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Flexural Behaviour of Reinforced Low Calcium Fly Ash based Geopolymer Concrete Beam

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Abstract- The production of Ordinary Portland Cement (OPC) causes pollution to the environment, due to the emission of CO2. Geopolymer Concrete,an alternate materialis introduced to replace OPC. Low Calcium Fly ash, a by-product from the coal industry, is widely available in the world. Silicate and Alumina are rich inFly ash.Hence it reacts with alkaline solution to produce Alumina silicate gel that binds the aggregate to produce a good concrete. The compressive strength increases with the increasing of fly ash fineness and thus the reduction in porosity can be obtained. The flexural behavior of Geopolymer concrete (GPC) beams and control cement concrete beams are examined. The designed compressive strength of concrete is 50N/mm2. A total of four beams is castover an effective span of 3000 mm and tested up to failure under static loads. The load-displacement response of the geopolymer concrete beams and control beams are obtained and compared with the theoretical results. The results show that thegeopolymer concrete beams exhibit increased flexural strength.The deflections at different stages including service load and peak load stage are higher for GPC beams.

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Abstract- The production of Ordinary Portland Cement (OPC) causes pollution to the environment, due to the emission of CO_2. Geopolymer Concrete,an alternate materialis introduced to replace OPC. Low Calcium Fly ash, a by-product from the coal industry, is widely available in the world. Silicate and Alumina are rich inFly ash.Hence it reacts with alkaline solution to produce Alumina silicate gel that binds the aggregate to produce a good concrete. The compressive strength increases with the increasing of fly ash fineness and thus the reduction in porosity can be obtained. The flexural behaviour of Geopolymer concrete (GPC) beams and control cement concrete beams are examined. The designed compressive strength of concrete is 50N/mm^2. A total of four beams is castover an effective span of 3000 mm and tested up to failure under static loads. The load-displacement response of the geopolymer concrete beams and control beams are obtained and compared with the theoretical results. The results show that thegeopolymer concrete beams exhibit increased flexural strength.The deflections at different stages including service load and peak load stage are higher for GPC beams.

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I. 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 emissionsCO_2. The production of one ton Portland cement produces approximately one ton of CO_2 to the atmosphere[1]. Many efforts are being made in order to reduce the use of Portland cement in Concrete. In order to finding an alternative cementing materials such as fly ash, silica fume, ground granulated blast furnace slag, rise husk ash etc. The 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[2]. The Geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement[3].

II. Geopolymer Concrete

The main constituents of geopolymersare the source materials and the alkaline liquids. The source materials for geopolymers based alumino-silicate should be rich in Silicon and Aluminium. Silicon and Aluminium are found in natural minerals such as kaolinite, clays, micas, and alousite, spinel, etc[4]. And also alternatively found in by-product materials such as fly ash, silica fume, slag, rice husk ash, red mud, etc. The alkaline liquids are formed from soluble alkali metals that are usually sodium or potassium based. The combination of sodium hydroxide with sodium silicate is known as alkaline liquids. The liquidsratios are 2.5.

III. Experimetal Programe

a) Materials

Low-calcium (ASTM Class F) fly ash obtained from Mettur Thermal Power Station, Tamilnadu is used in this research[5]. Acoarse 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[6].The properties of aggregate used Specific gravity of fine and coarse aggregate -2.66 and2.70, Fineness modulus of fine and coarse aggregate - 2.43 and 6.71.

b) Alkaline Liquid

It is recommended that the alkaline liquid is prepared by mixing sodium silicate and sodium hydroxide solutions 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) withSodium Hydroxide (NaOH) ratio by mass of 2.5 is used. The sodium hydroxide with 97-98% purity in pellet form is commercially available. The solids are dissolved in water to make a solution with the required concentration. The 14 Molar (14 M) solutionsare used[7]. Since the molecular weight of Sodium Hydroxide is 40, the mass of NaOH solids in a solution varies depending on the concentration of the solution. The materials required for making geopolymer concrete is shown in figure 1. The M 50 grade 1:1.25:2.45 is tried in this research[8]. The same ratio of mix is tried in the geopolymer concrete also. The constituents of geopolymer concrete of 14 Molarity Sodium Hydroxide for M50 grade concrete (1:1.25:2.45) is shown in Table 1.

c) Mixing, Casting and Curing

The geopolymer concrete is manufactured by adopting the conventional techniques used in the

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manufacture of Portland cement concrete. The fly ash and the fine aggregate which are dry mixed together in 50-litre 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'naphthalene sulphonate' super plaster is added and the entire batch mix for four minutes[9]. 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 110mm shown in figure 2. The prepared concrete is kept in moulds of specimen cubes, cylinder, prisms and beams shown in figure 3.

Table 1 : Constituents of Geopolymer Concrete

DESCRIPTION	QUANTITY
FLYASH	510 kg / m^3
Na_2SiO_3 / NaOH	2.5
(Na_2SiO_3 + NaOH) / FLYASH	0.45
NaOHsolid	36.80 kg / m^3
WATER (added with NaOHsolid)	28.91 kg / m^3
Na_2SiO_3 Solution	164.30 kg / m^3
Fineaggregate	637.50 kg / m^3
Coarseaggregate(<10mm)	1249.50 kg / m^3
Super plaster	4 Lit./ m^3
24 Hours Curing (Hot air)	75° C

Figure 1 : Materials for Geopolymer Concrete

Figure 2: Slump Test

After casting the specimens, they are kept in rest period in room temperature for one day. The term 'Rest Period' is coined to indicate the time taken from completion of casting of test specimen to the start ofcuring at an elevated temperature[10]. The geopolymer concrete specimens areplaced in an autoclave for 24 hours, hotcuring at a temperature of 75°C before it is de-moulded (figure 4). The compressive strength of geopolymer concrete cubes is increaseswith the increase in age. The densityofgeopolymer concrete is around 2350 kg/m^3.

Figure 3 : Casting of Specimens

Figure4 : Specimens in Curred Beam

IV. Experimental Investigation

The test program consists of casting and testing fourbeamsingiven size 125 X 250 X 3200 mmout of which two are control cement concrete beams and other two are geopolymer concrete beams.The beams designed as under reinforced section[11]. It is reinforced with 2-16 # and 1-12 # at bottom, 2–12 # at top using 6mm diameter stirrups @ 150 mm c/c. The control cement concrete beams cast using M50 grade (1:1.25:2.45) with water cement ratio of 0.32and Fe415 grade steel[12, 13]. Ordinary Portland cement, natural river sand and the crushed granite of maximum size 12.5 mm are used for control concrete. High yield strength deformed (HYSD) bars of 16 and 12 mm diameter with mean strength of 485 N/mm^2 is used.The elastic modulus of the concrete is found as 2.53x10^4N/$mm^2$and the Poisson ratio found on 0.14.The control beams and geopolymer concrete beams are designated as RCC-I, RCC-II and GPC-I, GPC-II respectively. The companion cubes 100 x100 x100mm size and cylinders 100mm diameter x 200mm height are also cast along with the beams and tested.

V. Test Setup

The test setup for flexural test is shown in figure5. The test specimen is mounted in abeam testing frame of 200kN capacity. The beams are simply supported over a span of 3000mm, and subjected to two concentrated loads placed symmetrically on the span. The distance between the loads is 1000mm.The load is applied on two points each 500mm away from the centre 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 atdifferent loads. The strain in concrete is measured using a Demecgauge. An automatic data acquisition unit is used to collect the data during test. LinearVariabledata Transformers (LVDTs) is placed atmid span and under the load points of beam. The load is appliedat intervals of 2.5 kN. The first crack loads are obtained by visual examination. The crack patterns of the geopolymer concrete beam (GPC-I) is shown in figure 6.

Figure 5 : Test Setup

Figure 6 : Crack Pattern GPC-I Beam

Table 2 : Summary of Test Results

Sl. No.	Beam Code	Ist Crack Load (kN)	Service Load (kN)	Yield Load (kN)	Ultimate load(kN)		Max. Deflection (mm)	
					Experimental	Numerical (ANSYS)	Experimental	Numerical (ANSYS)
1	RCC – I	20.00	64.67	95.00	97.00	96.00	55.00	53.00
2	RCC – II	17.50	62.34	92.50	93.50	96.00	52.00	53.00
3	GPC – I	20.00	68.34	100.00	102.50	100.00	60.00	55.00
4	GPC – II	20.00	65.00	97.50	98.50	100.00	57.00	55.00

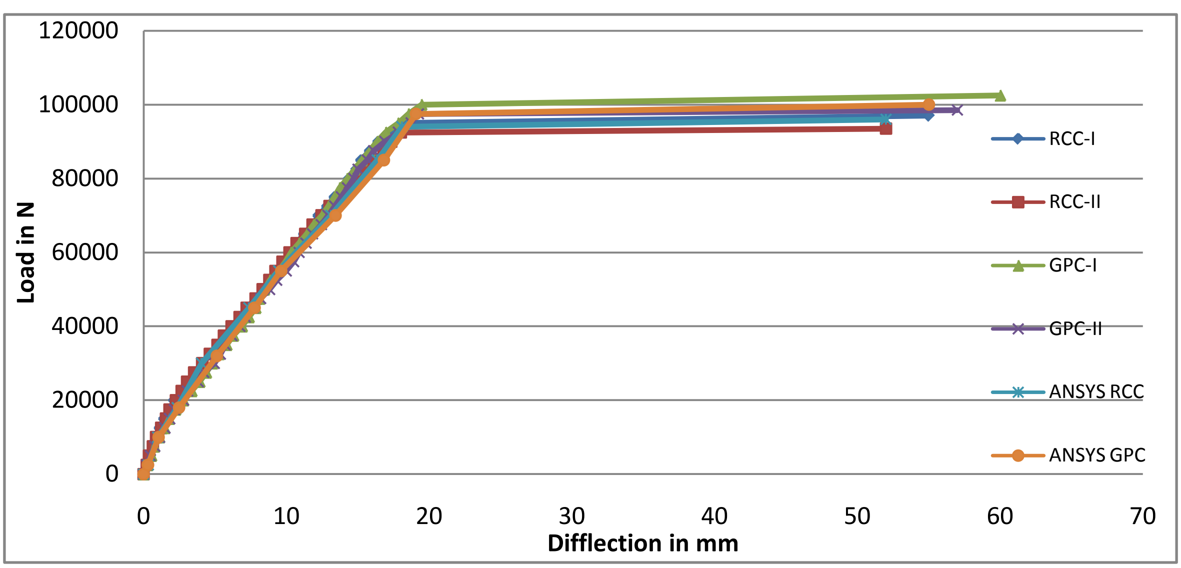

Figure 7 : Load - Deflection Relationships for RCC and GPC Beam

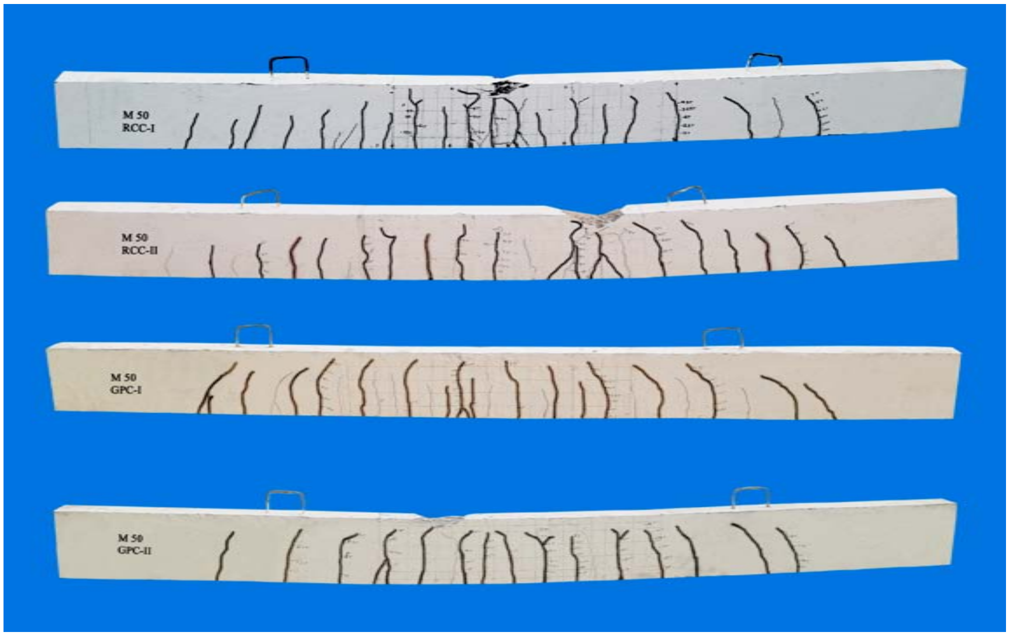

Figure 8 : Crack pattern of RCC and GPC beams

VI. Numerical Calculation

Use of FEA software ANSYS is adopted for predicting the loaddisplacementresponse from the control beams and geopolymer concrete beams-numerically. The mesh model defined 733 nodes and 700 elements. The programme offers solid65 for beam element (figure 9), and link8 for steel element (figure 10). The generated model for beamsare RCC-I, RCC-II and GPC-I,GPC-II. A typical deflected shapeat ultimate stage of GPC-I is shown infigure 11. The experimental and numerical (ANSYS) loaddeflectioncurves are compared for both control beam RCC-I, RCC-II and GPC-I, GPC-II are shown in figure 8. It can be seen that the predicted deflections are in closeagreement with the experimental results[14]. Comparisons ofultimate loads for experimental and numerical (ANSYS) results are shown in Table 2.

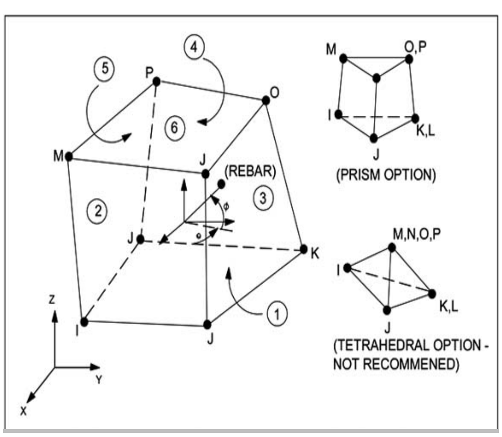

Figure 9 : Solid65 Geometry

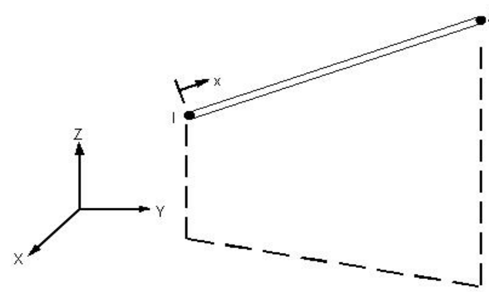

Figure 10 : Link 8 Geometry

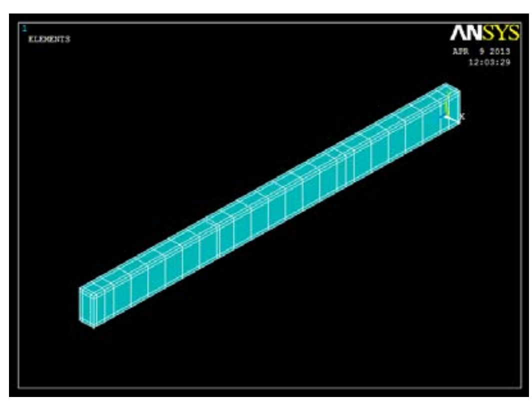

Figure 11 : Mesh Modelling

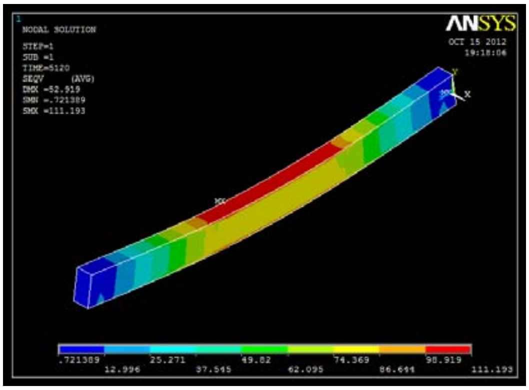

Figure 12 : A Typical Deflected Shapes

VII. Results And Disscussions

The average compressive strength of cement concrete cubes and geopolymer cubes are obtained as 57.5 N/mm^{2}and 59.0 N/mm^{2}respectively. The test results of strength, deformation properties of control beams and geopolymer beams are reported in Table 2. The load-deflection relationship is obtained using deflection measurements from LVDTs and strain data collected from Demec gauges for control beams and geopolymer concrete beams under static monotonic loading are presented. From the load deflection it is clear that the geopolymer beams exhibit similar behaviour with respect to the control beams, and crack pattern of all the beams are shown in figure 8.

VIII. Conclusions

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

a) The compressive strength of cement concrete and geopolymer concrete cubes are obtained as57.5 N/mm^{2}and 59.0 N/mm^2. The slump of geopolymer concrete is obtained as 110 mm even without any addition of water.
b) The load deflection characteristics obtained for the cement concretebeams 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.
c) The average service load of geopolymer concrete beams shows 7.9% higher than the cement concrete beams.
d) The average ultimate load carrying capacity of geopolymer concrete beams shows 5.68% higher than cement concrete beams.
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.

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