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Ductility Index for Class F Fly Ash Based Reinforced Geopolymer Concrete Beams

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ABSTRACT

This paper presents the experimental investigation on low calcium class F based reinforced geopolymer concrete beams, cast for different percentage of tension reinforcement, with varying molarities of sodium hydroxide and ratio of sodium silicate to sodium hydroxide solution. The preliminary investigation on compressive strength, split tensile strength and flexural strength were carried out to assure that geopolymer concreter behaves like conventional cement concrete. Sixteen reinforced geopolymer concrete beams were cast to study the ductility behaviour of reinforced geopolymer concrete beams by varying the percentage of tension reinforcement. The test results of reinforced geopolymer concrete were validated with respect to load-deflection characteristics of the reinforced geopolymer concrete beams and ductility in accordance with the provisions given in Indian standard code IS: 456-2000 for reinforced Portland cement concrete.
The ductility indices calculated for the reinforced geopolymer concrete beams in the present investigation have clearly shown that the acceptable lower bound of ductility index is ensured for moment redistribution, at the limit state of serviceability. The crack propagation observed for the reinforced geopolymer concrete beams is very similar to that obtained in reinforced cement concrete beams.

Keywords: Geopolymer Concrete, Compressive Strength, Flexural Strength, Split Tensile Strength, Percentage Of Reinforcement, Ductility Index.

RESEARCH SIGNIFICANCE

Acceptable Ductility index for reinforced concrete is very essential when used as flexural members and reinforced geopolymer concrete beams are to be assessed to assure that geopolymer concrete behaves like ordinary Portland cement concrete when used as structural members such as beams, columns and slabs. Special equipments were designed to cure reinforced geopolymer concrete beams of span
2300 mm x 200 mm x 300 mm along with the mould and a cover plate to achieve desired flexural strength and an acceptable ductility index

INTRODUCTION

Geopolymer was first applied to describe a family of alkaline aluminosilicate binders formed by alkali activation of aluminosilicate minerals. There are two main constituents in geopolymer viz., the source material and alkaline liquids. The source material for geopolymerization should be rich in silicon and aluminium. These could be obtained in the low calcium fly ash which is a byproduct from burning of coal in the thermal power plants.

Most of the fly ash particles are solid spheres and the particle sizes in fly ash vary from less than 1 µm to more than 100 µm with the typical particle size measuring less than 20 µm. Their surface area is typically 300 to 500 m^2/kg, although some fly ashes can have surface areas as low as 200 m^2/kg and as high as 700 m^2/kg. Fly ash is primarily silicate glass containing silica, alumina, iron, and calcium. The relative density or specific gravity of fly ash generally ranges between 1.9 and 2.8 and the color is generally gray. India's thermal power plants produce an estimated 100 million tonnes of fly ash per annum. Of this, Raichur thermal power plant situated in Karnataka state alone generates about 1.5 million tonnes at 4,000 tonnes daily. Out of this, 80 per cent is fly ash and 20 percent is bottom ash. This ash needs to be disposed of every day.

OBJECTIVES OF THE STUDY

The focus of the present study is to identify the salient parameters that influence the mix proportions and the properties of low calcium fly ash based geopolymer concrete and flexural behavior of reinforced geopolymer concrete beams. The compressive strength is selected as the bench mark parameter. This is not unusual because compressive strength has an intrinsic importance in the structural design of concrete.

In the present experimental research work, low calcium class F fly ash obtained from Raichur thermal power plant, Karnataka state, India is used as the base material.

A combination of sodium silicate solution (Na2SiO3) and sodium hydroxide (NaOH) solution is chosen as the alkaline liquid. Sodium based solutions are chosen because they are cheaper than potassium based solutions. The sodium hydroxide solution is prepared by dissolving the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of Molar (M).

For instance, NaOH solution with a concentration of 8M consists of 8×40 = 320 gms of NaOH solids (in pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. Sodium silicate solution is obtained from manufacturer, the chemical composition of sodium silicate solution is

Na2O= 14%, SiO2=31%, H2O=55%, and as the ratio of SiO2:Na2O is less than 2.85; the sodium silicate solution is alkaline in nature. The other characteristic of sodium silicate solution is specific gravity and is equal to 1.60 g/cc. The combined coarse and fine aggregates are used in two groups such as group-I: coarse aggregates 20mm (10%), 12.5mm (15%), 10mm (20%), 6.3mm (25%) and fine aggregates (30%) passing through 2.36mm sieve. Group-II: 12.5mm (15%), 10mm (20%), 6.3mm (35%) and fine aggregates (30%) passing through 1.18mm sieve. To improve workability Naphthalene sulphonated based super plasticizer CONPLAST SP430 is used. Though in geopolymer concrete no water is required but as the concentration of sodium hydroxide increases and also the ratio of sodium silicate to sodium hydroxide is higher, there will be demand of water for achieving workability. Hence, in the present study extra water is added to an amount of 1-4% of fly ash content. The experimental research work is undertaken on geopolymer concrete with the following objectives:

1. To arrive at a mix proportion of fly ash based geopolymer concrete, the density of geopolymer concrete is assumed to be equivalent to that of Portland cement concrete.
2. To understand the effect of sequence of adding the alkaline liquid to the solids constituents in the mixture.
3. To understand the effect of varying sodium hydroxide concentration.
4. To understand the effect of varying ratio of sodium silicate to sodium hydroxide solution.
5. To study the geopolymer concrete properties such as the compressive strength, tensile strength, flexural strength, density and workability.
6. To study the ductility of reinforced geopolymer concrete beams by varying the percentage of tension reinforcement.
7. To compare the behaviour of reinforced geopolymer concrete beams in flexure with the provisions in the Indian Standard code for the behaviour of reinforced Portland cement concrete beams with regard to deflection limits, and moment of resistance.
8. To validate the experimental results with respect to load-deflection characteristics of the reinforced geopolymer concrete beams, ultimate moment capacity, cracking moment and ductility in accordance with the provisions given in IS: 456-2000 for reinforced Portland cement concrete.

EXPERIMENTAL PROGRAMME

Mix Proportion

IS 456-2000 prescribes minimum grade of ordinary Portland cement concrete to be used for reinforced structural members must be M20 grade and the mix proportion to be designed should be as per SP-23/IS:10262-2009. In the case of geopolymer concrete, to arrive at a mix proportion, a trial and error method is adopted in the present investigation. Assuming the density of geopolymer concrete to be equivalent to ordinary Portland cement concrete, and at the first instance, a mix proportion for geopolymer concrete is taken to be equal to 1:1.35:3.15:0.35 (low calcium fly ash: fine aggregates: coarse aggregates: combined alkaline solution of sodium hydroxide and sodium silicate). For the geopolymerization process to take place, a temperature in between 60^0 C to 90^0 C is required. In the present study, oven dry curing method is adopted by manufacturing the geopolymer concrete in the mixer with the variations in molarity of sodium hydroxide, variations in the ratio of sodium silicate to sodium hydroxide and variation in the dosage of super plasticizer, keeping other constituents constant. The cubes, prisms and cylinders of geopolymer concrete are cast and are inserted in the oven along with mould and cover plate for a period of 24 hours at a constant temperature of 60^0 C for the first stage of investigation on properties of geopolymer concrete.

The experiments are conducted on the geopolymer concrete to study the properties such as workability, density, compressive strength, split tensile strength, flexural strength, and permeability, resistance to sulphuric acid and magnesium sulphate attack and non destructive test with rebound hammer in the first stage to investigate whether geopolymer concrete behaves similar to ordinary Portland cement concrete.
Oven dry curing method is adopted to cure the specimens kept in the specially designed ovens at a constant temperature of 60 degree Celsius for a period of 24 hours. Then the specimens were left in ambient conditions of temperature and humidity for the remaining 27 days.
Geopolymer concretes are manufactured with the combined coarse and fine aggregates used in two groups such as group-I: coarse aggregates 20mm (10%), 12.5mm (15%), 10mm (20%), 6.3mm (25%) and fine aggregates (30%) passing through 2.36mm sieve. Group-II: 12.5mm (15%), 10mm (20%), 6.3mm (35%) and fine aggregates (30%) passing through 1.18mm sieve. The study involves:

1. Effect of variation in Molarity of sodium hydroxide solution 8M, 10M, 12M and 14M keeping the ratio of sodium silicate to sodium hydroxide constant;
a) Without addition of super plasticizer,
b) With 1% addition and
c) With 2% addition of super plasticizer by weight of fly ash.
2. Effect of variation in the ratio of sodium silicate to sodium hydroxide solution 0.4, 1.0 and 2.5 keeping the molarities of the sodium hydroxide constant;
a) Without addition of super plasticizer,
b) With 1% addition of super plasticizer and
c) With 2% addition of super plasticizer by weight of fly ash. A total number of 1320 cube specimens, 504 cylinder specimens and 216 prism specimens of geopolymer concrete were manufactured for investigations on strength characteristics.

In the second stage, a total number of 32 reinforced geopolymer concrete beams of size 2.4m X 0.2m X 0.3m are cast and cured oven dry at a temperature of 60^0 C for a period of 24 hours and then left in ambient conditions of temperature and humidity for the remaining 27 days. The beams are subjected to two point loads at one-third of span considering the pure bending criteria. First crack load, ultimate load, maximum deflection at mid-span, ductility, crack propagation are recorded.
The study involves:

1. Variation in the ratio of sodium silicate to sodium hydroxide in the combined alkaline solution used for the manufacture of reinforced geopolymer concrete beams keeping other parameters constant.
2. Variation in the Molarity of sodium hydroxide in the combined alkaline solution used for the manufacture of reinforced geopolymer concrete beams keeping other parameters constant.
3. Variation in the percentage of tensile reinforcement in the reinforced geopolymer concrete beams.

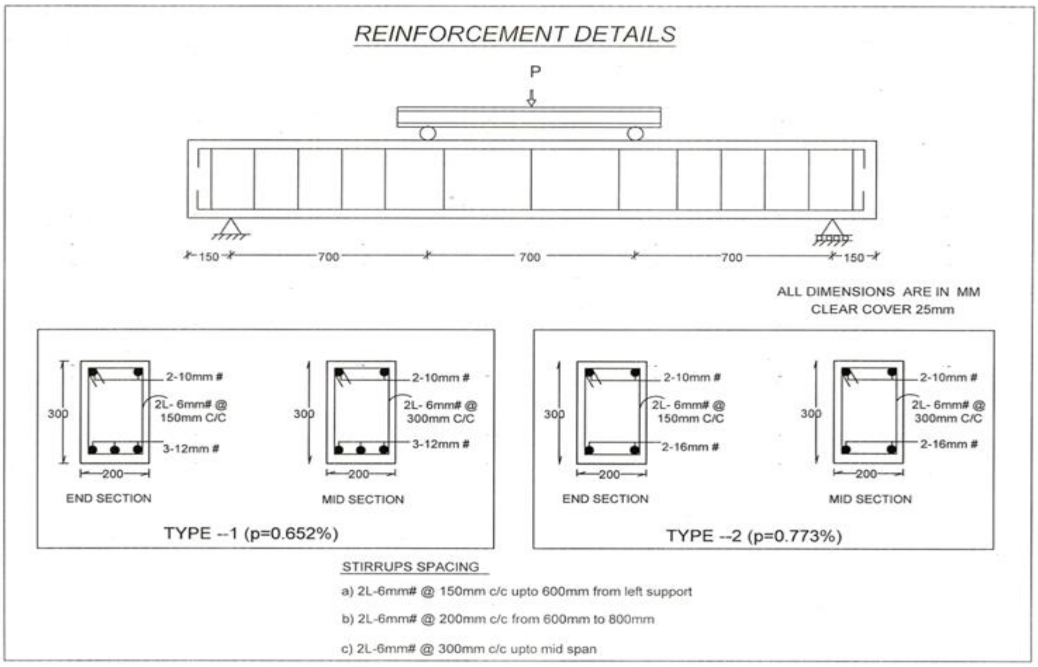

Fig. 1 loading arrangement of the geopolymer concrete beam

RESULTS AND DISCUSSIONS

Fig.2. Oven dry curing of Cubes, Cylinders and Prisms

Fig.3. Oven dry curing of reinforced geopolymer concrete Beams

Fig.4. Testing of reinforced geopolymer concrete beams under two point loadings- B15

Table: 1 Deflection characteristics for typical A_1, A_2, A_3, A_4 Beams

A_1		A_2		A_3		A_4	
Load (KN)	Δ (mm)	Load (KN)	Δ (mm)	Load (KN)	Δ (mm)	Load (KN)	Δ (mm)
0	0	0	0	0	0	0	0
2.5	0.305	2.5	0.3	2.5	0.05	2.5	0
5.0	0.400	5.0	0.5	5.0	0.1	5	0
11.5	1.005	10.0	1.0	10	0.15	10	0.3
14.5	1.501	15.020.0	1.4	15	0.9	15	0.45
17.5	1.802	25.0	1.7	20	1.0	20	0.9
21.0	2.382	30.0	2.5	25	1.1	25	1.3
25.0	2.100	35.0	3.0	30	2.0	30	1.4
29.0	2.150	40.0	3.5	35	2.2	35	1.95
32.5	2.900	45.0	4.0	40	2.85	40	2.7

34.5	3.420	50.0	4.8	45	3.4	45	3.1
38.0	3.650	55.0	4.8	50	3.45	50	3.35
42.5	4.010	60.0	5.6	55	4.20	55	3.9
48.5	4.500	65.0	6.0	60	4.6	60	4.5
52.5	5.120	70.0	6.85	65	6.0	65	5.2
59.5	5.610	75.0	6.85	70	6.6	70	6.0
62.0	6.520	80.0	7.7	75	7.55	75	6.35
65.0	7.120	85.0	8.1	80	8.60	80	7.0
70.0	7.310	90.0	8.7	82.14	9.36	85	8.4
72.5	8.050	94.0	9.7			90	9.7
78.85	8.920	94.96	11.0188			95	11.5
78.00	10.120					95.9	11.530

DUCTILITY INDICES

Table 2: Ductility index with two percentages of tensile reinforcement for A-series of reinforced geopolymer concrete beams

Beam designation	Percentage of tensile reinforcement	Short term deflection (mm)	Ultimate deflection (mm)	Ductility index= ultimate deflection/short term deflection
A_1	0.652	2.380	8.900	3.144
A_2	0.652	2.614	11.188	4.280
A_3	0.652	2.431	9.360	3.850
A_4	0.652	2.626	11.530	4.390
A_5	0.652	2.727	10.670	3.912
A_6	0.652	2.790	12.435	4.456
A_7	0.652	2.985	11.501	3.852
A_8	0.652	2.800	11.646	4.159
A_9	0.773	2.586	10.200	3.944
A_{10}	0.773	2.706	9.822	3.611
A_{11}	0.773	2.671	10.050	3.762
A_{12}	0.773	2.720	12.391	4.555
A_{13}	0.773	2.888	11.202	3.878
A_{14}	0.773	2.897	13.481	4.653
A_{15}	0.773	3.128	12.100	3.868
A_{16}	0.773	3.361	15.642	4.653

Table 3: Ductility index with two percentages of tensile reinforcement for B-series of reinforced geopolymer concrete beams

Beam designation	Percentage of tensile reinforcement	Short term deflection (mm)	Ultimate deflection (mm)	Ductility index= ultimate deflection/short term deflection
B_1	0.652	2.281	8.625	3.781
B_2	0.652	2.372	8.900	3.752
B_3	0.652	2.333	8.961	3.840
B_4	0.652	2.411	9.364	3.883
B_5	0.652	2.522	9.450	3.747
B_6	0.652	2.547	9.732	3.820
B_7	0.652	2.671	10.253	3.838
B_8	0.652	3.072	11.854	3.858
B_9	0.773	2.346	9.900	4.219
B_{10}	0.773	2.484	9.563	3.849

B_{11}	0.773	2.476	9.621	3.885
B_{12}	0.773	2.669	10.350	3.877
B_{13}	0.773	2.682	10.320	3.847
B_{14}	0.773	2.726	10.351	3.797
B_{15}	0.773	2.651	10.050	3.791
B_{16}	0.773	3.283	13.282	4.045

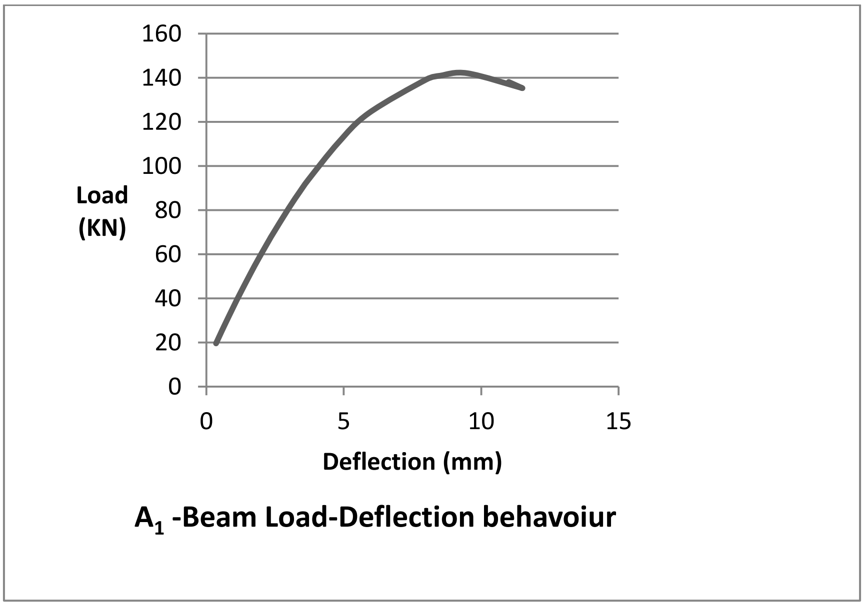

Fig.6. Typical load-deflection characteristics of A1 reinforced geopolymer concrete beam

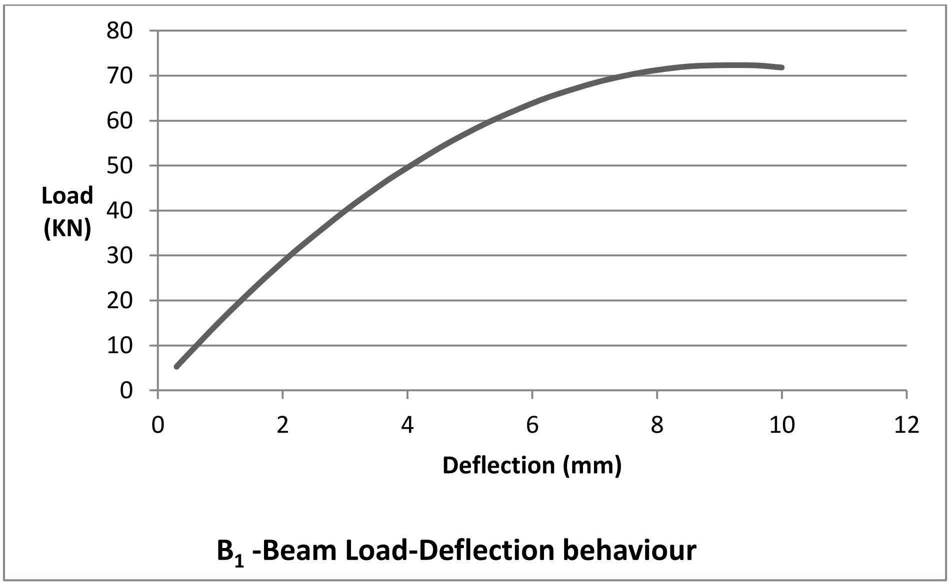

Fig.7. Typical load-deflection characteristics of B1 reinforced geopolymer concrete beam

Reinforced geopolymer concrete beams are designed as under reinforced beams with two percentages of tensile reinforcement as indicated in Table 2 and 3. It is observed from the experimental investigation that the deflection and cracking characteristics of all the beams are similar to reinforced concrete beams manufactured with ordinary Portland cement. Though temperature media is very essential for the geopolymerization process to take place for the organic bonds to form and a property to bind fly ash and aggregates with sodium hydroxide and sodium silicate solutions, the use of fly ash to an extent of 100 percent replacement is achieved

LITERATURE REVIEW

[1] **Joseph Davidovits (1994, 2004, and 2006)** Geopolymer institute, France, is the founder scientist to develop geopolymer technology. In fact, the name geopolymer concrete was first introduced with a concept that the fly ash which is a by-product of coal being burnt for the production of power in the power plants is originated from coal which is a geological material. In 1972, a team of ceramicist introduced aluminosilicate kaolin which reacts with sodium hydroxide at 100 degree Celsius and poly condenses to form tecto aluminosilicate or hydro sodalite which when mixed with fly ash and other materials, develops a cementitious property. To define the importance of this chemistry, in 1976, the author established a new terminology that served to properly classify mineral polymers.

[2] **Djwantoro Hardjito, S. E. Wallah, D. M. J. Sumajouw and B. V. Rangan (2004)** have studied on the development of geopolymer Concrete. They say that efforts are needed to reduce green house gas emissions. Based on the experimental research, the authors concluded that compressive strength can be enhanced with the increase in the molarities of sodium hydroxide and ratio of sodium silicate to sodium hydroxide ratio with a steam curing period 24 hours to 96 hours.

[3] **Djwantoro Hardjito, et al., (2004)** have studied on factors influencing the compressive strength of fly-ash based geopolymer Concrete. The authors have taken different parametric studies such as age of concrete, curing time, curing temperature, quantity of super plasticizer, the rest period prior to curing and the water content in the mix and concluded that compressive strength of geopolymer concrete does not vary with age and curing the concrete specimens at higher temperature and longer curing period will result in higher compressive strength. Furthermore the commercially available Naphthalene based super plasticizer improves the workability of fresh geopolymer concrete. The start of curing period of geopolymer concrete can be delayed at least up to 60 minutes without significant effect on the compressive strength.

[4] **D. Hardjito, S. E. Wallah, D. M. J. Sumajouw and B. V. Rangan (2005)** have studied on manufacture and engineering properties of fly ash Test results were carried out on 100 mm * 200 mm cylindrical geopolymer concrete specimens and showed that a good agreement exists between the measured stress-strain relations of fly ash based geopolymer concrete and those predicted by a model developed originally for Portland cement concrete.

[5] **Ioanna Giannopuulou and Dimitrios Panias (2005)** have studied on structure, design and application of Geopolymer materials and say that the term geopolymer was firstly applied to describe a family of alkaline aluminosilicate binders formed by the alkali activation of aluminosilicate minerals. The authors suggested that geopolymer belong to the family of inorganic polymers which are macromolecules linked by covalent bonds and having Si-O-Al back bone.

[6] **Hardjito and B. V. Rangan, Research Report GC1 (2005)** have carried out an extensive experimental investigation on the development, manufacture, behavior and applications of low calcium fly ash based geopolymer concrete. They came to the conclusion that higher concentration of sodium hydroxide solution results in higher compressive strength, similarly higher the ratio of sodium silicate to sodium hydroxide by mass higher the compressive strength. They also concluded that low calcium fly ash based geopolymer concrete has very little drying shrinkage, low creep; excellent resistance to sulphate attack and good resistance to acid attack.

SUMMARY

The acceptable lower bound value of ductility index to ensure serviceability limit state for moment redistribution is 3.

Geopolymer concrete with group-I type of aggregates used in A-series of beams with two percentages of reinforcement of 0.652% and 0.773%, the ductility index calculated with the ratio of ultimate deflection and short term deflection is in the range of 3.144 to 4.653 for A1 to A16 beams and is in the acceptable limits.

In similar observations, Geopolymer concrete with group-II type of aggregates used in B-series of beams with two percentages of reinforcement of 0.652% and 0.773%, the ductility index calculated with the ratio of ultimate deflection and short term deflection is in the range of 3.781 to 4.045 for B1 to B16 beams and is in the acceptable limits.

Therefore, it may be concluded that, the behaviour of Geopolymer concrete is similar to the ordinary Portland cement concrete structural components.

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