International Journal of Structural and Civil Engineering
ISSN : 2277-7032 Volume 2 Issue 11 (November 2013)
http://www.ijsce.com/ https://sites.google.com/site/ijscejournal

Flexural Behaviour of Low Calcium Fly ash Based Geopolymer Concrete Beams

S.Kumaravel[1], S.Thirugnanasambandam[2],
[1]Assistant Professor, [2]Associate Professor,
[1, 2] Department of Structural Engg., Annamalai University,
Annamalainagar - 608 002, India.

Abstract

The production of Ordinary Portland Cement (OPC) causes pollution to the environment, due to the emission of CO_2. Geopolymer concrete (GPC) is an alternate material for OPC. Low calcium fly ash, a by-product from the coal industry is widely available in the world. Silicate and alumina are rich in fly ash and hence reacts with alkaline solution to produce alumina silicate gel that binds the aggregate to produce a good concrete. The designed compressive strength of concrete is 50 N/mm^2. A total of four beams is cast over an effective span of 3000 mm and tested up to failure under static loads. The flexural behaviour of GPC beams and OPC beams are examined. The load displacement response of those beams are obtained and compared with the theoretical results. The deflections at different stages including service load and ultimate load stage are higher and exhibit increased flexural strength for GPC beams.

Keywords: Fly ash, alkaline solution, Geopolymer concrete, Beams, Load deflection behaviour.

1. Introduction

Concrete is widely used as one of the important construction material. Portland cement is the main component of making concrete. The cement industries are responsible for the emissions of CO_2 [1]. The production of one ton Portland cement produces approximately one ton of CO_2 to the atmosphere [2]. Many efforts are being made in order to reduce the use of Portland cement in concrete. In order to find an alternative cementing materials such as fly ash, silica fume, ground granulated blast furnace slag, rise husk ash etc. We proposed an alkaline liquid that could be used to react with the silicon (Si) and aluminium (Al) to produce binders. Because of the chemical reaction that takes place in the polymerization process, Davidovits coined the term “Geopolymer” to represent these binders and has got wide applications as traditional cementitious binders [3-5]. The advantage of that binder is significantly reduced greenhouse emissions. Geopolymers exhibits a high compressive strength, low shrinkage, fast or slow setting, acid resistance, fire resistance and low thermal conductivity [6]. The geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement.

Corresponding author: E-mail:smk_au@yahoo.com.

2. Preparation of Concrete

2.1 Fly ash and Aggregates

Low-calcium (ASTM Class F) fly ash obtained from Mettur Thermal Power Station, Tamilnadu is used in this study. A coarse and fine aggregates used by the concrete industry are suitable to manufacture geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of geopolymer concrete. The properties of aggregate used specific gravity of fine and coarse aggregate - 2.66 and 2.70, fineness modulus of fine and coarse aggregate - 2.43 and 6.71 [7, 8].

2.2 Alkaline Solution

The alkaline solution is prepared by mixing sodium silicate and sodium hydroxide and allowing the mix for a minimum period of 24 hours to the reaction of polymerization. The sodium silicate solution is commercially available in different grades. The sodium silicate solution (Na_2SiO_3) with sodium hydroxide (NaOH) ratio of 2.5 is used [9]. The sodium hydroxide with 98% purity in pellet form is commercially available. The solids are dissolved in water to make a solution with the required concentration. The 14 mole (14 M) solution is used. Since the molecular weight of sodium hydroxide is 40, the mass of NaOH solids in a solution varies depending on the concentration of the solutions [10].

2.3 Concrete

The M 50 grade concrete ratio 1:1.25:2.45 are tried in this study. The OPC concrete prepared using fine aggregate, coarse aggregate and binder (cement) water cement ratio 0.32 + super plaster [11]. The geopolymer concrete is prepared by altering the binder only. The constituents of geopolymer concrete of 14 molarity sodium hydroxide for M 50 grade concrete are given in Table 1. The materials required for making geopolymer concrete is shown in Figure 1.

Table1 Constituents of Geopolymer Concrete

Description	Quantity
Fly ash	510 kg/m^3
NaOH solid	36.80 kg/m^3
Water (to dissolve NaOH)	28.91 kg/m^3
Na_2SiO_3 Solution	164.30 kg/m^3
Alkaline solution / Fly ash (ratio)	0.45
Fine aggregate	637.50 kg/m^3
Coarse aggregate	1249.50 kg/m^3
Super plaster	4 liters /m^3

International Journal of Structural and Civil Engineering
ISSN : 2277-7032 Volume 2 Issue 11 (November 2013)
http://www.ijsce.com/ https://sites.google.com/site/ijscejournal

2.4 Mixing and Curing

The geopolymer concrete is manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. The fly ash and the fine aggregate which are dry mixed together in 50 liter capacity pan-mixer for three minutes. The saturated surface dry (SSD) coarse aggregate is mixed with the fly ash and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch. The alkaline solution with super plaster is added and the entire batch mix for four minutes. The fresh concrete is cast and compacted by the usual methods used in the case of Portland cement concrete. The workability of fresh concrete is measured by means of the conventional slump test. The slump measured is 110 mm shown in Figure 2.

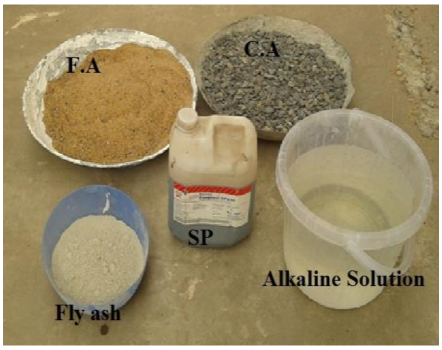

Figure 1 Materials for GPC

Figure 2 Slump Test

The prepared concrete is kept in moulds of specimen cubes, cylinders, prisms and beams shown in Figure 3. The geopolymer concrete specimens after casting are kept in rest period in room temperature for one day and it is kept in hot air curing at an elevated temperature of 75ºC in an autoclave for 24 hours is shown in Figure 4. The specimens are kept curing in a room temperature for about the test period.

Figure 3 Casting of Specimens

Figure 4 Curing Chamber

International Journal of Structural and Civil Engineering
ISSN : 2277-7032 Volume 2 Issue 11 (November 2013)
http://www.ijsce.com/ https://sites.google.com/site/ijscejournal

3. Experimental Investigation

The test program consists of casting and testing four beams in given size 125 x 250 x 3200 mm out of which two are control cement concrete beams and other two are geopolymer concrete beams. The beams are designed under reinforced section [12]. It is reinforced with 2-16 # and 1-12 # at bottom, 2-12 # at top using 6 mm diameter stirrups @ 150 mm c/c. The control cement concrete beam is cast using M 50 grade (1:1.25:2.45) and immersed in water for 28 days (curing) [13]. In the same way geopolymer concrete is casted and cured (24 hours hot air). Both the beams are tested after the 28^{th} day. The control beams and geopolymer concrete beams are abbreviated as RCC-I, RCC-II and GPC-I, GPC-II respectively. The cubes, cylinders are tested at 7, 14 and 28 days and prism at after the 28^{th} days.

3.1 Test Setup

The test setup for flexural test is shown in Figure 5. The test specimen is mounted in a beam testing frame of 200 kN capacity. The beams are simply supported over a span of 3000 mm, and subjected to two concentrated loads placed symmetrically on the span. The distance between the loads is 1000 mm. The load is applied on two points each 500 mm away from the center of the beam towards the support. Dial gauges of 0.001mm least count is used for measuring the deflections under the load points and at mid span for measuring the deflection. The dial gauge readings are recorded at different loads. The strain in concrete is measured using a Demec gauge. An automatic data acquisition unit is used to collect the data during test. Linear Variable Data Transformers (LVDT) is placed at mid span and under the load points of beam. The load is applied at intervals of 2.5 kN. The flexure cracks are initiated in the pure bending zone. As the load increased, existing cracks propagated and new cracks developed along the span. In the case of beams with larger tensile reinforcement ratio some of the flexural cracks in the shear span turned into inclined cracks due to the effect of shear force [14]. The first crack loads are obtained by visual examination and maximum load crack patterns of the beam is shown in Figure 6.

Figure 5 Test Setup

Figure 6 Crack Pattern of Beam

4. Numerical Calculation

Use of FEA software ANSYS is adopted for predicting the load displacement response from the control beams and geopolymer concrete beams numerically. The programme offers solid65 for beam element (Figure 7), and link8 for steel element (Figure 8). For beam generation total mesh model defined 700 nodes and 733 elements are required [15, 16]. The generated model for beams are RCC-I, RCC-II and GPC-I,GPC-II. A typical deflected shapeat ultimate stage of GPC-I is shown in Figure 11. The experimental and numerical (ANSYS) load deflection curves are compared for both control beam RCC-I, RCC-II and GPC-I, GPC-II are shown in Figure 9. It can be seen that the predicted deflections are in close agreement with the experimental results.

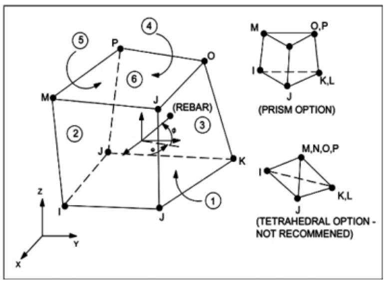

Figure 7 Solid65 Geometry

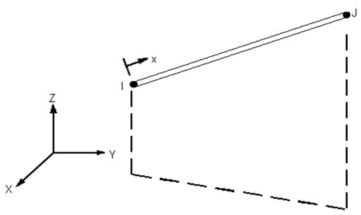

Figure 8 Link8 Geometry

5. Results and Disscussions

The average compressive strength of cement concrete cubes and geopolymer concrete cubes are obtained as 57.5 N/mm^2 and 59.0 N/mm^2 respectively. The first crack load, service load and yield laods are given, ultimate load and maximum deflection are compared for experimental and numerical results in Table 2. The load-deflection for geopolymer beams exhibit similar behaviour with respect to the control beams as shown in Figure 9, and crack pattern of all the beams as shown in Figure 10.

Table 2 Summary of Test Results

Beam Code	Crack Load (kN)	Service Load (kN)	Yield Load (kN)	Ultimate load (kN)		Max. Deflection (mm)	
				Exp.	ANSYS	Exp.	ANSYS
RCC-I	20.00	64.67	95.00	97.00	93.25	55.00	48.00
RCC-II	17.50	62.34	92.50	94.50	93.25	52.00	48.00
GPC-I	20.00	68.34	100.00	102.50	96.00	60.00	53.50
GPC-II	20.00	65.00	97.50	99.50	96.00	57.00	53.50

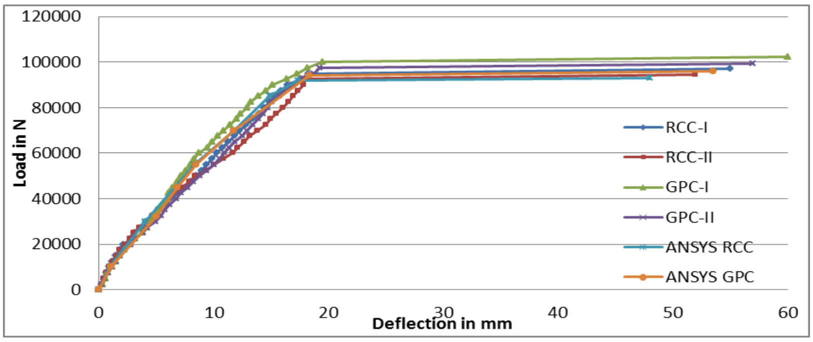

Figure 9 Load-deflection Relationships for RCC and GPC Beams

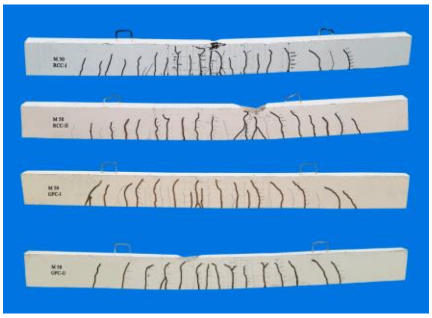

Figure 10 Crack Pattern of Beams

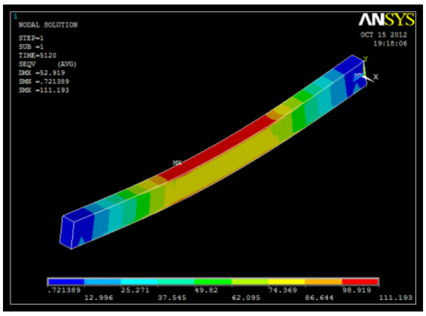

Figure 11 A Typical Deflected Shapes

6. Conclusions

The research investigations carried out on the reinforced geopolymer concrete beams and conventional Portland cement concrete beams are to be concluded that:

a. The load deflection characteristics obtained for the cement concrete beams and geopolymer concrete beams are almost similar curvature. The first cracking load of geopolymer concrete beams shows slightly higher when compared to cement concrete beams.
b. As per IS-456:2000, the crack width under service load is within the permissible limit.
c. The yield load and ultimate load carrying capacity of geopolymer concrete beams slight higher than the cement concrete beams.
d. The experimental results are higher when compared with numerical results by 6.5%.
e. The crack patterns and failure modes observed for geopolymer concrete beams are found to be similar to the cement concrete beams. The beams failed initially by yielding of the tensile steel followed by the crushing of concrete in the compression face.

International Journal of Structural and Civil Engineering
ISSN : 2277-7032 Volume 2 Issue 11 (November 2013)
http://www.ijsce.com/ https://sites.google.com/site/ijscejournal

References

1. McCaffrey, R.: Climate change and the cement industry, Global Cement and Lime Magazine, pp. 15-19 (2002)
2. Malhotra, V.M., and Mehta, P.K.: High-performance, high-volume fly ash concrete, Supplementary Cementing Materials for Sustainable Development, Ottawa, Canada (2002)
3. Davidovits, J.: High-alkali cements for 21st century concretes in concrete technology, In Proceedings of V. Mohan Malhotra Symposium (1994)
4. Davidovits, J.: Chemistry of geopolymer systems, terminology, In Proceedings of Geopolymer- 99, International Conferences, France (1999)
5. Duxson, P., Fernandez-Jimenez, A., Provis, J.L., Lukey, G.C., Palomo, A., and van Deventer, J.: Geopolymer technology: the current state of the art, Journal of Materials Science, vol. 42, pp. 2917-2933 (2007)
6. Hardjito, D., and Rangan, B.V.: Development and properties of low calcium fly ash based geopolymer concrete, Research report GC1, Curtin University of Technology, Perth, Australia (2005)
7. Ivan Dia Z Loya, E., Erez, N., and Allouche.: Mechanical properties of fly ash based geopolymer concrete, ACI Mat. J., pp. 300-306 (2011)
8. Nuruddin, M.F., Qazi, S.A., Kusbiantoro, A., and Shafiq, N.: Utilization of waste material in geopolymeric concrete, ICE J. of Cons. Mat., pp. 45-52 (2010)
9. Rangan, B.V.: “Low-calcium fly ash based geopolymer concrete”, Concrete Construction Engineering Handbook, Editor-in Chief: E.G. Nawy, Second Edition, CRC Press, New York (2008)
10. Sumajouw, M.D.J., and Rangan, B.V.: Low calcium fly ash based geopolymer concrete: reinforced beams and columns, Research report GC3, Curtin University of Technology, Perth, Australia (2006)
11. IS 10262: Concrete Mix Proportioning Guidelines, Bureau of Indian Standards, New Delhi (2009)
12. IS 456: Plain and Reinforced Concrete, Code of Practice, Bureau of Indian Standards, New Delhi (2000)
13. Rashid, M.A., and Mansur, M.A.: Reinforced high-strength concrete beams in flexure, ACI Structural Journal, pp. 462-472 (2005)
14. Arivalagan, S.: Flexural Behaviour of Reinforced Fly ash Concrete Beams, International Journal of Structural and Civil Engineering, vol.1(1), pp. 11-17 (2012)
15. Saifullah, I.M., Nasir-uz-zaman, S.M.K., Uddin, M.A., Hossain., and M.H. Rashid.: Experimental and Analytical Investigation of Flexural Behaviour of Reinforced Concrete beam, International Journal of Engineering & Technology, vol.11, pp. 188-193 (2011).
16. Patil, S.S., Shaikh., Niranjan, B.R.: Experimental and Analytical Study on Reinforced Concrete deep beam, International Journal of Modern Engineering Research, vol.3, pp. 45-52 (2013)