ISSN 2229-5518

EXPERIMENTAL INVESTIGATION ON GEOPOLYMER CONCRETE USING PERIWINKLE SHELL ASH

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ABSTRACT

The devastating effect of Ordinary Portland Cement production due to CO_2 emission into the atmosphere has necessitated higher demand for a more environment friendly binder such as a geopolymer for concrete production. Geopolymer binder is a combination of alumina and silica containing by-products with hydroxide and silicate solutions. In this study, periwinkle shell ash and metakaolin were used to make geopolymer concrete. A combination of NaOH and Na_2SiO_2 was used as the alkaline liquid. This experimental study aims to investigate the suitability of periwinkle shell ash in geopolymer concrete production, which includes the chemical and physical properties of source materials and compressive strength test, water absorbtion properties of the of geopolymer concrete. Grade 25 OPC and geopolymer concrete were prepared using an equivalent mix ratio of 1:1.5:3 for the control and test specimens respectively. Concrete cubes of size 100mm×100mm×100mm were prepared and allowed to oven dry at 90^{o}C for 24 hours before room temperature curing at 7, 28, 56, and 90 days. The final result showed that, the compressive strength of the concrete increased with increase in curing age, while the strength reduced with increase in periwinkle shell ash percentage. Water absorption increased with increase in periwinkle shell ash.

Keywords: *Periwinkle Shell Ash, Geopolymer Concrete, Compressive Strength, Water Absorption*

INTRODUCTION

Geopolymer is an alternative binder to the Ordinary Portland Cement which can be used in concrete production. It is made from local materials that contains silica and aluminium basically, and are activated by alkaline solution. Geopolymerisation involves the chemical reaction of the alumino-silica oxides with alkali polysilicates yielding polymeric bonds. High temperature curing is normally required in geopolymer concrete production to enhance the geopolymerization process (Olivia *et al.*, 2016).

Concrete is the most vital material used in the construction industry for building various forms of infrastructures such as roads, bridges, fences, pavements, houses etc. The most conventionally used binding material in concrete production is the Ordinary Portland Cement. However, the manufacturing process of the OPC comes with a lot of pollution to the environment by the emission of CO_2 in to the atmosphere in a large quantity (Davidovits 1994). The activities involved in the production of cement produces about 1.5 billion tons of CO_2 into the atmosphere annually, hence causing global warming, which is a serious threat to the environment (Lloyd *et al.*, 2010). Therefore, researchers are in search of an alternative cement that can be used as a binder that can be used in place of the OPC, that can be more environment friendly and uses less raw materials (Shiva *et al.*, 2017; Hardjito *et al.*, 2007). The geopolymerization reaction leads to the formation of a structure that is similar to that of a rock which is good for the construction industry (Malkawi *et al.*, 2016).

Periwinkle shells are widely available in large quantity in almost all Niger Delta communities as waste materials (Mmom *et al.*, 2010). Dahunsi *et al.*, 2002 reported the use of periwinkle shell ash as partial replacement for cement in concrete production, which yielded a good result. Yabefa *et al.*, 2019 also reported the strength properties of a geopolymer binder incorporating periwinkle shell ash which showed good strength development. Hence, this study aims to produce geopolymer concrete using combination of periwinkle shell (PSA) ash and metakaolin (MK). The metakaolin was replaced in varying percentages by PSA to study its effect on the compressive strength of the geopolymer concrete (Hardjito *et al.*, 2005; Adam 2009).

2. MATERIALS AND METHODS

2.1 Materials

Periwinkle shells were calcined at a temperature of 800^{o}C to obtain the periwinkle shell ash (PSA) while Kaolin was calcined at a temperature of 750^{o}C to obtain metakaolin (MK) depending on their deferential thermal analysis (DTA) results respectively. After calcining, the source materials

ISSN 2229-5518

were then grinded and sieved in the BS sieve size of 75-micron before used in this study. The chemical and physical properties of PSA and MK are presented in Table 2.1 and Table 2.2.

A combination of sodium silicate (Na_2SiO_3) gel and sodium hydroxide (NaOH) solution was used as the alkaline liquid in this study. Sodium silicate solution in the gel form was bought from a commercial dealer at Lagos, its properties are given in Table 2.3. The sodium hydroxide in the pellets form with 98% purity was dissolved in crystalline water to prepare the solution. A 12 molarity concentration of sodium hydroxide solution was used in this study. A 12 molar concentration indicates that, 12x40 = 480grams of NaOH per litre of solution (Ranjini et al., 2014).

The fine aggregates used in this study are river sand sourced from the Bodija market in Ibadan. The sands were free from all forms or organic or visual impurities, hence conforming to the requirements of BS 882 (1982). The coarse aggregates used in this study were crushed granites sought from a local query in Ibadan, Nigeria. The physical properties are shown in Table 2.3 and Table 2.4 respectively.

Plate 2.1: Periwinkle shells

Table 2.1: The Chemical Composition of Periwinkle Shell Ash and Metakaolin

Constituent Oxide	**PSA (%)**	**MK (%)**
Silica Oxide (SiO_2)	13.88	65.45
Aluminium Oxide (Al_2O_3)	6.60	28.0
Ferrous Oxide (Fe_2O_3)	3.57	1.42
Calcium oxide (CaO)	59.05	3.23
Magnesium oxide (MgO)	1.02	0.00
Sodium oxide (Na_2O)	1.87	0.00

Potassium oxide (K_2O)	0.25	0.00
Lead oxide (P_2O_3)	0.52	0.14
Manganese oxide (MnO)	0.84	0.00
Sulphite (SO_3^{-2})	5.28	0.79
Vanadium oxide (V_2O_5)	0.03	0.0056
Copper oxide (CuO)	0.036	0.0003
Zinc Oxide (ZnO)	0.05	0.073
Loss on Ignition (LOI)	5.26	1.22

Table 2.2: Properties of Periwinkle Shell Ash (PSA) and Metakaolin (MK)

S/No.	Property	Periwinkle Shell Ash	Metakaolin
1.	Loss on Ignition	5.26	1.22
2.	SiO_2+ Al_2O_3+ Fe_2O_3	24.05	95.69
3.	Specific gravity	2.51	2.51

Table 2.3: Properties of Sodium Silicate

S/NO.	Constituents	Result
1.	SiO_2	34.78%
2.	NaO2	16.22%
3.	Water	49%
4.	Viscosity	400Cp
5.	Specific gravity	1.386

Table 2.4: Physical properties of fine aggregates

S/No.	Property	Result
1.	Specific gravity	2.38
2.	Bulk density	1760kg/m3
3.	Fineness modulus	2.69
4.	Water absorption	1%

ISSN 2229-5518

Table 2.5: Physical properties of coarse aggregates

S/No.	Property	Result
1.	Specific gravity	2.63
2.	Bulk density	1570kg/m3
3.	Fineness modulus	2.40
4.	Water absorption	1%

2.2 Mix Design for Geopolymer Concrete

The mix design for the periwinkle shell ash based geopolymer concrete was reached in accordance with the miodified guidelines for geopolymer mix proportions (Anutadha et al.,2012). Hence, the mix ratio for geopolymer solid, fine aggregates and coarse aggregates considered in this study was 1:1.5:3 which conform to the method used by Shivakumar *et al.*, (2017). Then the water to geopolymer solid (W/GPS) used for this study is 0.1 (Ragan 2014) to calculate for the volume of extra water. Therefore, the volume of extra water used = 0.1 × 380.69 = 38.069kg. This mix design for M25 geopolymer concrete is also in accordance with the modified guidelines for geopolymer mix proportions. Periwinkle shell ash to metakaolin ratio of 0:100, 10:90, 20:80, 30:70, 40:60 and 100:0 were used. The liquid to binder ratio and sodium silicate to sodium hydroxide ratios used were 0.8 and 2.5 respectively.

2.3 Mix Design for OPC Concrete

The conventional OPC concrete mix was made to produce control specimens by taking an equivalent mix ratio of 1:1.5:3 for cement, sand and granites respectively. This also conforms to Grade-25 concrete in accordance with IS 10262-1985. Hence, the mix propotions for the geopolymer concrete are calculated as follows;

Table 2.6: Mix proportions for OPC concrete specimens Mix 15

SAMPLE ID	OPC (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	w/c

Mix 15	436	654.5	1308.5	0.45

Table 2.3: Mix proportions for Geopolymer concrete specimens Mix 16

SAMPLE ID	PSA:MK	PSA (kg/m^3)	MK (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Na_2SiO_3 (kg/m^3)	NaOH (kg/m^3)	H_2O (kg/m^3)
Mix 16A	0:100	0	380.7	554.4	1293.6	122.36	48.95	38.10
Mix 16B	10:90	38.1	342.6	554.4	1293.6	122.36	48.95	38.10
Mix 16C	20:80	76.2	304.6	554.4	1293.6	122.36	48.95	38.10
Mix 16D	30:70	114.2	266.5	554.4	1293.6	122.36	48.95	38.10
Mix 16E	40:60	152.3	228.4	554.4	1293.6	122.36	48.95	38.10
MIX 16F	100:0	380.7	0	554.4	1293.6	122.36	48.95	38.10

2.4 Mixing, Casting and Curing

Cube size of 100mm x 100mm x 100mm were used for the casting of the concrete specimens. The alkaline solution was prepared a day before the day of casting. Concrete ingredients were properly dry mixed manually for 5 minutes before inclusion of alkaline liquid, and extra water. The internal surfaces of the moulds were lubricated with oil before the casting enhance easy demoulding. Newly casted cubes were demoulded after 24 hours at room temperature before elevated temperature curing at 90^{o}C for another 24 hours before specimens are allowed to cure at room temperature for 7, 28, 56 and 90 days before testing.

Plate 3.1: Geopolymer Concrete Mixing

3. RESUSLTS AND DISCUSSIONS

3.1 Sieve Analysis of Fine Aggregates

In this study, the fine aggregates used are river sands obtained from a local source, i.e. Bodija market in Ibadan, Nigeria. The sand was free from clay and organic impurities and sieved on the IS sieve size of 4.75mm. The tables below present the physical properties of fine aggregates such as gradation and fineness modulus which were tested in accordance with the IS:2386.

Table 2.4: Sieve Analysis of fine aggregates

S/NO.	Sieve Number	Weight Retained (g)	Percentage wt. Retained	Percentage wt. Passing	Cumm. wt. %Ret.
1.	4.75	7.2	1.81	98.19	1.81
2.	2.36	34.7	8.71	89.48	10.52
3.	1.18	96.2	24.16	65.32	34.68
4.	850	49.9	12.53	52.79	47.21
5.	600	47.9	12.03	40.76	59.24
6.	425	41.6	10.45	30.31	69.69
7.	212	50.6	12.71	17.6	82.4
8.	150	29.9	7.51	10.09	89.91
9.	75	35.6	8.94	1.15	98.85
10.	Pan	4.6	1.15		100
	Total	**398.2**			

Fineness modulus of fine aggregate = $\frac{\text{Cumulative percentage weight retained}}{100}$

$$FinessModulus(FM) = \frac{1.81 + 10.52 + 24.68 + 59.24 + 82.4 + 89.91}{100} = 2.69$$

Hence, the sand can be classified as medium class sand.

3.2 Compressive Strength

The compressive strength test result is shown in Table 3.1 and graphically illustrated in Figure 3.1 below. The normal conventional OPC concrete were casted for the grade-25, and the specimens were immersed in the water for curing for the required number of days before testing.

Plate 3.1: Concrete crushing

Table 3.1: Compressive Strength test of Geopolymer Concrete

Sample ID	**PSA:MK**	**7 days (N/mm^2)**	**28days (N/mm^2)**	**56 days (N/mm^2)**	**90 days (N/mm^2)**
M15CS	OPC	20.7	23.87	25.87	26.47
Mix $15A_C$	0:100	22.43	26.30	27.30	27.40
Mix $15B_C$	10:90	20.90	25.0	25.87	26.20
Mix $15C_C$	20:80	18.90	22.20	22.43	22.50
Mix $15D_C$	30:70	12.70	19.10	20.13	20.30
Mix $15E_C$	40:60	12.10	18.0	18.21	19.50
Mix $15F_C$	100:0	10.90	13.7	14.10	14.40

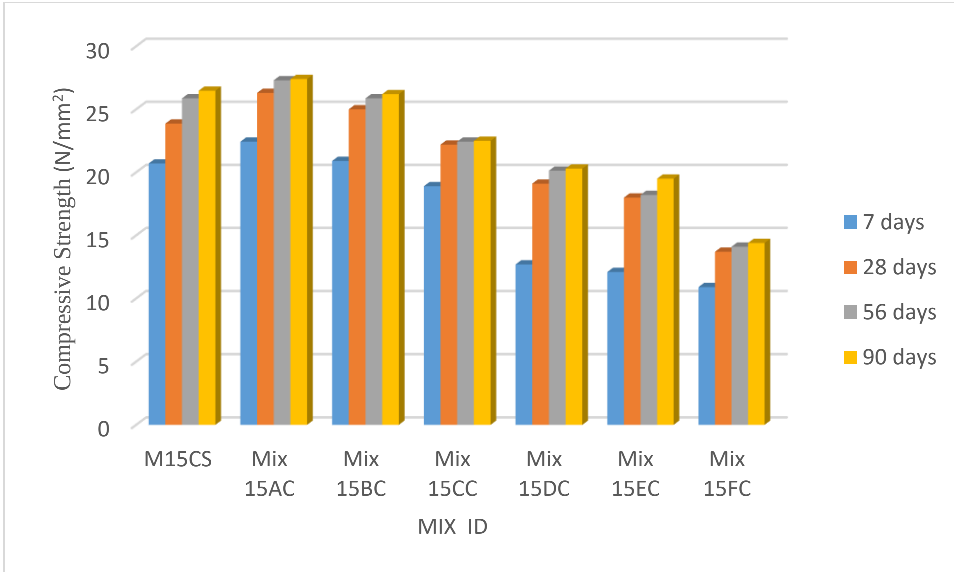

Figure 3.1: Compressive Strength of Geopolymer Concrete (N/mm^2)

Table 3.1 presents the average compressive strength at 7, 28, 56 and 90 days of Ordinary Portland cement concretes and the Geopolymer cement concretes produced with 0, 10, 20, 30, 40 and 100% of PSA blended with metakaolin. The result showed that, the compressive strength increased generally with increase in concrete curing days.

3.3 Water Absorption Test

The water absorption test was done in accordance with BSS 1881-122. The three specimens were placed in the drying oven for 72 ± 2 h. Then each specimen was weighed, and completely immersed in water for 30 ± 0.5 minutes. Each specimen was then removed and properly cleaned with dry cloth until all free water was removed from the surface. Then, each specimen was Weighed.

$$\% \text{ Absorption} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

Table 3.2: Water Absorption Test Result for OPC and GPC Concrete at 90 days

Sample ID	PSA:MK	Wet Weight (kg)	Oven Dry Weight (kg)	Water Gain	Average %Absobtion
Mix 15	**OPC**	2.51	2.36	0.15	**6.36**
Mix 16A	0:100	2.42	2.38	0.04	**1.82**
Mix 16B	10:90	2.38	2.30	0.08	**3.47**
Mix 16C	20:80	2.43	2.33	0.10	**4.14**
Mix 16D	30:70	2.49	2.37	0.12	**4.91**
Mix 16E	40:60	2.48	2.25	0.11	**5.10**
Mix 16F	100:0	2.39	2.26	0.13	**5.91**

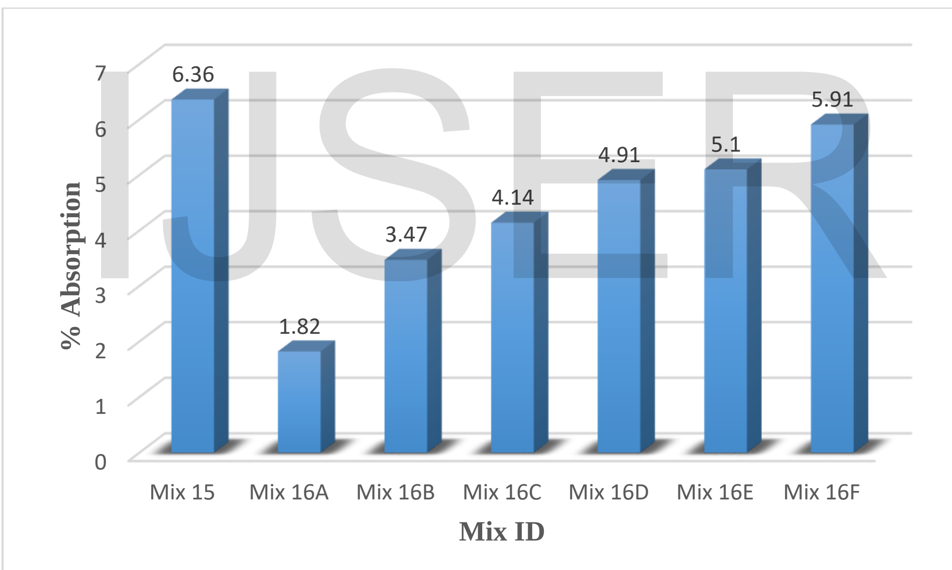

Figure 3.2: Percentage Water Absorption

Figure 3.2 presents an illustration of the average water absorption capacities of the various test specimens. Mix 15, which is the normal OPC concrete has the highest water absorption capacity of 6.36%, while the PSA based geopolymer has water absorption capacities ranging from 1.82%, 3.47%, 4.14%, 4.91%, 5.1%, 5.91% for the various specimens Mix 16A to Mix 16F respectively. Therefore, the percentage water absorption increased with increase in the percentage of periwinkle shells ash. However, the percentage absorption of the geopolymer is less than the OPC concrete in all the mixes.

4. CONCLUSION

1. The compressive strength test result showed that, increase in periwinkle shell ash resulted in decrease in the compressive strength of the geopolymer concrete.

2. The compressive strength of the concrete increased with increase in curing days in all the mixes.

3. The compressive strength of the geopolymer concrete with 0% PSA was higher than the OPC control, however, geopolymer concrete with 10%, 20%, and 30% of PSA also gave a substantial strength that can be used as a structural concrete.

4. The test result on water absorption of the concrete specimens showed that, percentage absorption of water increased with increasing content of periwinkle shell ash. However, the percentage absorption of water in all the geopolymer concrete specimens was less than the OPC control concrete.

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