Effect of various parameters on the workability and strength properties of geopolymer concrete

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Abstract. In the present study, effect of various molarities of NaOH, various fly ash content and alkaline activator solution (AAS) / fly ash(FA) ratios on the workability of geopolymer concrete(GPC) are studied along with the effect of use of Na_2SiO_3/NaOH and K_2SiO_3/KOH as alkaline activator solutions and various fly ash contents on the compressive strength of geopolymer concrete mixes. Observations shows that both Na_2SiO_3/NaOH and K_2SiO_3/KOH gives better performance for different molar, AAS/FA and oxide ratios. Class C GPC has better performance than Class F GPC. It was found that the increase in molarity decreases workability of geopolymer concrete. Also, the workability increases with increase in fly ash (FA) content and AAS/FA ratio in geopolymer concrete. Compressive and split tensile strengths decrease with increase in fly ash content.

1 Introduction

In India, coal with an ash level of about 40% is mostly utilised for thermal power generation. As a result, massive amounts of fly ash (FA) are produced in thermal power plants, generating a slew of disposal issues. FA disposal is becoming increasingly problematic, as only 15% of FA is now used for high-value-added uses such as concrete and building blocks, with the balance being used for land filling. Only around a quarter of the total yearly FA generated in the globe is actually used. For almost 60 years, fly ash has been utilised as a mineral additive component in Portland pozzolan mixed cement. The byproduct of blast furnaces used to produce iron is ground granulated blast furnace slag (GGBS). [2]GGBS is a non-metallic, glassy, granular substance made mostly of calcium and various base silicates and aluminates. Slag with a specific surface area of 400 to 600 m2/kg will be processed to less than 45 micron from a coarser, popcorn-like friable structure (Blaine). The particle size of GGBS is approximately identical to that of cement. Geopolymer concrete was invented by Prof. Davidovits of France in the mid-1970s. He used the notion of aluminosilicate gel binding action to create inorganic polymer of alumino-silicates by combining silica and alumina from specially treated clay (metakaolin). GPCs are inorganic polymer composites with excellent strength and resistance to chloride penetration, acid assault, and other factors. When compared to typical concretes, they are made by alkali activating industrial aluminosilicate waste materials like FA and GGBS. They have a very low greenhouse footprint. Geopolymers, unlike typical Portland/pozzolanic cements, do not use calcium-silicate-hydrates (CSHs) for matrix formation and strength, instead relying on the polycondensation of silica and alumina precursors. Source materials and alkaline liquids are the two major components of geopolymers. The raw materials should be silicon (Si) and aluminium (Al) rich alumino-silicates (Al). Fly ash, silica fume, slag, rice-husk ash, red mud, and other by-product products are examples. Because GPCCs are a novel class of materials, unlike traditional cement concretes, traditional mix design techniques are not typically relevant. The creation of GPCC mixes necessitates a comprehensive review of the components available.

2 Geopolymer synthesis

The source material must be rich in Silicon (Si) and Aluminum (Al), and an alkali activator such as sodium/potassium hydroxide is required for geopolymer production. In comparison to potassium hydroxide (KOH) with the addition of silicate solution to increase the dissolving process, sodium hydroxide (NaOH) is frequently utilised for geopolymer synthesis. The study indicates that geopolymers containing potassium activators have a reduced liquid requirement. The findings

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of the tests demonstrate that potassium activators improve component reactivity and hence compressive strength. Although sodium silicate and potassium silicate serve comparable functions as alkali activators, the K2SiO3/KOH components must be prepared differently from Na2SiO3/NaOH. The use of sodium silicate, on the other hand, has been proven to be more successful because sodium hydroxide solution promotes greater silicate and aluminate monomer breakdown from Fly ash. In comparison to KOH, geopolymer samples containing sodium hydroxide (NaOH) have a greater compressive strength. NaOH has the maximum compressive strength of 47.92 MPa, whereas KOH has a compressive strength of 29.65 MPa. Because Na+ has a lower ionic size than K+, it is more active and facilitates the dissolving of Si4+ and Al3+ ions from fly ash. Sodium silicate solution has a higher viscosity than potassium silicate solution, which allows it to use less liquid phase, resulting in lower porosity, shrinkage, compressive strength, and durability. In this study, two types of fly ashes were utilised to create geopolymer concrete: C class (high calcium content) and F class (low calcium content) as per ASTM C618, in order to analyse the influence of high and low CaO content fly ashes on the polymerization process. In low calcium fly ash based geopolymer concrete mixes, sodium aluminosilicate hydrate (N-A-S-H) gel is the main reaction product, whereas calcium silicate hydrate (C-S-H) and calcium aluminosilicate hydrate (C-A-S-H) gels coexisted with sodium aluminosilicate hydrate (N-A-S-H) gel as the main reaction products in high calcium fly ash When cured at room temperature, the high CaO concentration improves the strength development.

3 Formulating the GPCC mixes

The compressive strength increased with increase in percentage of GGBS and also with an increase in AAS/ ratio. Thus, we can say that there is consistent increase in strength for an increase in AAS/ ratio from 0.40 to 0.50 but the strength has greatly reduced when the AAS/ ratio is further decreased, which shows the scarcity of fluid cannot impart strength due to weak activation. The mix ingredients of geopolymer concrete are

1. 16M NaOH/KOH
2. SiO_2/Na_2O = 2.0 or SiO_2/K_2O=2.0
3. Na_2SiO_3/NaOH= 2.5 or K_2SiO_3/KOH=2.5
4. Fly Ash = 450 kg/m^3
5. Alkali Activator solution (AAS) / Fly ash =0.40
6. Fine aggregate=505 kg/m^3
7. 20mm Coarse aggregate= 1246 kg/m^3
8. 60°C temperature oven heat cured for 24h period
9. Rest period = 0 days (casted cubes are immediately sealed and kept in oven with moulds on)

Mix design is developed as per IS:10262 procedure and the powdery content of Portland cement is replaced by equivalent solid volume of Geopolymeric Source Material (FA) and liquid portion of water by Activator Solution on equal volume basis in Geopolymer Concrete while Aggregate content remains same in both the concretes.

It is noted here the liquid component of GPCs is not readily available in the market, unlike water in case of conventional concrete. It is also worth noting there that the effective specific chemical additives such as retarders, accelerators, etc (which are very common for Portland cements) are not yet specifically developed for geopolymers. Therefore, field adjustments would not be easy always.

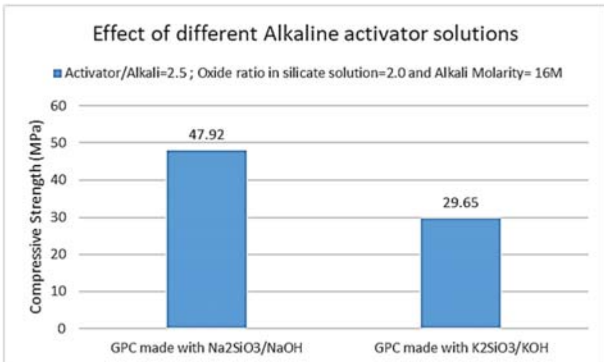
Because GPCs are a novel class of building materials, there are no standard mix design methods for them, unlike ordinary cement concrete. As a result, the proportioning of GPC was done by trial and error, with strength and workability qualities in mind. There was no more water added. When compared to a 0 day rest time, it was shown that a 1 day rest period offers a greater compressive strength.

6 Effect of different types of Alkaline activator solutions

In this study two types of alkaline activator solutions such as Na_2SiO_3/NaOH and K_2SiO_3/KOH are used to study their effect on the compressive strength of geopolymer concrete (GPC).

Table 1. Compressive strength of GPC made with various alkaline activator solutions

Type	Compressive Strength (MPa)
GPC made with Na_2SiO_3/NaOH	47.92
GPC made with K_2SiO_3/KOH	29.65



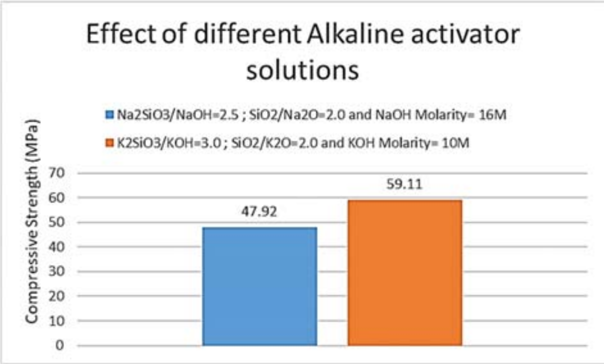


Fig. 1. Compressive strength of GPC made with various alkaline activator solutions

Literature shows that K_2SiO_3/KOH yields better performance than Na_2SiO_3/NaOH and also K_2SiO_3/KOH alkali activator solution is expensive. But in our study the it was observed that the K_2SiO_3/KOH performance was inferior to Na_2SiO_3/NaOH, which proves that adopted alkali concentration (16M), oxides ratio (2.0) and activator/alkali ratio (2.5) may yield superior performance for Na_2SiO_3/NaOH but did not work for K_2SiO_3/KOH. So, after much trials, the optimum ratio values are obtained using which GPC mixes made with K_2SiO_3/KOH are developed.

Due to the high calcium concentration available in Class C raw fly ash material, GPC manufactured with Class C fly ash has a greater compressive strength at ambient temperature than GPC created with Class F fly ash. Because GPC produced with Class F fly ash fails to attain structural integrity at room temperature, it is treated to 60°C heat curing. At high temperatures, GPC produced with Class F fly ash outperforms GPC created with Class C fly ash in terms of strength.

It was found that the increase in molarity decreases workability of geopolymer concrete. Also, the workability increases with increase in fly ash (FA) content and AAS/FA ratio in geopolymer concrete. Past literature reports that the improved workability was noticed when M-sand was used in geopolymer concrete.

Workability decreases with decrease of AAS/FA ratio but compressive strength increases. Compressive and split tensile strengths decrease with increase in fly ash content.

Table 2. Compressive strengths of GPC made with different types of fly ashes

Type	Initial Setting time (minutes)	Compressive Strength (MPa)	Curing Type
GPC made with Class C fly ash (>20% CaO as per ASTM)	254	37.22	Ambient curing for 28 days
	254	55.34	Heat curing at 60°C temperature; Rest period=1 day
GPC made with Class F fly ash (<10% CaO as per ASTM)	2889	35.34	Ambient curing for 28 days
	Not applicable	47.92	Heat curing at 60°C temperature; Rest period=0 day

Table 3. Workability of GPC mixes made with various molarities of NaOH

	NaOH Molarity	Slump (mm)
AAS/FA=0.50 Na_2SiO_3/NaOH=2.5 SiO_2/Na_2O=2.0 Fly Ash = 450 kg/m^3 Fine aggregate=505 kg/m^3 20mm Coarse aggregate= 1246 kg/m^3	8M	205 (Shear slump)
	10M	163
	12M	144
	14M	128
	16M	109
	18M	54

Table 4. Workability of GPC mixes made with different fly ash content

	Fly Ash(kg/m^3)	Slump (mm)
AAS/FA=0.50 Na_2SiO_3/NaOH=2.5 SiO_2/Na_2O=2.0 NaOH Molarity= 16M Fine aggregate=505 kg/m^3 20mm Coarse aggregate= 1246 kg/m^3 Density of Concrete=2426 kg/m^3	300	50
	350	67
	400	89
	450	109
	500	129
	550	166

Table 5. Workability of GPC mixes made with different AAS/FA ratio

Na_2SiO_3/NaOH=2.5	AAS/FA ratio	Slump (mm)

SiO_2/Na_2O=2.0 NaOH Molarity= 16M Fly Ash = 450 kg/m^3 Fine aggregate=505 kg/m^3 20mm Coarse aggregate= 1246 kg/m^3	0.40	88
	0.50	109
	0.60	137
	0.70	164
	0.80	202
	0.90	234(Collapse)

Table 6. Strengths of GPC mixes made with different fly ash content

	Fly Ash(kg/m$^{3)}$	Compressive Strength (MPa)	Split-tensile Strength (MPa)
AAS/FA=0.50 Na_2SiO_3/NaOH=2.5 SiO_2/Na_2O=2.0 NaOH Molarity= 16M	300	51.02	4.82
	350	49.13	4.44
	400	48.39	3.98
	450	47.92	3.67
	500	35.90	3.32
	550	31.25	2.86

7 Conclusions

1. If formulated meticulously GPC made with K_2SiO_3/KOH yields better performance than GPC made with Na_2SiO_3/NaOH. Otherwise both alkaline activator solutions are achieving the intended strengths at their respec
2. Due to the high calcium concentration available in Class C raw fly ash material, GPC manufactured with Class C fly ash has a greater compressive strength at ambient temperature than GPC created with Class F fly ash. Because GPC produced with Class F fly ash fails to attain structural integrity at room temperature, it is treated to 60°C heat curing. At high temperatures, GPC produced with Class F fly ash outperforms GPC created with Class C fly ash in terms of strength.
3. It was found that the increase in molarity decreases workability of geopolymer concrete. Also, the workability increases with increase in fly ash (FA) content and AAS/FA ratio in geopolymer concrete.
4. It was found that the increase in molarity decreases workability of geopolymer concrete. Also, the workability increases with increase in fly ash (FA) content and AAS/FA ratio in geopolymer concrete.
5. Compressive and split tensile strengths decrease with increase in fly ash content.

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