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Effects of rest period on the strength performance of geopolymer concrete

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Abstract. The study investigated the effects of rest period on the short-term mechanical property of geopolymer concrete (GPC) that could possibly be easy to embrace in the field to achieve an optimum strength performance. The study utilized both corncob ash (CCA) and ground granulated blast furnace slag (GGBFS) as sustainable construction binders with a view to building sustainable infrastructure. Also, sodium silicate gel (Na_2SiO_3) and sodium hydroxide (NaOH) solution was used as an alkaline activator, and prepared in 14 molar concentration of NaOH pellets using a mix ratio of grade 30 MPa and grade 40 MPa concretes. GGBFS was substituted in 0, 20, 40, 60, 80, and 100% by volume of CCA. The rest periods (RP) for the fresh concrete were selected as 1, 2, 3, 4 and 5 days before being demoulded. Thereafter, the concrete samples were removed from the moulds and cured under ambient conditions for 7, 28, 56 and 90 days. The compressive strength of the hardened concrete samples was then determined. The study findings reveal an optimum strength performance at 4 days rest period for all classes of concrete produced when compared with 1, 2, 3 and 5 days. Thus, this result can be practically employed and incorporated in the design of geopolymer concrete and at the construction site.

Keywords: geopolymer concrete; corncob ash, ground granulated blast furnace slag; sodium silicate; sodium hydroxide; compressive strength; rest period

1. Introduction

Globally, the yearning for the low-carbon footprint and eco-friendly materials for the development of sustainable infrastructure cannot be overemphasized. In 2018, *the World Health Organization* and *the United Nations for Environment Programme* laid emphasis on the need for reduction of carbon dioxide (CO_2) discharge to the atmosphere due to its negative impacts on the human lives and the environment [1-2]. And one of the ways to reduce this menace is the development of geopolymer concrete. Geopolymer concrete comprises sustainable composites materials of geological origin, rich in aluminium and silicon such as GGBFS, fly ash (FA), metakaolin (MK), etc., and activate with an alkaline liquid such as silicate and hydroxide solutions of sodium and potassium, resulting in hardened product [3]. It is an innovative and green concrete in the engineering field. Geopolymer concrete (GPC) is a substitute concrete to Portland limestone cement (PLC) concrete as a result of its excellent engineering properties and environmental advantages [3]. Aside from water, PLC is being recognized as the most utilized binder in the construction industries.

However, it has been affirmed that the production of one tonne of Portland cement requires 1.5 tonnes of mineral extractions as well as 5000 MJ of energy, and generates 1.0 tonne of carbon dioxide. Whereas, the manufacture of GGBFS requires about 1300 MJ of energy and generates 0.07 tonne of carbon dioxide equivalent [3]. Thus, the utilization of GGBFS in the production of geopolymer concrete can significantly reduce the CO_2 emission into the atmosphere.
The utilization of pozzolanic materials such as corncob ash, silica fume, rice husk ash and fly ash as supplementary materials in the green concrete's production delay the setting time and early age strengths. But in a bid to attain a geopolymer concrete which can be cured at ambient conditions, *Nath and Sarker* in 2014, and *Parthiban, Saravanarajamohan, Shobana, and Bhaskar* in 2013 established that the blend of GGBFS, pozzolan and alkaline liquid produced a geopolymer concrete with high mechanical strength and excellent durability properties when compared with conventional concrete produced with PLC [4-5]. This births the adoption of GGBFS and CCA as sustainable binders in this study. Moreover, many researchers have utilized the CCA and GGBFS in the concrete production and they were found to be sustainably attainable [6-20]. Furthermore, rest period which is the period considered from the completion of the casting of concrete samples to the commencement of samples' curing at various curing conditions has been experimentally studied by various researchers to determine the day that is best suited for a particular geopolymer concrete to exhibit its optimum strength.

In 2009, *Malathy* conducted an experimental investigation on the influence of 3 days and 5 days rest period on the compressive strength of FA-based GPC using 14 molar concentration of NaOH solution and a ratio of Na_2SiO_3 gel to NaOH solution as 2.5: 1 for grades 30, 40 and 50 MPa concrete. It was discovered that 3 days rest period exhibited the highest compressive strength at both 7 and 28 days curing for all grades of concrete produced when compared with 5 days rest period [21]. In the same vein, *Vora and Dave* in 2013, examined the effect of rest period on the strength performance of low calcium class F processed FA-based GPC using grades 35 and 40 MPa concretes as mix design proportion. It was found that 1 day rest period, in manifested a higher compressive strength when compared with 0 day rest period [22]. In 2014, *Kumar, Murari, and Sharma* also studied the influence of rest period on the compressive strength of FA-based GPC. A substantial increase in compressive strength was observed in the 3 days rest period when compared with 1 and 2 days rest period [23]. Likewise, *Gargav and Chauhan* in 2016 conducted a research on the effect of rest period on the strength performance of FA-based geopolymer using 14 molar concentration of NaOH pellets at a ratio of 2:1 for Na_2SiO_3 gel and NaOH solution respectively. The optimum compressive strength was obtained at 3 days rest period when compared with 1, 2 and 4 days rest period [24]. In 2017, *Harle* also carried out the effect of rest period on the fly ash-based geopolymer concrete. The study adopted 12 molar concentration of NaOH pellets and a ratio of Na_2SiO_3 gel to NaOH solution as 1.7: 1. It was affirmed that 5 days rest period produced the highest compressive strength when compared with 1, 2, 3, 4, 6 and 7 days rest period [25]. Moreover, *Lake and Waghmare* in 2018, investigated the influence of rest period on the strength performance of pozzocrete fly ash-based geopolymer concrete, activated with 16 molar concentration of NaOH solution at a ratio Na_2SiO_3 gel: NaOH solution as 2.5: 1. It was observed that the compressive strength increased with increasing rest period but 7 days rest period gave the target strength when compared with 1, 3, 7, 14 days rest period [26].

Thus, this study investigates the effect of 1, 2, 3, 4 and 5 days rest period on the strength performance of GGBFS-based GPC incorporated with CCA. The alkaline liquid was prepared based on the 14 molar concentration of NaOH pellets while the ratio of Na_2SiO_3 gel to NaOH solution was set at 2.5: 1. Comparing these selections with Portland limestone cement concrete (PCC), 12 molar and 16 molar concentrations of NaOH pellets, higher performance on the strength properties of slag-based geopolymer concrete incorporated with corncob ash was obtained [6-7].

2. Materials and Methods

2.1. Materials

Both fine aggregate (FA) (12.5 mm in size) and coarse aggregate (CA) (19mm in size) were sourced from Ota, Nigeria. The aggregates were both used in conformity with the specification of the *American Standards for Testing and Materials (ASTM)* [27].

Alkaline liquids, 99% purity of NaOH pellets and Na_2SiO gel were both used and obtained from Lagos, Nigeria. Corncobs were sourced in Agbonle, Nigeria. They were sun-dried for 5 days to aid the burning process. Afterwards, they were burnt to ash to obtain corncob ash (CCA) under controlled temperature (600 ^{0}C) on a pilot scale gas furnace to lower the emission of carbon dioxide to the atmosphere. The ash was then obtained in accordance with the method stated by *Oyebisi et al.* in 2018 [10-11]. The oxides compositions of CCA was obtained based on the previous studies [10-11].

Granulated blast furnace slag (GBFS) was obtained from the Federated Steel Mills, Ota, Nigeria. The preparation, fineness particle size and its oxide composition were obtained based on the procedure set out by Oyebisi *et al.* in 2018 [10-11].

Finally, water for the mixing and production process was obtained from the Covenant University laboratory, Ota, Nigeria, and conformed to the *British Standard* [28].

2.2 Mix Design of Concrete Proportion

The concrete mix proportion was designed in conformity to the *British Standard* [29]. In the course of the mix design, water absorptions, specific gravities and moisture contents of the constituents in the mix were considered. The design proportions and identifications is shown in Table 1. The results of the mix proportions for grade 30 MPa concrete (M 30) and grade 40 MPa concrete (M 40) are presented in Table 2 and Table 3 respectively.

Table 1. Concrete design proportions

S/N	Proportions	Mix ID
1	100% GGBFS + 0% CCA	G 1
2	80% GGBFS + 20% CCA	G 2
3	60% GGBFS + 40% CCA	G 3
4	40% GGBFS + 60% CCA	G 4
5	20% GGBFS + 80% CCA	G 5
6	0% GGBFS + 100% CCA	G 6

Table 2. Mix design quantity for M 30 GPC

S/N	Constituent	Weight (Kg/m^3)	Specific gravity	Absolute volume (M^3)	Adjusted volume (M^3)	Ratio
1	GGBFS/CCA	390	2.90/2.44	0.134	0.142	1.00
2	FA	675	2.60	0.260	0.276	1.94
3	CA	1031	2.64	0.390	0.414	2.92
4	NaOH solution	60	1.49	0.040	0.042	0.30
5	Na_2SiO_3 gel	150	1.60	0.094	0.100	0.70
6	Air content	2.00	-	0.020	0.021	0.04
7	Total	2306		0.943	1.000	6.90

Table 3. Mix design quantity for M 40 GPC

S/N	Constituent	Weight (Kg/m^3)	Specific gravity	Absolute volume (M^3)	Adjusted volume (M^3)	Ratio
1	GGBFS/CCA	500	2.90/2.44	0.172	0.182	1.00
2	FA	585	2.60	0.225	0.238	1.31
3	CA	1031	2.64	0.391	0.414	2.28
4	NaOH solution	60	1.49	0.040	0.042	0.23
5	Na_2SiO_3 gel	150	1.60	0.094	0.100	0.55
6	Air content	2.00	-	0.020	0.021	0.12
7	Total	2328		0.942	1.000	5.49

2.3 Preparation of Alkaline Activators (AAs)

The alkaline activators were prepared in accordance with the previous studies [10-11] and in conformity with the chemistry laboratory procedure [30] (see Figure 1a).

2.4 Mixing, Casting and Curing

The constituents were thoroughly mixed for about 10 minutes, filled in the moulds and compacted accordingly. The manual casting was employed. Thereafter, the concrete samples were kept in the rest period (RP) for 1, 2, 3, 4 and 5 days at room temperature before being demoulded (see Figure 1b). Then, the samples were removed from the moulds and cured under the ambient conditions (23-28 ºC; 60%-65% relative humidity) till the testing day. A set of two specimens were prepared per each mix for each test

2.5 Experimental Tests

The compressive strength of the hardened concrete samples was determined in conformity to the requirements of the *British Standard* [31] (see Figure 1c). Three samples were made for each mix with 150 mm standard size cubes, tested at 7, 28, 56 and 90 days.

Figure 1 (a). AAs preparation (b) concrete cubes in RP (c) strength test

3. Result and Discussions

3.1 Oxides compositions of CCA and GGBFS

The oxide compositions of both CCA and GGBFS are presented in Table 4 and Table 5 respectively. And from the tables, it is clearly shown that both CCA and GGBFS satisfied the requirements specified by the *ASTM* [32] and the *American Concrete Institute* [33] respectively. Therefore, it can be established that both CCA and GGBFS used are suitable materials in the production of GPC.

Table 4. Oxide compositions of the CCA used

Composition	SO_3	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	M.C	LOI
Properties (%)	1.25	60.50	8.78	9.13	12.62	1.23	0.65	1.25	0.49
ASTM C 618 Requirements	≤ 4%	$SiO_2+Al_2O_3+Fe_2O_3 > 70\%$			-	≤ 4%	> 0.70	≤ 3%	≤10%

Table 5. Oxide compositions of the GGBFS used

Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	Na_2O	M.C	LOI
Properties (%)	36.52	35.77	14.11	0.92	1.08	9.45	0.30	0.52	0.32
ACI 233R Requirements	32-45	32-42	7-16	0.1-1.5	0.7-2.2	5-15	-	-	-

3.2 Compressive Strength

Figure 2 to Figure 5 and Figure 6 to Figure 9 show the results of compressive strengths of GPC at 7, 28, 56 and 90 days curing for grade 30 MPa concrete and grade 40 MPa concrete respectively, and how the strength performances have been influenced by the rest period for 1, 2, 3, 4 and 5 days. From Figure 2 to Figure 5, it was observed that 5 days rest period exhibited the highest compressive for all curing days and concrete types when compared with 1, 2, 3 and 5 days rest period for grade 30 MPa concrete. A similar trend also occurred in grade 40 MPa concrete where 4 days rest period displayed the highest compressive strength when compared with other days of the rest period (RP) (Figure 6 to Figure 9). The higher compressive strength witnessed in 4 days rest period when compared with 1, 2, 3 and 5 days rest period substantiated the findings of *Harle* in 2017 that 5 days rest period produced the highest compressive strength when compared with 1, 2, 3, 4, 6 and 7 days rest period [25]. The result was also in line with *Gargav and Chauhan* in 2016 that 3 days rest period manifested the highest compressive strength when compared with 1, 2 and 4 days rest period [24]. Thus, the higher compressive strength exhibited in 4 day rest period can be attributed to the attainment of full polymerization by the chemically reactive activation of both the GGBFS/CCA and the alkaline liquid [34].

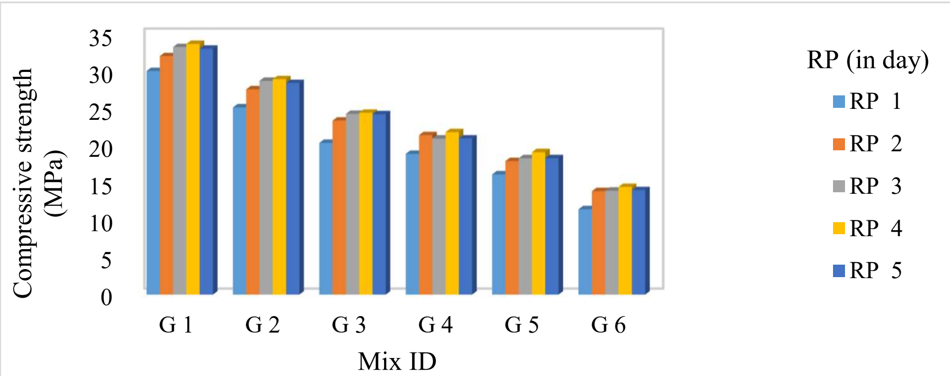

Figure 2. Chart of compressive strength against rest period at 7 days (M 30)

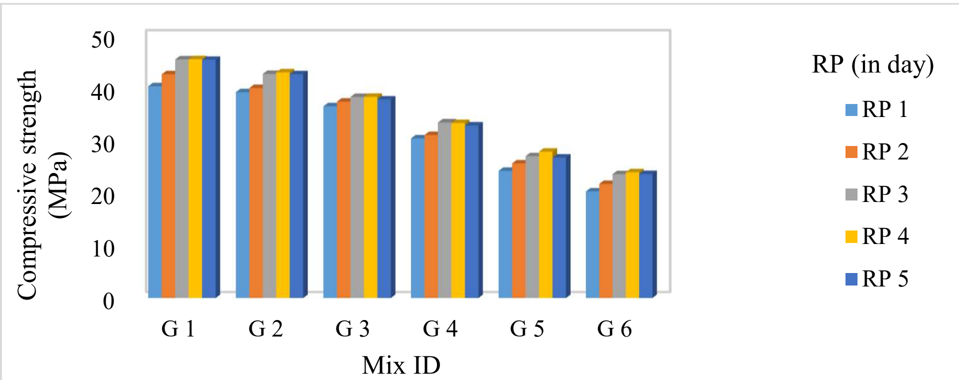

Figure 3. Chart of compressive strength against rest period at 28 days (M 30)

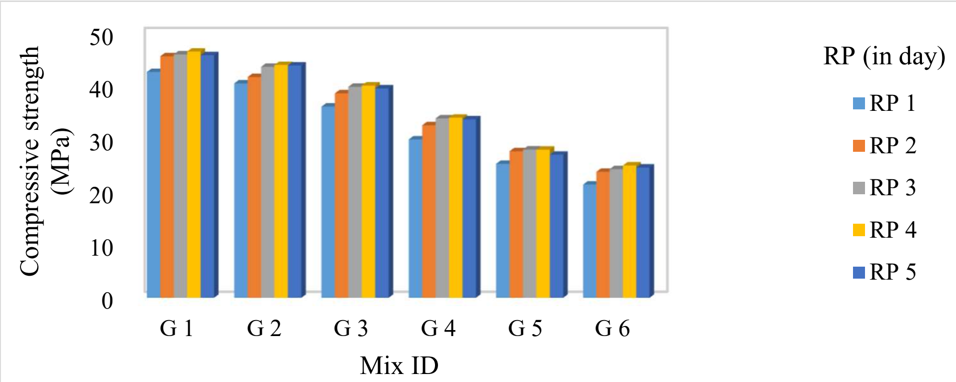

Figure 4. Chart of compressive strength against rest period at 56 days (M 30)

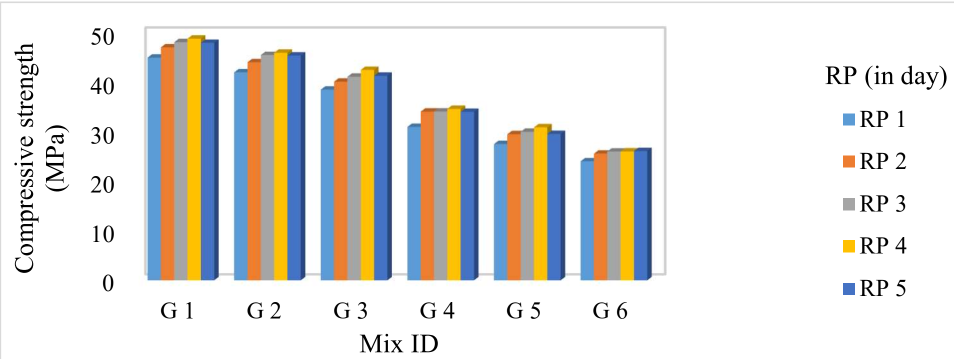

Figure 5. Chart of compressive strength against rest period at 90 days (M 30)

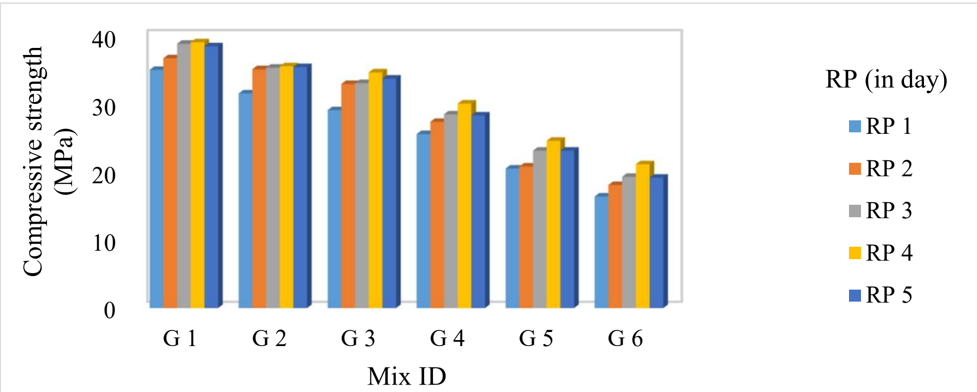

Figure 6. Chart of compressive strength against rest period at 7 days (M 40)

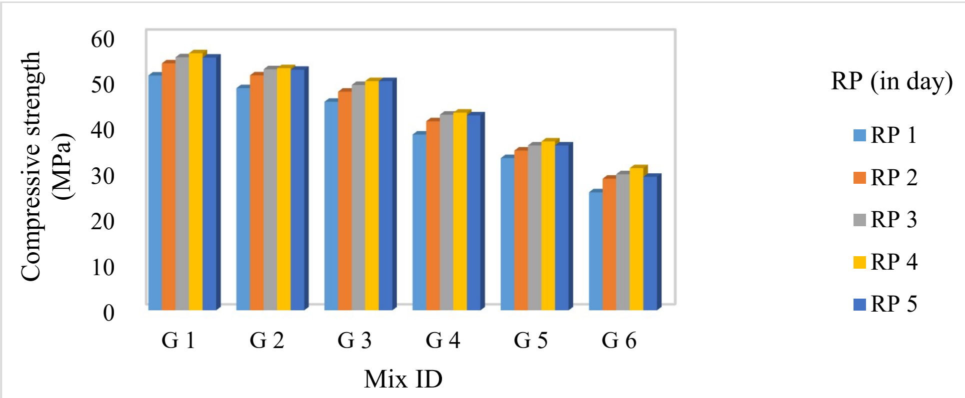

Figure 7. Chart of compressive strength against rest period at 28 days (M 40)

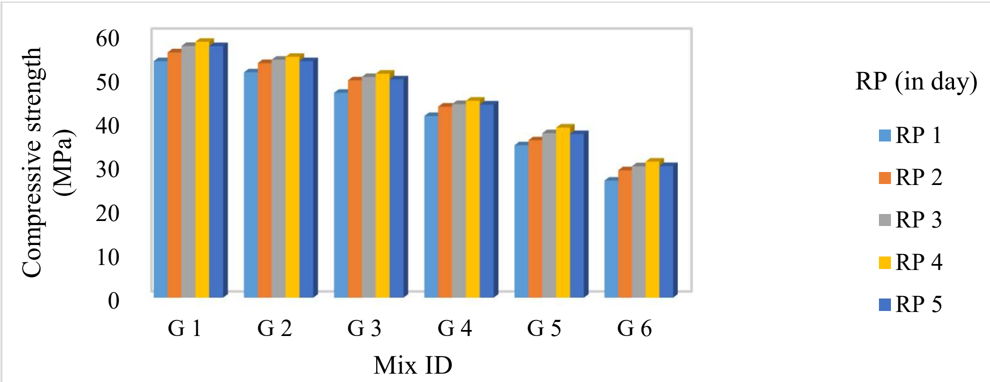

Figure 8. Chart of compressive strength against rest period at 56 days (M 40)

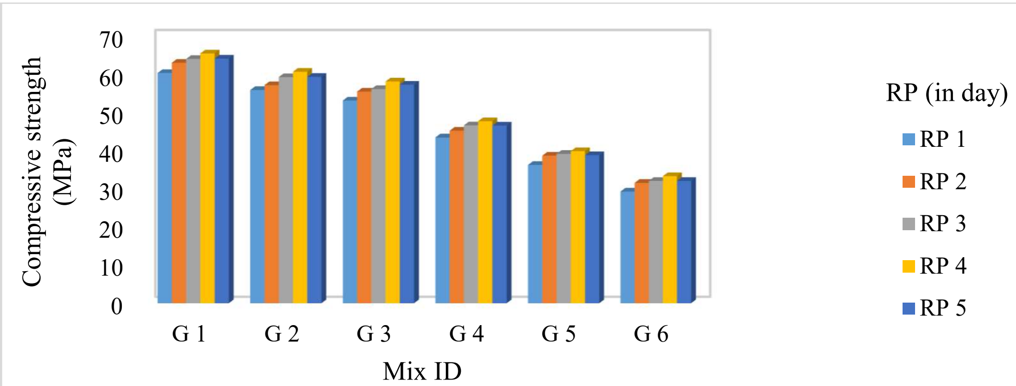

Figure 9. Chart of compressive strength against rest period at 90 days (M 40)

4. Conclusion

Owing to the findings from this study, it is concluded that the rest period influences the strength performances of geopolymer concrete. And considering this effect, it can be seen that 4 days rest period exhibited the optimum compressive strength for the polymeric reaction between the GGBFS/CCA and the alkaline activators for all concrete types. Therefore, this study contributed to sustainable construction materials for sustainable building. It also provided a method of determining the strength performance of geopolymer concrete in the construction industry to avert infrastructural failure.

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