Parametric studies on the properties of geopolymer concrete

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Abstract. In the current study, effect of Alkali Activator solution (AAS) / Fly ash (FA) ratios and various molarities of NaOH on the compressive strength of geopolymer concrete (GPC) is studied keeping Na_2SiO_3/NaOH=2.5 and SiO_2/Na_2O=2.0 optimal ratios constant. For AAS/FA=4.0 and 16M NaOH combination yields better strength so this combination is chosed as optimal. From studies it is found that the optimum temperature for curing is 60°C and optimum period of curing is 24 h based on the compressive strengths achieved.

1 Introduction

Formation of Geopolymer binder has basic reaction mechanism in three stages

1. Dissolution of Si_4^+ and Al_3^+ ions from the fly ash and GGBS into NaOH solution
2. Hydrolysis or gelation
3. Condensation by Na_2SiO_3

After 3 stages of reaction, 3D networks of silicon-oxygen-aluminum framework with silicon and aluminum tetrahedral linked in three directions by sharing all the oxygen atoms are formed.

2 Materials and Mix Proportions

From the past research conducted by V Srinivasa Reddy et al. it was reported that the 16M NaOH gives maximum compressive strength. So 16M NaOH is adopted for further study. Similarly based on past work done by the authors, SiO_2/Na_2O ratio of 2.0 is maintained in Na_2SiO_3 solution and molar ratio of Na_2SiO_3/NaOH= 2.5 by mass are adopted for further studies.
Materials used to develop geopolymer concrete mixes to study the the effect of temperature and period of heat curing is presented below:

- 16M NaOH
- SiO_2/Na_2O = 2.0
- Na_2SiO_3/NaOH= 2.5 by mass
- Fly Ash = 450 kg/m^3
- Alkali Activator solution (AAS) / Fly ash =0.40
- Fine aggregate=505 kg/m^3
- 20mm Coarse aggregate= 1246 kg/m^3
- Slump required= 100mm
- Heat Curing
- No superplasticizer used

Sodium hydroxide solution is prepared before 24 hrs. Sodium silicate solution and sodium hydroxide solutions are mixed before 30 minutes of concrete making. Rest period adopted is 0 days means kept in oven with moulds sealed, immediately after casting. Rest period is the period before keeping in oven for curing from the time of casting.

3 Effect of Alkali Activator solution (AAS) / Fly ash (FA) ratio

The below table presents the compressive strength of geopolymer concrete (GPC) mixes made with different ratios of AAS/FA ratios and various molarities of NaOH. The adopted ratios for Na_2SiO_3/NaOH=2.5 and SiO_2/Na_2O=2.0 based on past research carried out by the authors. Geopolymer concrete mixes are oven cured at temperature 60°C for a period of 24h. Rest period is 0 days means kept in oven immediately after casting with moulds sealed.

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Table 1. Effect of Alkali Activator solution (AAS) / Fly ash (FA) ratio on compressive strength for various GPC mixes made with different molarities of NaOH

AAS/FA ratio	Compressive Strength (MPa)					
	Na_2SiO_3/NaOH=2.5; SiO_2/Na_2O=2.0					
	NaOH Molarity					
	8M	10M	12M	14M	16M	18M
0.35	21.22	30.12	31.22	33.09	35.29	31.57
0.40	27.46	36.13	37.21	40.73	47.92	41.69
0.45	26.16	33.10	34.09	34.47	43.20	37.23
0.50	25.52	27.80	29.07	29.68	39.23	33.35
0.55	21.15	26.83	28.66	22.85	26.88	23.39
0.60	19.27	25.35	26.11	17.87	21.02	18.29
0.65	16.79	22.09	22.75	16.08	18.92	16.46
0.70	15.82	20.81	21.43	14.25	16.77	14.59
0.75	14.38	18.92	19.49	12.07	14.20	12.35
0.80	13.00	17.11	17.62	10.90	12.82	11.15
0.85	12.66	16.66	17.16	9.36	11.01	9.58
0.90	11.42	15.02	15.47	9.27	10.90	9.48

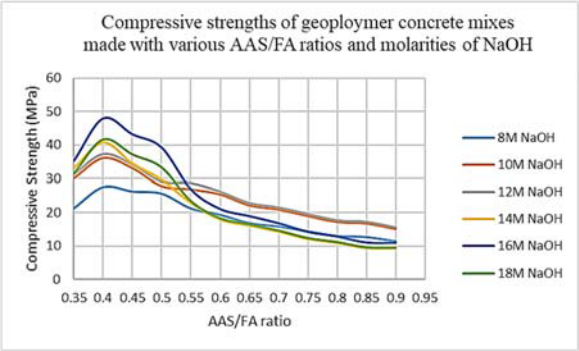

Fig.1. Compressive strength for various GPC mixes made with different molarities of NaOH and for various Alkali Activator solution (AAS) / Fly ash (FA) ratios

In the present study, geopolymer concrete mixes are developed and the effect of temperature and period of heat curing is also studied and found that the optimum temperature for curing is 60°C and optimum period of curing is 24 h based on the compressive strengths achieved. So, this study confirms that beyond 24 h period, heat curing is not required.
In the current study, geopolymer concrete mixes are oven cured at three different temperatures for 30°C, 60°C and 90°C for various periods of curing such as 12h,24h ,48h,72h and 96h.

Table 2. Effect of temperature and period of heat curing on compressive strength

Compressive Strength (MPa)			
	30°C Oven curing	60°C Oven curing	90°C Oven curing
12h	15.54	24.67	25.01
24h	30.19	47.92	48.16
48h	30.36	48.19	48.64
72h	30.38	48.22	48.67
96h	30.88	49.02	49.49

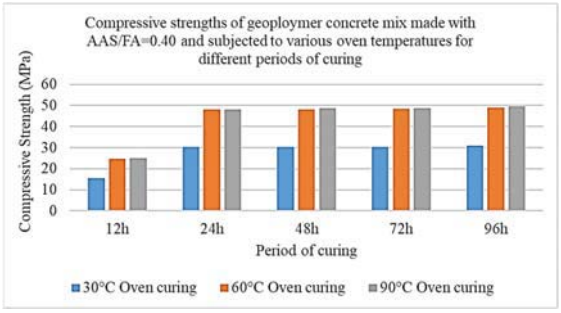

Fig 2. Effect of temperature and period of heat curing on compressive strength

It is observed that the compressive strength increases as temperature of oven curing increases from 30°C to 90°C and also with the period of curing from 12h to 96h. The optimum combination of temperature 60°C and period of curing 24h is chosen as there is no significant improvement of compressive strength is observed beyond 60°C temperature and 24h period of oven curing. So, it can be recommended that beyond 24 hrs period, heat curing is not required.

4 Factors affecting Initials setting times

Data procured from previous studies is:

- 16M NaOH
- SiO_2/Na_2O = 2.0 in Na_2SiO_3
- Na_2SiO_3/NaOH= 2.5 by mass

Sodium hydroxide solution is prepared before 24 hrs. Sodium silicate solution and sodium hydroxide solutions are mixed before 30 minutes of making powder paste. Use of FA alone will not set the GPC

immediately after casting. Initial setting of geopolymer concrete made with fly ash alone is very high, no setting is observed even after 2 days of casting making demoulding process delayed. So ground granulated blast furnace slag (GGBS) is added to reduce the setting time.

Table 3. Effect of GGBS on the initial setting time

Type	Initial Setting time(min)
GPC made with FA	2889
GPC made with FA+15%GGBS	193
GPC made with FA+25%GGBS	101
GPC made with FA+50%GGBS	34

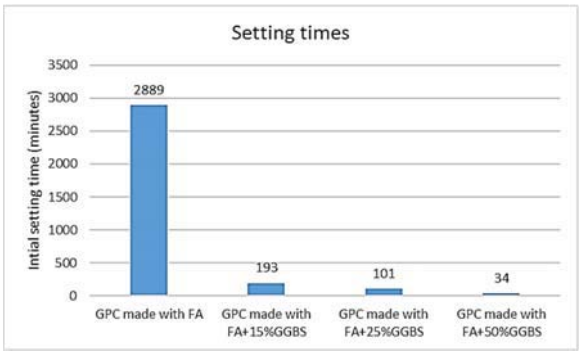

Fig. 3. Effect of GGBS on the initial setting time

Table 4. Effect of NaOH molarity on the setting times

	Setting times (minutes)	NaOH Molarity					
		8M	10M	12M	14M	16M	18M
GPC made with FA+50%GGBS	Initial	143	111	89	55	34	23
	Final	1879	1567	1243	990	556	435

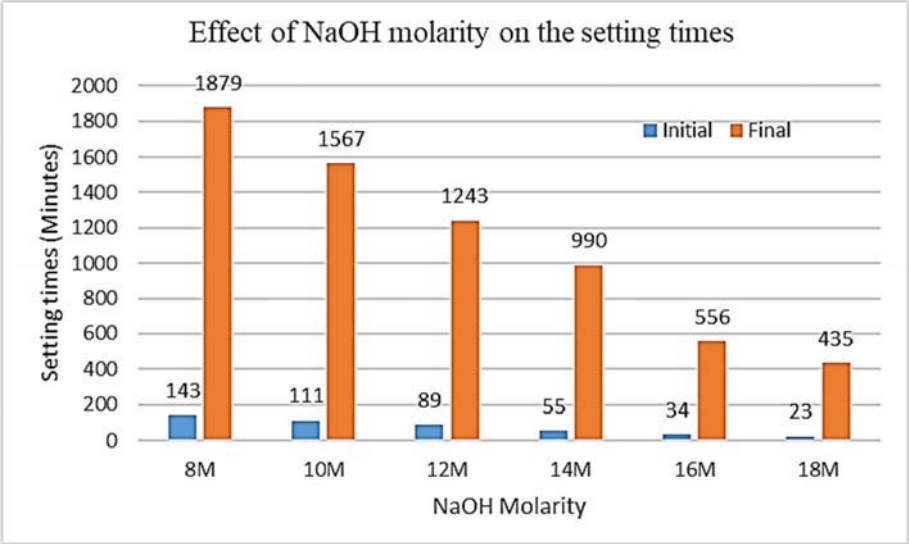

Fig.4. Effect of NaOH molarity on the setting times

The increase of sodium hydroxide molarity decreases the initial and final setting times. NaOH concentration is a main reason for leaching out of Si_4^+ and Al_3^+ ions from fly ash; therefore, the time of setting tends to increase with the decrease in the molarity of NaOH

If fly ash alone is used then it is suggested to seal the concrete moulds and keep it in oven with the moulds. So, rest period in the case of fly ash based geopolymer is zero otherwise if GGBS is added to fly ash then the rest period may vary from 1- 3 days and keep in oven without seal after demoulding. Many researchers reported that the addition of silica fume and GGBS may decrease the setting times of geopolymer concrete drastically and lets the concrete set quickly due to formation of additional strength imparting products based on calcium content available in GGBS.

5 Conclusions

Based on the studies made following conclusions are arrived at-

1. Alkali Activator solution (AAS) / Fly ash (FA) ratio=0.40 yields highest compressive strength for 16M NaOH with Na_2SiO_3/NaOH=2.5 and SiO_2/Na_2O=2.0.

2. The optimum combination of temperature 60°C and period of curing 24h is chosen as there is no significant improvement of compressive strength is observed beyond 60°C temperature and 24h period of oven curing. So, it can be recommended that beyond 24 hrs period, heat curing is not required.
3. Initial setting of geopolymer concrete made with fly ash alone is very high, no setting is observed even after 2 days of casting making demoulding process delayed. So ground granulated blast furnace slag (GGBS) is added to reduce the setting time
4. The increase of sodium hydroxide molarity decreases the initial and final setting times. NaOH concentration is a main reason for leaching out of Si_4^+ and Al_3^+ ions from fly ash; therefore, the time of setting tends to increase with the decrease in the molarity of NaOH
5. Many researchers reported that the addition of silica fume and GGBS may decrease the setting times of geopolymer concrete drastically and lets the concrete set quickly due to formation of additional strength imparting products based on calcium content available in GGBS.

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