Study on Characteristics of Geopolymer Concrete

Ward Nasser Al Banna and Kiran Kumar Poloju

Abstract Cement is used in enormous quantities for concrete applications in construction projects across the world which contributes to CO_2 emissions. Geopolymer concrete (GPC) is a cutting-edge construction material used as a substitute for ordinary Portland concrete (OPC) as it reduces cement usage and preserves the environment through the utilization of by-product materials. This study aims to find out how the molarity of sodium hydroxide affects the durability and strength of geopolymer concrete, as well as the appropriate GGBS/fly ash proportion in GPC. The paper has concentrated on characteristics of workability, compressive strength, and durability properties such as drying shrinkage and sorptivity. Curing procedures, Na_2SiO_3/NaOH ratio, and alkaline/binder ratio were all taken into account in the study. The findings state that increased molarity up to 14_M and 100% of GGBS in fly ash achieves the best strength and durability performance of GPC. A 1.5 Na_2SiO_3/NaOH ratio and curing at elevated temperatures have also been proven to improve the strength and durability of GPC. The study found that the geopolymer concrete is exceedingly durable and is highly recommended as a construction material.

Keywords Geopolymer concrete · Molarity · Alkaline activator · Sodium silicate · Sodium hydroxide · Strength characteristics

1 Introduction

In recent times, concrete is one of the important materials in the construction field all around the world due to the availability of its materials, low cost, resilience, and longevity. In ordinary Portland concrete (OPC), the main constituent to bind the aggregates together is cement, which is used in a very tremendous quantity for

---

W. N. Al Banna (✉) · K. K. Poloju
Department of Civil Engineering, Middle East College, Seeb, Oman

K. K. Poloju
e-mail: kpoloju@mec.edu.om

P. G. Kumar et al. (eds.), *Recent Advances in Civil Engineering*, Lecture Notes
in Civil Engineering 233, https://doi.org/10.1007/978-981-19-0189-8_44

concrete applications that are around 1.6 billion tons yearly. The cement manufacturing process in this amount is a massive cause of greenhouse gases emission which is responsible for 7% of total carbon dioxide emissions into the atmosphere each year across the world, and this is a crucial matter taken into consideration since these released gases are causing an atmospheric pollution. Therefore, many studies focus nowadays on finding a suitable alternative for cement in concrete applications to reduce the environmental degradation caused by cement manufacturing process. Provided that by-products from different industries are disposed off as waste materials to exposed lands, which as a result contributes to an environmental pollution [1]. Geopolymer concrete (GPC) is a cutting-edge construction material used as a substitute for (OPC) due to its environmental benefits as it is made by utilizing by-products. The term "geopolymer" was invented in 1978 by Davidovits which represents mineral polymers linking with a covalent bond. Geopolymer is formed by activating a pozzolanic material that is rich in aluminum (Al) and silicon (Si) with an alkaline solution and binds the aggregates in GPC at an elevated temperature, this chemical reaction is known as the geopolymerization process. Mainly produced by mixing Ground Granulated Blast Fruance Slag (GGBS) and Fly Ash with aggregates and an alkaline activator. Alkaline activator is controlled by Sodium Silicate to Sodium Hydroxide (SS/SH) ratio [2]. According to [3], the alkaline activator solution can be prepared using either sodium hydroxide (NaOH) or potassium hydroxide (KOH), it was proved in their study higher alkalinity level is provided by the KOH, whereas higher potency for monomer liberation was by the NaOH solution. However, a mixture of both sodium silicate and sodium hydroxide is the alkaline solution often used. A study conducted by Poluju [4] on alkaline solution impact on compressive strength of geopolymer mortar, they have used combined and single solutions, the combined solution used were combination of Na_2SiO_3 and NaOH, while the single solution was a Na_2SiO_3 solution. They have also examined the strength with varying replacement of fly ash with GGBS up till 100%, their findings observed a higher strength with a single solution and mixtures of 100% of GGBS. Molarity in GPC reflects the molar concentration of sodium hydroxide given by its number of moles per liter of solution. As it increases, the viscosity of solution increases which improves strength properties, [5] executed a study on GPC in terms of workability and compressive strength with varying molarities from 8 to 12 M and fly ash replacement with GGBS by 30–70%. The results demonstrated that the increase of GGBS content and molarity decrease workability and increases the strength. Another experimental study was conducted by Babu [6]on the concentration of NaOH on GPC strength properties with molarities of [6 M, 8 M, 10 M] and 2 SS/SH ratio. The results indicated maximum strength by 10 M. Ganesan [7] have studied the influence of alkaline activator/binders ratio on the compressive strength of geopolymer concrete up to 56 days of ambient curing. The mixture was prepared with 1:2:5 ratio of sodium hydroxide/sodium silicate solutions. The solution to binder ratios tested ranged from 0.30 to 5. It has been indicated that the strength continued to increase until 56 days of curing, and decreased with increasing the ratio, the alkaline solution/binder ratio of 0.30 had attained the higher strength. A durability comparison study was carried out by Luhar [8] on sorptivity and water absorption of m25 grade of GPC and OPC. Their findings have shown that geopolymer concrete is more durable than conventional concrete as both the sorptivity and water absorption were less in geopolymer concrete. Dave [9] have carried out a study on GGBS based GPC with two more binders which are fly ash and silica fume, hence, the mixtures will be tested containing overall of three binders. They were prepared with 14 M with a SS/SH Sodium ratio of 3. Five mixtures were prepared, first mixture was prepared with GGBS only, three mixtures incorporated silica fume with GGBS and last two mixtures were prepared using fly ash, silica fume, and GGBS. It has been indicated from the findings that the GGBS based GPC mixture resulted in the highest sorptivity, following the mixtures with silica fume and GGBS. While the lowest sorptivity value was observed by the mixture with the three binders; fly ash, silica fume, and GGBS. Therefore, the study comes to a conclusion that fly ash and GGBS combination for GPC mixture reduces sorptivity which is an indication of a denser structure with less pore spaces, the combination of these binders reduces the pore structure by increasing the packing density. Heat curing is a very significant factor affecting geopolymer concrete performance, [10] have carried out a research on the curing method impact on the compressive strength of GPC, the samples were prepared using 10 M, with a 1.75 SS/SH ratio and a 0.4 activator/fly ash ratio. The results were compared by curing under ambient and hot temperature at 75 °C, it has been found that heat curing samples had attained higher strength, the sample was also compared with OPC where it was also shown that heat curing can contribute to a strength higher than the OPC. Additionally, SEM analysis was also done to observe the shape of the particles of fly ash, sodium silicates, and sodium hydroxide. The results have observed a rounded and circular shape for the fly ash particles and comparing the silicon particles between fly ash and Na_2SiO_3 solution, finer particles were observed by the Na_2SiO_3 solution. Furthermore, hydrargillite-like layer structure was noticed by the particles of sodium (Na) in NaOH. Geopolymer mortar strength was examined by Shinde [11] in terms of alkaline/binder ratio which varied between 0.2 and 0.8 and Na_2SiO_3/NaOH ratios varying from 1 to 3, with heat curing of temperatures from 40 to 100 °C. Highest strength was attained by the alkaline/binder ratio of 0.5 and 1.5Na_2SiO_3/NaOH ratio, higher ratios decreased the strength. Whereas the temperature of heat curing at 80 °C is the optimum temperature for heat curing as further increase of temperature leads to decrease in strength. Activation impact has been studied by Zhang [12] in terms of crystalline phases formation using sodium hydroxide alone comparing it with the addition of sodium silicate. The study was carried out using XRD, SEM, and other testing methods. They reported that the crystallite formation is significantly reduced by the presence of sodium silicate, while the use of sodium hydroxide alone can increase crystalline zeolite formation. Rovnanik [13] have analyzed curing temperatures (10–80 °C) and methods' effect on GPC strength and microstructure properties. The results have inferred that the gain of strength is faster with elevated temperatures, however, the samples have observed deterioration after 28 curing days. While the ambient cured samples had low strength gain but on the other side, they have exhibited better properties after 28 curing days. Performance of geopolymer concrete is also affected by the type of fly ash which are classified into Class C and Class F, higher calcium presence in class C may affect the geopolymerization process and interfere with the microstructure, therefore, low calcium fly ash is more preferable [14]. A study was conducted by Bakharev [15] on the durability of geopolymer concrete after exposing the samples to 5% of acetic and sulphuric acid solutions and compared with OPC. The study deduces that geopolymer concrete has higher resistance to acids than OPC. Another comparison study between GPC and OPC was reported by Mali [16] on abrasion resistance and water absorption of GPC samples, it has been inferred that GPC has much higher resistance to abrasion wear and absorption of water compared to OPC which makes it excellent in durability properties. The aim of this research paper is to examine properties of GPC in terms of its workability, compressive strength, and durability according to the literatures. Parameters considered in this study will include molarity of NaOH, curing methods, GGBS/fly ash proportions, and SS/SH ratio.

2 Methodology

Instead of hydrating cement, geopolymer concrete is developed by chemically activating industrial by-products which contain aluminosilicates by an alkaline solution. Geopolymer concrete can be made by mixing GGBS, fly ash, coarse and fine aggregate, and alkaline activator. GGBS is a by-product of steel industry and fly ash is a thermal industry by-product, both are rich in silica and alumina and used as fine powder form. Conventional standard sizes of coarse and fine aggregates are used in GPC similarly as used in OPC. An incorporation of both solutions (H_2SO_4 & Na_2Sio_2) is mixed for alkaline solution. This solution when reacted with silica and alumina of the materials, a binder material will be formed [17].

To develop geopolymer concrete using these materials, alkaline solution is first prepared according to the molarity of sodium hydroxide. Molarities commonly used range between 6 and 18 M. To prepare an alkaline solution with 10 M of NaOH, the molarity (10 M) is multiplied by the molecular weight of NaOH (40 g/mol) which gives 400 g of NaOH pellets. This weight is taken into a liter of jar with adding water and mixing them together, NaOH solution is then weighed. To prepare the amount of sodium silicate according to Na_2SiO_3/NaOH ratio, if 1.5 ratio is selected, then 1.5 is multiplied by NaOH solution weight and is added to the mixture. Due to the heat generated as a result of NaOH dissolution in water, mixture is left for a day before use. After 24 h of alkaline solution preparation, required quantity of binders are mixed with the aggregates according to mix proportion and activated with the alkaline solution. From the available literature, specimens are cured under ambient and heat temperatures to undergo geopolymerization. This study will be carried out as a research study by collecting data from previous studies. Varying molarities and SS/SH ratios will be examined from different studies on workability, compressive strength, and durability properties of geopolymer concrete.

3 Results and Discussion

3.1 Results

3.2 Discussion

GGBS and strength ratio effect on workable and strength is represented by Figs. 1 and 2, strength ratios (1.5 and 2.5), GGBS of 10 and 20% content were examined. The results infer that increased content of GGBS and reduced ratio of SS/SH to 1.5 has increased the workability and strength. Workability, strength, and sorptivity results of GPC are presented in Table 1 with varied molarities (8, 10, 12) and fly ash substitution with GGBS. It is demonstrated from results that the increased substitution of fly ash with GGBS till 100% has increased the strength, reduced the workability and sorptivity. Moreover, higher molarity (12 M) has increased strength, decreased

Fig. 1 GGBS & SS/SH ratio impact on compressive strength [18]

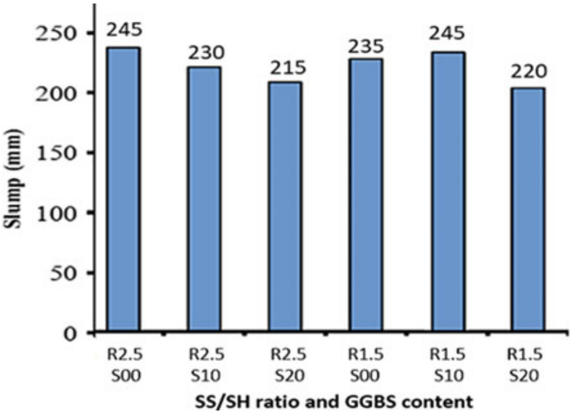


Fig. 2 GGBS & SS/SH ratio impact on workability [18]

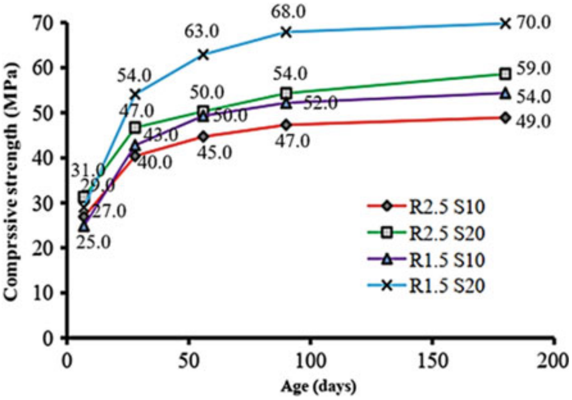


Table 1 GGBS and molarity effect on workability, strength and sorptivity [1]

Molarity (M)	% Replacement of fly ash by GGBS	Slump values (mm)	Compressive Strength (MPa)		Sorptivity mm/mm$^{0.5}$
			14 days	*28 days*	
8	100	34	36.6	44.5	1.06
	90	35	35.6	42.9	1.13
	60	36	33.9	40.8	1.29
	30	38	35.5	37.2	1.40
	0	40	29.2	35.6	1.52
10	100	50	41.4	46.8	1.01
	90	51	40.5	45.4	1.09
	60	53	38.4	43.2	1.15
	30	56	36.1	42.5	1.35
	0	58	35.5	40.6	1.43
12	100	67	43.5	53.2	0.90
	90	68	42.8	40.5	0.95
	60	71	41.03	47.5	1.04
	30	73	39.4	45.09	1.20
	0	75	35.4	43.5	1.31

workability, and sorptivity. Compressive strength with 12 M has increased from 43.5 to 53.2 MPa with increment of GGBS content from 0 to 100%, while the sorptivity reduced from 1.31 to 0.90 mm/mm$^{0.5}$. Whereas for increasing molarity from 8 to 12, the strength has increased from 44.5 to 53.2 MPa, and sorptivity reduced from 1.06 to 0.90 mm/mm$^{0.5}$. Figures 4 and 6 show the molarities (8–14 M) impact on strength and ultrasonic pulse velocity (UPV) of GPC, increasing molarity from 8 to 14 has increased the strength for all grades and UPV results. Comparing strength of GPC mixtures with OPC, GPC with molarities 12 and 14 can achieve higher strength than OPC. Figures 3 and 5 show the curing impact on their strength and UPV, the strength increased and UPV also increased when samples were oven-cured than ambient cured. Also, UPV was tested with varying fly ash/GGBS proportion, sample having 25% of GGBS has the highest velocity than samples with higher GGBS content or no replacement at all. Sorptivity results are presented in Figs. 7 and 8 for two examined phases, first phase in Fig. 7 shows results for varying fly ash/GGBS proportions either fly ash-based, GGBS-based or equal proportions. Second phase in Fig. 8 is varied molarities (M6–M14). The results illustrate that GGBS reduces sorptivity, as the fly ash-based GPC had the highest sorptivity (0.3 mm/mm$^{0.5}$) while GGBS based GPC had the lowest sorptivity (0.23 ^{mm}/mm$^{0.5}$). 6 M mixture had the highest sorptivity (0.36 mm/mm$^{0.5}$) than the 14 M mixture which had the least sorptivity (0.11 mm/mm$^{0.5}$), hence, increasing molarity reduces sorptivity. Drying shrinkage in Fig. 9 examines GPC with GGBS content (0, 10%, 20%) and compared with OPC. Increased GGBS content in GPC reduced shrinkage more than OPC sample.

Figure 10 observes shrinkage results with dry and steam curing, it is inferred that steam curing leads to less shrinkage than dry curing. Results in Figs. 11 and 12 show shrinkage values in two phases, phase 1 examined GGBS content (10–20%) effect and phase 2 examined impact of 2.5 and 1.5 SS/SH ratios. Least shrinkage was noted by GGBS of 20% and 1.5 SS/SH ratio. Figures 13 and 14 show resistance of GPC and OPC to abrasion and acid attack, it is illustrated that GPC has higher abrasion resistance and acid attack resistance.

All results prove that increasing molarity and GGBS content with reducing SS/SH ratio and oven curing improves GPC strength and durability. High molarity indicates an increase in NaOH concentration, hence, silicate and aluminate monomers are greatly dissoluted. As a result, strength and durability of GPC are improved because leaching of these compounds induces stronger geopolymerization. On the other side, due to cohesiveness of increased NaOH concentration, workability is reduced [1]. Increasing SS/SH ratio increases the viscosity of mixture, which restricts the flowability. This decreases the workability, additionally, strength and durability are affected too because SS/SH ratio increment decreases NaOH solution and hydroxide ions. Thus, gel is decreased and GPC microstructure is adversely affected [18]. Decreased workability with adding GGBS is due to its shape which has larger surface area than

Fig. 3 Effect of curing on compressive strength [19]

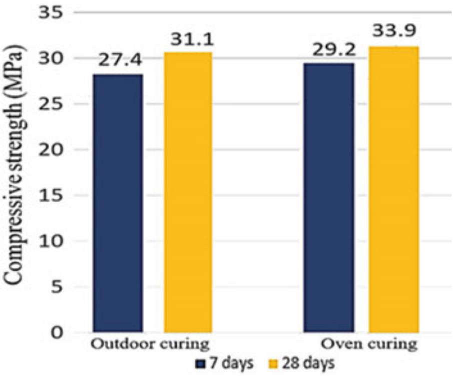
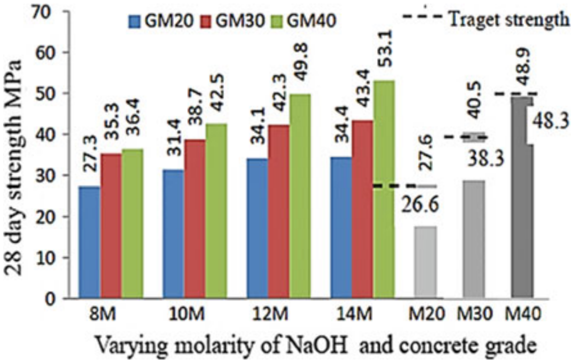


Fig. 4 Effect of molarity on compressive strength [20]



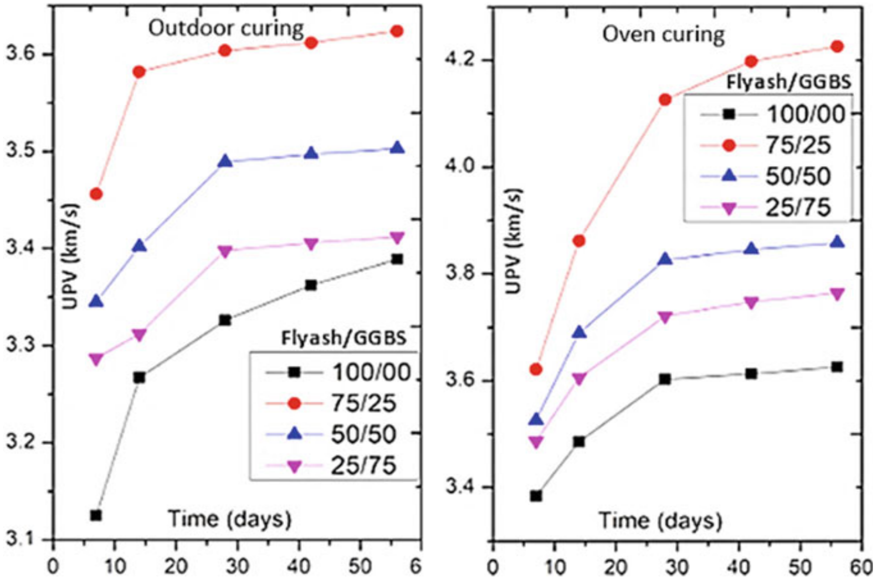


Fig. 5 Effect of curing on UPV [21]

Fig. 6 Effect of molarity on UPV [22]

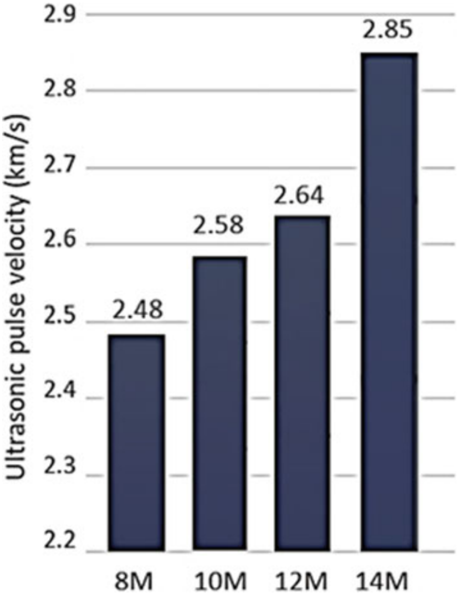


Fig. 7 Effect of GGBS on sorptivity [23]

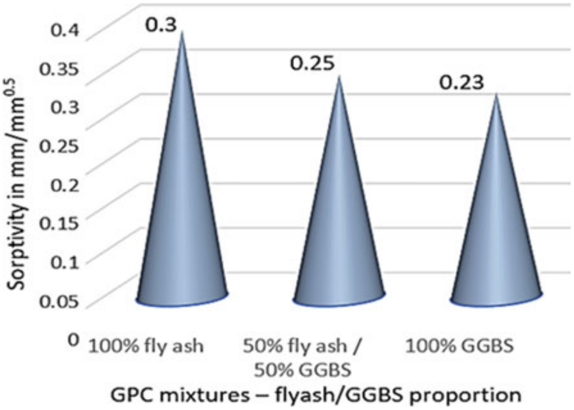


Fig. 8 Molarity effect on sortivity [23]

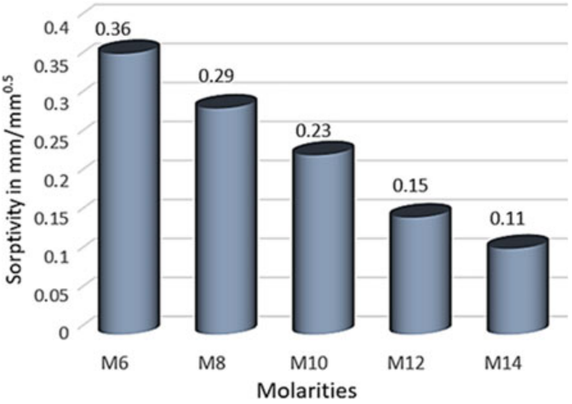


Fig. 9 Impact of GGBS on drying shrinkage [24]

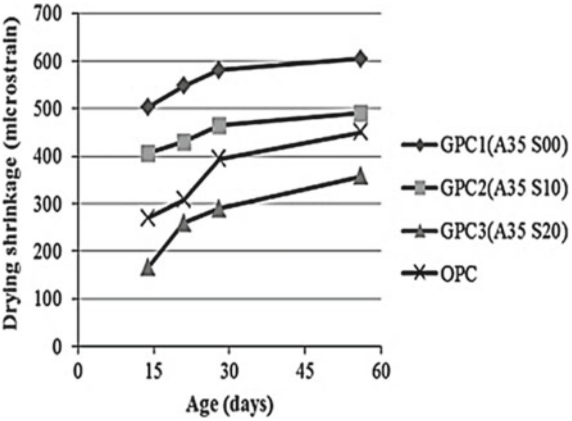


Fig. 10 Impact of curing on drying shrinkage [25]

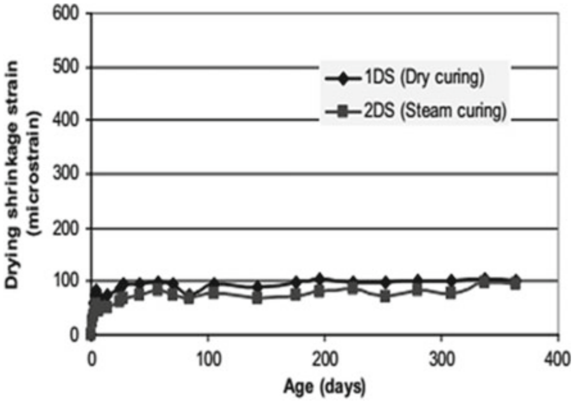


Fig. 11 Impact of GGBS on drying shrinkage [26]

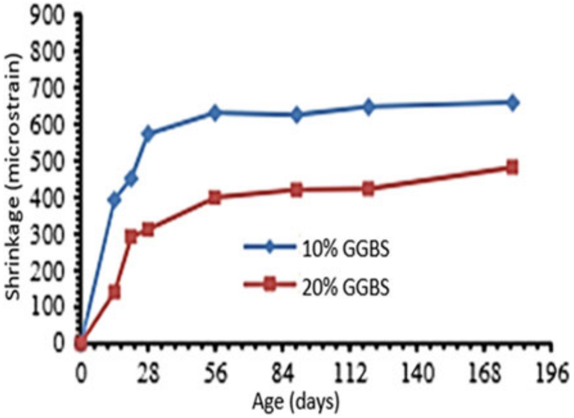


Fig. 12 SS/SH ratio impact on drying shrinkage [26]

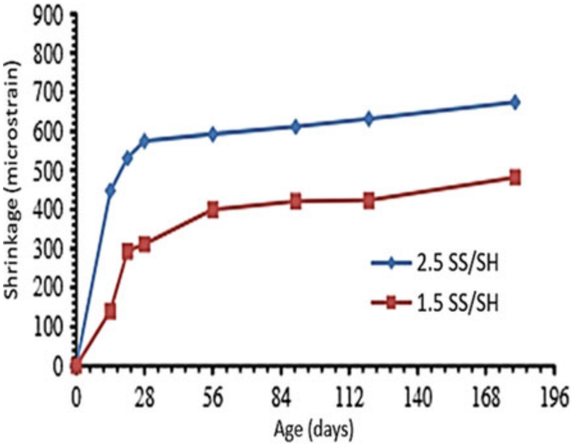


Fig. 13 Abrasion resistance [26]

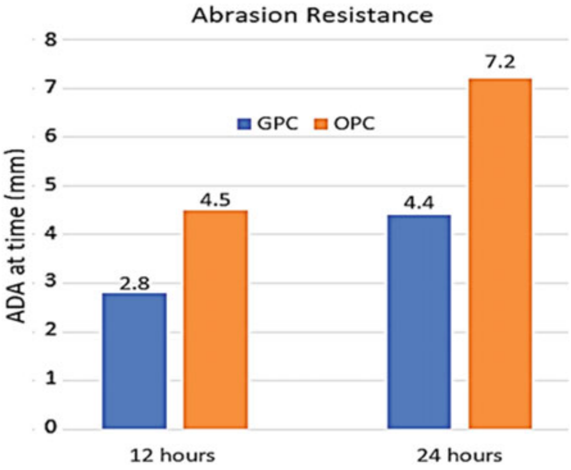
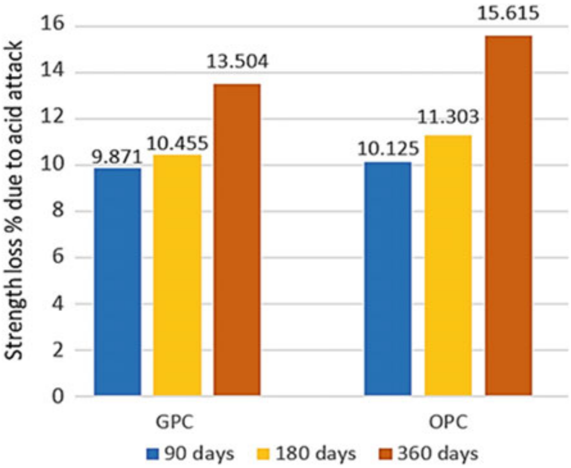


Fig. 14 Strength loss due to acid attack [27]



fly ash. This leads to more water demand, thus workability is reduced. The shape of GGBS also improves the bonding property which increases strength and durability. In addition, GGBS is higher in calcium oxide than fly ash, hence when used in GPC the chemical reaction is improved. A denser and less porous microstructure is formed [23]. Curing at elevated temperatures causes water content in GPC sample to be given out as the water is vaporized. As a result, pores in GPC contain less moisture, shrinkage is negligible at this point, and strength and durability are improved [25]. Generally, all samples had low shrinkage since they were below 1000 micro strain, this falls within the acceptable range in accordance with the Australian standard AS1379-2007 [26].

4 Conclusion

Geopolymer concrete strength and durability properties were examined according to previous literature. The study has found that the GPC is exceedingly durable and is highly recommended as a construction material as it assists to reduce cement usage and preserves the environment through the utilization of by-product materials. The findings of this study can be concluded as followed:

- Workability can be improved by increasing molarity of NaOH up to 12 M, reducing strength ratio to 1.5 and GGBS percentage in fly ash.
- Compressive strength is increased by increasing NaOH molarity up to 14 M, reducing strength ratio to 1.5, increasing GGBS content, and using oven curing.
- UPV can be increased by heat curing and increasing molarity of NaOH to 14 M.
- Sorptivity can be reduced by increased molarity up to 14 M and 100% GGBS content.
- Drying shrinkage can be minimized by increasing GGBS content to 20%, decreasing strength ratio to 1.5, and using steam curing.
- GPC has better durability and resistance to abrasion and acid attack than OPC.

References

1. Gowda N, Shivananda K (2019) Studies on geopolymer concrete with GGBS as partial replacement to fly ash. Int Res J Eng Technol 6(12):806–812. https://1library.net/document/q7wrnvnz-studies-geopolymerconcrete-ggbs-partial-replacement-fly-ash.html
2. Sharma A, Ahmad J (2017) Experimental study of factors influencing compressive strength of geopolymer concrete. Int Res J Eng Technol 4(5):1306–1313. https://www.academia.edu/33549768
3. Bhattacharyya K, Gupta M, Ishwarya G, Singh B (2015) Geopolymer concrete: a review of some recent developments. Constr Build Mater 85:78–90. https://doi.org/10.1016/j.conbuildmat.2015.03.036
4. Poluju K, Srinivasu K, Rao M (2020) Study on mechanical characterization of geopolymer cement mortar with single solution and combined solution. J Xi'an Univ Archit Technol 12(8):481–487. https://www.researchgate.net/publication/343627471_Study_on_Mechanical_Characterization_of_Geopolymer_Cement_Mortar_with_Single_Solution_and_Combined_Solution
5. Arun R, Nagaraja S, Mahalingasharma S (2018) Combined effect of flyash & GGBS on workability and mechanical properties of self compacting geopolymer concrete. Int J Pure Appl Math 119(15):1369–1380. https://www.acadpubl.eu/hub/2018-119-15/4/743.pdf
6. Babu N, Rahul B, Kumar Y (2017) Experimental study on strength and durability properties of GPC with GGBS. Int J Civil Eng Technol 8(4):39–50. https://iaeme.com/Home/issue/IJCIET?Volume=8&Issue=4
7. Ganesan N, Babu C, Meyyapan P (2019) Influence of alkaline activator ratio on compressive strength of GGBS based geopolymer concrete. Mater Sci Eng 561:1–6. https://iopscience.iop.org/article/https://doi.org/10.1088/1757-899X/561/1/012083
8. Luhar S, Khandelwal U (2015) A study on water absorption and sorptivity of geopolymer concrete. SSRG Int J Civil Eng 2(8):1–9. https://doi.org/10.14445/23488352/IJCE-V2I8P101

9. Dave S, Bhogayata A, Arora K (2019) Durability study of geopolymer concrete cured at ambient temperature. Constr Build Mater 1:1–8. https://ukiericoncretecongress.com/Home/files/Proceedings/pdf/UCC-2019-131.pdf
10. Hassan A, Arif M, Shariq M (2019) Effect of curing condition on the mechanical properties of flyash-based geopolymer concrete. SN Appl Sci 1:1–9. https://doi.org/10.1007/s42452-019-1774-8
11. Shinde B, Kadam K (2015) Properties of fly ash based geopolymer mortar. Int J Eng Res Technol 4(7):971–974. https://www.ijert.org/research/properties-of-fly-ash-based-geopolymer-mortar-IJERTV4IS070750.pdf
12. Zhang B, Makenzie K, Brown I (2009) Crystalline phase formation in metakaolinite geopolymers activated with NaOH and sodium silicate. J Mater Sci 44:4668–4676. https://doi.org/10.1007/s10853-009-3715-1
13. Rovnanik P (2010) Effect of curing temperature on the development of hard structure of metakaolin-based geopolymer. Constr Build Mater 24(7):1176–1183. https://doi.org/10.1016/j.conbuildmat.2009.12.023
14. Lloyd N, Rangan B (2010) Geopolymer concrete with fly ash. In: Second international conference on sustainable construction materials and technologies, vol 3, pp 139–143. https://www.researchgate.net/publication/228825101_
15. Bakharev T (2005) Resistance of geopolymer materials to acid attack. Cem Concr Res 35(4):658–670. https://doi.org/10.1016/j.cemconres.2004.06.005
16. Mali B, Abraham A (2005) Study on geopolymer concrete used for paving blocks. Int J Innov Res Adv Eng 3(9):62–66. https://doi.org/10.6084/m9.figshare.4052382
17. Kulkarni S (2018) Study on geopolymer concrete. Int Res J Eng Technol 12(5):784–788. https://www.irjet.net/archives/V5/i12/IRJET-V5I12146.pdf
18. Deb P, Nath P, Sarker P (2014) The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature. Mater Design 62:32–39. https://doi.org/10.1016/j.matdes.2014.05.001
19. Goriparthi M, Rao G (2017) Effect of fly ash and GGBS combination on mechanical and durability properties of GPC. Adv Concr Constr 5(4):313–330. https://doi.org/10.12989/acc.2017.5.4.313
20. Mohankumar G, Manickavasagam R (2017) Study on the development of class C fly ash-based GPC by ambient curing. Int J Appl Eng Res 12(7):1227–1231. https://www.ripublication.com/ijaer17/ijaerv12n7_19.pdf
21. Verma M, Dev N (2021) Effect of ground granulated blast furnace slag and fly ash ratio and the curing conditions on the mechanical properties of geopolymer concrete. Struct Concr 1–15. https://doi.org/10.1002/suco.202000536
22. Budh D, Warhade N (2014) Effect of molarity on compressive strength of geopolymer mortar. Int J Civil Eng Res 5(1):83–86. https://www.ripublication.com/ijcer_spl/ijcerv5n1spl_13.pdf
23. Sudhan M, Brahmini A (2016) A study on performance of geopolymer concrete. Int J Sci Eng Technol Res 5(21):4223–4230. http://ijsetr.com/uploads/421563IJSETR10436-767.pdf
24. Deb P, Nath P, Sarker P (2013) Properties of fly ash and slag blended geopolymer concrete cured at ambient temperature. New Develop Struct Eng Constr 5(7):1–6. https://doi.org/10.3850/978-981-07-5354-2_M-55-433
25. Edward S (2009) Drying shrinkage of heat-cured fly ash-based geopolymer concrete. Mod Appl Sci 3(12):14–21. https://doi.org/10.5539/mas.v3n12p14
26. Deb P, Nath P, Sarker P (2015) Drying shrinkage of slag blended fly ash geopolymer concrete cured at room temperature. Procedia Eng 125:(4)594–600. https://doi.org/10.1016/j.proeng.2015.11.066
27. Ramujee K, Potharaju M (2014) Permeability and abrasion resistance of geopolymer concrete. Indian Concr J 88(12):34–43. https://www.researchgate.net/publication/288388226