Experimental Validation of Geopolymer Concrete Beams using Finite Element Analysis

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Abstract

Vital efforts are needed all over the world to develop environment-friendly construction materials which can be produced using minimum possible natural resources and to minimise environment pollution. In this context, geopolymer concrete has emerged as potential substitute for conventionally used Ordinary Portland Cement Concrete. Analysis of response of concrete structural components for various types of loading is very important to develop safe and efficient structure. Even though experimental procedure for analysis is widely used, it is time consuming and costly. Thus finite element analysis of individual structural components is preferred. The performed study investigation attempts to compare the results of reinforced geopolymer concrete beam under transverse loading using software package ANSYS11 to that obtained from theoretical analysis.

Keywords:*Finite Element Analysis,Geopolymers*

1. Introduction

Portland Cement is widely used in concrete industry since many decades, however it releases large amount of CO_2 into the atmosphere during its manufacture [1]. Geopolymer technology is one of the new technologies attempted to reduce the use of Portland Cement in concrete. Geopolymers are amorphous to semi-crystalline three dimensional alumina-silicate polymers similar to zeolites[2].

Geopolymers are environment friendly materials which do not emit green house gases during polymerisation process. Also moderate energy is needed to produce them. Geopolymers can be made from source material such as fly-ash, waste product of coal-fired power station with Silicon and Alumiminium content and alkaline solution[3].

The geopolymer technology was first time introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymer technology could reduce the CO_2 emission caused by cement industries. Davodovits proposed that an alkaline liquid could be used to react with alumino-silicate in a source material of geological origin or in by-product materials like fly-ash to make a binder[4].

Fly-ash is the most common source material for making geopolymers. Normally good high strength geopolymers can be made from class F fly-ash[5]. Geopolymer is synthesised by mixing alumino-silicate reactive material with strong alkaline solution such as sodium silicate and sodium hydroxide or potassium silicate and potassium hydroxide. The mixture can be cured at room temperature [6]. The alkaline activating solution is important for dissolving of Aluminium and Silicon atoms to form geopolymer precursors and finally alumino-silicate material.

2.Experimental Investigation

2.1 Materials

The following materials have been used in the experimental study[9]

a. Fly-ash(class F) collected from Raichur thermal power plant having specific gravity 2.00
b. Fine aggregate: sand confirming to Zone-III of IS:383-1970[13] having specific gravity 2.51 and fineness modulus of 2.70.
c. Coarse aggregate: Crushed granite confirming to IS: 383-1970[13] having specific gravity 2.70 and fineness modulus of 5.85.
d. Water: Clean potable water for mixing
e. Alkaline liquids: Specific gravity of

i. Sodium Hydroxide(NaOH)=1.16
ii. Sodium Silicate=1.57

Tests were conducted on specimen of standard size as per IS:516-1959[14]. Details of tests conducted and specimens used are given in Table1.

2.2Mix Design of Geopolymer concrete

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 77% of the entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. The density of geopolymer concrete is taken similar to that of OPC as $2400kg/m^3$ [8]. The details of mix design and its proportions for different grades of GPC are given in Table2.

2.3 Alkaline Solution

In geopolymerization, alkaline solution plays an important role. The most common alkaline solution used in geopolymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate (K_2SiO_3). In this study, a combination of sodium hydroxide and sodium silicate was chosen as the alkaline liquid. Sodium based solutions were chosen because they are cheaper than Potassium based solutions. Generally sodium hydroxide and sodium silicate are readily available in market in the form of pellets and gel (liquid).

2.4 Preparation, Casting and Curing of geopolymer concrete

The alkaline activator solution used in GPC mixes was a combination of sodium hydroxide solution, sodium hydroxide pellets and distilled water. The role of AAS is to dissolve the reactive portion of source materials Si and Al present in fly ash and provide a high alkaline liquid medium for condensation polymerization reaction. To prepare sodium hydroxide solution of 8 molarity (8M), 320 g of sodium hydroxide flakes was dissolved in water. The mass of NaOH solids in a solution will vary depending on the concentration of the solution expressed in terms of molar, M. The pellets of NaOH are dissolved in one litre of water for the required concentration. When sodium hydroxide and sodium silicate solutions mixed together polymerization will take place liberating large amount of heat, which indicates that the alkaline liquid must be used after 24 hours as binding agent.

GPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry on pan for about three minutes. The liquid component of the mixture is then added to the dry materials and the mixing continued usually for another four minutes [Fig. 1 and 2]. The addition of sodium silicate is to enhance the process of geopolymerization [7]. For the present study, concentration of NaOH solution is taken as 8M with varying ratio of Na_2SiO_3 / NaOH as 2, 2.5, 3 and 3.5 for all the grades of GPC mixes.

The workability of the fresh concrete was measured by means of conventional slump test (Fig. 3). In order to improve the workability, superplasticizer Conplast SP-430 with a dosage of 1.5% by mass of the fly ash was added to the mixture. Extra water (other than the water used for the preparation of alkaline solutions) and dosage of super plasticizer was added to the mix according to the mix design details. The fly ash and alkaline activator were mixed together in the mixer until homogeneous pate was obtained. This mixing process can be handled within 5 minutes for each mixture with different ratios of alkaline solution. Heat curing of GPC is generally recommended, both curing time and curing temperature influence the compressive strength of GPC [7]. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded specimens were kept at 60°C for 24 hours in an oven. The demoulded procedure is similar to that of routine conventional concrete.

Fig. 1: Mixing of alkaline solution

Fig. 2: Mixing of GPC

Fig.3.Slump cone test

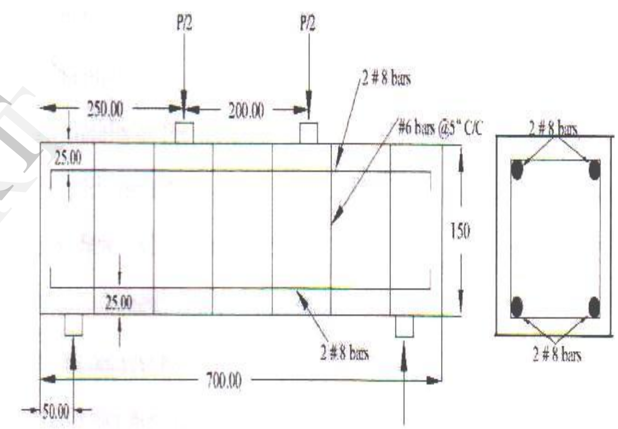

Fig.4. Reinforced flexural beam details

Table 2: Geopolymer concrete mix design details

Materials (kg/m^3)										
Grade	Coarse aggregates (mm)			Fine sand	Fly ash	Na_2SiO_3/ NaOH	NaOH solution	Na_2SiO_3 solution	Super Plasticizer	Extra water
	20	14	7							
M-50	277.20	369.60	646.80	554.40	380.69	2.00	47.70	95.41	6.13	40.88
						2.50	40.89	102.22	6.13	40.88
						3.00	35.78	107.33	6.13	40.88
						3.50	31.80	111.31	6.13	40.88

3. Finite Element Modelling using ANSYS

The experimental results of reinforced flexural geopolymer concrete beams were verified theoretically, using finite element software 'ANSYS'

Concrete: Solid 65 element was used to model the concrete material, since it has capability of both cracking in tension and crushing in compression. The solid element has eight nodes with three degrees of freedom at each node translations in the nodal x, y and z directions (Fig. 5).

Steel: the steel for the finite element models was assumed to be an elastic-perfectly plastic material and identical in tension and compression. . Link 8 elements were used to create the flexural and shear reinforcement. Two nodes are required for this element such that each node has three degrees of freedom, translations in the nodal x, y and z directions. The element is also capable of plastic deformation (Fig. 6) [10].

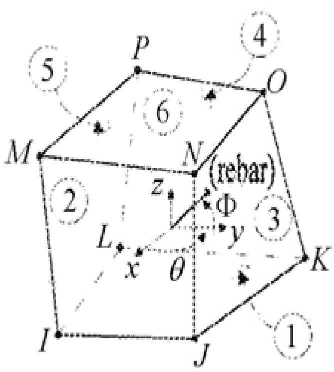

Fig. 5 Solid 65 element

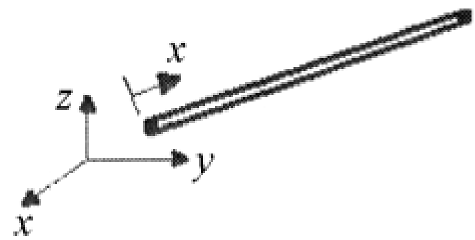

Fig. 6 Link 8 element

The modeled beam is shown in Fig. 7 and 8.

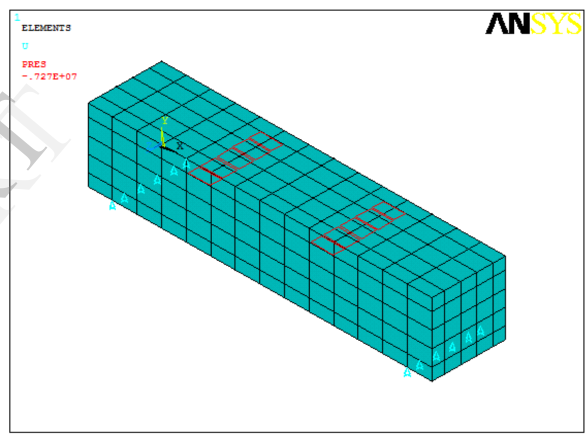

Fig. 7 Loading arrangement on beam

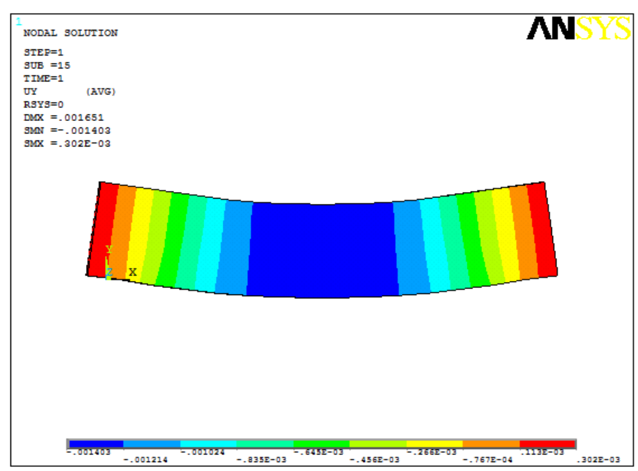

Fig. 8 Deflection of beam in ANSYS

4. RESULTS AND DISCUSSIONS

4.1 Flexural Strength

The IS:456-2000 [12] represents the relationship between the concrete flexural tensile strength (f_t) and the compresive strength (f_{ck}) by $f_t = 0.7(f_{ck})^{0.5}$. The ultimate flexural strength of M-50 grade geopolymer concrete with varying alkaline ratio is presented in Table 3 and Table . As the alkaline ratio increases the flexural strength increases, up to a certain extent, since the increment in ratio will lead to presence of water to geopolymer concrete, hence we can observe that there is reduction in strength. The flexural strength results of GPC were in par with the empirical relation of OPC. Hence we can conclude that the obtained results of GPC are in good agreement with the expression suggested by Indian Standards for OPC.

4.2 Deflection

The experimental and analytical results are presented in Table 3. The results obtained from ANSYS are inpar with the experimental results throughout the entire range of behavior and failure mode. The bond between the concrete and steel reinforcing is assumed to be perfect in the finite element analysis, but for the actual beams the assumption would not be true, slip generally occurs.

Table3.Comparison of ultimate load values

Grade	Molarity	Ratio of Alkaline soluton	Ultimate load		
			Experimental	ANSYS	% variation
M50	8	2.00	90.25	99.50	10.25
		2.50	119	128	7.56
		3.00	116	124	6.90
		3.50	112	120	7.14

Table4.Comparison of deflection values

Grade	Molarity	Ratio of Alkaline soluton	Ultimate load		
			Experimental	ANSYS	% variation
M50	8	2.00	1.50	1.36	10.30
		2.50	2.05	1.90	7.90
		3.00	1.80	1.65	9.10
		3.50	1.85	1.71	8.19

5. CONCLUSIONS

Based on the experimental investigations done the following conclusions can be drawn:

- The fly ash can be used to produce geopolymeric binder phase which can bind the aggregate systems consisting of sand and coarse aggregate to form geopolymer concrete (GPC). Therefore these concretes can be considered as eco-friendly materials.
- The study showed that the strength of geopolymer concrete can be improved by decreasing the water/binding and aggregate/binding ratios. It was observed that water influences the geopolymerization process and the hardening of concrete. Inclusion of increased binder content enhances the geopolymerization and affects the final strength.
- The optimum dosage for alkaline solution can be considered as 2.5, because for this ratio, the GPC specimens produced maximum strength results.
- The finite element model is able to simulate the nonlinear behaviour of beams. The load-deflection behaviour observed from experimental and predicted by ANSYS are in good agreement.
- The Ultimate loads obtained from ANSYS are higher than ultimate load values obtained experimentally. And deflections for ultimate loads from ANSYS are lesser than deflections obtained from experiments. This is because we assume beam to be stiffer and the bond between concrete and rebars to be perfect in ANSYS , but in practice it is not true, generally slip occurs.

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