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Mathematical model for predicting stress-strain behavior of low calcium fly-ash based geopolymer concrete

Nutakki Sai Ketana[1*], *Srinivasa Reddy* V[2], *M V* Seshagiri Rao[3], *and S* Shrihari[4]

[1]M. Tech (Structural Engineering), Department of Civil Engineering, GRIET, Hyderabad, India.
[2]Professor of Civil Engineering, GRIET, Hyderabad, India.
[3]Professor of Civil Engineering, CVR College of Engineering, Hyderabad, Telangana.
[4]Professor of Civil Engineering, VJIT, Hyderabad, India.

Abstract. The focus of the study was to identify the stress strain behavior of geo polymer concrete and salient parameters that influence the mixture proportions and the properties of low calcium fly ash- based geo polymers concrete. To develop geopolymer concrete the chemical proportions are alkaline liquid solution/fly-ash ratio=0.5, Sodium silicate/sodium hydroxide ratio=2.5,16M NaOH and SiO_2/Na_2O ratio=2.0. The geopolymer concrete mixes have shown improved stress values for the same strain levels compared to that of controlled concrete mix. Normalized stress strain curves are used to compare the behaviours of geopolymer concrete. It can be observed that geopolymer concrete has improved strains for the same stress when compared to conventional concrete. Geopolymer concrete mixes have shown improved stress values for the same strain levels compared to that of controlled concrete mixes.

1 Introduction

Early investigations on alkali activated binder (AAB) date back to the beginning of the 20th century thanks to pioneering work by Kühl in Germany which was on vitreous slags activated with alkali materials [1]. However, it was only in the last decade that they gained international attention as alternative to Portland cement (PC) based binders, mainly due to the potential reduction of associated CO_2 emissions and for their inherent properties such as high strength, good resistance to chemical degradation, thermal stability and fire resistance, among others [2]. Factors such as dosage of alkali solutions, water content, elevated curing temperatures (60 to 100 °C) and curing time are considered to be the important factors influencing the properties of geopolymer or alkali activated concretes (AAC). The parameters considered in the design procedure for obtaining required compressive strength and workability were water to geopolymer solid ratio, alkali solution/fly ash and alkali solution/water ratios. The focus of the study was to identify the stress strain behavior of geo polymer concrete and salient parameters that influence the mixture proportions and the properties of low calcium fly ash- based geo polymers concrete.

2 Preparation Of Geopolymer Concrete

The Basic Materials required for Geopolymer Concrete are Fine Aggregate, Coarse Aggregate, Fly ash, Sodium Silicate (Na_2SiO_3), Sodium Hydroxide (NaOH), Ground Granulate Blast Slag (GGBS). Sodium Hydroxide is in the form of Pallets and Sodium Silicate is in Liquid Form. Sodium Hydroxide pellets are taken and dissolved in water. It is strongly advised that the sodium hydroxide solution be made 24 hours ahead of time, since it will solidify into a semi-solid liquid condition if left unattended for more than 36 hours. As a result, the ready-to-use solution must be utilised within this time frame. To create a solution with the appropriate concentration, the solids must be dissolved in water. The molar concentration of sodium hydroxide solution might differ. The mass of NaOH solids in a solution changes with the solution's concentration. The focus of the study was to identify the stress strain behaviour of geo polymer concrete. The Basic Materials required for Geopolymer Concrete are Fine Aggregate, Coarse Aggregate, fly ash, Sodium Silicate (Na_2SiO_3), Sodium Hydroxide (NaOH), Ground Granulate Blast

[1] Corresponding author: ketananutakki@gmail.com

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Slag (GGBS). Sodium Hydroxide is in the form of flakes and Sodium Silicate is in Liquid Form.

3 Sodium Hydroxide Solution

Pellets of sodium hydroxide are ingested and dissolved in water. It is strongly advised that the sodium hydroxide solution be made 24 hours ahead of time, since it will solidify into a semi-solid liquid condition if left unattended for more than 36 hours. As a result, the ready-to-use solution must be utilised within this time frame. To create a solution with the appropriate concentration, the solids must be dissolved in water. The molar concentration of sodium hydroxide solution might differ. The mass of NaOH solids in a solution changes with the solution's concentration.

4 Mix Proportions

For each 1m^3 of concrete,

- Weight of fly-ash =400kg
- Alkaline liquid solution/fly-ash ratio=0.5(adopted from past literature)
- Weight of AAS=400*0.5=200 kg
- Sodium silicate/sodium hydroxide ratio=2.5 (adopted from past literature)
- 16M NaOH (adopted from past literature)
- SiO_2/Na_2O ratio=2.0 (adopted from past literature)
- Mass of NaOH= 200/ (1+2.5) =57.14kg
- Mass of Na_2SiO_3=200-57.14=142.86 kg
- Mass of aggregate=2400-400-200=1800kg
- Ratio of fine aggregate: coarse aggregate(20mm) =0.4:0.6
- Mass of sand=0.4*1800=720kg
- Mass of coarse aggregate =1080kg
- Na_2SiO_3: NaOH: fly ash: sand: coarse aggregate(20mm) = 0.358:0.142:1:1.8:2.7

The above GPC mix ingredients are considered based on various trial mixes and strength achieved is equivalent to that of M20 grade normal concrete.

5 Stress Strain Behaviour

The aim of this study is to determine the stress-strain behaviour of Geo polymer concrete experimentally. Cylinders of standard size 150 x 300 mm are cast , cured for 28 days and tested in uni-axial compression under strain control as per IS: 516-1999 to understand the stress-strain behaviour of Geopolymer concrete considered. The test setup for stress-strain measurements is shown in Fig.1

Fig.1.: Test setup for stress-strain measurements

Table 1. Experimental stress strain values of Conventional Concrete

Strain	Stress N/mm^2	Normalized stress	Normalized strain
0	0	0	0
0.00008	2.26	0.079	0.018
0.00022	4.43	0.155	0.050
0.00044	6.58	0.230	0.101
0.00079	8.45	0.295	0.181
0.00129	11.82	0.413	0.295
0.00153	13.79	0.481	0.350
0.00178	15.83	0.553	0.407
0.00202	17.09	0.597	0.462
0.00228	19.23	0.671	0.522
0.00263	21.62	0.755	0.602
0.00324	24.36	0.851	0.741
0.00358	25.42	0.888	0.819
0.00402	27.68	0.966	0.920
0.00437	28.64	1.000	1.000
0.00482	28.41	0.992	1.103

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0.00508	27.67	0.966	1.162
0.00518	23.54	0.822	1.185

Table 2. Experimental stress strain values of Geopolymer Concrete

Strain	Stress N/mm^2	Normalized stress	Normalized strain
0.0000	0	0	0
0.0001	2.26	0.074	0.018
0.0002	4.43	0.145	0.061
0.0004	6.58	0.216	0.104
0.0008	8.05	0.264	0.151
0.0013	11.82	0.387	0.247
0.0015	13.79	0.452	0.283
0.0018	15.83	0.519	0.337
0.0020	17.09	0.560	0.380
0.0023	19.23	0.630	0.419
0.0026	21.62	0.708	0.493
0.0032	23.85	0.781	0.566
0.0036	25.25	0.827	0.622
0.0040	28.88	0.946	0.785
0.0044	29.79	0.976	0.885
0.0048	30.34	0.994	0.935
0.0051	30.52	1.000	1.000
0.0052	29.02	0.951	1.029
0.0000	26.62	0.872	1.056
0.0001	24.89	0.816	1.066

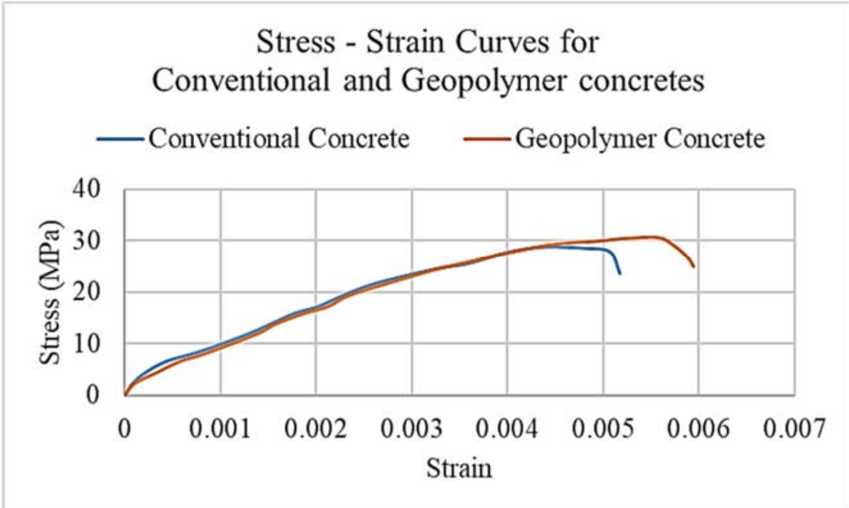

Fig. 1. Experimental stress strain values of Conventional and Geopolymer Concrete

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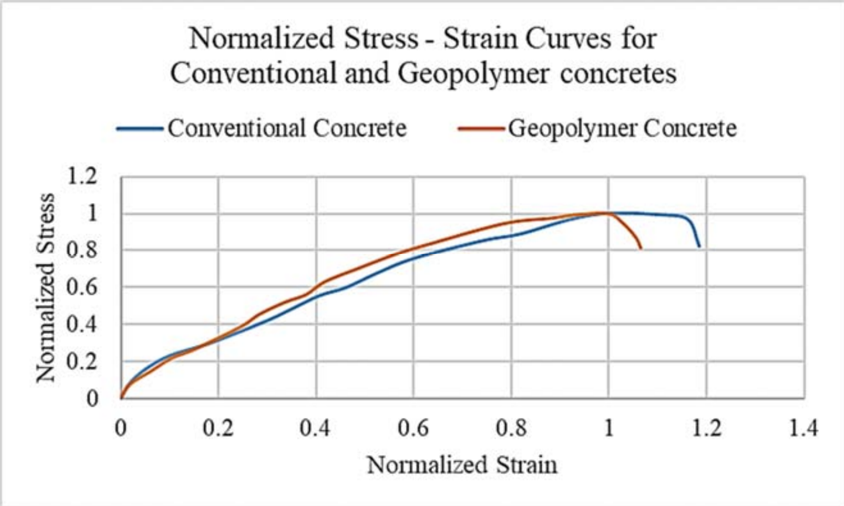

Fig. 2. Experimental normalized stress strain values of Geopolymer Concrete

Table 3. Peak stress values and their corresponding strains

Conventional Concrete		Geopolymer concrete	
Peak Stress f_o	Corresponding strain at peak stress $\in_o$	Peak Stress f_o	Corresponding strain at peak stress $\in_o$
28.64	0.00437	30.52	0.00558

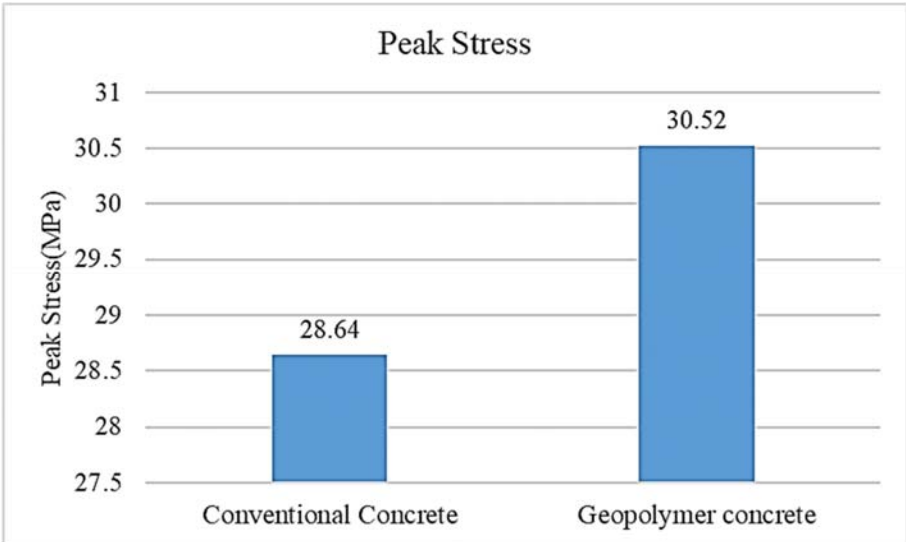

Fig 3. Peak stress values for Conventional and Geopolymer Concrete

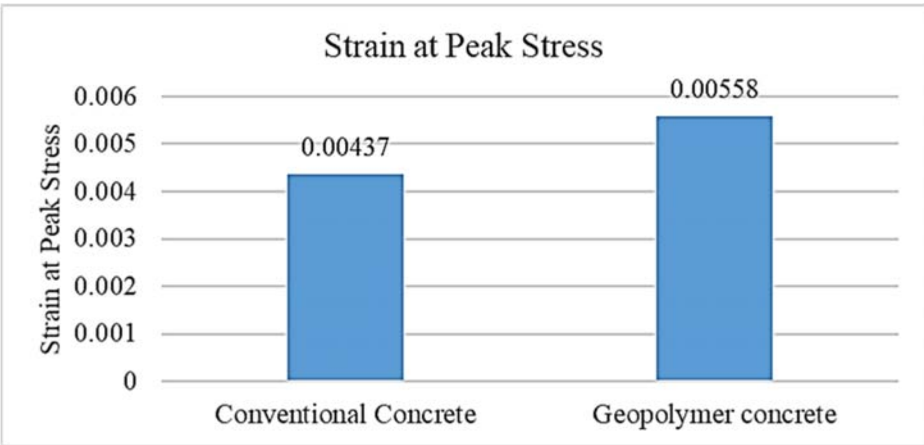

Fig 4. Peak stress values for Conventional and Geopolymer Concrete

The stress-strain curve for mix is drawn using the values of stresses and strains, using the average values of the three cylinders' findings. The related normalised stress-strain values are derived by dividing each stress value by the peak stress and dividing each strain value by strain at peak strain from the stress-strain values of controlled and geo polymer concrete mixes. The average normalised stress-strain curves for controlled and geo polymer concrete are displayed using the normalised stress-strain values of the two concrete mixes. From the observations made from stress-strain curves of all the controlled and geopolymer concrete mixes, the stress-strain behavior is observed to be almost similar. The only difference is that geo polymer concrete mixes have shown improved stress values for the same strain levels compared to that of controlled concrete mixes. It can be observed from stress strain curves that for geopolymer and conventional concrete, the shape of the ascending part of the stress-strain curve is more linear and steeper. The strain at peak stress is slightly higher, and the slope of the descending part is steeper in geopolymer concrete as compared to normal strength concrete. That was due to the decrease in the extent of internal micro cracking in geopolymer concrete. Strains attained are more in geopolymer concrete indicating its ductile nature of its microstructure.

6 Conclusions

The following conclusions may be derived from the experimental data gathered during the course of this study:

1. When compared to a controlled concrete mix, the geo polymer concrete mixes showed better stress values at the same strain levels.
2. The average strain at peak stress for controlled and geo polymer concrete is extremely near to the strain at peak stress for controlled concrete in axial compression, which is 0.002 according to IS 456-2000.
3. The stress-strain curves for controlled and geo polymer concrete obtained in the experiment show a similar pattern. When compared to controlled concrete mixes, geopolymer concrete mixes showed improved stress values for the same strain levels. The form of the ascending section of the stress-strain curve for typical concrete is more linear and steeper, as can be seen from stress-strain curves.
4. Normalized stress strain curves are used to compare the behaviours of geopolymer concrete. It can be observed that geopolymer concrete has improved strains for the same stress when compared to conventional concrete.

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