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Effect of molarity of sodium hydroxide and molar ratio of alkaline activator solution on the strength development of geopolymer concrete

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Abstract. In the current study, effect of SiO_2/Na_2O ratio in Sodium silicate (Na_2SiO_3) solution, Na_2SiO_3/NaOH ratio and molarity of NaOH on the compressive strength of geopolymer concrete. A geopolymer mix design is formulated with various mixes are casted with alkali activator solution (AAS) / fly ash (FA) =0.5 and constant fly ash content. The molar ratio of SiO_2/Na_2O in Na_2SiO_3 solution is altered from 1.50 to 3.00 for different ratios of Na_2SiO_3/NaOH (2.0, 2.5 and 3.0) and also for various molarities of NaOH (8M,10M,12M,14M,16M and 18M) are studied for their synergic effect on the compressive strength of geopolymer concrete. Results highlighted that the 16M NaOH yields high compressive strength when SiO_2/Na_2O in Na_2SiO_3 solution is around 2.00 to 2.40 and Na_2SiO_3/NaOH=2.5.

1 Introduction

Geopolymer is a new development in the world of concrete in which cement is totally replaced by pozzolanic materials like fly ash, ground granulated blast furnace slag and activated by highly alkaline solutions to act as a binder in the concrete mix [1,2,3]. For the selection of suitable ingredients of geopolymer concrete to achieve desire strength at required workability, an experimental investigation has been carried out for the gradation of geopolymer concrete and a mix design procedure is proposed on the basis of quantity and fineness of fly ash, quantity of water, grading of fine aggregate, fine to total aggregate ratio.[4,5,6,7,8,9,10][1]

2 Sodium hydroxide (NaOH) solution

Various molarities of NaOH are considered for study are 8M,10M,12M,14M,16M and 18M. The quantity of NaOH flakes to be mixed in distilled water is estimated based on the molarity. The molecular weight of NaOH is 40 which is determined in the lab, so for example to prepare 10M NaOH, sodium hydroxide flakes of 400 gram(10x40) were dissolved in one litre of deionized water then the total volume of the NaOH solution becomes 1.10 litres or 1100 ml. It was observed that for one gram of NaOH flake added to one litre water, the increase in volume of total solution is 0.25 ml. So, 400 grams added to one litre of deionized water will increase the total volume by 400 x 0.25=100 ml which means to prepare one litre volume of NaOH solution, NaOH flakes to be added to one litre deionized water is (400/1100) x 1000=364 grams. Hence, the molarity of NaOH solution is reduced to 9.1 M (364/40) instead of 10 M.

Table 1. Quantity of NaOH flakes to be added to distilled water to prepare NaOH solution

Molarity NaOH flakes	NaOH flakes to be added to make NaOH solution (grams)	Molarity of NaOH solution
8M	296	7.4M
10M	364	9.1M
12M	429	10.7M
14M	491	12.3M
16M	552	13.8M
18M	610	15.3M

3 Sodium silicate (Na_2SiO_3) solution

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Factory prepared Sodium silicate solution with various compositions of SiO_2/Na_2O from 1.50 to 3.0 are procured. Sodium silicate solution has nearly 50-57% of water. Sodium silicate solution is added to sodium hydroxide solution before 30 to 60 min of mixing of concrete.

4 Mix Design

Mix design and component proportioning in alkali-activated concrete appear to be complicated due to the numerous factors involved. As a result, there is currently no standard mix design technique for alkali-activated binders concrete. Following the standards provided in IS 10262:2009, the basic mix proportions are determined. Maximum cement content provision given in the IS 456 code is adopted to arrive at following mix proportions.

- Fly Ash = 450 kg/m^3
- Alkali Activator solution (AAS) / Fly ash =0.5
- $Na_2SiO_3/NaOH$ ratios adopted are 2.0, 2.5 and 3.0
- Fine aggregate=505 kg/m^3
- 20mm Coarse aggregate= 1246 kg/m^3
- Slump required= 100mm

No superplasticizer used for the study.

5 Effect of SiO_2/Na_2O ratio in Sodium silicate (Na_2SiO_3) solution

In this section, the effect of SiO_2/Na_2O ratio on the compressive strength of various geopolymer concrete specimens developed using various molarity of NaOH and molar ratios is studied. Molar ratio is defined as ratio of $Na_2SiO_3/NaOH$ in Alkaline Activator solution. Alkaline Activator solution (AAS) / Fly ash ratio is maintained constant at 0.5. Compressive strengths of various geopolymer concrete specimens developed using various molarity of NaOH and molar ratios are presented in tables 2-4.

Table 2. Compressive strengths of geopolymer concrete mixes developed using various molarities of NaOH and $Na_2SiO_3/NaOH$ ratio=2.0 for different SiO_2/Na_2O ratios

SiO_2/Na_2O	Compressive Strength (MPa)					
	$Na_2SiO_3/NaOH$=2.0					
	NaOH Molarity					
	8M	10M	12M	14M	16M	18M
1.50	3.74	4.08	4.26	4.35	5.75	4.89
1.60	4.22	4.60	4.81	4.91	6.49	5.51
1.70	5.71	6.22	6.50	6.64	8.78	7.46
1.80	10.98	11.97	12.51	12.78	16.89	14.35
1.90	13.18	14.37	15.02	15.34	20.27	17.23
2.00	20.42	22.24	23.26	23.74	31.38	26.68
2.10	20.41	22.23	23.25	23.74	31.38	26.67
2.20	19.87	21.65	22.64	23.11	30.55	25.97
2.30	19.38	21.10	22.06	22.53	29.78	25.32
2.40	17.75	19.34	20.22	20.64	27.29	23.19
2.50	11.05	12.04	12.58	12.85	16.98	14.44
2.60	9.42	10.26	10.73	10.95	14.48	12.31
2.70	7.92	8.63	9.02	9.21	12.18	10.35
2..80	6.82	7.43	7.77	7.94	10.49	8.91
2.90	4.80	5.23	5.47	5.58	7.38	6.28
3.00	4.64	5.06	5.29	5.40	7.14	6.06

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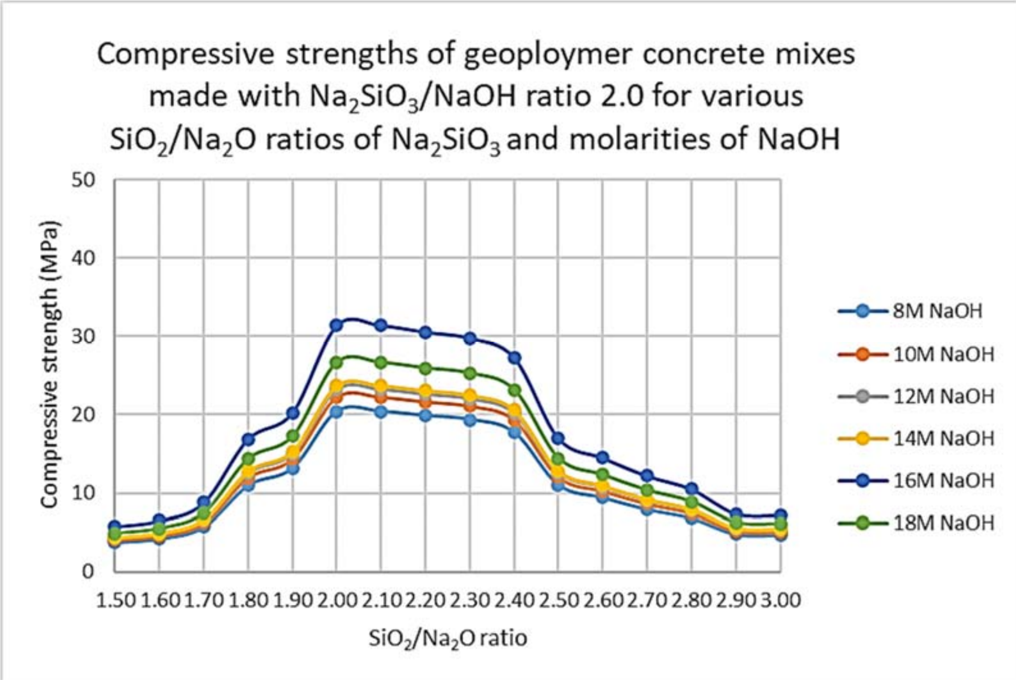

Fig.1. Compressive strengths of geopolymer concrete mixes made with Na_2SiO_3/NaOH ratio=2.0 for various molarities of NaOH and for different SiO_2/Na_2O ratios

Table 3. Compressive strengths of geopolymer concrete mixes developed using various molarities of NaOH and Na_2SiO_3/NaOH ratio=2.5 for different SiO_2/Na_2O ratios

SiO_2/Na_2O	Compressive Strength (MPa)					
	Na_2SiO_3/NaOH=2.5					
	NaOH Molarity					
	8M	10M	12M	14M	16M	18M
1.50	4.68	5.10	5.33	5.44	7.19	6.11
1.60	5.28	5.75	6.01	6.14	8.11	6.89
1.70	7.14	7.77	8.13	8.30	10.97	9.32
1.80	13.73	14.96	15.64	15.97	21.11	17.94
1.90	16.48	17.96	18.77	19.17	25.34	21.54
2.00	25.52	27.80	29.07	29.68	39.23	33.35
2.10	25.51	27.79	29.06	29.67	39.22	33.34
2.20	24.84	27.06	28.30	28.89	38.19	32.46
2.30	24.22	26.38	27.58	28.16	37.23	31.65
2.40	22.19	24.17	25.27	25.80	34.11	28.99
2.50	13.81	15.05	15.73	16.06	21.23	18.05
2.60	11.77	12.83	13.41	13.69	18.10	15.39
2.70	9.90	10.79	11.28	11.51	15.22	12.94
2..80	8.53	9.29	9.71	9.92	13.11	11.14
2.90	6.00	6.54	6.84	6.98	9.23	7.85
3.00	5.80	6.32	6.61	6.75	8.92	7.58

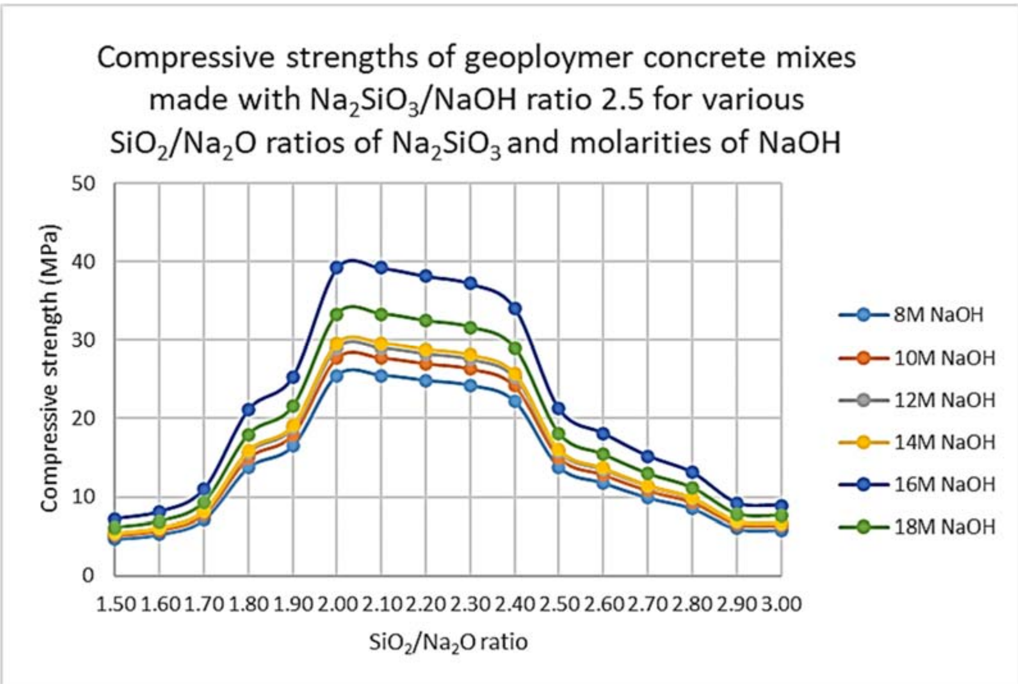

Fig.2. Compressive strengths of geopolymer concrete mixes made with Na_2SiO_3/NaOH ratio=2.5 for various molarities of NaOH and for different SiO_2/Na_2O ratios

SiO_2/Na_2O	Compressive Strength (MPa)					
	Na_2SiO_3/NaOH=3.0					
	NaOH Molarity					
	8M	10M	12M	14M	16M	18M
1.50	4.35	4.64	4.80	5.06	6.69	5.68
1.60	4.91	5.23	5.41	5.71	7.54	6.41
1.70	6.64	7.07	7.32	7.72	10.20	8.67
1.80	12.77	13.61	14.08	14.85	19.63	16.68
1.90	15.33	16.34	16.89	17.83	23.57	20.03
2.00	23.73	25.30	26.16	27.60	36.48	31.02
2.10	23.72	25.29	26.15	27.59	36.47	31.01
2.20	23.10	24.62	25.47	26.87	35.52	30.19
2.30	22.52	24.01	24.82	26.19	34.62	29.43
2.40	20.64	21.99	22.74	23.99	31.72	26.96
2.50	12.84	13.70	14.16	14.94	19.74	16.79
2.60	10.95	11.68	12.07	12.73	16.83	14.31
2.70	9.21	9.82	10.15	10.70	14.15	12.03
2..80	7.93	8.45	8.74	9.23	12.19	10.36
2.90	5.58	5.95	6.16	6.49	8.58	7.30
3.00	5.39	5.75	5.95	6.28	8.30	7.05

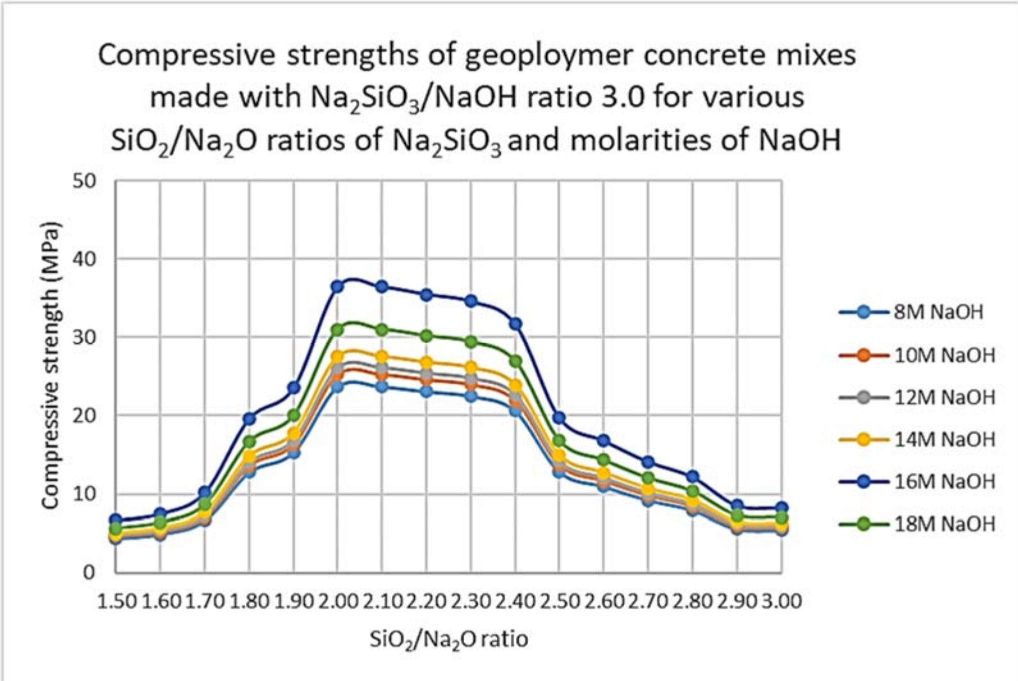

Fig.1. Compressive strengths of geopolymer concrete mixes made with Na_2SiO_3/NaOH ratio=2.0 for various molarities of NaOH and for different SiO_2/Na_2O ratios

Based on the compressive strength attained, it was observed that for the optimum SiO_2/Na_2O in Sodium silicate should be between 2.00-2.40. From the current study SiO_2/Na_2O ratio of 2.0 found to give high compressive strength. Three molar ratios of Na_2SiO_3/NaOH are considered for the current study. Of which the molar ratio of Na_2SiO_3/NaOH =2.5 by mass yields high compressive strength so this molar ratio is recommended. Even the literature suggests similar results reported by other researchers. Therefore, sodium silicate solution with composition Na_2O = 16.37 %, SiO_2 = 34.35 % and H_2O = 49.28 % and Sodium hydroxide solution having 13.8 M concentration are chosen after various trials on the basis of cube compressive strength, whereas Alkaline Activator solution (AAS) / Fly ash ratio is maintained constant at 0.50 throughout the experiment on the basis of workability. Workability of geopolymer concrete was measured by flow table apparatus and cubes of 150 mm side were cast and tested for compressive strength after specified period of oven heating. The temperature of oven heating was maintained at 60 °C for 24 h duration and tested after one day of oven heating. It was observed that the results of workability and compressive strength are well match with the required degree of workability and compressive strength. So, proposed method is used to design of 30 MPa strength range geopolymer concrete. The major reaction product for the low-calcium fly ash system is sodium aluminosilicate hydrate (N-A-S-H) gel. The dissolving of Si4+ and Al3+ ions from sneaky ash to create aluminosilicate materials is usually done using sodium hydroxide solution, whereas sodium silicate solution includes soluble silicate species and is used to enhance the condensation process of alkali-activated binders (in this case the fly ash). Because the concentration of NaOH is a major factor in the leaching of Si4+ and Al3+ ions, the time required for setting tends to rise as the molarity of NaOH decreases. The fine aggregate is local river sand (RS), which has a specific gravity of 2.52 and a fineness modulus of 2.20, while the coarse aggregate is crushed granite stone, which is 20mm in size. As liquid activators, sodium hydroxide solution (NaOH) and sodium silicate solution (Na2SiO3) were employed. The viscosity of AAS is greater than that of tap water.

6 Mixing of Geopolymer concrete

1. Fine and coarse aggregates were mixed together for 60 seconds before being added to the geopolymer concrete mix.
2. The NaOH solution was then added, and they were stirred for another 30 seconds.
3. Fly ash was added after 30 seconds, and the mixture was stirred for 60 seconds.
4. After that, the Na2SiO3 solution was added to the mixture, and it was stirred for another 60 seconds until the mixture was homogenous.

Increased water-to-cement ratios in Portland cement concrete produce a reduction in strength development, as does an excess OH concentration of 18M in the geopolymer mix. Furthermore, a higher concentration of NaOH solution may cause the polymerization process to be disrupted. It was discovered that increasing the leaching out of Si4+ and Al3+ ions from fly ash particles enhances the sodium aluminosilicate hydrate (N-A-S-H) gel, resulting in high strength, at a concentration of 16M NaOH.

7 Conclusions

Based on the results obtained the following are conclusions drawn:

1. In the present study alkaline activator solution (AAS) / fly ash (FA) =0.5 and constant fly ash content are adopted
2. The optimum molar ratio of SiO_2/Na_2O in Na_2SiO_3 solution is found to be around 2.00 to 2.40
3. The optimum $Na_2SiO_3/NaOH$ is found to be 2.5
4. The optimum molarity for NaOH is found to be 16M to achieve a strength of range 20-30 MPa.

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