Effects of Nigeria Palm Oil Fuel Ash (POFA) and Ground Granulated Blast Furnace Slag (GGBS) on Compressive Strength of Geopolymer Concrete

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ABSTRACT

Concrete modification with agricultural and industrial wastes is the trending field of materials design globally in other to reduce cement consumption and global warming. In this research, effects of locally sourced Palm Oil Fuel Ash (POFA) as Supplementary Cementitious Material (SCM) on strength characteristics of ground granulated blast furnace slag (GGBS) based geopolymer concrete in Nigeria were investigated. A sodium silicate gel (Na_2SiO_3) and sodium hydroxide (NaOH) solutions of 14 molar concentration were used as an alkaline activator in the mix design. A total of 36 specimens with a designed mix of 50Mpa concrete were used in accordance with ACI and ASTM guidelines. The substitution levels of 100, 75, 50, 25 and 0%(GGBS), 0, 25, 50, 75 and 100% (POFA) and 100% (PLC) were employed in producing the geopolymer mixes (GPC0, GPC1, GPC2, GPC3, GPC4 and GPC5) with GPC0 been the control sample and thermal curing done at a temperature of 60-80ºC in an oven for approximately 24hrs. The principal characteristics measured was early compressive strength development of geopolymer concrete at 7-day and 28-day hydration periods. The results indicated that specimen in 14M alkaline solution gave an optimal substitution level of 75% GGBS and 25% POFA with compressive strength of 68.37MPa, which was approximately 36.74% and 21.05% higher than the target strength and value obtained for control specimen with measured strength of 56.48MPa at 28days hydration period respectively. Therefore, GGBS-POFA based geopolymer concrete is a sustainable and environmentally friendly means of concrete production with an improved Engineering Properties.

Key words: Alkaline activator, Compressive Strength, Geopolymer concrete, ground granulated blast furnace slag (GGBS), Pal Oil Fuel Ash (POFA).

1.0 Introduction

Concrete is majorly produced with Portland cement as binder and is the most widely used construction materials due its inherited properties (Malhotra, 2000; Amri et al., 2018; Amran et al., 2021; Buari et al., 2021a). Globally, more than 10 $\times 10^9$ tons of concrete are made annually (Mehta, 1999; Malhotra, 2000; Oyebisi et al., 2019; Buari et al., 2020a). However, researchers have proven that high consumption of Portland limestone cement in conventional concrete production is major source of global warming and ozone layer depletion because of high volume of greenhouse gases released during cement production (Olutoge et al., 2013; Ademola et al., 2013; Turner and Collins, 2013; Buari et al.,2020b; Buari et al., 2021b). The need for alternative means of concrete production is major concern of construction materials experts because of daily increase of infrastructure demand due to rapid population growth and the need for economic, environmentally friendly and sustainable concrete design. Geopolymer concrete production has been proven to be the most effective alternative to conventional concrete production (Saafi, 2013; Singh, 2014; Thomas et al., 2017). Geopolymers are aluminosilicate molecular units that can be produced by the geopolymerization processes and its concrete is a relatively new development in the materials design development. In geopolymer concrete production, cement is completely replaced by pozzolanic materials, and activated by alkaline solutions which acts to bind the aggregates in a concrete mix (Ayachit et al., 2016). In Nigeria context, geopolymers are sustainable due to availabilities of various agricultural and industrial wastes such as Groundnut shell, Corn cob, Rice husk, Metakaolin, Palm Oil fuel, Ground granulated slag, fly ash, silica fume and blast furnace slag (Das et al., 2018). Nigeria ranked fifth as largest producer of palm oil globally (United States Department of Agriculture, 2019). Processing wastes from palm oil are typically dumped in landfills, endangering the environment and squandering land resources that could have been used for other productive purposes (Malkawi et al., 2018). With encouraging results, wastes produced from palm oil have recently been employed as additional resources in the manufacturing of concrete. These materials include oil palm shell (OPS), palm oil clinker (POC), and palm oil fuel ash (POFA) (Mannan and Ganapathy, 2004). A by-product of blast furnace production, ground granulated blast furnace slag (GGBS) is a cementitious substance created when molten slag is forced into a pit filled with steam or water, or both. As cementitious material, the by-product of this procedure is ground into a fine powder (Prabu et al., 2014). The low production cost of geopolymer concrete can be attributed to its energy-efficient procedures, low shrinkage properties, and excellent heat resilience, as demonstrated by Saafi et al. (2013). Additionally, prior studies have demonstrated that incorporating GGBS and agricultural waste into the design of geopolymer concrete can enhance the material's workability, setting time, and mechanical characteristics (Zarina et al., 2013; Prabu et al., 2014; Das et al., 2018). For these reasons, the present study examines the effects POFA and GGBS, on the compressive strength of geopolymer concrete produced by varying the amounts of ground granulated blast furnace slag (GGBS), palm oil fuel ash (POFA), and 14 molar concentrations of the alkaline solution.

2.0 Materials and Methods

The materials used in this study were obtained locally in Ede, Osun state. They included drinkable water for curing and mixing, ground granulated blast furnace slag (GGBS), palm oil fuel ash (POFA), Portland limestone cement, fine aggregates (river sand), coarse aggregates (granite stone), and sodium hydroxide (NaOH). The POFA was produced by three hours of calcination at 650 °C in an electrical furnace. The Coarse aggregate (granite stone) of 19mm and white river sand of 4.75mm diameter maximum sieve sizes used conform to the requirement of BS EN 14449:2005. The cement used for control samples (Dangote Portland limestone Cement) was obtained from the open market and conform to the requirements of BS EN 197-1:2000 for Ordinary Portland Cement. All aggregates are free of deleterious organic matter as specified by (BS EN 933-11 2009). Aggregates were dried to remove the moisture content and eliminate the possibility of increasing the water content in the concrete mix. Consequently, the practical and material analyses were carried out at the Structural Laboratories and Soil Mechanics of the Department of Building and civil engineering, Federal Polytechnic, Ede. Geopolymer concrete specimens were thermally cured in an oven at 60±3°C for approximately 24 hours. The target strength of 50MPa was obtained through Various trial mixes and all materials properties were determined through obtainable standards. The physical and chemical properties of all materials are shown in table 1 and 2 respectively.

Table 1.0: Physical properties of materials used

Property	**Coarse aggregate.**	**Fine aggregate.**	**GGBS.**	**POFA**	**OPC.**
size (mm)	19.00	4.5	4.5	-	-
Water absorption (%)	0.39	1.14	0.21	-	-
Specific gravity	2.59	2.21	2.91	2.44	3.12
Fineness modulus	6.21	2.27	1.19		
Colour			Grey		Grey
Passed on a 45-µm (No. 325) sieve (%)			100		99

Source: Laboratory Analysis, 2023

Table 2.0: Chemical compositions of materials used for experimental work

Major Oxide. Composition.	%Composition. of OPC	%Composition. of POFA	%Composition. of GGBS
Ferrous oxide (Fe_2O_3)	3.89	4.48	0.40
Silica (SiO_2)	20. 70	54.6	34.96
Calcium Oxide (CaO)	62.84	13.97	41.12
Aluminum Oxide (Al_2O_3)	4.78	7.22	13.33
MagnesiumOxide (MgO)	2.08	4.56	8.10
Sodium Oxide (Na_2O)	0.37		……
Potassium Oxide (K_2O)	0.38	0.85	……
Mn2O3	……		0.83
Sulphite (SO_3-)	1.45	0.49	0.51
LOI	2.80	4.7	1.30

Source: Laboratory Analysis, 2023.

2.1 **Mixes**

For this study, a specially blended mixture was used to achieve the goal strength of 50 MPa at 28 days of hydration period. Varying substitution level of GGBS and POFA was also adopted at 100:0, 75:25, 50:50, 25;75and 100:0 % for the production of geopolymer concrete cubes. The concrete mix was then weighed and divided into five portions for the different batches with a label GPC0-GPC5 with label GPC0 as control experiment. The choice of this percentage replacement and alkaline activator quantities used were based on review of similar research work carried out by (Ofuyatan et al, 2021, Oyebisi, 2019, Zarina et al., 2013) with their substitution levels varies between 5 and 100% for geopolymer concrete design. 100 x 100 x 100mm were produced for compressive strength and density tests respectively. A total of 36 cubes were produced for various examinations. The specimens were cured in water for hydration period of 28 days. Tables 3 and 4 below present various constituent materials proportion and geopolymer concrete design of the study

Table 3.0: Constituent Materials Proportion

Constituent Material	Proportion	Quantity per Sample
Coarse Aggregates	2.5	1.0 Kg
Fine Aggregates	2.0	0.8 Kg
Binders = (PLC) / (GGBS and POFA)	1.0	0.4 Kg
Water/Alkaline Solution)	0.5	200 ml

Table 4.0: Sample design for Geopolymer concrete (GPC0-GPC5)

Sample	Coarse Aggregates [kg]	Fine Aggregates [kg]	GGBS [%]	CEMENT [%]	GGBS [kg]	POFA [%]	POFA [kg]	NaOH Solution [ml]	Na_2SiO_3 Solution [ml]
GPC0	1	0.8	0	100	0	0	0	-	-
GPC1	1	0.8	100	0	0.4	0	0	57	143
GPC2	1	0.8	75	0	0.3	25	0.08	57	143
GPC3	1	0.8	50	0	0.2	50	0.16	57	143
GPC4	1	0.8	25	0	0.1	75	0.24	57	143
GPC5	1	0.8	0	0	0	100	0.32	57	143

Source: Laboratory Analysis, 2023.

3.0 Results and Discussion

The influence of admixtures, relationship between compressive strength and density of geopolymer concrete were investigated by various researchers (Zarina et al., 2013, Oyebisi, 2019, Ofuyatan et al, 2021 and Buari et al., 2022), and they concluded that these properties are interrelated and any change in one of these properties will influence the other.

Table 5.0: Compressive Strength of Designed Geopolymer concrete

Samples	**Samples composition.**	**Compressive Strength. [MPa]**	
		7days	28days
GPC0	0% GGBS and 0% POFA	34.65	56.48
GPC1	100% GGBS and 0% POFA	36.76	61.03
GPC2	75% GGBS and 25% POFA	44.12	68.37
GPC3	50% GGBS and 50% POFA	17.19	24. 86
GPC4	25% GGBS and 75% POFA	7.42	10.10
GPC5	0% GGBS and 100% POFA	-----	-----

Source: Laboratory Analysis, 2023. GPC5 (0% - 100% POFA) did not set nor harden as specimens collapsed after demolding.

3.1 Compressive Strength

POFA, like other pozzolanic materials, reacts with the Ca(OH)2 generated during the hydration of cement and GGBS to make a filler substance that fills in the pores in the concrete after it is finely divided. Therefore, as seen in table 5.0, more POFA addition will result in a reduction of compressive strength when Ca(OH)2 is depleted during the hydration process. Comparing the first two mixes with 100% GGBS – 0% POFA and the latter two with 50% GGFBS – 50% POFA and 25% GGBS – 75% POFA, respectively, Figures 1.0 and 2.0 demonstrate an improvement in average compressive strength. Additionally, the 28-day average compressive strengths of GPC1 and GPC2 are 8.06% and 21.05% higher, respectively, than the control mix (GPC0), while GPC3 and GPC4's are 59.12% and 81.15% lower, respectively, than the GPC0. Upon demolding, GPC5 specimens collapsed, indicating that they did not harden or set. The aforementioned results suggest that GPC1 and GPC2 are more suitable for commercial and industrial structures, as well as situations requiring high thermal and chemical resistance, because they can withstand and resist more compressive loading without cracking or deflecting than the control mix (GPC0) of PLC. GPC3 and GPC4, on the other hand, are appropriate for light-weight concrete design.

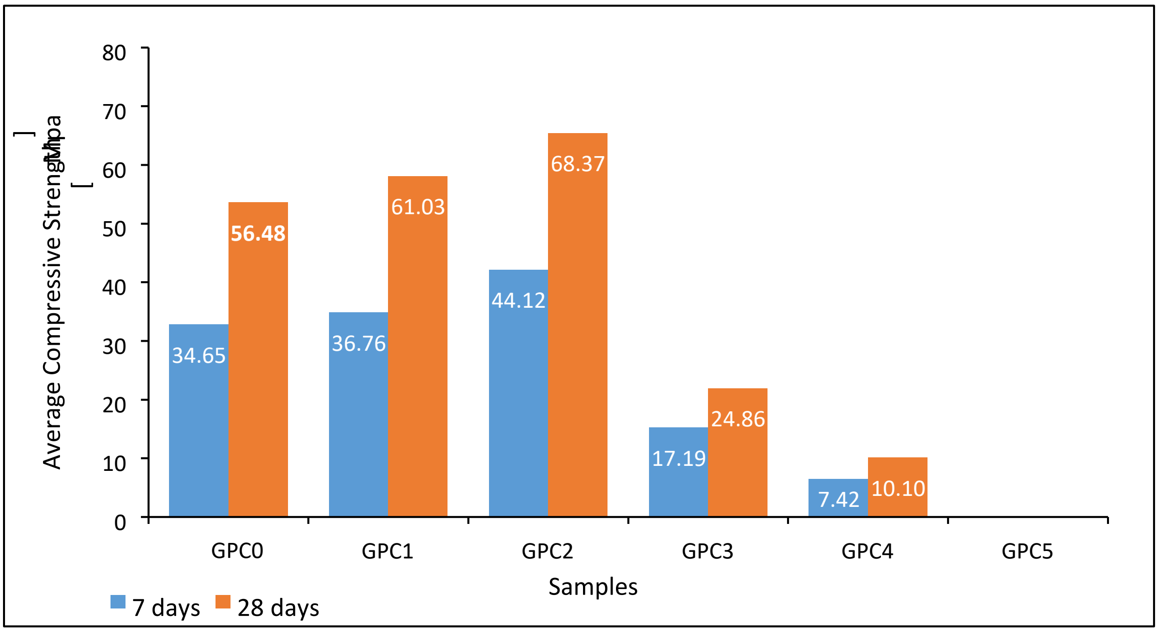

Fig. 1.0: Average Compressive Strength of GPC

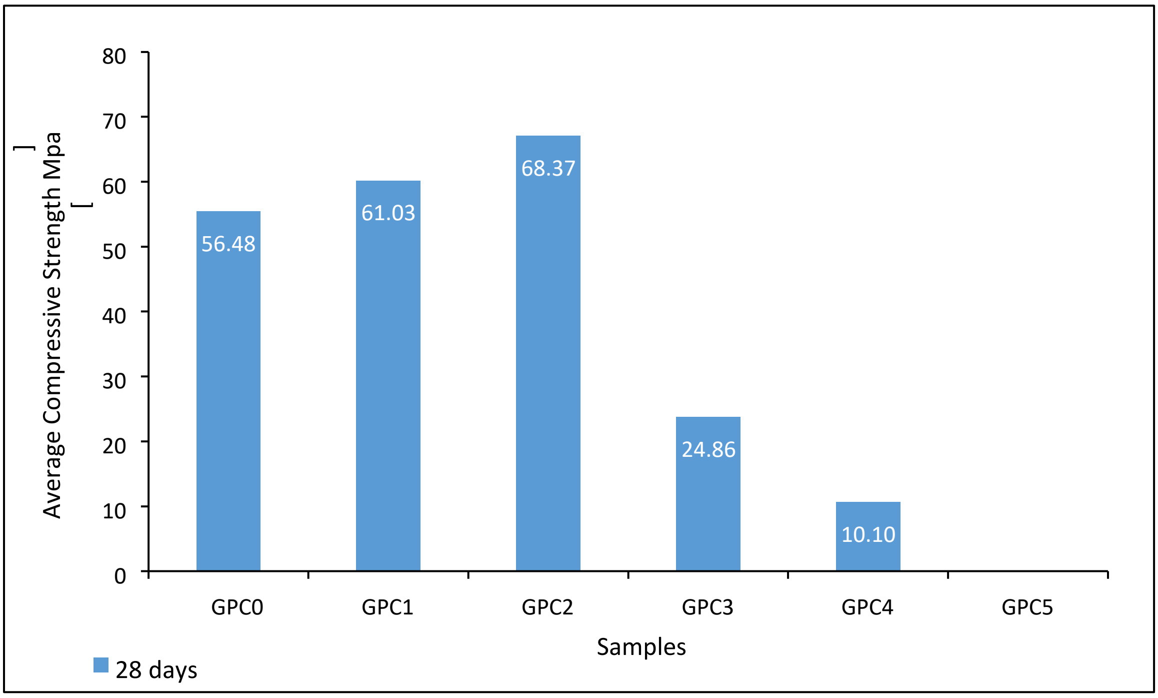

Fig. 2.0: Maximum Compressive Strength of GPC0 – GPC5 at 28 days

3.2 Analysis of Density Test

The average density of the GPC mixes dropped as the POFA content increased, as seen in Fig. 3.0. The average density at 7 days decreased by 1.13%, 2.16%, 3.98%, and 9.61% for GPC1, GPC2, GPC3 and GPC4 respectively, against the control sample (GPC0). The obtained average density at 28 days hydration were 0.87%,1.30%, 3.17% and 6.51% for GPC1, GPC2, GPC3 and GPC4 respectively. The results above demonstrate why GPC1 and GPC2 have greater compressive strengths than GPC3 and GPC4 by examining solely the average densities of the GPC mixtures. This is due to the fact that the density of concrete greatly affects its mechanical qualities; a denser concrete will often have a stronger strength and fewer voids, making it less permeable to water and other soluble elements. Furthermore, it is anticipated that GPC1 and GPC2 will have greater durability and less water absorption. The variation in average densities of PLC and 14 molar concentration GPC mixes after 7- and 28-days curing periods is shown in Figure 3.0 below.

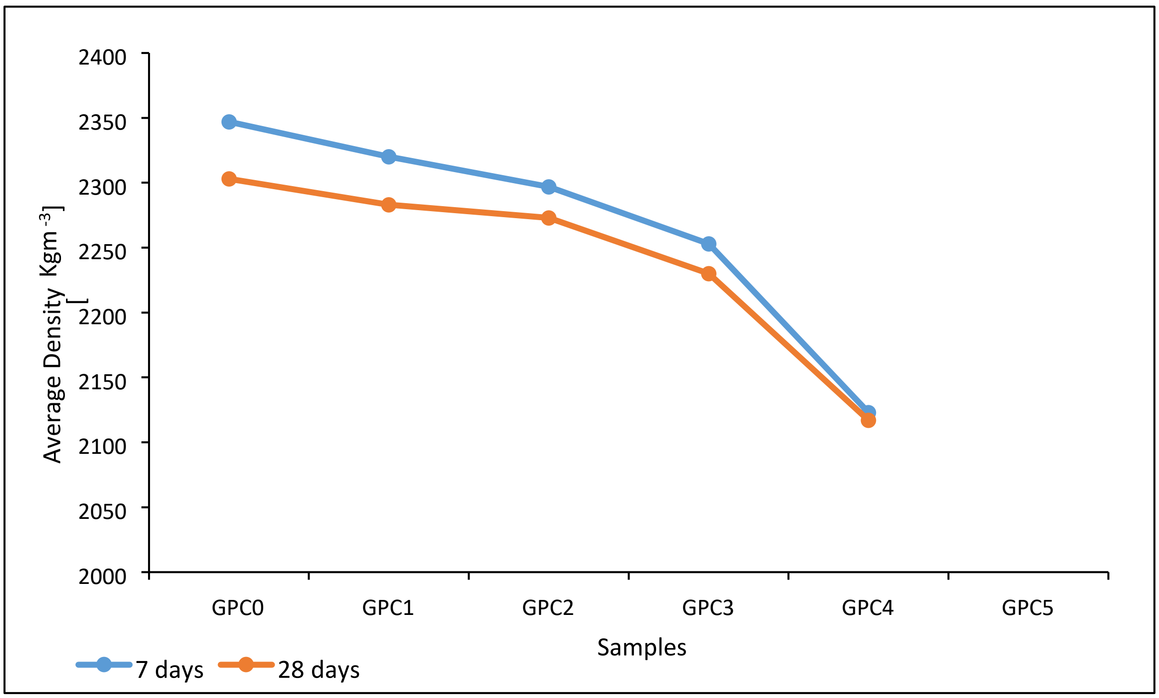

Fig. 3.0: Average Densities of GPC and PLC Samples

3.3. The best percentage replacement for GGBS and POFA

Figures 1.0 and 2.0 demonstrate that GPC2, or 75% GGBS – 25% POFA, is the mix with the best percentage replacement of GGBS and POFA. Its average density is 2273 Kgm-3, and its maximum average compressive strength is 68.37 MPa. Consequently, 75% GGBS - 25% POFA is the ideal ratio for GGBS and POFA substitution.

4.0 Conclusion

From research analysis and results, the following conclusions were made:

i. POFA is a feasible binder as it displayed great compressive strength at 25% incorporation with GGBS after 7- and 28-days hydration periods when compared with the control mix of PLC. The highest compressive strengths obtained from the GPC mixes were 27.33% and 21.05% higher than that of the PLC after 7 and 28 days respectively.
ii. The optimal substitution level was obtained in GPC2 containing 75% GGBS – 25% POFA with an alkaline solution of 14M. This mix was deemed the strongest mix achieving the highest compressive strength of 65.41MPa.
iii. The maximum substitution level with workable properties for GPCs was taken at 75% POFA incorporation and any further substitution led to concrete collapse.
iv. The GGBS and POFA can be used in the design and production of Geopolymer concrete with improvement in Compressive strength.

5.0 Recommendation

In order to enhance the practice of building and civil engineering in the field of building Structures and Materials Engineering based on the results obtained from this study, the following recommendations are made:

1. Utilizing geopolymer concrete (GPC) in construction with POFA content not exceeding 25% as compressive strength begin to reduce with further increase in POFA content.
2. Enhanced study on geopolymer concrete, particularly in the areas of cost-effectiveness and curing temperature and period. Although alkaline activators replace water in GPC mixes, producing a concrete of high compressive strength, its contents are relatively

expensive to manufacture therefore discouraging construction industries to commercialize geopolymer concrete in replacement of PLC concrete.

3. Using other mineral admixtures (Fly ash, Rice Husk Ash or Meta-kaolin) in combination with POFA and slag in the production of GPC to enhance mechanical properties.

CONFLICT of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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