Evaluating the Influence of Palm kernel Shell ash on Ire Clay Geopolymer Concrete Cured at Ambient Temperature

ABSTRACT

There is an abundance of clay deposit in Ire Ekiti which can serve as geopolymer source material and Palm kernel shell exist as a massive agro waste in south western Nigeria. This study evaluates the effect of palm kernel shell ash (PKSA) as an additive on the compressive strength of Ire clay geopolymer concrete. Palm kernel shell was burned at 650^{o}C for 2 hours in a furnace. Natural clay collected from Ire Ekiti was manually pulverized, air dried and calcined in a furnace at 750^{o} for 2 hours. The Geopolymer concrete was prepared at a mixing ratio of 1:2:3. The material constituents were calcined clay (source material), 12M of NaOH and Na_2SiO_3 (ratio of NaOH to Na_2SiO_3 was 2:5), river sand and 12.5mm granite were the fine and coarse aggregates respectively while PKSA of 0%,7.5% and 15% of the calcined Ire Clay content were used as additive in preparing the geopolymer concrete. Geopolymer concrete specimens were cured at ambient temperature till testing at different maturity ages of 7, 14 and 28 days. It was generally observed that increasing the percentage of PKSA as additive strongly improved the compressive strength gain with maturity of the Ire clay geopolymer concrete. At 28 days maturity, 7.5% PKSA addition improved the compressive strength by 166% while 15% PKSA addition improved the strength by 181% increase. The highest compressive strength was 7.67N/mm^2 at 15% PKSA addition on 28 day. Conclusively, Ire clay and PKSA are viable source material and additive respectively for geopolymer concrete production. Further study on the durability is recommended.

Keywords: Clay, geopolymer, Palm kernel shell ash, compressive strength, source material

1. INTRODUCTION

Due to its low cost, superior mechanical and physical qualities, low energy consumption, and reduced greenhouse gas emissions as compared to ordinary concrete, Geopolymer concrete has garnered a lot of interest [1] [2]. As Geopolymer concretes do not contain Portland cement and the powder binder utilized is typically an industrial/agricultural waste or minimally-processed natural material, it has been reported that they have a smaller carbon footprint than conventional concrete and are environmentally friendly [3].

The results of investigations on a variety of Geopolymer concrete's short- and long-term performances, as well as on large-scale reinforced Geopolymer concrete members, show that the material is appropriate for the production of precast concrete products used as structural elements in building construction [4]. According to reports, the Global Change Institute (GCI), located at the University of Queensland in Australia, is the first structure in the world to use structural Geopolymer concrete manufactured from slag and fly ash. Additional applications of Geopolymer concretes on-site have been reported [5] [6].

Researchers hypothesized that binders could be produced by reacting an alkaline liquid with silicon (Si) and aluminum (Al) in a geologically derived source material or in by-product materials such as fly ash, agro waste ash like rice husk ash. As a result, the word "Geopolymer" was created to characterize these binders because polymerization is the chemical reaction that occurs under such circumstances [1] [4]. When silica (Si) and aluminum (Al) materials are combined with alkaline activator solutions in a chemical reaction to form a Si - O - Al polymer link, Geopolymer paste is created. Typically, alkaline solutions consist of polysilicate materials that dissolve in a NaOH or KOH solution [7]. Research on

Geopolymer concrete is shifting from chemistry to engineering applications and commercial production according to [8] [9].

Alkaline activator solutions, silicon (Si), and aluminum (Al) rich source materials are the key components of Geopolymer. The raw ingredients for Geopolymer could include natural minerals like kaolinite and clays, as well as industrial or agricultural waste products including fly ash, rice husk ash, GGBFS, silica fume, and red mud [6] [10] . According to [11], as an activator in the geopolymerization process, solutions of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) can be used. Water is a component of a Geopolymer mixture, but it has no significant effect on the chemical reaction occurring there; it merely aids in producing a workable or uniform mixture [12].

[13] incorporated palm oil fuel ash (POFA) as a unique of the agricultural waste products that can be produced from palm oil, alongside palm fiber and shells. POFA has been studied as a pozzolanic material that can partially supplant Portland cement in concrete and other cement composites [7].

[14[discovered that increasing the amount of POFA in high-strength concrete reduces the water permeability of concrete, cement consumption, and the price of high-strength concrete. This application of POFA is deemed environmentally friendly because it reduces the quantity of waste sent to landfills.

The kind and nature of the raw materials, alkaline activators, and curing conditions have been recognized as the most influential aspects of geopolymerization. Typically, silica- and alumina-rich raw materials are utilized. Controlling the leaching of alumina and silica from raw materials is significantly influenced by alkali concentration [15]. Activation of silicates enhances the solubility of raw materials and generates advantageous mechanical characteristics. Diverse curing conditions are recorded for different raw materials and activators [16]. The majority of researchers have reported that geopolymer concretes are mostly cured at high temperatures [17] [18]. In addition, literature on the use of PKSA as an additive in geopolymer concrete is scant. This study endeavors to determine the impact of palm kernel shell ash as an additive on Ire clay geopolymer concrete cured at room temperature.

2. MATERIAL AND METHODS

2.1 Materials

a. Natural clay soil collected from Ire Ekiti, southwestern Nigeria, was pulverized manually and calcined by heating the natural clay at 750^oC in a furnace for 2 hours. The calcined clay (CC) was used as a source material.

b. Palm kernel shells (agricultural waste material) were collected in sacks from a local oil palm mill in Ijan Ekiti, southwest Nigeria. The empty shells were washed and sun-dried, they were calcined under controlled burning at 650^oC for 2 hours. The collected ash was further ground into a finer consistency. The ashes were sieved using a 75um sieve to remove any foreign matter and larger ash particles; only the fine ashes that passed through the 75um sieve were collected. In this work, palm kernel shell ash (PKSA) was employed as an additive in the manufacturing of Geopolymer concrete.

c. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were chosen as activators since they are the most established and manageable alkali materials due to the ease of handling them as well as being the commonest available activators. The proportion of Sodium Silicate (Na_2SiO_3) to Sodium Hydroxide (NaOH) was ratio 2:5. Sodium Hydroxide has a molecular weight of 40. 480 grams of sodium hydroxide were dissolved in 1000 milliliters of water to create a 12 mol solution (12 x 40 = 480). To make 480 grams of sodium hydroxide (NaOH), one liter of sodium silicate (Na_2SiO_3) was used. Distilled water was used in diluting the alkaline to the required molarity.

d. The fine aggregates used was naturally occurring river sand obtained from Ado Ekiti metropolis. On physical inspection, it was free from debris, clay and impurities. The river sand conformed to [23] grading zone II.

e. The coarse aggregate used was 12 mm crushed granite collected from a quarry site in Ekiti State, southwest, Nigeria. The aggregates passing through sieve size 12mm downward to the 4mm sieve were used.

2.2 Preliminary tests on materials

Chemical analysis of the calcined clay (CC- source material) and palm kernel shell ash (PKSA-additive) were performed in the laboratory to determine their chemical constituents. Specific gravity of the CC and PKSA were also determined.

While the clay and silt content was determined using the field settling method, the specific gravity, water absorption, and particle size distributions (dry sieving method) were carried out for the coarse and fine aggregates in accordance with [19] [20] [21] , respectively.

2.3 Sample preparation

The specimen was prepared by both weight and volume batching; the additive, source material and the aggregates were batched by weight while the alkaline solution was done by volume. A design mix ratio of 1:2:3 Geopolymer concrete mass (indicating 1 part Geopolymer gel, 2 parts fine aggregate &3 parts coarse aggregate) was adopted. PKSA was included as additives in proportion of 0 %, 7.5 % and 15% of the source material (CC) in respective batches of the mix. The proportions of the material constituents are depicted in Table 1.

The fresh Geopolymer concrete was compacted in three layers into the prepared 50 ×50×50 mm^3 steel cube. The cubes containing the fresh Geopolymer concrete were covered with large polythene sheet to avoid evaporation. After casting for 24 hours, Geopolymer concrete cube samples were demolded and properly labeled. Three test samples were cast for varying testing ages of 7, 14, and 28 days. The test samples were cured at room temperature in open air in the laboratory till the specified testing age.

Table 1: Material Constituents Proportion

Materials	GCP0%	GCP7.5%	GCP15%
Alkaline mixture (cm^3)	96.3	96.3	96.3
Calcined clay (source material) (g)	316.5	316.5	316.5
River sand (fine aggregate) (g)	633.0	633.0	633.0
Granite (coarse aggregate) (g)	949.5	949.5	949.5
PKSA (Additive) (g)	0	23.74	47.48
Additive (%)	0 %	7.5 %	15 %

2.4 Specimen Testing

The compressive strength test was performed using a wizard basic compression test machine that was electronically controlled. The test specimens were positioned in the hydraulic testing frame and a force was supplied until failure. The prism halves were centered relative to the machine's plates to within 0.5 mm and longitudinally so that the end face of the prism overhangs the plates by roughly 10 mm. The highest force exerted and specimen dimensions were subsequently recorded, and the specimen's compressive strength was calculated.

3. RESULTS AND DISCUSSION

3.1 Oxide composition

The oxide compositions of the calcined clay (CC) and the palm kernel shell ash (PKSA) are presented in Table 2. Silicon oxide (SiO_2) content in the clay and the PKSA were 58.96 % and 55.20 % while aluminum oxide (Al_2O_3) contents were 19.85 % and 12.1 % respectively. However, the Fe_2O_3 content in PKSA (7.92%) was more than twice the content in CC (3.31 %). It was also observed that all the other oxides safe CuO are higher in PKSA compared to CC. The sum of the SiO_2, Al_2O_3 and Fe_2O_3 in CC and PKSA were 82.12 % and 75.22 %, respectively. The results indicated that clay is an exceptionally good source material for geopolymer concrete.[22] [11] observed similar effect. PKSA as an additive, has an amorphous nature with high silica content, thus, owing to its high pozzolanicity, it is anticipated that it will enhance the qualities of geopolymer concrete.

Table 2: Oxide composition of calcined clay and PKSA

Oxides	Ire calcined clay (%)	Palm kernel shell ash (%)
SiO_2	58.96	55.2
Al_2O_3	19.85	12.1
Fe_2O_3	3.31	7.92
CaO	0.36	5.42
P_2O_5	0.11	3.15
K_2O	0.23	4.32
MgO	0.38	3.3
Na_2O	1.91	2.1
MnO	0.01	0.2
CuO	0.21	0.05
LoI	11.26	2.21

3.2 Physical properties of materials

The summary of chosen aggregate physical attributes is presented in Table 3. As required by [23], the clay and silt concentration of the river sand is less than 4%. The specific gravity of granite is 2.80, while its water absorption is 1.30. In addition, the fine aggregate consists of well-distributed, clean river sand with a specific gravity of 2.67 and a water absorption of 2.3, as shown in the table. Specific gravity of aggregates (fine and coarse) contributes to concrete strength [24]. The values as presented in Table are in tune with reported values for fine aggregates and coarse aggregates. Result of particle size distribution result is depicted in Figure 1. The result indicates that the size of the coarse aggregate used ranges between 12.5mm and 4.75mm. According to [25], such size range of aggregate is suitable for concrete work.

Table 3: Material properties

Properties	Calcined Clay	PKSA	River sand	Granite
Specific gravity	2.57	1.38	2.67	2.8
Water absorption %	-	-	2.3	1.3
Clay content %	-	-	0.46	0.23
Colour	Reddish brown	Black	Light brown	Blueish grey

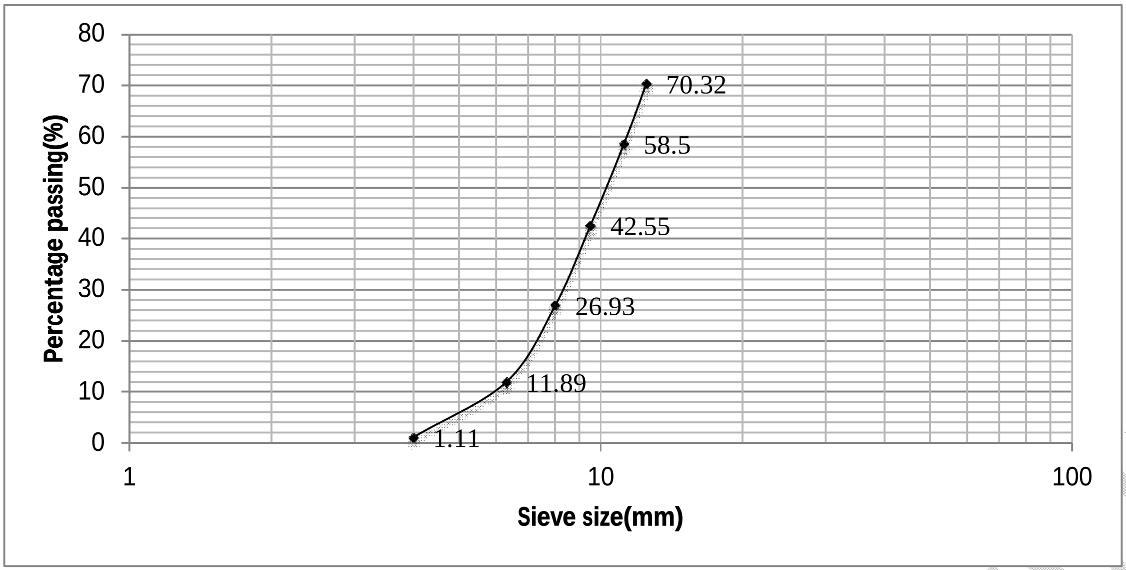


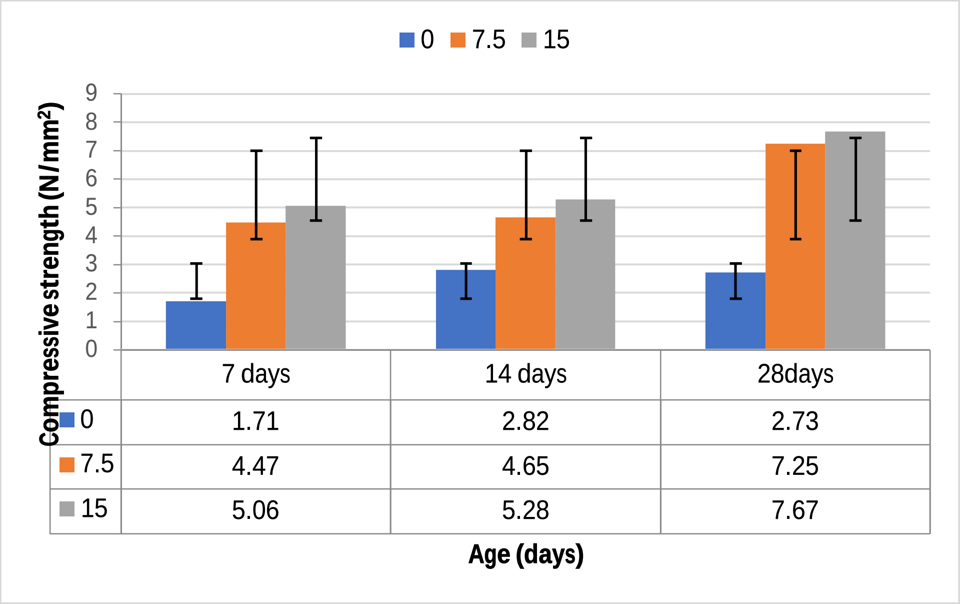
Figure 1: Sieve analysis for coarse aggregate.

3.3 Compressive strength

Figure 2 illustrates the compressive strength values of Ire clay geopolymer concrete with PKSA as an additive, cured at room temperature in open air for 7, 14, and 28 days. As a result of the curing's enhancement of continuous hydration, the compressive strength of the samples progressed with age. At 7 days and 28 days, the compressive strength values were 1.71N/mm^2 and 2.82N/mm^2, respectively, the control sample without additive increased in compressive strength by 65 percent.

At 7days maturity, addition of 7.5% and 15 % PKSA had improved the compressive strength by 161% and 196 % increments respectively. At 14 days maturation, the compressive strength of Ire clay Geopolymer concrete with 7.5% and 15% PKSA addition increased by approximately 65 and 87 percent, respectively, compared to the values at 7 days maturity. At 28 days maturity, the addition of 7.5% PKSA increased compressive strength by 166%, whilst the addition of 15% PKSA increased strength by 181%. Generally, it was noticed that increasing the proportion of PKSA as an additive has a beneficial effect on the increase in compressive strength with age of Ire clay Geopolymer concrete.[26] [7] noted similar performance when they used agro waste ashes in concretes. This finding is attributable to the filler action of the PKSA in the Geopolymer composite. The additive must have refined the pore structure of the concrete. [13] reported similar characteristics of agricultural wastes ash in concrete.

Even when cured at room temperature, the compressive strength of Ire Geopolymer concrete increased with age. It is common and typical for the compressive strength of concrete to increase with age. This is a result of the geopolymerization process resulting in increased strength.



	7 days	14 days	28days
🟦 0	1.71	2.82	2.73
🟧 7.5	4.47	4.65	7.25
⬜ 15	5.06	5.28	7.67

Figure 2: Effect of PKSA as additive on the compressive strength of Ire clay geopolymer concretes

4. CONCLUSIONS

The impact of PKSA as an additive on Ire clay Geopolymer concrete cured at room temperature has been assessed. Increasing the PKSA content as an additive has a favorable impact on the rise in compressive strength with age, even when Geopolymer concrete is cured at room temperature. Ire clay and PKSA are viable materials and additives for the creation of Geopolymer concrete, respectively. This will increase the application and acceptance of Geopolymer in underdeveloped regions such as Ire Ekiti and other rural areas.

To establish the durability performance of Ire clay goepolymer concrete with PKSA, additional research is required. In addition, different additives may be used to increase the qualities of Ire Clay Geopolymer concrete for widespread structural applications.

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