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COMPARATIVE STUDY OF THE COMPRESSIVE STRENGTH OF KAOLIN-BASED GEOPOLYMER AND STANDARD SANDCRETE

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ABSTRACT

This paper investigates the possibility of producing a durable geopolymer sandcrete with natural kaolin obtained from Kutigi, Niger State, Nigeria. The geopolymer sandcrete was cured at elevated temperature (100 ^oC) and its compressive strength was compared with that of the conventional sandcrete. The polycondensation process of aluminosilicate mineral using alkaline activator significantly influenced the compressive strength of the geopolymer sandcrete. It was observed that the geopolymer sandcrete unlike the control (standard sandcrete) showed increased compressive strength by 92.6% after 28 days of curing in ambient conditions. The initial high thermal (100 ^oC) condition could have resulted in the enhanced dissolution of aluminosilicate monomer which supports the development and refinement of the microstructure coupled with increased polycondensation process, hence the increased compressive strength observed in the geopolymer sandcrete.

1. INTRODUCTION

It is widely acknowledged that global warming is caused by high concentration of greenhouse gases (GHG) such as carbon dioxide (CO_2) in the atmosphere (Abdullahi et al., 2016; Naik and Kumar, 2010). To avoid the irreversible effects of climate change, GHG emissions must be stabilized and reduced within the shortest possible time (Budzianowski, 2012). Portland cement is an indispensable construction material, which plays a tremendous role in infrastructure development in developing countries (Abdullahi et al., 2016; Gambhir, 2007); however, there are numerous new challenges attributed to its ever increasing usage. Research has shown that cement production utilizes large quantities of raw materials coupled and it is highly energy-intensive, thus leading to high emission of carbon dioxide. About 1000 kg of carbon dioxide gas is discharged into the atmosphere for every 1000 kg of ordinary Portland cement (OPC) produced (Fernando et al., 2008). About 7% of the global carbon dioxide emission into the atmosphere comes from cement industries (Mehta, 2001). Hence, there is a need to find alternative types of cement for the production of sandcrete which is environmentally friendly. A potential alternative in the reduction of environmental impact from sandcrete industry and its availability in lowering the overall production cost is the use of natural kaolin for geopolymer production.

Davidovits (1994) developed an ecofriendly binder called geopolymer as a result of polymerization process of aluminosilicate from geological origin or by-product materials, such as fly ash and slag with alkaline solutions. Geopolymer is a green cementitious binder compared to ordinary portland cement because it does not depends on limestone calcinations that produces CO_2 (Davidovits, 1994). Research has shown that thermal curing of geopolymer could significantly improve the compressive strength through enhanced reaction kinetics (Somaratna et al., 2016; Huang et al., 2016). However, extensive investigations into the possibility of increasing the green credentials and durability of geopolymer at ambient conditions are on-going. Kwasny et al. (2016) has shown that it is possible to cast structural elements within 3 – 12 hours without external heat to enhance the compressive strength development. Most of the recent research on the engineering properties of sandcrete focused on the CO_2 sequestration using kaolin for partial replacement of cement. On the other hand, only limited information is available on the properties of geopolymer sandcrete in the developing countries like Nigeria.

The objective of this research was to study the compressive strength of geopolymer sandcrete cured at an elevated temperature at varying age and to compare the strength with that of the conventional sandcrete.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Ordinary Portland cement

Dangote brand of ordinary portland cement (OPC) with ISO 9001: 2008 meeting NIS 444-1:2003 (SON/MAN CAP/CB/4211) was used throughout the investigation for the production of standard sandcrete (control). The chemical composition of the cement was obtained from X-ray Fluorescence (XRF).

2.1.2. Fine sharp sand

Natural sharp sand with particle size distribution conforming to American society for testing and materials (ASTM) was used for the investigation. The fine aggregate was cleaned free of clay, loam, dirt and organic matter. The particle size distribution of the aggregate was carried out using a mechanical sieve shaker stack of British Standard sieve (H-4325). The siliceous sand had a specific gravity of 2.66, an average moisture content of 0.92% and coefficient of uniformity of 2.95.

2.1.3. Supplementary aggregate material

Natural Kaolin from Lavun local Government area of Niger State, Nigeria was used throughout the investigation as aluminosilicate precursor material for the production of the geopolymer sandcrete. The particle size distribution of kaolin used is shown in Figure 1 with coefficient of uniformity of 2.

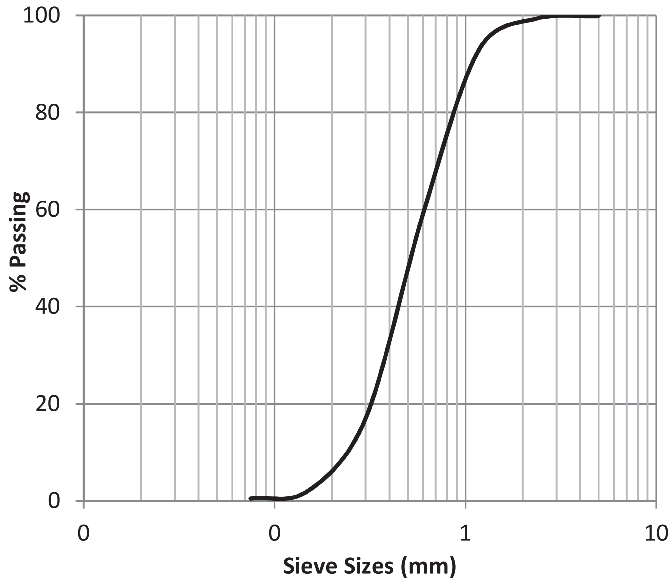


Figure 1: Particle size distribution of kaolin

2.1.4. Potable water

Potable water obtained from Federal Polytechnic bore-hole in Bida, Niger State, Nigeria that conformed to NIS 554: 2007 was used for the investigation.

2.1.5. Characterization of starting materials

The starting materials (Natural Kaolin, Cement and aggregates) for the research work were characterized using X-ray Diffractometer (XRD) (Model: DY614 Empyrean by Panalytical), Scanning Electron Microscopy (SEM) (Field Emission Gun Nova NanoSEM 230) and Dispersive X-ray Fluorescence (EDXRF) (Model: MiniPal4 embedded with X'pert HighScore Plus Software) to determine the mineralogical compositions, the microstructural changes and oxides compositions respectively.

2.1.6. Activator

A mixture of analytical grade sodium hydroxide (97% purity) and Sodium silicate solution (Na_2O-3.72%, SiO_2-34.16% and H_2O-47.2%) was used in the present investigation as the catalytic liquid for the production of the geopolymer sandcrete.

2.1.7. Specimen preparation

Currently, no standardized mixed design for geopolymer sandcrete is available, hence mixes are designed by trial (Kishanrao, 2013). Two sets of sandcrete specimens designated as "C" and "G" of the same workability per set were prepared. The first set "C" constituted the control (standard sandcrete (S-S)) and consisted of fifteen (15) different specimens labelled C_1 to C_{15} with a constant standard mix design proportion based on NIS (2000). The second set "G" is geopolymer sandcrete (G-S) specimens for which the cement was completely substituted with natural Kaolin. The geopolymer sandcrete consisted of 15 different samples (G_1 to G_{15}) with 14 M concentration of NaOH solution. The mix design proportions are presented in Table 1.

Table 1: Mix design proportion for standard sandcrete and geopolymer sandcrete

Mix Design ID	C	G
Cement (g)	33.70	-
Sand (g)	202.3	202.3
Kaolin (g)	-	33.70
Water (g)	16.85	16.85
NaOH (g)	560	560
Na_2SiO_3 (g)	560	560
Molarity (M)	14	14
Curing Temperature (^oC)	25-30	100
Initial curing Age (day)	1-28	1-28

2.2. Specimen Production

The method adopted by Abdullahi et al. (2016) for sandcrete production was adopted. The standard sandcrete and geopolymer specimens were prepared using a fixed cement-to-sand and kaolin-to-sand ratio of 1:6 (NIS 87: 2000), a water-to-cement ratio (W/C) of 0.5 (NIS 87: 2000) and potable water that conformed to NIS (554: 2007) was used for preparing the mortars. The concentrations of activator liquid were determined by dissolving a known mass of sodium hydroxide in 1 dm^3 of distilled water. The prepared sodium hydroxide solution was mixed with the solution of sodium silicate in the ratio of 1:1 according to Budh and Warhade (2014). The concentration of NaOH solution used in preparing the geopolymer samples was 14 M. Geopolymer sandcrete samples were prepared by mixing the pulverised kaolin and alkaline solution in a planetary mixer for 5 minutes. The siliceous sharp sand was mixed into this geopolymer mortar paste for 5 minutes. The mortar samples were rammed into a mould of size 50 mm x 50 mm x 50 mm in two layers, compacted and smoothed. The specimens were fully compacted by hand using a standard tamping bar according to Gambhir, (2007). After casting, the geopolymer sandcrete samples were left at ambient conditions for 2 hours and were cured in an electric oven at 100 ^oC for 12 hours. The samples were demoulded and stored at ambient conditions until tested.

2.3. Compressive Strength Test

The compressive strength test for Standard sandcrete (S-S) (C), Geopolymer-sandcrete (G-S) (G) mortar were carried out at 1,7, 14, 21 and 28 days of curing in ambient conditions using Hydraulic Powered Press Machine Model No. 526 (OGAWA SEIKI CO., LTD., Tokyo, Japan).

3. RESULTS AND DISCUSSION

3.1. Characterization of Starting Materials

The oxide compositions of the starting materials are presented in Table 1 while the morphological and mineralogical compositions are shown in Figures 2 and 3 respectively. The analysis of the composition showed that mineral kaolin consist of 46.08% SiO_2 and 38.34% Al_2O_3 as the primary components required for the geopolymerization reaction. This is in agreement with literature (Kusbiantoro *et al.,* 2012; Davidovits, 1994). Figure 2 presents a typical SEM micrograph of sand and kaolin crystal grits before mixing. The degree of homogenization could be attributed to the enhanced mineral dissolution during production of the sandcrete samples. The XRD patterns of kaolin and sand presented in Figure 3 indicate heterogeneous compositions with peaks of graphite, kaolinite, rutile, silica and magnesium silicate.

Table 2: Comparative oxide compositions of sand, cement and kaolin as determined by XRF

Compound	Sand (%)	Cement (%)	Kaolin (%)
SiO_2	93.58	15.71	46.08
Al_2O_3	0.93	3.87	38.34
Fe_2O_3	1.13	2.47	0.19
TiO_2	0.28	0.18	0.67
CaO	0.82	61.09	0.26
MgO	0.11	1.15	0.16
Na_2O	0.42	0.12	0.21
K_2O	0.95	0.37	0.43
MnO	0.058	0.02	-
BaO	0.14	-	-
LOI	1.36	11.22	13.66

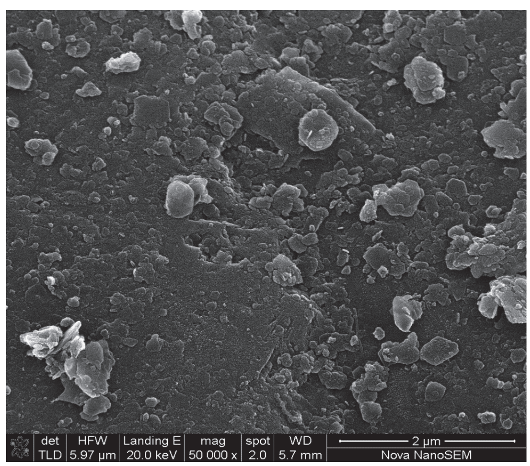


Figure 2: SEM photomicrograph of sand and kaolin mixture

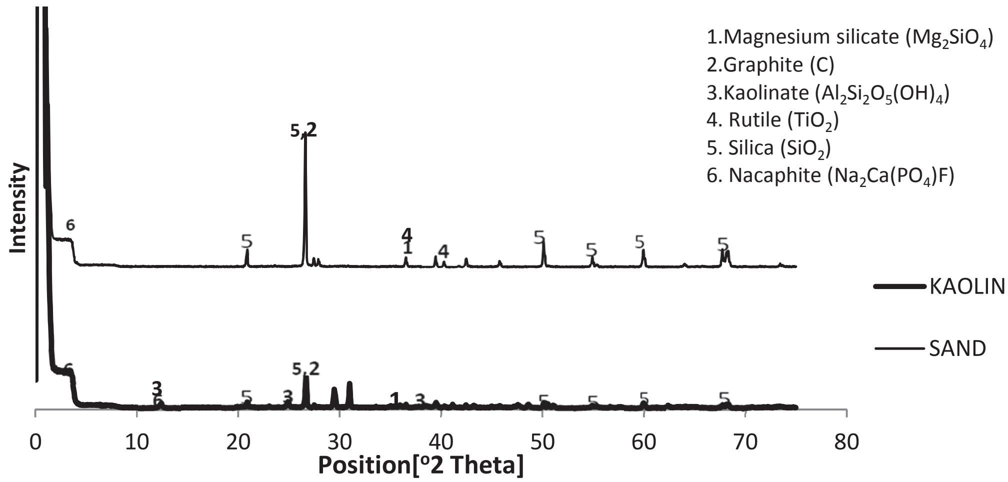
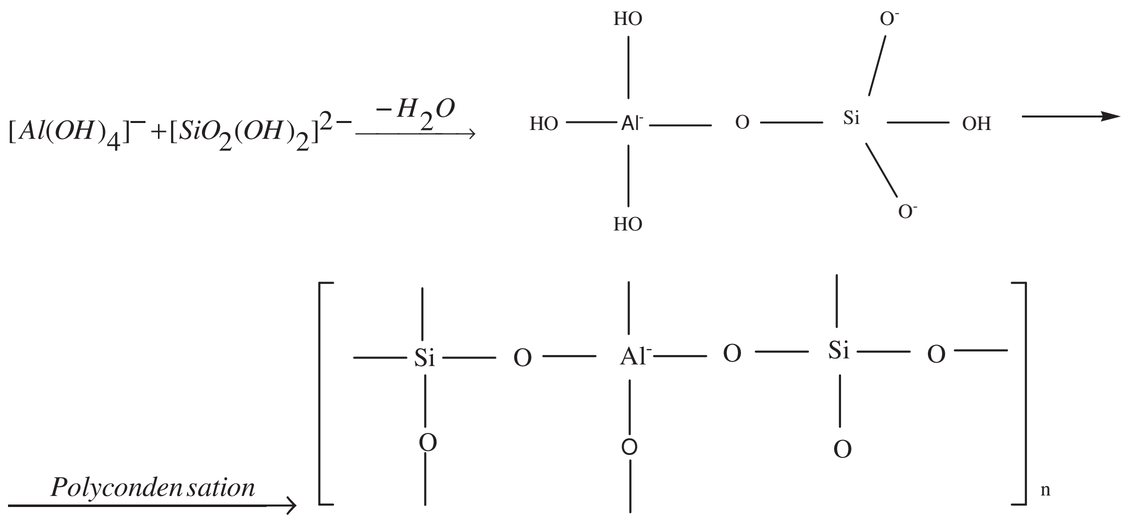


Figure 3: Comparative XRD analysis of sand and kaolin

3.2. Compressive Strength

The basic indicator that shows the performance of hardened sandcrete is the compressive strength, since it provides a fundamental description on the quality of products (Kusbiantoro et al., 2012). The compressive strengths of 1 – 28 days for standard sandcrete (S-S) and geopolymer sandcrete (G-S) samples are presented in Figure 4. The results showed an increase in compressive strength with age. The compressive strengths for S-S (control) varied from 1.4 to 3.59 MPa while G-S varied from 45.2 to 49.1 MPa after 28 days of curing in ambient conditions. The control sandcrete composite exhibited lower compressive strength compared to geopolymer composites. This could be attributed to the absence of admixture (pozzolans) necessary for the formation of more calcium-silicate–hydrate (C-S-H), high porosity due to possible leaching of portlandite and slow carbonation reaction in the matrix composite (Abdullahi et al., 2016). Odigure (2002) also reported similar results. However, the increased compressive strength for the geopolymer sandcrete could be attributed to the high initial curing temperature at an early age and the concentration of alkaline activator coupled with high percentage of silica and alumina (SiO_2 and Al_2O_3) compounds in the natural kaolin as indicated by the XRF analysis. Zuhua et al. (2009) reported high compressive strength on geopolymer made from calcined kaolin cured at 80 °C. The mobilization of Si^{4+} and Al^{3+} ions appears to be key to increasing mechanical performance of the geopolymer sandcrete when compared with the control. During the production of geopolymer sandcrete, the transportation of hydroxyl ion onto kaolin particle increases the dissolution of aluminosilicate species and consequently the gelation of supersaturated aluminosilicate solution as indicated by the assumed possible reactions (Equations 1 and 2) (Rovnanik, 2010).

$$2SiO_2.Al_2O_3 + 3OH^- + 3H_2O \rightarrow 2[Al(OH)_4]^- + [SiO_2(OH)_2]^{2-} \quad (1)$$



(2)

In addition, the curing of the geopolymer sandcrete at elevated temperature showed increased dissolution of alumina and silica precursor from kaolin through polymerization of hydroxide ions (Teoreanu, 1991). The formation of Al-Si bond coupled with the polycondensation reaction in geopolymer sandcrete sample could have resulted to the increased compressive strength with age.

It was also observed that the absence of excess water during geopolymer sandcrete production coupled with external exposure conditions presented a consistent strength development trend as depicted in Figure 4. During the dissolution of mineral kaolin, the Al-O and Si-O bonds on kaolin surface are broken as they are subjected to the polymerization effect of OH^-.

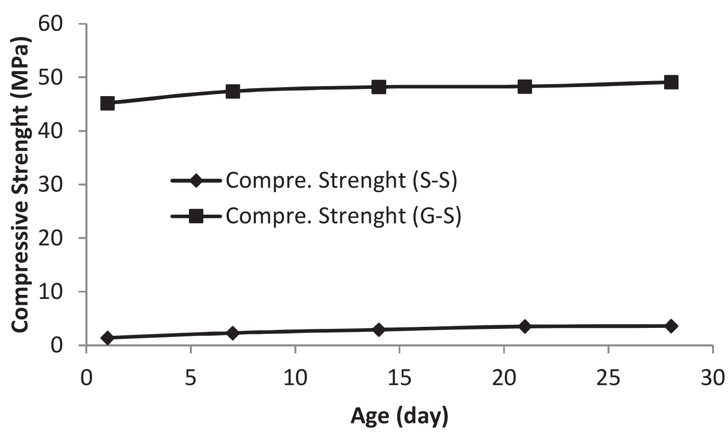


Figure 4: Compressive strength of standard sandcrete and geopolymer sandcrete at varying age

The high temperature is used to enhance and to generate more OH^- ions in the solution. At this elevated temperature, more Al-O and Si-O bonds are broken hence rapidly producing supersaturated aluminosilicate solution for further polycondensation. High dissolution rate of silica species from kaolin particles supports the coagulating mechanism of Na^+ with dissolved monomeric silicate to construct more geopolymer gels hence provide more connectivity to resist high load (Wijnen et al., 1990; Rangan, 2008). Excess Water hindered the polycondensation process as well as the hydroxide activity in the sandcrete system (Tevreanu et al., 1991).

4. CONCLUSION

This research work was aimed at evaluating the potentiality of Kutigi kaolin as a raw material for producing geopolymer sandcrete and to carry out comparative strength analysis with standard sandcrete. In this study, the effect of ambient curing temperature and age of standard sandcrete and kaolin based geopolymer was carried out as it affects compressive strength development with age. The increased compressive strength at an early age could be attributed to the enhanced polycondensation reaction at high curing temperature and Kutigi kaolin is a potential mineral for the production of durable geopolymer sandcrete for developing countries.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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