free moisture content of 0.18% was used as fine aggregate; crushed granite of 20mm maximum size with specific gravity of 2.70, bulk density of 2535kg/m^3, water absorption of 18.79%, free moisture content of 1.18%, AIV of 14.65 and ACV of 24.84. The properties of aggregates were obtained from tests conducted in accordance to [28].

The periwinkle shell was locally sourced from *Chobe* market in Jos North Local Government of Plateau State, Nigeria. It washed with clean water to remove dirt and sun dried. The burning process was done in kiln to a temperature of 800^oC at the Ceramics Department of ATBU, Bauchi and then pulverized into powder. In order to reduce the use of the darker ashes and consequently minimize the use of ash with high carbon content, the burnt periwinkle shell was made to pass through 75µm sieve for 10 minutes to obtain a fine periwinkle shell ash that would be suitable for blending with cement. The physical and chemical properties of PSA are presented in Tables 1 and 2 respectively.

2.2 Methods

2.2.1 Batching of materials

The volume of compacted concrete is equivalent to the sum of the absolute volume of the materials that make up the concrete. Therefore, batching was done by weight according to the properties of each material determined earlier and based on the concrete mix design to strength of $25Nmm^{-2}$ at 28 days curing period. The blended concrete mix was prepared using ordinary Portland cement that was partially substituted by 10, 20, 30 and 40% periwinkle shell ash as illustrated and presented in Table 3. The mix proportion obtained was approximately1:3:4.

Concrete cubes and cylinders were cast using specified moulds and demoded after 24 hours. They were subsequently cured for the specified periods before the tests were carried out. The water permeability and water sorptivity tests were conducted at the Civil Engineering laboratory ATBU, Bauchi, Nigeria.

2.2.2 Water Permeability Test

The falling permeability method was used to test for the water permeability of the concrete according to [29] and the results are presented in Table 4. Coefficient of water absorption is a measure of permeability of concrete [30]. This is determined by measuring water uptake in dry concrete in a time of one hour. Concrete cylinders of diameter 75mm and 100mm height were prepared. The specimens were tested at 28days and 56days curing periods for both interrupted and uninterrupted conditions. The specimens were placed into the permeameter cell, water tight using candle wax (Permeameter is made of non-corrodible material with a capacity of 1000 ml, with an internal diameter of 100±0.1 mm and effective height of 127.3±0.1 mm) in the bottom and the tank was filled with water for concrete to get saturated. After saturation, the inlet nozzle of the mould was connected to the stand pipe and the water was allowed to flow until steady flow was obtained. The time interval ‘t’ for a fall of head in the stand pipe ‘h’ was noted and repeated three times to determine ‘t’ for the same head. The permeability (Kt) was calculated as follows:

$$Kt = \frac{3.84 \text{ x a x L xlog}\left(\frac{h1}{h2}\right) \text{ x } 0.00001}{\text{A x t}} \quad \text{(m/s)}$$

Where Kt = Permeability (m/s)

A = cross section area of manometer tube used (mm^2)

A = cross section area of specimen in permeameter cell (mm^2)

t = measured time interval (s)

L = length of specimen (m)

h_1 = start level manometer tube = y_1- h_0 (m)

h_2 = end level manometer tube = y_2- h_0 (m)

2.2.3 Sorptivity and water absorption Test

The sorptivity was determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used as the test fluid. The cylinders after casting were cured in water for 90 days. The specimen size measured 100mm diameter x 50 mm height after drying in an oven at temperature of 100 + 10 °C and placed in water with level not more than 5 mm above the base of the specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating (candle wax). The quantity of water absorbed in time period of 30 minutes was measured by weighting the specimen on a digital balance. Surface water on the specimen was wiped off with a dampened tissue and each weighting operation was completed within 30 seconds. Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t) I=S.t½

Therefore S=I/ t½

Where; S= sorptivity in mm,

t= elapsed time in mint.

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$I = \Delta w / Ad$

Δw= change in weight = $W_2 - W_1$

W_1 = Oven dry weight of cylinder in grams

W_2 = Weight of cylinder after 30 minutes capillary suction of water in grams.

A= surface area of the specimen through which water penetrated.

d= density of water

The results are as given in Table 5.

Water absorption was determined using:

Water absorption = $\frac{W2-W1}{W1} \times 100$ (%). The results are given in Table 6

III. RESULTS AND DISCUSSION

3.1 Physical Properties

The specific gravity of PSA obtained was 2.17 which is less than that of OPC (3.15) and lies between 2.0-2.40 conforming to the requirement stipulated in [31] for pozzolana. The loose bulk density of PSA was found to be $930 kg/m^3$ and compacted bulk density of $1057 kg/m^3$. The ratio of the loose to compacted bulk density is 0.88, which lies between 0.86 - 0.96 as stipulated by [32] for non-light materials. 26.6% of the PSA was retained on the 75µm sieve, which conforms to the requirement of [31]

3.2 Chemical Properties

According to BS EN 450.1 [33] and ASTM C618 [31], the major requirements for a material to be classified as pozzolana, the total percentages of Al_2O_3, SiO_2 and Fe_2O_3 must not be less than 70%. 15.57%, 34.74% and 0.12% are the values for Al_2O_3, SiO_2 and Fe_2O_3 respectively obtained and their sum is 50.43%. However, the material has a high value of calcium oxide of 37.54%. The SO_3 percentage in the ash is under 5% which conforms to [31] requirement for pozzolana.

3.3 Sorptivity and water absorption

The values of sorptivity and water absorption are presented in Tables 5 and 6 respectively. The Sorptivity value increased with increase in PSA and higher values obtained in interrupted curing which agrees with [27]. The control has sorptivity values of 8.74 and 8.19 x 10^{-8} $mm/min^{0.5}$ for interrupted and uninterrupted respectively. 10% replacement of cement with PSA has the lowest sorptivity value of 8.83 and 8.49 x 10^{-8} $mm/min^{0.5}$ for interrupted and uninterrupted curing respectively which is higher than the sorptivity values for 10% optimum replacement with fly ash (2.32 $mm/min^{0.5}$) as indicated by [27].

Water absorption followed the same trend as in sorptivity. The control had values of 2.28 and 1.89% for interrupted and uninterrupted curing respectively while 10% replacements of PSA shows lower values of 2.41% and 1.95% for interrupted and uninterrupted curing respectively but the values are higher compared to 1.59% water absorption for an optimum of 10% replacement with fly ash as indicated by [27].

3.4 Water Permeability

The permeability was taken at 28, 56 and 90 days curing period and the results are presented in Table 4. There was no significant change in the permeability with increase in curing period, which agrees with [25] which states that lower permeability indicates greater strength but there was a slight increase in permeability with increase in the quantity of PSA.

The interruption curing also did not show much effect on the permeability probably due to low permeability of the concrete, the values were too small to spot variance.

The values ranged from 1.0 - 1.5 x 10^{-10}m/s. Rinker [34] stated that the permeability of a good-quality concrete is about 1×10^{-10} centimetres per second.

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IV. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion The sorptivity of periwinkle shell ash at optimum percentage replacement of 10% PSA were 8.83 and 8.49 x 10^{-8} mm/$min^{0.5}$ for interrupted and uninterrupted curing conditions respectively.

Water absorption at 10% replacement of PSA was found to be 2.41 and 1.95% at 90 days interrupted and uninterrupted curing regime respectively with respect to the control mix.

Water permeability was low and there was no significant change in the permeability with increase in curing period but there was slight increase with increase in the quantity of PSA

4.2 Recommendations

1. PSA is recommended for structures exposed to water such as bridges and dams.
2. PSA is recommended for used to replace cement up to 40% when using low strength concrete where late curing period of 90 days is desired.

Table 1: Physical Properties of PSA

Physical Property	PSA
Fineness passing through sieve size 75µm (%)	26.60
Bulk density loosed (kg/m^3)	930
Bulk density compacted (kg/m^3)	1057
Specific gravity	2.17
Appearance	Very fine powder
Colour	Grey

Table 2: Chemical Properties of PSA

Elemental Oxide	% Composition
SiO_2	34.74
Al_2O_3	15.57
K_2O	0.03
MnO	0.02
Fe_2O_3	0.12
SO_3	0.04
CuO	0.03
Cr_2O_3	0.007
CaO	37.54
TiO_2	0.01
BaO	0.02
SrO	0.19
ZrO_2	0.002

Table 3: Mix Proportion of the Concrete used

Percentage replacement (%)	Cementitious Materials (Kg/m^3)		Water		Aggregate	
	OPC	PSA	Amount of water over Control (%)	Actual water content (Kg/m^3)	Fine (Kg/m^3)	Coarse (Kg/m^3)
0	292.31	0	-	190	948.31	1069.38
10	263.08	29.23	103.08	195.85	948.31	1069.38
20	233.85	58.46	107.69	204.61	948.31	1069.38
30	204.62	87.69	110.77	210.46	948.31	1069.38
40	175.39	116.92	113.85	216.32	948.31	1069.38
Ratio	**1** **1**				**3.24** **3**	**3.65** **4**

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Table 4: Water Permeability of the Blended Concrete

Percentage of PSA to OPC (%)	Density (Kg/m^3)	Permeability X 10^{-10} (m/s) Curing periods (days) 28	56	90
Interrupted				
0	2350	1.0	1.1	1.1
10	2340	1.1	1.2	1.2
20	2330	1.3	1.3	1.3
30	2310	1.3	1.5	1.3
40	2300	1.3	1.4	1.3
Uninterrupted				
0	2370	1.0	1.0	0.9
10	2350	1.1	1.1	1.0
20	2330	1.1	1.1	1.1
30	2330	1.2	1.1	1.1
40	2310	1.2	1.2	1.1

Table 5: Sorptivity at 90 days curing

Percentage replacement with PSA (%)	W2-W1 (g)	A*d x 10^6	I x 10^6	Sorptivity x 10^{-8} $mm/min^{0.5}$
Interrupted				
0	20.6	7.85	2.62	8.74
10	20.8	7.85	2.65	8.83
20	22.9	7.85	2.92	9.72
30	23.1	7.85	2.94	9.80
40	24.1	7.85	3.07	10.22
Uninterrupted				
0	19.3	7.85	2.46	8.19
10	20.0	7.85	2.55	8.49
20	21.5	7.85	2.74	9.12
30	22.1	7.85	2.81	9.38
40	22.2	7.85	2.83	9.42

Table 6: Water Absorption at 90 days curing

Percentage replacement with PSA (%)	W1 (g)	W2-W1 (g)	Water Absorption (%)
Interrupted			
0	903.0	20.6	2.28
10	864.5	20.8	2.41
20	878.9	22.9	2.61
30	971.7	23.1	2.38
40	865.6	24.1	2.78
Uninterrupted			
0	1019.0	19.3	1.89
10	1028.1	20.0	1.95

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20	964.9	21.5	2.23
30	912.0	22.1	2.42
40	912.8	22.2	2.43

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