IMPACT OF SODIUM HYDROXIDE CONCENTRATIONS ON THE COMPRESSIVE STRENGTH OF PERIWINKLE SHELL ASH BLENDED METAKAOLIN BASED GEOPOLYMER MORTAR.

B.E Yabefa[1], F.A Olutoge[2], F. C. Sagba[3], T.E Gede[4]

[1,3] *Department of Agricultural/Environmental Engineering, Niger Delta University, Wilberforce Island, Amassoma, Bayelsa State.*

[2] *Depaartment of Civil Engineering, University of the West Indies, Trinidad and Tobago, Port of Spain*

[4] *University of Benin, Edo State, Nigeria.*

yabefabranly@yahoo.com

Abstract

This experimental investigation presents the influence of sodium hydroxide concentration on the compressive strength of periwinkle shell ash based geopolymer binder. Due to the unbearable environmental problems associated with the manufacturing process of Ordinary Portland cement, use of locally available materials are encouraged in the construction industry. The geopolymer binder is formed by activating pozzolans with an alkaline solution. Molar concentrations of NaOH such as 6M, 8M, 10M, and 12M were used in this study, while the liquid to binder ratio was kept at 0.8, and sodium silicate to sodium hydroxide ratio was 2.5. Periwinkle shell ash was used to replace metakaolin at 0%, 10%, 20% 30%, 40% and 100%. The size of the cube specimens is 70.7mm× 70.7mm × 70.7mm. Mortar cubes were oven cured at 90^{o}C for 24 hours before room temperature curing at 7, 14 and 28 days before testing. The results showed that, increase in molarity of sodium hydroxide also increased the compressive strength of the geopolymer binder in all the different mixes. The maximum compressive strength of 22.9N/mm^2, 18.3N/mm^2, 17.5N/mm^2, 16.5N/mm^2 were obtained at 10%, 20%, 30%, 40% of PSA respectively at 12M NaOH concentration.

Keywords: *Sodium hydroxide, Sodium silicate, Compressive strength, periwinkle shell ash, geopolymer*

1. INTRODUCTION

The geopolymer technology proposed by Davidovits in 1978 is a better alternative to the Ordinary Portland Cement (OPC) in concrete production, due to the minimal emission of pollutants into the environment in the production process of geopolymer binders compared to the manufacturing process of OPC.

It is a commonly known fact that, OPC production consumes considerable energy and also emits a large volume of CO_2 in to the atmosphere, which causes environmental pollution. Still yet, OPC is the main binding agent used in the production of concrete in the construction industry across the world, hence prompting a search for a less environment polluting material (Mahotra 2002). The choice of the geopolymer technology in this case is outstanding. Davidovits proposed that, an alkaline liquid can be used to react with silica-aluminate based geological materials or industrial by products to produce binders (Sonal *et al.*, 2014) which he called geopolymers (Davidovits 1994). Geopolymer is made of two main compounds, namely, the alkaline liquid and source materials. The alkaline liquids conventionally used in geopolymer production are sodium silicate or potassium silicate and sodium hydroxide or potassium hydroxide (Sonal *et al.*, 2014). The dissolution and polycondensation reaction between an alkaline silicate solution and alumino silicate binder leads to the formation of Geopolymers (Davidovite 1994).

Geopolymer mortar or concrete are also prepared as the normal OPC mortar or concrete, but the only difference is that, the binder is a geopolymer binder instead of the Portland cement (Hardjito et al., 2005). The most commonly used industrial by-products for geopolymer binders are fly ash, metakaolin, rice husk ash, ground granulated blast furnace slag and other materials that are pozzolanic in nature. Hence, the use of these waste materials as source materials for producing an alternative binder to the OPC is a major advancement towards the beneficial use of industrial by-products and reduce their effects and the adverse effect of cement production in the environment (Sonal *et al.*, 2014). Chareerat *et al.*,2006 reported that, replacement of traditional fly ash material with metakaolin by up to 30 percent (by mass) yielded compressive strength values of 30–50 MPa for mortar.

It has been reported that, periwinkle shell ash (PSA) is a by-product with pozzolanic properties which can be used as a substitute for cement in concrete production (Dahunsi 2002). Hence, the study aims to investigate the impact of varying molar concetration of sodium hydroxide (NaOH) on compressive strength of a geopolymer binder incorporating periwinkle shell ash (PSA).

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Periwinkle Shell Ash

The periwinkle shell ash (PSA) is a fine grainy particle obtained by calcination of periwinkle shells at a temperature of 800^{o}C. The ash was then grinded and sieved in a 75-micron sieve before used in this study. The chemical composition analysis of the ash was done in the light house laboratory at Effurun, Delta State as presented in Table 2.1.

2.1.2 Metakaolin

The metakaolin used in this study was obtained when Kaolin was calcined at a temperature of 750°C in a local kiln at Agudama-Epie, Yenagoa, Bayelsa State. It was then sieved with the BS sieve size 75-micron before used in this study.

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: Physical properties of Periwinkle Shell Ash (PSA) and Metakaolin (MK)

S/No.	Property	PSA	MK
2.	SiO_2+ Al_2O_3+ Fe_2O_3	24.05	95.69
3.	Specific gravity	2.51	2.51

2.1.3 Water

The water used in this study was a tap water obtained from the Civil Engineering Department, University of Ibadan. It was free from all forms of visible impurities and organic maters in accordance with BS 3148 (1985).

2.1.4 Fine Aggregates

The sand used for this study conforms to the requirements of BS 882 (1982). The sands were river sands bought from the popular Bodija market at Ibadan, Oyo State, Nigeria.

Table 2.3: 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%

2.1.5 Alkaline Liquid

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. The sodium hydroxide in the pellets form with 98% purity was dissolved in crystalline water to prepare the solution. Various molar concentrations of sodium hydroxide solutions such as 6M, 8M, 10M and 12M were used in this study. A 12 molar concentration of NaOH indicates that, 12x40 = 480grams of NaOH per litre of solution (Ranjini *et al.,* 2014).

Table 2.4: Properties of Sodium Silicate

S/NO.	Constituents	Result
1.	SiO_2	34.78%
2.	NaO_2	16.22%
3.	Water	49%
4.	Viscosity	400Cp
5.	Specific gravity	1.386

2.2 Mix Proportions, Mixing, Casting, Curing

In this study, four different molarities of sodium hydroxide solution such as 6M, 8M, 10M, 12M were prepared. Heat curing is generally required for activating the aluminosilicate based materials with alkalis to produce the geopolymer binder (Shivaji *et al.,* 2015). Hence, the specimens were heat cured in an oven at 90^{o}C for 24 hours before they were kept at room temperature until the day of testing. Table 2.6 to Table 2.7 below presents the mix proportions for the various specimens.

Plate 2.1: Oven Curing of Geopolymer Specimens

Table 2.5: Mix proportions for Geopolymer mortar Mix 11

Sample ID	PSA:MK	Molarity (NaOH)	SS/SH	L/B	W/B	B/FA	PSA (g)	MK (g)	FA (g)	Na_2SiO_3 (g)	NaOH (g)	Extra H_2O
Mix 11A	0:100	6M	0.8	2.5	0.13	0.33	0	200	600	114.3	45.7	26
Mix 11B	10:90	6M	0.8	2.5	0.13	0.33	20	180	600	114.3	45.7	26
Mix 11C	20:80	6M	0.8	2.5	0.13	0.33	40	160	600	114.3	45.7	26
Mix 11D	30:70	6M	0.8	2.5	0.13	0.33	60	140	600	114.3	45.7	26
Mix 11E	40:60	6M	0.8	2.5	0.13	0.33	80	120	600	114.3	45.7	26
Mix 11F	100:0	6M	0.8	2.5	0.13	0.33	200	0	600	114.3	45.7	26

Table 2.6: Mix proportions for Geopolymer mortar Mix 12

Sample ID	PSA:MK	Molarity (NaOH)	SS/SH	L/B	W/B	B/FA	PSA (g)	MK (g)	FA (g)	Na_2SiO_3 (g)	NaOH (g)	Extra H_2O
Mix 12A	0:100	8M	0.8	2.5	0.13	0.33	0	200	600	114.3	45.7	26
Mix 12B	10:90	8M	0.8	2.5	0.13	0.33	20	180	600	114.3	45.7	26
Mix 12C	20:80	8M	0.8	2.5	0.13	0.33	40	160	600	114.3	45.7	26
Mix 12D	30:70	8M	0.8	2.5	0.13	0.33	60	140	600	114.3	45.7	26
Mix 12E	40:60	8M	0.8	2.5	0.13	0.33	80	120	600	114.3	45.7	26
Mix 12F	100:0	8M	0.8	2.5	0.13	0.33	200	0	600	114.3	45.7	26

Table 2.7: Mix proportions for Geopolymer mortar Mix 13

Sample ID	PSA:MK	Molarity (NaOH)	SS/SH	L/B	W/B	B/FA	PSA (g)	MK (g)	FA (g)	Na_2SiO_3 (g)	NaOH (g)	Extra H_2O
Mix 13A	0:100	10M	0.8	2.5	0.13	0.33	0	200	600	114.3	45.7	26
Mix 13B	10:90	10M	0.8	2.5	0.13	0.33	20	180	600	114.3	45.7	26
Mix 13C	20:80	10M	0.8	2.5	0.13	0.33	40	160	600	114.3	45.7	26
Mix 13D	30:70	10M	0.8	2.5	0.13	0.33	60	140	600	114.3	45.7	26
Mix 13E	40:60	10M	0.8	2.5	0.13	0.33	80	120	600	114.3	45.7	26
Mix 13F	100:0	10M	0.8	2.5	0.13	0.33	200	0	600	114.3	45.7	26

Table 2.8: Mix proportions for Geopolymer mortar Mix 14

Sample ID	PSA:MK	Molarity (NaOH)	SS/SH	L/B	W/B	B/FA	PSA (g)	MK (g)	FA (g)	Na_2SiO_3 (g)	NaOH (g)	Extra H_2O
Mix 14A	0:100	12M	0.8	2.5	0.13	0.33	0	200	600	114.3	45.7	26
Mix 14B	10:90	12M	0.8	2.5	0.13	0.33	20	180	600	114.3	45.7	26
Mix 14C	20:80	12M	0.8	2.5	0.13	0.33	40	160	600	114.3	45.7	26
Mix 14D	30:70	12M	0.8	2.5	0.13	0.33	60	140	600	114.3	45.7	26
Mix 14E	40:60	12M	0.8	2.5	0.13	0.33	80	120	600	114.3	45.7	26
Mix 14F	100:0	12M	0.8	2.5	0.13	0.33	200	0	600	114.3	45.7	26

3. RESULTS 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 is made 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 bulk density, specific gravity, gradation and fineness modulus which were tested in accordance with the IS:2386.

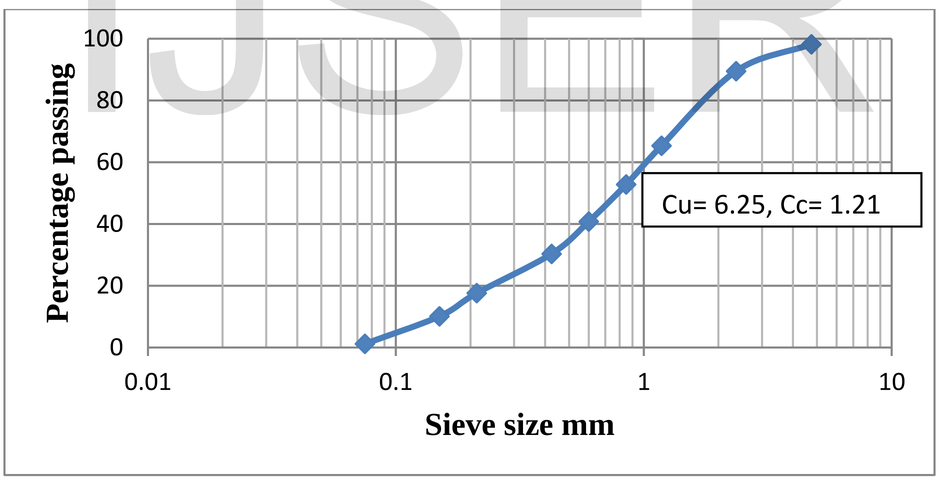

Figure 3.1: Particle size distribution of fine aggregates

The uniformity coefficient and coefficient of curvature of fine aggregates

Uniformity Coefficient $Cu = \frac{D_{60}}{D_{10}} = \frac{1.0}{0.16} = 6.25$

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Coefficient of Curvature $Cu = \frac{(D_{30})^2}{D_{10} \times D_{60}} = \frac{0.44^2}{0.16 \times 1.0} = 1.21$

The particle size distribution of the fine is shown in figure 4.2 above. The uniformity coefficient for the fine aggregates is 6.25, which implies that, the fine aggregates are suitable for mortar and concrete production, and its coefficient of curvature of 1.21 also lies within the required range of values. The particle size distribution curve for the sand shows that, the aggregate falls within the lower and upper limit of the grading requirement for natural aggregates in accordance with the BS 882 (1992). Therefore, the sand is suitable for mortar and concrete production.

3.2 Compressive Strength

The compressive strength results of 7, 14, and 28 days are presented in Table 3.1, 3.2, 3.3, and 3.4 respectively. They are also illustrated in Figure 3.1, 3.2, 3.3, 3.4 respectively. In these mixes, the alkaline liquid to binder ratio, and the sodium silicate to sodium hydroxide ratio were not varied, and kept at 0.8 and 2.5 respectively. The concentration of NaOH solutions used were 6M, 8M, 10M, and 12M. The difference between the mixtures is the concentration of the NaOH in terms of Molarity. All the mixes showed increase in strength as the concentration and curing age increased. As Sodium Hydroxide (NaOH) concentration increased, compressive strength increases (Anuar *et al.*, 2011; Shuang *et al*., 2012; Posi *et al*., 2013; Sata *et al*., 2013).

Plate 3.1: Geopolymer Mortar Cubes

Table 3.1: Compressive strength of geopolymer mortar Mix 11

Sample ID	7 days (N/mm^2)	14 days (N/mm^2)	28 days (N/mm^2)
Mix 11A	17.3	19.40	19.5
Mix 11B	10.5	15.50	15.7
Mix 11C	10.0	11.55	13.6
Mix 11D	9.1	10.55	12.0
Mix 11E	8.20	9.45	10.5
Mix 11F	7.0	7.75	8.3

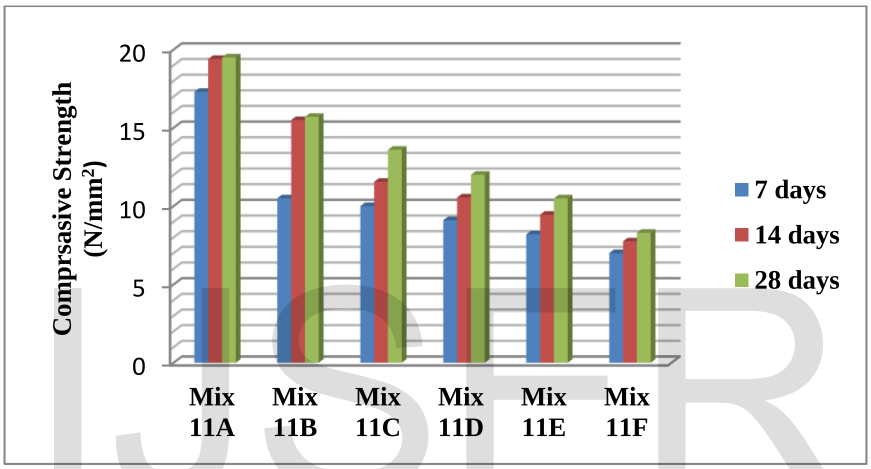

Figure 3.2: Compressive strength of GPC mortar with 6M concentration

Table 3.2: Compressive strength of geopolymer mortar Mix 12

Sample ID	7 days (N/mm^2)	14 days (N/mm^2)	28 days (N/mm^2)
Mix 12A	18.3	19.05	20.1
Mix 12B	16.2	17.4	17.9
Mix 12C	13.7	14.7	16.7
Mix 12D	10.6	13.4	16.9
Mix 12E	8.40	12.05	15.7
Mix 12F	7.5	9.2	9.9

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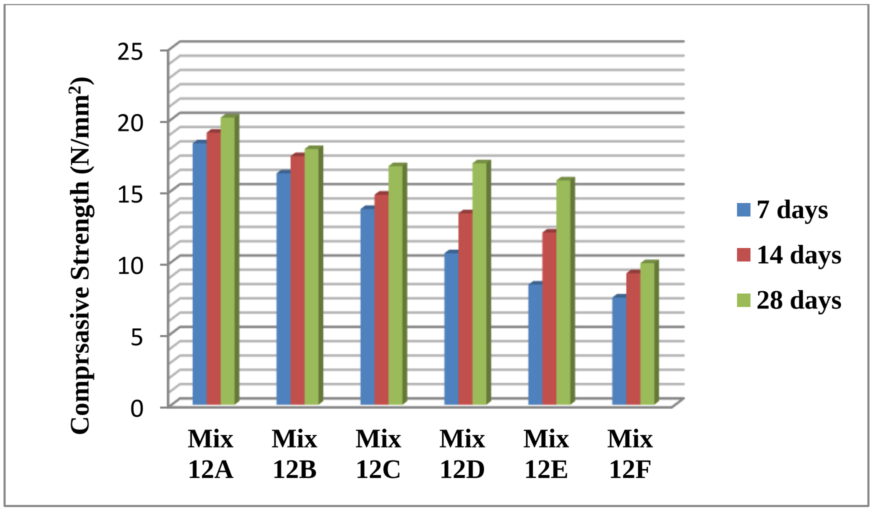

Figure 3.3: Compressive strength of GPC mortar with 8M NaOH concentration

Table 3.3: Compressive strength of geopolymer mortar Mix 13

Sample ID	7 days (N/mm^2)	14 days (N/mm^2)	28 days (N/mm^2)
Mix 13A	18.50	21.0	21.60
Mix 13B	17.20	19.50	20.30
Mix 13C	14.00	15.10	17.80
Mix 13D	11.10	13.80	16.98
Mix 13E	9.20	13.0	15.89
Mix 13F	7.68	9.81	10.20

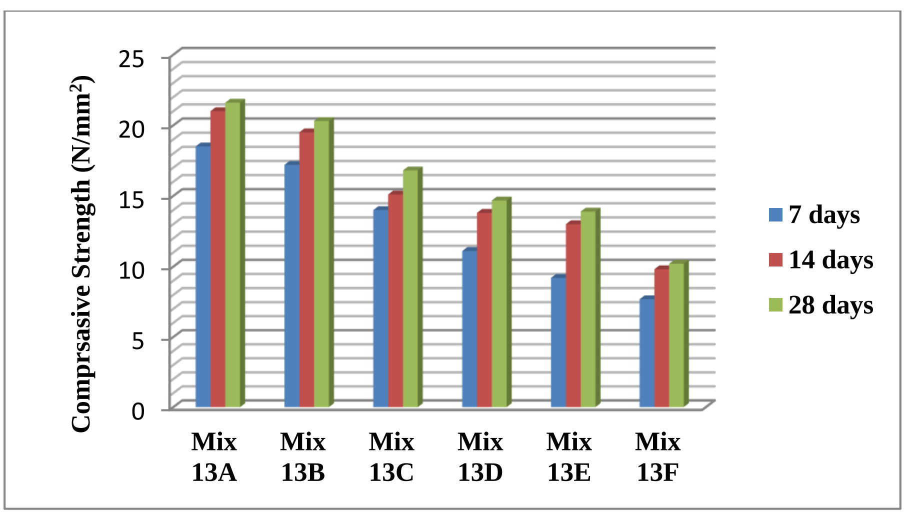

Figure 3.4: Compressive strength of GPC mortar with 10M NaOH concentration

Table 3.4: Compressive strength of geopolymer mortar Mix 14

Sample ID	7 days (N/mm^2)	14 days (N/mm^2)	28 days (N/mm^2)
Mix 14A	22.90	24.4	25.0
Mix 14B	22.0	22.55	22.9
Mix 14C	16.70	17.6	18.3
Mix 14D	14.75	17.5	17.5
Mix 14E	12.95	15.9	16.2
Mix 14F	12.20	14.8	15.2

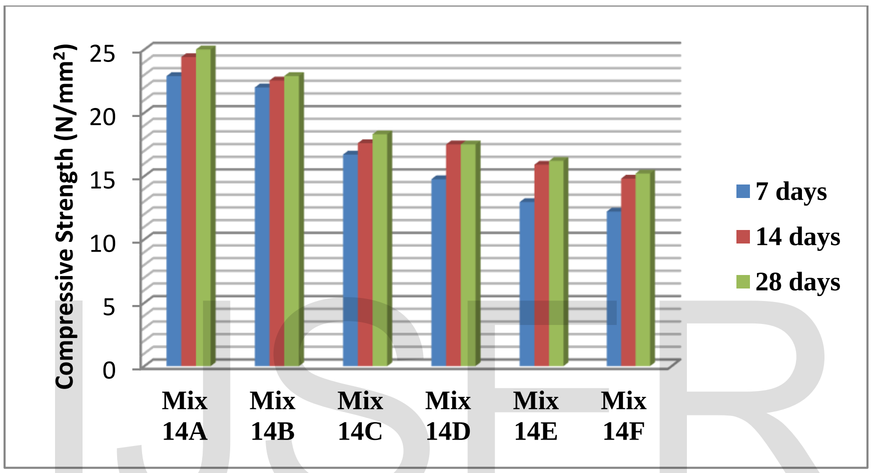

Figure 3.5: Compressive strength of GPC mortar with 12M NaOH concentration

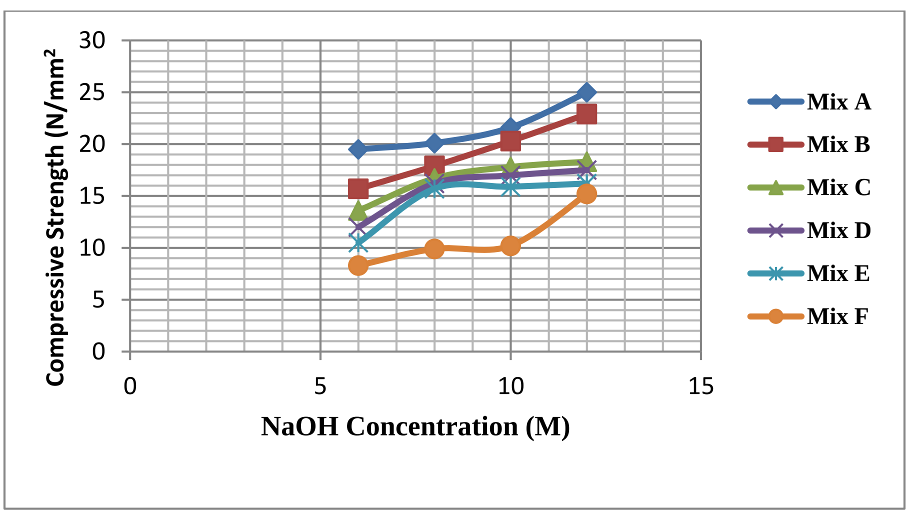

Figure 3.6: Effect of NaOH molarity on the compressive strength of GPC mortar

Figure 3.6 presents the relationship between the concentration of NaOH and the 28 days compressive strength of the various blends of PSA/MK.based geopolymer mortar. It shows that, the Mix 14 with 12M concentration of NaOH got the highest strength of 25.0, 22,9, 18.3, 17.5, 16.2N/mm^2 in all the various blends of PSA to MK designated as mix A, B, C, D, E respectively. Again, Mix 14F with 100% PSA also gave a strength of 15.2N/mm^2. Mix 14 was followed by mix 13 in the strength development. Therefore, it showed that, the compressive strength of the PSA blended MK based geopolymer binder is affected by the change in the concentration of the NaOH. However, Mix 11 with 6M concentration of NaOH also gave a very good range of compressive strength results in all the blends as shown in Table 3.1.

4. Conclusion

1. It was observed that, the compressive strength of geopolymer mortar increased with increase in molarity of sodium hydroxide (NaOH) solution.
2. The increase in the percentage of periwinkle shell ash also leads to reduction in the strength of the geopolymar mortar.
3. The compressive strength of the geopolymer mortar increased with increase in the number of curing days.
4. Sodium hydroxide is very corrosive to the skin, eye and nose, hence, needs to be handled with care when working with it.
5. The maximum compressive strengths of 22.9N/mm^2, 18.3N/mm^2, 17.5N/mm^2, 16.5N/mm^2 were obtained at 10%, 20%, 30%, 40% of PSA respectively at 12M NaOH concentration at 28 days of curing. Hence, PSA can be used as a source material for geopolymer binder production in combination with other conventionally used materials for gepopolymer production.

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