UJEAS

UNIZIK JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 5(1), June (2025), 2086-2097
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Preliminary Investigation of the Material Properties of Metakaolin Based Geopolymer Concrete (MKGPC) Using NaOH and Na_2SiO_3 as an Activator

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Abstract
The study focus on the material properties of MKGP concrete. Metakaolin to alkaline liquid ratio (MK/AL) used was 0.8 with grade 20 concrete. The highest soundness value recorded at mix ratio 1:4 for 8M and 12M molar concentration was 1.3mm and 1.1mm respectively. Which clearly indicates that the MKGP is unsound as the value gotten was below 10mm. Also, for 8M molar concentration the initial alkaline liquid ($NaOH:Na_2SiO_3$) ratio for 1:1 and 1:4 are 48mm and 18mm and final setting time alkaline liquid ratio for 1:1 and 1:4 are 216mm and 83mm. Similarly, for 12M molar concentration the initial ALr ($NaOH:Na_2SiO_3$) for 1:1 and 1:4 are 39mm and 15mm and final setting time ALr for 1:1 and 1:4 are 175mm and 79mm. This implies that initial and final setting time decreases with decrease in NaOH content and an increase Na_2SiO_3 content also reduce the setting times. The highest slump value obtain for 8M and 12M concentration was 133mm and 124mm respectively at ALr 1:4. This shows that increase in molarity of NaOH decreases workability and a gain in workability was record due to increase in sodium silicate content. XRF result of metakaolin shows that Al_2O_3 and SiO_2 content is 93.92% which indicate a good pozzolanic material. The compressive strength of the material increased as the curing age increases. More so, it was observed that for 8M and 12M molar concentration, the highest compressive strength was 28.8 N/mm^2 and 29.7 N/mm^2 respectively and was obtained at a mix ratio of 1:3.

Keywords: Geopolymer concrete, metakaolin, workability, setting times and soundness

1. Introduction

The progressive increase in the demand for concrete highly depend on the continue intake of Portland cement as a building materials. It was established (Oluwafemi *et al.*, 2024) that from the year 1995 to 2022 the production of Portland cement has tremendously increase from 1.5 to 4.1 billion metric tons respectively. However, climate change for many years has become a worrisome fact in which the major causes are the cement manufacturers by emitting harmful (greenhouse) gases like CO_2 into the atmosphere. It was also established that about 2.4 Giga tons of CO_2 which constitute to approximately about 26% of global emissions are from cement industries (Oluwafemi *et al.*, 2024). Several researchers like (Dalhatu, 2017) have develop cementious supplementary product such as granulated blast furnance, fly ash which are waste from industries and local available product like metakaolin and rice husk ash to replace Portland cement.

Metakaolin is used in this research as the source material and according to Sanjay *et al.*, (2013), metakaolin is obtained by heat-treating of kaolin, a natural, finely divided, alumina silicecous mineral to remove impurities and it is abundant in Nigeria. According to Getso (2014), Kaolin can be obtained in abundance from approximately about 16 states in Nigeria. Geopolymer was found to be an alternative material to Portland cement due to its merit in terms of environmental protection and energy utilization since 50% of energy saving is achieved during manufacturing as compared to normal concrete (Thamilselvi *et al.*, 2017). Geopolymerization is the chemical reaction that take place between silicate (Si), aluminate (Al) and naturally available source materials such as metakaolin obtain by calcination of kaolin at a very high temperature ranging from (650 ^{0}C to 850 ^{0}C) or as fly ash which is an industrial waste with alkali liquids or activators combine to develop or form geopolymer binders content Ma *et al.*, 2018 and Morsy *et al.*,

2014. The weightiest constituents material in geopolymer concrete mixed production are alumina to silicates ratio constituents in metakaolin formulation, which is anticipated to range from 1.5 to 5.08% to form the geopolymer product (Bello *et al.*, 2023). Geopolymer paste or gel refers to as the latest species of concrete cementing agent due to its minimal emission and conservation of CO_2. It is also referred to as the latest binder of the 21st century and this is because no Portland cement is added to the mix. However, there is urgently need to check the suitability of the material properties of metakaolin based geopolymers for its benefic in terms of environmentally friendly, ease of production and strength enhancement to the traditional concrete.

2.0 Materials and methods

2.1 Materials

The material use in this research study are portable water, Na_2SiO_3, and NaOH of Analytical grade, BDH Chemical England, Kaolin obtain from Kankara, Katsina, Metakaolin obtain by calcinations of kaolin at the Dept. of Chemical Eng. ABU Zaria, fine Aggregate and Coarse Aggregate obtained in Zaria.

2.2 Methods

2.2.1 Raw kaolin analysis and its beneficiation into metakaolin

The Raw Kankara kaolin clay, was sourced from Kankara village in Katsina state, Nigeria. 10 g of the sample was taken for XRF analysis which was carried out as adopted from the work of Dewi *et al.,* (2018). The clay was crushed using a mortar and pestle in order to size reduce larger lumps of the clay. It was then soaked in water to break up the small lumps and the colloidal suspension. It was then allowed to stand for three days in which it was periodically stirred and fresh water added after removing the previous one daily by decantation method. This is to remove the soluble impurities in the clay. The kaolin suspension thereafter was sieved twice using a 50-micron sieve in order to get rid of the intermediate coarse particles on the third day. The kaolin fraction obtained at this stage is referred to as fully beneficiated sample. The beneficiated clay was then dried at 120°C over night to ease handling and obtain zero moisture content. Subsequently, the fully beneficiated sample was characterized using X-ray spectrometry by adopting the standard procedure.

2.2.2 Properties of Metakaolin based Geopolymer Paste (MKGPP) for both 8M and 12M Molar Concentration.

2.2.2.1 Consistency Test of MKGPP

The consistency test conducted on MKGPP was in accordance with BS EN 196-3 (2005), using the Vicat apparatus at the Dept. of Civil Eng. ABU Zaria.

2.2.2.2 Setting Times Test of Metakaolin based Geopolymer Paste (MKGPP)

The setting times test performed on MKGPP was done in accordance with BS EN 196-3 (2005), using the Vicat apparatus at the Dept. of Civil Eng. ABU Zaria.

2.2.2.3 Soundness Test of Metakaolin based Geopolymer Paste (MKGPP)

The test carried out on MKGPP was in accordance with BS EN 196-3 (2005) at the Dept. of Civil Eng. ABU Zaria.

2.2.3 Investigation into the Effect of $NaOH:Na_2SiO_3$ on Geopolymer Concrete

Compressive strength and slump test were the testes that was performed on the geopolymer concretes which are done with respect to BS EN 12390-2:(2009). Geopolymer concrete cubes (100mm by 100mm) was casted by mixing the metakaolin proportion and the alkaline activators (Na_2SiO_3: NaOH) together. The change in molarity and the activators ratio was examined in order to establish a homogenous mix formulation. The concentration was varied from 8M to 12M molar concentration and the alkaline liquid ratio range from 1:1 to 1:4 of ($NaOH:Na_2SiO_3$). The activators (NaOH) were prepared and mixed in a well proportion manner while allowing it to rest for 24 hours. The metakaolin, fine and coarse aggregate with the activators and additional water was mixed in an electric concrete mixer which was later placed in the mould. It was then placed on an electric table vibrator for adequate compaction based on BS EN 12390-2:(2009). It was later de-mould after 24hrs and it was subjected to various curing days.

2.2.4 Mix Design for Metakoalin Based Geopolymer Concrete

The absolute volume method was used to design a concrete having a strength of 20 N/mm^2. A mix ratio of 1:1.5:3 for metakaolin, fine and coarse aggregate respectively. MK/Alkaline liquid ratio of 0.8 was used in designing a grade 20 geopolymer concrete.

2.2.5 Curing of Geopolymer Concrete.

The concrete specimen was cured in two separate ways i.e at ambient and oven cured. The ambient curing was done after 24 hours of casting then the sample is de-mould and insert in a polyethylene bags. It is allow to rest at room temperature for the next curing days. Similarly, oven curing was carried out after 24 hours and then de-mould and it was also inserted in a polyethylene bags to enhance the polymerization process which result to higher compressive strengths. The samples were then put in an electric oven at 60 ^{0}C for the next 24 hours after which is allow to rest for the next curing days.

2.2.6 Compressive strength properties.

The compressive strength tests was carried out based on BS EN 12390-2 (2009) on 42 concrete cubes (100mm × 100mm × 100mm) specimens for both 8M and 12M molar concentration with the aid of universal testing machine of 2500kN maximum capacity. The tests were performed at 7, 14, 28 and 56 days curing period for both ambient and oven cured. The specimens were loaded until it failed in compression, after which the failure loads were recorded and therefore the compressive strength (CS) was analyzed using equation 1.

$$CS = {}^{F_L}/_{A} \qquad 1$$

Where CS is the Compressive Strength (N/mm^2), F_L is the failure load (N), A is the area of concrete cube specimen (mm^2).

2.2.7 SEM analysis of harden geopolymer paste

Scanning Electron Microscopy (SEM) was used to examine the morphology of the geopolymer paste for both 8M and 12M molar concentrations. The samples were cut to the size of the sample holder, which is 10 mm by 10 mm standard. The samples were inserted in Quorum (Q150R ES) machine where the specimen was coated with a thin layer of gold. Thereafter the specimen were view via a monitor connected to the machine, where different magnification where capture, in which 100 µm was selected. The operating voltage used was 10 kV.

2.2.8 BET analysis of the harden geopolymer paste

The surface area was determined by using the Brunauer-Emmett-Teller (BET) method. The geopolymer gel sample was outgassed for 24 hours at temperature of 105^{O}C before measurement was taken. This technique was adopted from the work of Federica *et al.*, (2021).

3.0 Result and Discussion

3.1 Elemental composition analysis of raw kaolin

Table 1 shows the physicochemical analysis of the kaolin obtained from Kankara, Kastina State. The summary of the results shown in Table 1 revealed the mineral oxides present in the kaolin.

Table 1: Chemical composition of the kaolin

Chemical Oxides (%)	**SiO_2**	**Al_2O_3**	**CaO**	**Fe_2O_3**	**M_gO**	**SO_3**	**TiO_2**	**K_2O**	**Na_2O**
% composition	54.9	40.6	1.57	0.98	0.13	0.42	0.84	0.26	0.20

As shown in the Table 1, the percentage composition of oxide of silica is 54.9 % and that of alumina oxide is 40.6 % while the oxide of iron (Fe_2O_3) among other is 0.98 %, which are in close agreement with what were reported in the work of Eisa *et al.*, (2021). As also reported by Rafik *et al.*, (2022) and Eisa *et al.*, (2021), the minimum total content of silica oxide (SiO_2), alumina oxide (Al_2O_3) and iron oxide (Fe_2O_3) should amount to 70 % or more for a good starting raw material, which is within the range of standard specification because, the total sum obtained in this work was 84.42 %. More so, the silica to alumina ratio of the starting raw kaolin is 1.37 which is close to the ratio (1.73) reported in the work of Eisa *et al.*, (2021). However, these values are below the range of standard specifications for a good geopolymer formulation with a characteristic maximum compressive strength, thus, the reason for treatment through calcination technique to remove inherent impurities which increase or enhance the strength performance of the geopolymer concrete

3.2 The beneficiated kaolin (Metakaolin) for geopolymer formulation feedstock

Table 2 presents the analyzed results of the beneficiated kaolin to form metakaolin. The significance of this beneficiation process is to reduce the impurities in the raw kaolin and makes it pure as much as possible for effective performance in the geopolymer concrete formation.

Table 2: Chemical composition of the metakaolin (beneficiated kaolin)

Chemical Oxides (%)	**SiO_2**	**Al_2O_3**	**CaO**	**Fe_2O_3**	**MgO**	**SO_3**	**TiO_2**	**K_2O**	**Na_2O**
% composition	57.21	36.71	4.69	0.69	0.02	0.00	0.091	0.06	0.11

As shown in Table 2, the amount of impurities such as SO_3, MgO and K_2O have reduced from 0.42, 0.13 and 0.26 % to 0.00, 0.02 and 0.06 % respectively, which gave rise to increase in silica oxide content from 54.9 to 57.21 % and subsequently, increased the silica to alumina ratio from 1.37 to 2.55 which is within the range (2-2.65) for a good compressive strength as reported in the works of Bashar *et al.*, (2019) and Hengels *et al.*, (2021). The removal of inherent impurities enhance the compressive strength of metakaolin based geopolymer concrete (MKGC).

3.3 X-ray fluorescence (XRF) analysis of the commercial sodium silicate (Na_2SiO_3)

Table 3 shows the XRF analysis carried out on the commercial sodium silicate gel to determine its purity and oxide composition. The result indicated that the sodium silicate is in pure form because, the sodium oxide contents and its oxide of silicate were recorded to be 20.1 and 77.9 % respectively, which summed up the two compounds to be 98 % as shown in Table 3.

Table 3. Chemical properties of sodium silicate (Na_2SiO_3).

Oxide	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl**	**K_2O**	**CaO**	**TiO_2**	**Mn_2O_3**	**Fe_2O_3**
Amount (%)	20.1	0.08	1.04	77.9	0.35	0.16	0.03	0.06	0.18	0.01	0.08

As also presented in Table 3, the other oxides compositions in the sodium silicate are useful in the geopolymer concrete formulation as iron (II) oxide with low content was identified alongside the other useful oxides such as titanium, manganese, copper, magnesium and calcium with low contents that are required to improve the strength.

3.4 Soundness of MKGP Paste 8M concentration

The results of the soundness test performed on MKGPP is presented in Figure 1 for 8M concentration. It was observed from Figure 1 soundness values of MKGPP increases as the alkaline liquid content increased. However, all the soundness values obtained for each ($NaOH:Na_2SiO_3$) ratio were within the acceptable limits as it conform with BS EN 196-3 (1995), which clearly indicate a range 0 -10 mm for sound and 10 mm above for unsound cement. The result is also in agreement with the work of Sulaiman and Aliyu, 2020.

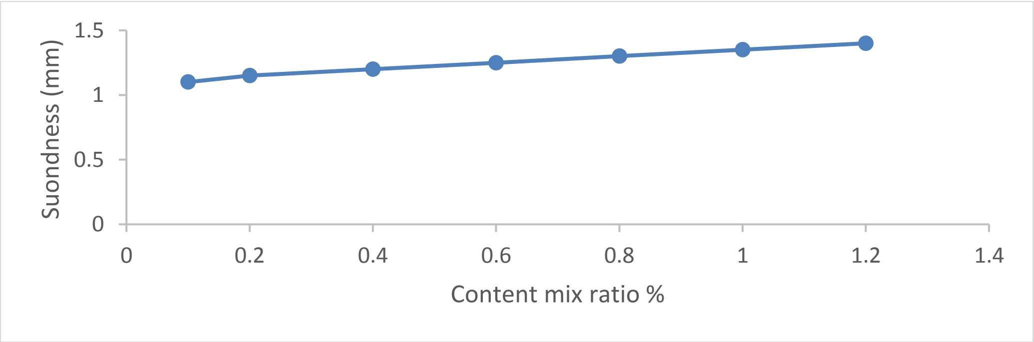


Figure 1: Effects of 8M molar concentration mix ratio on the soundness

3.5 Soundness of MKGP Paste 12M concentration

The results of the soundness test performed on MKGPP is presented in Figure 2 for 12M concentration. It was observed from Figure 1 soundness values of MKGPP increases as the alkaline liquid content increased. However, all the soundness values obtained for each ($NaOH:Na_2SiO_3$) ratio were within the acceptable limits as it conform with BS EN 196-3 (1995), which clearly indicate a range 0 -10 mm for sound and 10 mm above for unsound cement. The result is also in agreement with the work of Sulaiman and Aliyu, 2020.

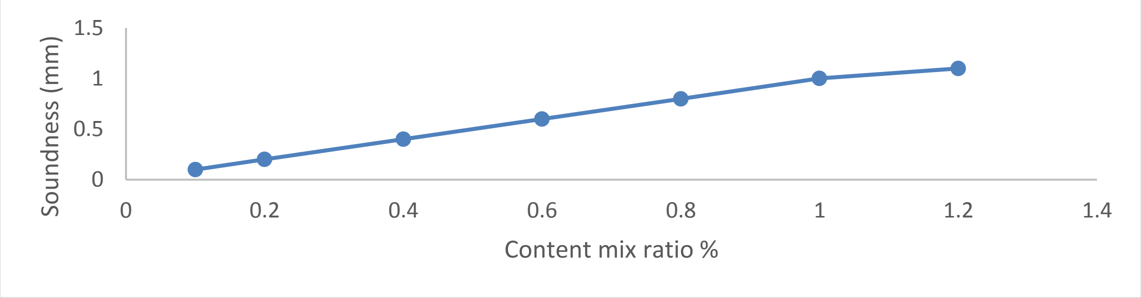


Figure 2: Effects of 12M molar concentration mix ratio on the soundness

3.6 Effects of Setting Time on the Geopolymer Paste/Gel for 8M Concentration.

The effects of setting time on the geopolymer paste for varying $NaOH:Na_2SiO_3$ ratio concentration is presented in Figure 3. As shown in the figure, at the mix ratio of 1:1, the initial setting time was increased drastically from 48 minutes to 216 minutes, while 40 minutes and 180 minutes were recorded as the initial and final setting time respectively for the mix ratio of 1:1.5.

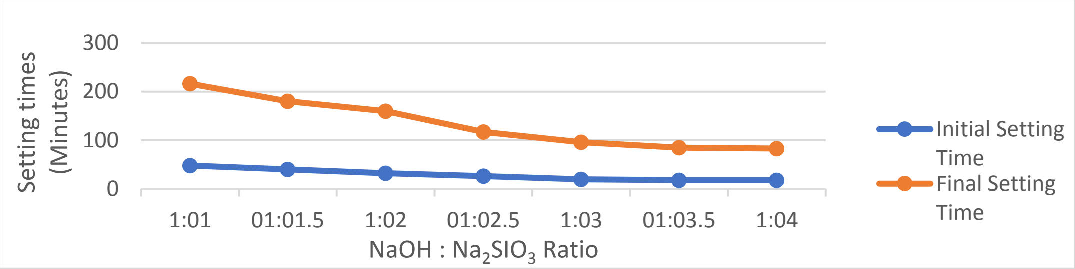


Figure 3: Initial and Final Setting time of metakaolin base geopolymer paste/gel for 8M concentration.

More so, it was observed from Figure 3 that, as the mix ratio formulation changes in the increasing order, the setting time decreased for both initial and final conditions. This is evidenced as the initial and final setting time recorded for the mix ratio 1:2 were 32 minutes and 160 minutes respectively, while 26 minutes and 117 minutes were recorded as the mix ratio was increased to 1:2.5. Furthermore, setting time obtained against the mix ratio 1:3, 1:3.5 and 1:4 was 20, 18 and 18 minutes respectively for the initial condition while their respective final setting time recorded were 96, 85 and 83 minutes, which is also consistent with the work of Hengels *et al.,* (2021). Additionally, the initial and final setting time variation against the different mix ratio exhibited in the 12M concentration as shown in Figure 4 are similar to the 8M concentration as previously explained in Figure 3. However, it was observed that, shorter setting times were recorded in the 12M concentration compared to the 8M concentration. This was justified with the initial setting time of 39 minutes recorded for the mix ratio 1:1 whose final setting time was recorded as 175 minutes as shown in Figure 4.

More so, as observed from the figure, as the mix ratio changes the setting time also reduced as evidence from the initial to the final setting of 31 to 140 minutes, 26 to 124 minutes, 22 to 110 minutes, 16 to 80 minutes and 15 to 79 minutes for the mix ratio 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5 and 1:4 respectively. These trends are similar and in good agreement with the work of Patrick *et al.,* (2023), who reported that, the setting time of geopolymer material is dependent on the concentration of aggregate formation.

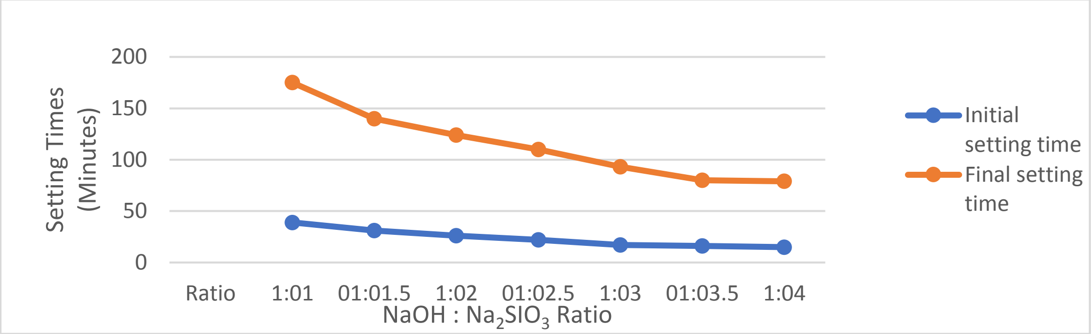


Figure 4: Initial and Final setting time of metakaolin base geopolymer paste/gel for 12M concentration.

3.7 Effects of Alkaline Solution on the Slump Property of the Geopolymer for the 8M and 12M Concentrations

The slump property of geopolymer concrete plays a crucial role in its workability, performance, and construction process, impacting aspects such as placement, compaction, bonding, durability, and overall quality of the finished structure. Thus, as shown in Figure 5, the slump property of the geopolymer concrete increased as the mix ratio formulations were increased. This is evidenced as the slump value at mix ratio 1:1 was recorded to be 75 mm for 8M concentration and was increased to 81 mm at mix ratio 1:1.5. It was further increased to 88, 102, 113 and 124 mm for mix ratio 1:2, 1:2.5, 1;3, 1:3.5 and 1:4 respectively.

Similarly, the slump property of the geopolymer material in terms of 12M concentration was also observed to have increased from 68 mm of mix ratio 1:1 to 74 mm at the mix ratio 1:1.5. The increasing order continued as the mix ratio changed to 1:2, 1:2.5, 1:3, 1:3.5 and 1:4 in which their respective slump property increased in the order of 82, 94, 105 and 116 mm as depicted in Figure 5. However, as observed from the figure, the 8M concentration exhibited higher slump properties when compared to the 12M concentration.

Additionally, as observed from the analysis shown in Figure 5, the concentration of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), directly impacts the geopolymerization reaction and the resulting rheological properties of the mixture, where higher concentrations of alkali activators typically lead to faster geopolymerization and increased viscosity, which can reduce slump. Conversely, lower concentrations may result in slower setting times and higher slump values due to reduced viscosity. This is consistent with the work of Bharath and Karthiyaini, (2020), who reported that, geopolymer concrete mixtures with high concentrations of alkali activators or other components typically exhibit reduced slump due to increased viscosity and rapid geopolymerization as also observed from this work. Therefore, the higher concentration accelerates the formation of the geopolymeric gel, leading to faster setting and stiffening of the mixture.

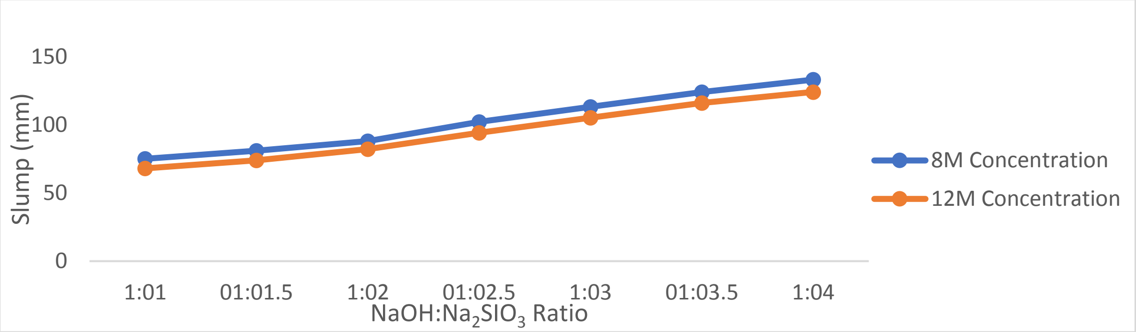
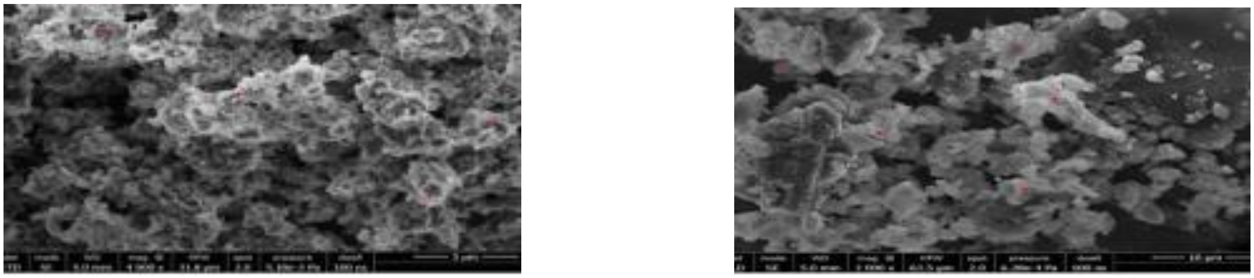


Figure 5: Relationship between Slump and alkaline liquid Ratio ($NaOH:Na_2SiO_3$) for 8M and 12M Concentrations.

3.8 SEM analysis of the micrographs MKGP paste for 8M and 12M concentration

The SEM micrographs presented in Figure 6a and b show the surface morphology of (MGPP) using 8M and 12M concentration of alkaline liquid solution respectively. As shown in 6a, the magnification of 5,000x, reveals a high porous structure with more visible voids. This morphology indicates a material with a lower surface area, which reduce the geopolymerization process. This is a clear indication of incomplete geopolymerization and or variabilitys in the chemical reaction process, which might be due to differences in the interaction interface between the metakaolin and the alkaline liquid solution.

Similarly, the SEM image in Figure 6b, also have equal magnification of 5,000x, which shows larger agglomerates with a comparatively smoother surface, with lesser visible voids and more consolidated (stable) structure displays a relatively dense and compact structure with visible particles and agglomerates. The presence of these larger, well-defined particles suggests increased in geopolymerization compared to lower concentrations, likely due to the higher molarity of the alkaline activator. This might imply that, the sample has a more compactible surface morphology, which enhance the compressive strength. The fine, rough texture and whitish particle clusters on the sample suggest extensive rate of chemical reactivity, which improve its workability and strength properties through the formation of a more stable network of aluminosilicate bonds.



(a). Magnification 5,000x, (b). Magnification 5,000x

Figure 6a & b shows the SEM micrographs of Metakaolin based Geopolymer Paste (MGPP) for 8M and 12M concentration respectively.

3.9 BET analysis of the geopolymer paste at ambient and oven cured temperatures for 12M concentration.

Table 4 presents the BET results of surface area, pore volume and pore size of the geopolymer paste for both ambient and oven cured temperature conditions. As shown in the table, the surface area of geopolymer paste at an oven cured temperature was recorded 128.5 m^2/g as compared to the value recorded against the ambient cured condition of 126.9 m^2/g, which indicates that, the oven cured temperature has more effect on the surface area of the geopolymer paste. Also, the increased in the pore size of the geopolymer concrete sample in terms of oven cured temperature condition with pore size value of 0.17 cm^3/g as compare to that of the ambient cured with pore size volume of 0.12 cm^3/g as shown in Table 4 can be attributed to the elimination of combustible impurities within the pores of the sample materials, thereby increasing accessibility within its surfaces. It’s also in good agreement with the work of Manvendra *et al.,* (2022).

Table 4: BET analysis of the geopolymer paste

Sample	BET surface area (m^2/g)	Pore volume (cm^3/g)	Pore size (mm)
Ambient cured condition	126.9	0.12	1.68
Oven cured condition	128.5	0.17	2.38

3.10 Effect of 8M molar Concentration at Ambient and Oven cured Geopolymer concrete weight formulation.

Figure 7 shows the effect of 8M concentration on the weight of the developed geopolymer materials at ambient and oven cured conditions of various ratio formulations (1:1, 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5 and 1:4). As shown in the Figure, the weight of the material decreases from 2.5 kg to 2.33 and 2.3 kg at an ambient and oven cured respectively at the end of day 7 of the investigation for mix ratio 1:1 formulation. Additionally, on the 14th day, the weight at the ambient cured decreased from 2.33 to 2.3 kg while it remained unchanged at the oven cured condition as shown in Figure 7. Similar trend was reported in the works of Ahmet *et al.,* (2023) and Enes, (2023).

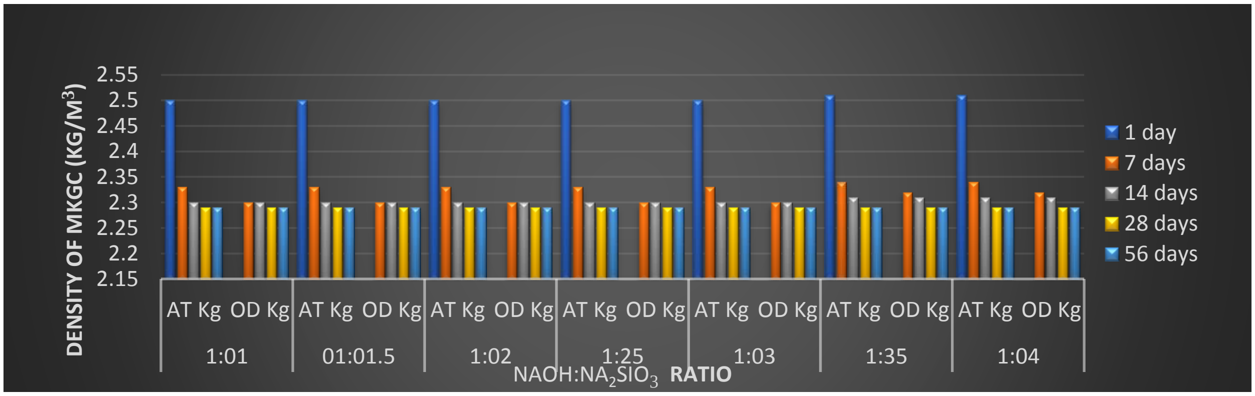


Figure 7: Effect of weight comparison at ambient and & oven cured for 8M concentration of varying ($NaOH:Na_2SiO_3$) mix ratio.

Additionally, the weight of the material decreased from 2.3 to 2.29 kg in both cases (i.e., at ambient and oven cured conditions) at the end of day 28th as presented in Figure 7. However, the weight of the geopolymer materials remains unchanged as they were stable at 2.29 kg on day 56 as evidence that, they have attained the maximum shrinkage level. These variations in the trends can be attributed to achieving the optimum mixing ratio condition, where the highest compressive strength from day 7 to day 56 were obtained for both ambient and oven cured conditions as also reported in the work of Bharath and Karthiyaini, (2020).

More so, similar trends were observed in the 8M (1:1.5) concentrations as shown in Figure 7 in which the weight of the materials at both ambient and oven cured conditions decreased from 2.5 kg to 2.33 kg in each case at the end of the 7th day which can be attributed to evaporation and moisture loss, but at the end of the 14th day, while it decreased from 2.33 to 2.3 kg at an ambient cured condition, it remained unchanged at the oven cured condition as shown in Figure 4.1. However, the weight decreased from 2.3 and 2.33 kg respectively to 2.29 kg in each case at the end of the 28th day. The higher temperature in the oven might have accelerated the process, leading to a slightly more significant weight loss, this is also consistent with the works of Bheem *et al*., (2023) and Enes, (2023). As observed from the Figure, they remained unchanged as the weight of the materials maintained at 2.29 kg at both ambient and oven cured conditions at the end of 56th day of investigation.

Additionally, as observed from the results variation trends, the stabilization of weight at some point, i.e., at ambient cured conditions after 14 days suggests an equilibrium reached where the material may have reached a point of moisture balance with its surroundings, while the lack of change in weight at the oven cured condition during the same period might indicate that the material stabilized faster or reached a different equilibrium under the elevated temperature. Also, the maintenance of weight at 2.29 kg at both ambient and oven cured conditions at the end of the 56th day suggests a consistent state of equilibrium or saturation, which further justified that, the materials have reached a point where further changes in weight are minimal or that the external conditions are not causing significant variations as also reported in the work of Bheem *et al.,* (2023).

Furthermore, similar trends were observed for mix ratio formulation 1:2, 1:2.5, 1:3, 1:3.5 and 1:4 respectively for the 8M concentration, in which on the material weight of the materials reduced from 2.5 kg in each case to 2.33 kg and gradually stabilized at 2.29 kg as the investigation time increased from the 1st day to the 56th day of study, in which the weight remained the same without any reduction as shown in Figure 7, indicating that there is a partial equilibrium state at some point, and later shows the consistent state of equilibrium when it stabilized at 2.29 kg. This is also similar to the report from the work of Enes, (2023).

3.11 Effect of 12M Molar Concentration at Ambient and Oven cured Geopolymer Concrete Weight Formulation.

Figure 8 shows the effect of oven temperature and that of ambient conditions on the weight of the developed geopolymer concrete for 12M concentration ($NaOH:Na_2SiO_3$) of mix-ratio 1:1, 1:1.5, 1:1.2, 1:1.2.5, 1:3, 1:3.5 and 1:4 Formulations respectively. As shown in the figure, the initial weight of 2.55 kg was reduced to 2.37 and 2.33 kg against ambient and oven cured respectively after 7-days for mix ratio formulation 1:1. Furthermore, at the end of the

14th day, the weight of both oven and ambient cured conditions reduced to 2.33 kg in each case, which gradually reduced to 2.3 kg at day 28 as shown in Figure 4.2. More so, it was observed that, there was no further decrease in the weight as they remained at 2.3 kg at the end of the 56th day of investigation.

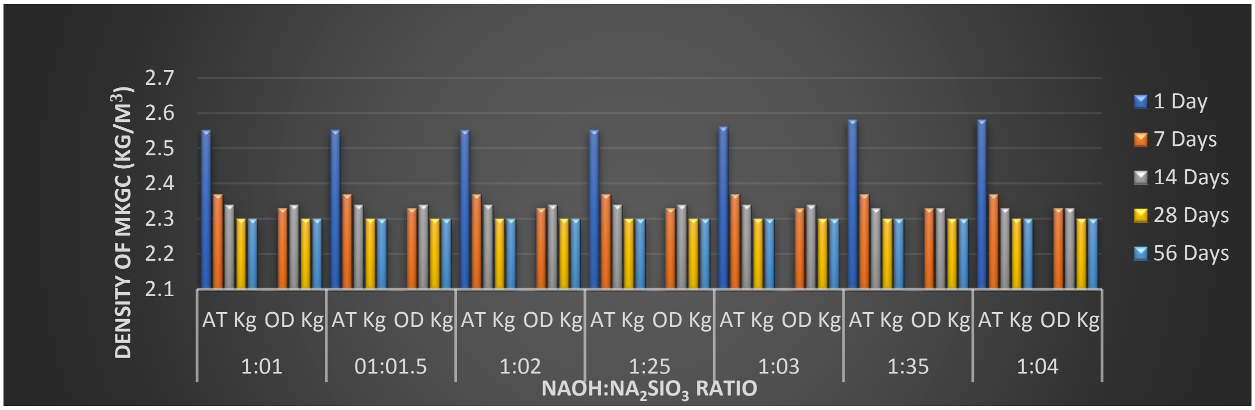


Figure 8: Effect of Weight Comparison at Ambient and & Oven Dry temperature for 12M Concentration varying ($NaOH:Na_2SiO_3$) mix ratio.

Additionally, similar trends were observed in the mix-ratio 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5, and 1:4 as depicted in Figures 8. The stability in weight of the developed geopolymer concrete despite variations in oven and ambient cured conditions after the 14th day of the study can be attributed to several factors. Firstly, geopolymer concrete undergoes a curing process involving chemical reactions between the alkali activators and the precursor materials, leading to the formation of a hardened matrix. However, it was observed that, after about the 14th day of the investigation, these reactions may reach completion, resulting in a stabilized weight. This is also in a close agreement with the works of Enes, (2023) and Ahmet *et al.,* (2023).

Additionally, it has been established literature (Ahmet *et al.,* 2023) that, at the initial curing period, significant changes occur in the internal structure of the concrete as it is densifies, and bonds strengthen, thereby once the internal structure is established, further weight changes may be minimal. Moreover, as reported by Ahmet *et al.,* (2023). More so, moisture content within the geopolymer concrete may fluctuate in the early curing stages due to evaporation, hydration, or ambient conditions. However, after a certain point, the concrete reaches a moisture equilibrium where the rate of moisture loss equals the rate of moisture absorption, resulting in a stable weight. Additionally, the internal microstructure of geopolymer concrete evolves during curing, leading to the development of a more compact and stable material. Based on these, once the microstructure reaches a certain level of maturity, further changes may be negligible. Therefore, these factors collectively contribute to the observed phenomenon of the weight of the developed geopolymer concrete remaining unchanged despite variations in curing conditions after the 14th day of the study. These changes may be due to intermediate interactions of the variable parameters in the mix with the temperature profile as also reported by Bashar *et al.,* (2019).

3.12 Effect of Alkaline Liquid Ratio on the Compressive strength of Geopolymer for 8M concentration

Figure 9 shows the effects of alkaline liquid treatment at different mix ratio formulation of 8M concentration on the compressive strength of the geopolymer material developed. As depicted in the figure, the compressive strength of the geopolymer material recorded were 16.4 and 17.6 N/mm^2 for the oven and atmospheric temperature respectively at the end of the 7th day against the mix ratio of 1:1. Furthermore, as observed from Figure 10, the compressive strength of the geopolymer were increased to 17.0, 19.6 and 19.9 N/mm^2 against the 14th, 28th and 56th days investigations respectively at the oven temperature condition. Similar increase in the compressive strength was observed at the atmospheric condition where the values recorded were 16.4, 20.4 and 27.7 N/mm^2 respectively.

Also, the compressive strength recorded for mix ratio of 1:1.5 for atmospheric temperature condition increased from 19.4 N/mm^2 at the 7th day to 21 N/mm^2 at the end of the 56th day. Similar increasing trend was observed on the oven temperature condition as the compressive strength value gradually increased from 20.1 N/mm^2 to 28.8 N/mm^2 between the 7th and 56th days of study.

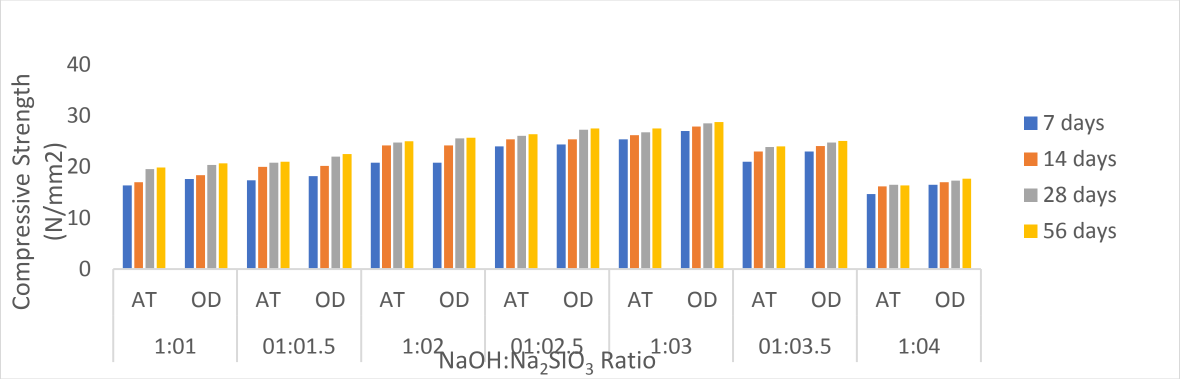


Figure 9: Relationship between Compressive Strength and Alkaline Liquid Ratio ($NaOH/Na_2SIO_3$) at Various Curing Age for 8M Concentration.

Additionally, as observed in Figure 9, there was a general increasing order in the compressive strength of the geopolymer material as the curing age was increased for both operating conditions for the mixing ratio of 1:2, 1:2.5, 1:3, 1:3.5 and 1:4 respectively. However, it was observed from Figure 7 that, the compressive strength generally increased as the mix ratio increased from 1:1 through 1:1.5, 1:2, 1:2.5 and 1:3 throughout all the investigation periods. However, there was sudden decreasing trends in the compressive strength of the geopolymer material at the mix ratio of 1:3.5 and 1:4 compared to the previous mix ratio formulation as depicted in Figure 9. Thus, this variable exhibition of the developed geopolymer can be attributed to its optimum performance condition, where the highest compressive strength value of 28.8 N/mm^2 was obtained at the optimum mixing ratio of 1:3.

3.13 Effect of Alkaline Liquid Ratio on the Compressive strength of Geopolymer for 12M concentration

More so, similar variation trends that was observed in the previous Figure 10 (for the 8M alkaline liquid treatment) were also observed in the 12M concentration treatment as depicted in Fig. 8. However, higher compressive strengths are obtained from 12M treatment when compared to the 8M treatment. This is evidence from the initial compressive strength value of 21.2 and 22.1 N/mm^2 obtained on the 7th day at atmospheric and oven temperature conditions respectively when compared to 16.4 and 17.6 N/mm^2 obtained for 8M concentration. The compressive strength of the geopolymer concrete increased at the end of the 14th day to 24.2 and 24.4 N/mm^2 for atmospheric and oven temperature conditions respectively as shown in Figure 10.

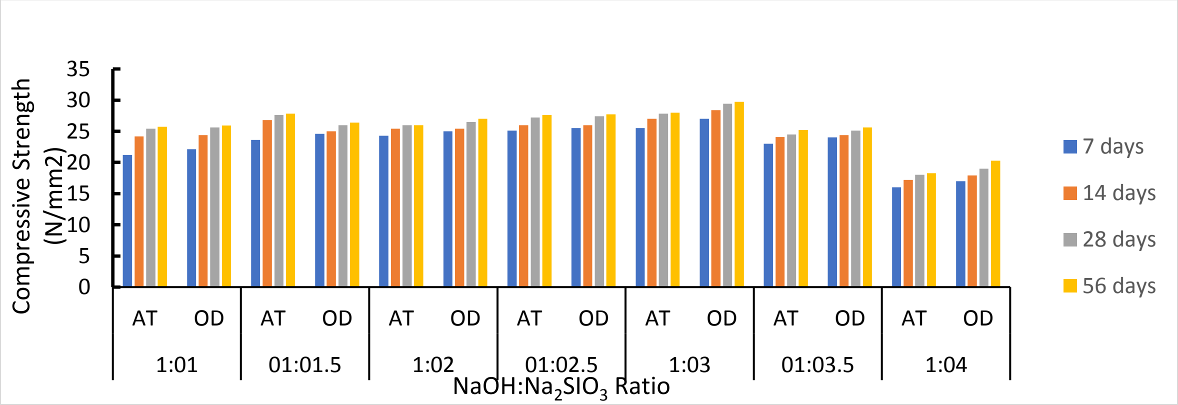


Figure 10: Relationship between Compressive Strength and Alkaline Liquid Ratio ($NaOH:Na_2SIO_3$) at Various Curing Age for 12M Concentration.

Furthermore, the compressive strength of the material generally increased as the curing age increased against the respective mix ratio 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5 and 1:4. However, as it was also observed previously from the 8M concentration formulation, the highest compressive strength of 29.7 N/mm^2 was obtained at the optimum mix ratio of 1:3 as shown in Figure 10.

However, geopolymer concrete has a better strength performance when compare to the conventional concrete as the compressive strength for grade 20 geopolymer concrete was establish to be 29.7 N/mm^2 while the traditional concrete is 20 N/mm^2. Approximately, about 90 percent of MK-GPC strength can be obtain in not more than 48 hours of casting while conventional concrete could only achieve 90 percent strength after 14 days of curing.

4.0. Conclusion

In this research study, the constituent material use satisfied the requirements outline by the standards. Therefore they are suitable for use in the geopolymer paste and concrete production. Setting time test performed at ambient temperature for both 8M and 12M molar concentration shows that the initial and final setting time for MKGPP mixes decreases with increase in NaOH solution. Also, an increase in the silica content decreases the setting time. However, the highest soundness value recorded on the geopolymer gel/paste for 8M and 12M concentration are 1.3mm and 1.1mm respectively. This is a clear indication that the gel/paste is sound as the values obtained are less than 10mm. More so, increase in molarity of NaOH and Na_2SiO_3 decreases the soundness of MKGPP. Increase in molarity increases the surface area of MKGPP, more so, an increase in the molarity of NaOH decreases the workability of geopolymer concrete. A gain in the workability was achieved as the Na_2SiO_3 content is increased and this is attributed to the high viscosity present in the Na_2SiO_3. Also, an increase in the compressive strength and density of MKGPC is due to the increase in sodium silicate content and sodium hydroxide content.

5.0 Recommendation

From the finds of this study, it is recommended that NaOH molarity should be adjust based on some specific application requirements. For applications requiring faster setting times (e.g., precast elements), a higher molarity (e.g., 12M) may be ideal, whereas for applications where extended workability is required, a lower molarity (e.g., 8M) should be considered. Also, other alkaline material should be investigated in other to determine it effect on geopolymer concrete production. For the purpose of transporting geopolymer concrete to the construction site, chemical admixture such as calcium sulphate should be added in the mix in other to delay or retard the setting time of geopolymer concrete.

Acknowledgements

I am grateful to the Petroleum Technology Development Fund (PTDF) for their financial support which made this research possible. PTDF Tower. Plot 1058 Memorial Drive, Opp Shehu Musa Yar'adua Center, Central Business District Cadastral Zone AOO Abuja, Nigeria.

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