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Experimental Investigation and Structural Behavior of Geopolymer Concrete

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Abstract: ***Concrete is the world's most versatile, durable and reliable construction material. Next to water, concrete is the most used material, which required large quantities of Portland cement. Ordinary Portland cement production is the second only to the automobile as the major generator of carbon dioxide, which polluted the atmosphere. This paper presents the results of a study on fly ash-based geo polymer concrete. The test parameters covered certain aspects of manufacture of geo polymer concrete. The paper also reports the effect of chemicals on Geo polymer concrete. The chemicals used include Hydrochloric acid(HCL), Sulphuric acid(H2SO4), Sodium sulphate(Na2SO4), Magnesium sulphate(MgSO4), Sodium chloride(NaCl). Total 72 cubes are casted for the experiment. Out of them 12 are used for Air and water curing for 14 and 28 days. Remaining 60 are used for 14 and 28 days tests of geo polymer concrete under the effect different chemicals.***

Keywords: Geopolymer, Portland cement, sodium hydroxide, curing, deflection

1. Introduction

In the context of increased awareness regarding the ill-effects of the over exploitation of natural resources, eco-friendly technologies are to be developed for effective management of these resources. Construction industry is one of the major users of the natural resources like cement, sand, rocks, clays and soils. The ever increasing unit costs of the usual ingredients of concrete have forced the construction engineer to think of ways and means of reducing the unit cost of its production. At the same time, increased industrial activity in the core sectors like energy, steel and transportation has been responsible for the production of large amounts like fly ash, blast furnace slag, silica fume and quarry dust with consequent disposal problem.

Therefore to preserve the global environment from the impact of cement production, it is now believed that new binders are indispensable to replace Portland cement (PC). In this regard, the Geopolymer concrete (GPC) is one of the revolutionary developments related to novel materials resulting in low-cost and environmentally friendly material as alternative to PC [1].

2. Literature Review

Abhilash P et al. [1] has done a study on effect of fly ash (FA) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer concrete (GPC) when they were replaced for cement at different replacement levels (FA50- GGBS50,FA75-GGBS25, FA100-GGBS0) using sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions as alkaline activators. Specimens were casted and cured for different curing periods like 7, 14, 28, 56 and 112 days at ambient room temperature to determine the mechanical properties of geopolymer concrete. Test results shows that as the percentage of GGBS in the mix is increasing, mechanical properties such as compressive strength, split tensile strength and flexural strength were increasing.

Paras S. Pithadiya et al. [2] has done a research whose objective of the work was to study the effect of GGBS in fly ash based geopolymer concrete and to study the effect of oven curing and ambient room temperature curing on them. And by replacing fly ash from 0 to 100% with GGBS and inspecting the fresh properties and hardened concrete properties at 7 days. The casted cube will be cured at normal room temperature and at 700C Oven heat provision for 24 hours and to ascertain the behavior of concrete mixed with GGBS, thereby examining the changes of properties like strength and durability.

Vignesh P and Vivek K [3] has done an attempt to study strength properties of geopolymer concrete using low calcium fly ash replacing with slag in five different percentages. Sodium silicate (103 kg/m^3) and sodium hydroxide of 8M (41 kg/m^3) solutions were used as alkaline solution in all 5 different mixes. The investigations are to be carried for the compressive strength, split tensile strength, flexural strength test on the concrete specimens. Hopefully one day in the near future geopolymer concrete will replace ordinary Portland cement as the most abundant man-made material on earth.

Vaibhav A. Kalmegh et al. [4] has presented a paper that reviews geopolymer concrete, it"s constituent, environmental benefits and strength also finding some solution to reduce the use of cement by replacing a percentage of it by fly ash

Sonal P. Thakkar et al. [5] has presented a paper that discussed various combinations of ground granulated blast furnace slag (GGBFS) and fly ash, as source material, to produce geopolymer concrete at ambient temperature. It has been generally accepted that heat treatment is required for producing geopolymer concrete which is considered a drawback affecting its applications. In this paper variation of source material i.e. Various combination of fly ash and GGBFS is done to achieve compressive strength for medium grade of concrete of M-25. Oven and ambient curing is done. It is found that geopolymer concrete with

GGBFS in fly ash as increases it gains strength and shows good strength at 3, 7 and 28 days even at ambient curing with increase in GGBFS content. While only slag based geopolymer concrete has higher strength at oven curing while rate of gain of strength is slower at ambient temperature as period increases.

3. Methodology

3.1 General

Concrete is the most abundant construction material and Portland cement, a major component of concrete, is the largest volume of construction material produced in the world. Ordinary Portland cement (OPC) is used as the primary binder to produce the concrete.

3.2 Concrete

Concrete is the product of mixing, aggregate, cement and water. The setting of concrete is a chemical reaction between the cement and the water, not a drying process. This reaction is called hydration, it evolves heat as does any chemical reaction, and the process is irreversible.

3.3 Cement

Cement is a mixture of limestone, clay, silica and gypsum. It is a fine powder which when mixed with water sets to a hard mass as a result of hydration of the constituent compounds. It is the most commonly used construction material.

3.4 Geopolymerization

Geopolymer are similar to zeolites in chemical composition, but they reveal an amorphous microstructure. They form by the co-polymerization of individual alumino and silicate species, which originate from the dissolution of silicon and aluminum containing source materials at a high pH in the presence of soluble alkali metal silicates. It has been shown before that geopolymerization can transform a wide range of waste alumino-silicate materials into building and mining materials with excellent chemical and physical properties, such as fire and acid resistance. The geopolymerization of 15 natural Al–Si minerals has been investigated in this paper with the aim to determine the effect of mineral properties on the compressive strength of the synthesized geopolymer.

3.5 Aggregates

Aggregates are usually distinguished between fine and coarse aggregate. Aggregates are classed as inert materials, such as washed natural sand (fine); and natural gravel, which can be crushed to produce the appropriate size and grading of aggregate, and similarly crushed, quarried stone (coarse).

3.6 Admixtures

Admixtures are the materials other than water, aggregates, or cement that is used as an ingredient of concrete or mortar to control setting and early hardening, workability, or to provide additional cementing properties.

3.7 Fly ash

Fly ash is the waste obtained as a residue from burning of coal in furnaces and locomotives. It is obtained in the form of powder. It is a good pozzalona the color of fly ash is either grey or blackish grey. Fly ash is one of the most abundant materials on the earth.

3.8 Ground granulated blast furnace (GGBS)

GGBS is obtained as a by-product of iron and steel in blast furnace to produce a glassy, granular product that is then dried and ground into a fine powder. These blast furnaces operate at a temperature of about 1,500 degrees centigrade and are fed with a carefully controlled mixture of iron-ore, coke and limestone.

3.9 Parameters that effects geopolymerization

3.9.1 Fineness of fly ash

The fineness of fly ash gives a major impact on the strength of the geopolymer concrete where it is seen that a processed fly ash with fineness of 542 m^2/kg shows a result of 80 MPa with 24 hrs continuous curing at 90ºC. With a lower fineness the strength decreases.

3.9.2 Temperature imposed to activator

Generally in the process of geopolymer concrete the polymerization takes place when the elevated temperature is applied to the mix after a rest period of 3 hrs to 2days but if we provide temperature to the alkaline solution prior to casting of concrete, a satisfactory result is obtained but with a particular temperature only. With a temperature of 45ºC produced a maximum compressive strength of 47MPa.

3.9.3 Molarity

Molarity of NaOH solution plays a vital role in the strength of geopolymer concrete. With a higher concentration of NaOH solution a higher compressive strength can be achieved.

3.9.4 Curing

Curing temperature is an important factor till now for the strength point of view of geopolymer concrete. The main polymerization process or the chemical reaction of geopolymer concrete takes place with the temperature imposed to it during the curing. It may attain almost its 70% strength with in the first 3 to 4 hours of hot curing. Longer curing time enhanced the polymerization process and results in a higher compressive strength.

3.9.5 Fly ash and alkaline activator ratio

Previous studies stated that the higher fly ash content with a higher alkaline activator content gives a high compressive strength than the lower one. A ratio of 3.3 to 4.0 can be used to obtain a better result.

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3.9.6 Water to geopolymer solid ratio

In this parameter the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of the water use in the making of the sodium hydroxide solution and the mass of extra water, if any, present in the mixture.

3.9.7 Sodium silicate to sodium hydroxide ratio

Earlier researchers concluded that a ratio of 1.0 of Na_2SiO_3 & NaOH gives a compressive strength up to 70 MPa. One paper concluded that a ratio of 2.5 gives a higher compressive strength than the 0.4. Sathonawaphak et al. further stated that geopolymer with a ratio of 1.5 gives the optimum result which was 48MPa. A ratio of 2.5 gives a result of 71 MPa. Based on all the considerations studied and mentioned above, the concrete is prepared accordingly and concrete cubes are being casted and tested. From the results of these tests a particular grade of concrete is chosen for the beam. These casted beams are cured and tested for their flexural behavior.

3.9.8 Flexural test on beam

The basic design criterion for any type of structure is safety, serviceability and economy. Due to these basic esteem properties of reinforced cement concrete (RCC) elements, they are abundantly used in all structural applications. For the structural use of RCC elements it must obey the following parameters. The structure must be safe and economical that it can perfectly resist both tension and compressive stress. The structure must be stiff and appear to be unblemished such that it should be resisted the bending moments and shear forces due to external applied loads. The structure must be economical by means of it can be able to resist all type of stress and availability of materials to make RCC.

4. Experimental Programme

4.1 General

The experimental programme was designed to study and determine the flexural response of the RGPC beams i.e., deflection, crack pattern and ultimate load, both experimentally and analytically. Both the results are compared to conclude the extent of replacing the GPC with the conventional concrete and also to design and analyze any structure using a finite element model (FEM). A comparative analysis is also carried out considering an experiment done on the conventional concrete beams with that of the RGPC experimental and numerical (ANSYS) results. The materials to be used are explained. For the present study concentration of NaOH solution is taken as 8M and the ratio of sodium silicate solution to sodium hydroxide solution (by mass) was 2.5 for these mixes. The details of the test conducted and specimens used in the study are as mentioned in the Table 4.1.

Table 4.1: Details of specimen and test conducted

Type of test	Size of the specimen	No. of specimens cast for different reinforced cond.
Flexural strength	1500 x 230 x 150 mm	6

Table 4.2: Details of mixture

Type of mix	Identification	Ingridient of concrete mix
Geopolymer Concrete	**GPC**	Fly ash, GGBS, Coarse aggregate, Fine aggregate, Alkaline solution, Super-plasticizer, water.

4.2 Materials

4.2.1 Flyash

Fly ash is the small particles collected by de-dusting systems of coal burning power plants. For the present study fly ash used was confirming to ASTM class F (shown in Figure 4.1). The physical and chemical properties of the fly ash are given in Table 4.3.

Table 4.3: Physical and chemical properties of fly ash

Properties	Experimental values	IS:3812-2003
Specefic gravity	2.08	-
Bulk density, g/cc	1.16	-
Fineness, m^2/kg	290	-
Color	Cream white	-
Oxide composition (% by mass)		
Silica (SiO_2)	52.0	SiO_2 + Al_2O_3 + Fe_2O_3 =70 min
Iron oxide(Fe_2O_3)	4.0	
Aluminum oxide(Al_2O_3)	33.9	
Calcium oxide(CaO)	1.2	-
Magnesium oxide(MgO)	0.81	5max
Titanium oxide(TiO_2)	0.27	-
Potassium oxide(K_2O)	0.83	-
Sulphur oxide(SO_3)	0.55	-
Alkali oxide	0.40	1.5max
Loss of ignition(LOI)	1.45	12max

4.2.2 Ground granulated blast furnace

GGBS is the by-product of the manufacture of the iron. It is very fine powder as shown in Figure 4.2. Molten slag, a secondary product of sintering of the raw materials which when quenched under high pressure water jets, granulates. For the present investigation GGBS was obtained from JSW steel plant, Bellary, Karnataka. The physical and chemical properties of GGBS are given in Table 4.3.

Table 4.4: Physical and chemical properties of GGBS

Properties	Experimental values	Values as per IS:12089-1987
Specific gravity	2.88	-
Bulk density, g/cc	1230	-
Fineness, m^2/kg	375	275min
Soundness Le-chatelier expansion (mm)	1.6	10max
Setting time (mintues) a. Initial b. Final	 170 308	 Not less than OPC
Compressive strength (MPa)	27.0 44.5	12min 32.5min
Oxide composition (% by mass)		

Silica(SiO_2)	35	70min
Iron oxide(Fe_2O_3)	1.3	
Aliminium oxide(Al_2O_3)	10	
Calcium oxide(Cao)	40.3	45
Magnesium oxide (Mgo)	8	17.0max
Sulphide sulphur	2.93	2max
Phosphorous	0.6	-
Alkali oxide	0.15	1.5max
Loss of ignition(LOI)	1.80	12max

4.2.3 Aggregates

Aggregates play a vital role in the properties of both fresh and hardened OPC and GPC, since aggregates (both fine and coarse) occupy about 70% of the total concrete value. Crushed basalt stone chips were used in the present investigation. The maximum size of the aggregate used was 20 mm.

Coarse aggregate

Crushed granite stones of size 20 mm and 10 mm were used as coarse aggregate.

Table 4.5: Details of Coarse aggregate

Specefic gravity	2.6
Fineness modulus	6.9
Water absorption	0.5%
Bulk density	1366.27 kg/m^3

Fine aggregate

Natural river sand was used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the sand are tested as per IS 2386 (Part III, 1963) [36].

Table 4.6: Details of Fine aggregate

Specefic gravity	2.5
Fineness modulus	2.12
Water absorption	0.5%
Silt content	3%

4.2.4 Sodium hydroxide

The sodium hydroxides are available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. The geopolymer concrete is homogenous material and its main process is to activate sodium silicate, so it is recommended to use sodium hydroxide with marginally lower cost. Its properties are as given in the Table 4.7.

Table 4.7: Properties of Sodium hydroxide solution

Appearance	Solution
Color	White colorless
Specific gravity	1.16

4.2.5 Sodium silicate

Generally sodium silicate is known as water glass or liquid glass, available in liquid (gel) form. It is used as raw material in detergents, pulp and paper, ceramic industry and manufacture of titanium-di-oxide. The weight ratio of SiO_2 to Na_2O is 2.5.

Table 4.8: Properties of sodium silicate

Chemical formula	$Na_2O.2SiO_2$
Na_2O	14.70%
SiO_2	29.40%
Water	55.90%
Appearance	Liquid (gel)
Color	Liquid yellow liquid
Specific gravity	1.57

4.2.5 Super plasticizer

In order to improve the workability of fresh concrete, high-range water-reducing naphthalene based super plasticizer purchased from FOSROC, was added to the mixture. It is Conplast SP 430 which is brown in color. The details are been presented in Table 4.9.

Table 4.9 : Properties of super plasticizers

Appearance	Brown liquid
Specific gravity	Typically 1.20 at 20°C
Chloride content	Nil to BS 5075
Air entrainment	Typically less than 2% additional air is entrained at normal dosages
Alkali content	Typically less than 72.0 g. Na_2O equivalent/litre of admixture. A fact sheet on this subject is available.

4.3 Mix design of geopolymer concrete

A mix design for M30 grade concrete is to be prepared for this study. In the design of the geopolymer concrete mix, coarse and fine aggregate is taken as 70% of entire mixture of mass. Fine aggregate is taken as 40% of the total aggregates. The remaining proportion of the entire mixture other than aggregates is of the binding materials fly ash and GGBS, where fly ash is of 80% and GGBS is 20% of the 34% (of entire mass of the mixture). The density of the geopolymer concrete is taken as 2400 kg/m^3 similar to that of OPC. The details of the mix design and its proportions for a single beam are detailed in the Table 4.11. Complete mix design details are given in the Annexure.

Table 4.10: Mix proportions of GPC for a single beam

Alkaline liquid ratio	0.5
Na_2SiO_3 (kg/mm^3)	10.1765
NaOH(kg/mm^3)	1.071
Water for NAOH(kg/mm^3)	3.035
Flyash(kg/mm^3)	22.855
GGBS(kg/mm^3)	5.713
Fine aggregate(kg/mm^3)	39.9925
Corse aggregate(kg/mm^3)	59.9985

4.4 Preparation of Alkaline solution

Alkaline solution places an important role in geopolymer synthesis for the dissolution of silica and alumina as well as for the catalysis of polymerization reaction. In this study, a combination of sodium hydroxide and sodium silicate was chosen as the alkaline liquid since sodium based solutions were cheaper than potassium based solutions.

4.5 Preparation, Casting and Curing Of Geopolymer Concrete

In the laboratory, the fly ash, GGBS and the aggregates were first mixed together dry on pan mixer for about three minutes. The liquid component of the mixer is than added to the dry materials and the mixing continued usually for another four minutes. Since the alkalinities of alkaline solutions used are very in geopolymer work and hence should be handled carefully, so for the safety purpose hand gloves were used during preparation and mixing of GPC. GPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In order to improve the workability, super plasticizer Conplast SP - 430 with a dosage of 2% by the total mass of fly ash and GGBS of a particular grade and then it was added to the mixture. The fly ash, GGBS and alkaline activator were mixed together in the mixture until homogenous paste was obtained. The fresh concrete has a stiff consistency and was glossy in appearance. The workability of the fresh concrete was measured by means of conventional slump cone test.

4.6 Testing Of Beams

A steel frame with inner dimensions of 600 mm x 180 mm x 340 mm (l x b x h) are arranged at the top and bottom to fix the dial gauges was used for measuring strains in compression and tension zone. Three dial gauges are fixed at the bottom section of the beam to record the strains in deflection. The beams are tested on the universal testing machine (UTM) of capacity 2000 KN under two point loading at middle third points of the span. The whole setup is placed on the UTM of 2000 ton capacity and the readings in the dial gauges are to be recorded for the incremental load of 0.5 ton initially up to the ultimate crushing load. Dial gauges at the top indicates the strain in compression and the dial gauges at the bottom indicates the strain in the tension. Beams are tested for ultimate load of cracking and ultimate load of crushing. The recorded dial gauge readings are used to plot load vs deflection for analysis.

5. Analytical Model of Beam Using Ansys

Usage of software for the analysis of the structure makes the work easier and also improves the extent of work that can not to carried out practically all times. The present study uses modeling and analysis of beam structure carried out by ANSYS software. This software is a finite element analysis that can be carried out on any kind of structure.

5.1 Geometry and Modelling

The finite element analysis (FEA) included modeling of geopolymer composite reinforced concrete beams with the dimensions and properties corresponding to beams tested experimentally in the laboratory. The dimension of the full-size beam is 1500 mm x 230 mm x 150 mm. By taking the advantage of the symmetry of the beam and loading, one quarter of the full beam was used for finite element modeling. This approach reduces computational time and computer disk space requirements significantly. Beam modeling is done using Solid65 for the concrete material providing modulus of elasticity and poission‟s ratios as the properties of the concrete. Similarly the reinforcement bars are given with respective properties and is incorporated with the solid using Beam188.

5.2 Real constants

Real constants are the indications of the specific elements that are to be defined in the modeling of the beam. Real constant set 1 is used for the Solid65 element.

5.3 Material properties

Material model number 1 refers to the Solid65 element which is the concrete. The element requires linear isotropic and multi linear-isotropic material properties to model them. In the modeling carried out for thus study, the inputs for the material properties of the concrete and the steel are the modulus of elasticity, Poisson’s ratio, stress-strain relationship of concrete. The modulus of elasticity of the geopolymer concrete was found experimentally as 2.4 MPa and the Poisson’s ratio of concrete was assumed as 0.20 for all the models.

5.4 Meshing

To obtain the satisfactory results from the solid 65 element a Hex-mapped meshing was chosen. Firstly the line division is done based on the required nodal criteria. Later volume meshing is created. The reinforcement in the model uses beam 188 elements that are connected to the nodes of the concrete mesh. Hence the concrete and the reinforcement share the same nodes.

5.5 Boundary conditions

The displacement boundary conditions are needed to constrain the model to a proper and unique solution. To ensure that the model acts same as that of the experimental beam structure the loading conditions and the boundary conditions of the beam in the ANSYS is applied same as that of the experiment. The symmetry boundary conditions are set first. Since it is the simply supported beam, the constraints for the boundary conditions are given at one support as UX, UY and other support as UY. The boundary conditions and the loading condition of the beam in the ANSYS are as shown in the Figure 5.3. The beams in the ANSYS are also analyzed for the crack pattern, ultimate load and deflection. The crack pattern in the software is analyzed considering the stress-strain parameters of the beam.

6. Tests and Results

6.1 General

During the experimental program, all the observations have been carefully recorded in a tabular form. While certain test results are presented in the tables certain other results are presented in the graphical form for better understanding.

The present chapter contains all the test results in various formats mentioned above. Based on the experimental and analytical test results the deflection and cracking pattern of the reinforced geopolymer concrete beams are discussed.

6.2 Physical properties

It is essential for any study to evaluate the basic properties of the material proposed to be used**.** Hence in the present investigation properties of all the ingredients are carried out. The specific gravity and fineness modulus of Cement, Fine aggregate and coarse aggregate was done. The results of the properties are tabulated in the experimental programme chapter.

6.3 Properties of fresh concrete

6.3.1 Workability

The workability of the freshly mixed concrete are measured using slump test and compaction factor test. The mix design of the concrete selected for the present study is M30 grade concrete. All the beams are casted with same grade of concrete but different percentages of steel. The slump value of the freshly mixed concrete was recorded as shown in the Table 6.1. The values of the slump and compaction factor differ considering the mixing and climatic conditions.

Table 6.1: Workability of concrete (Slump and compaction factor)

GPC Mix grade	Day of casting	Slump (mm)	Compaction Factor
M30	1	85	0.984
M30	2	75	0.944
M30	3	70	0.89

6.4 Beam testing

6.4.1 Flexural test setup

The beam specimens were 150 mm wide and 230 mm deep in the cross section. They were 1500 mm in length and simply supported over an effective span of 1200 mm. The clear cover of beam was 20 mm. The beams designed for different percentages of steel. The percentages of tensile steel are tabulated below. The test specimen was mounted in a loading frame of 2000 KN capacity. The load was applied on two points of 400 mm away from center of the beam towards the support. The beams were cleaned and white washed with a thin coat of white surface to facilitate the detection of cracks and the propagation of cracks. Dial gauges are used having a magnetic base. The least count of dial gauge was 0.01 mm. The points at which dial gauges to be fixed were cleaned.

6.4.2 Behavior of beam

The beam specimens used in this investigation were tested under two point static loading until failure. The most common thing observed was as the load on the beam increased, it started to deflect and flexural cracks developed along the span. The entire beam specimen failed in the same fashion due to yielding of the tensile steel (primary tension failure) followed by crushing of concrete at the compression face (secondary compression failure). During the testing of beams the events that occurred are first cracking, yielding of the tensile reinforcement, crushing of concrete at the compression face and spalling of concrete cover.

6.4.3 Failure modes and crackpatterns

Concrete has a high compressive strength but its tensile strength is comparatively very low. Hence, small tensile stresses can easily cause cracks. Cracking is considered to be one of the most important limit states of serviceability. Since, the beams are tested with two point loading, the cracks initiated with pure bending zone. This observation was true with under-reinforced as well as balanced sections of the beams. The type of crack developed was due to bending.

6.5 Crack Patterns

After failure, all beams showed typical structural behavior in flexural, no horizontal cracks were observed at the level of reinforcement, which indicated that were no occurrences of bond failure. The flexural cracks initiated in the pure bending zone as expected. As the load increased existing cracks propagated and new cracks developed along the span. The flexural cracks gave way to inclined cracks due to effect of shear force. These inclined cracks were prominent in case of beam specimens with higher percentages of tensile reinforcements. The spacing of cracks varied along the span. The crack patterns observed for GPC beams were found to be similar to the OPC beams. All beams failed in flexure in a ductile manner accompanied by crushing of the concrete in the compression zone. As the load carrying capacity of the beam increased with higher percentage reinforcement the cracks observed had inclination of 30° to 40°.

Figure 6.1: Deflected beam and crack patterns

6.6 Experimental Load vs Deflection Curves

Deflection is also discussed as one of the important serviceability limit states and it is to be satisfied in the design of structures. The IS: 456 - 2000 recommends a ratio of L/d $\leq$ 20, which is sufficient to restrict the deflections to an in case of simply supported beam. The load-deflection curves for the beams of different percentages in steel are as shown in the Figures 6.2 through 6.9.

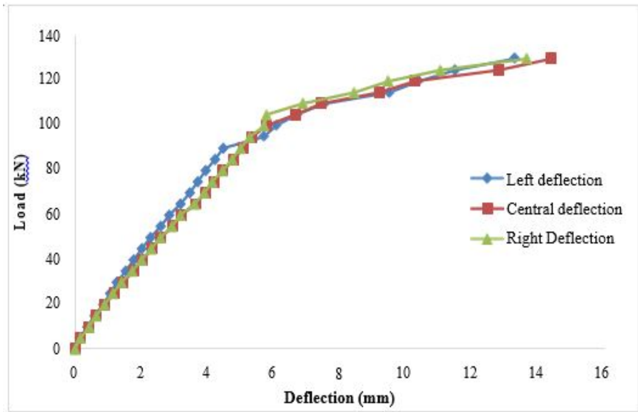

Figure 6.4: Load vs deflection of UR – 1

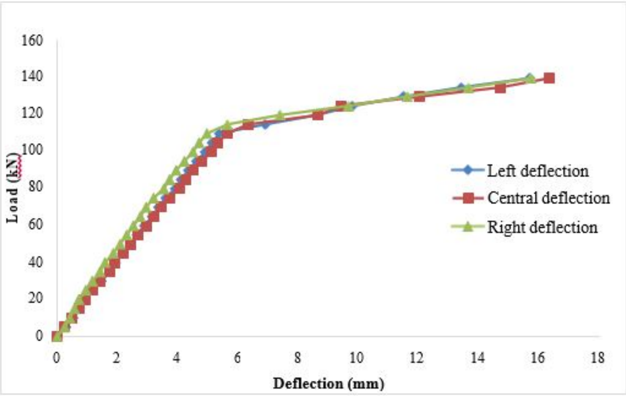

Figure 6.5: Load vs deflection of UR - 2

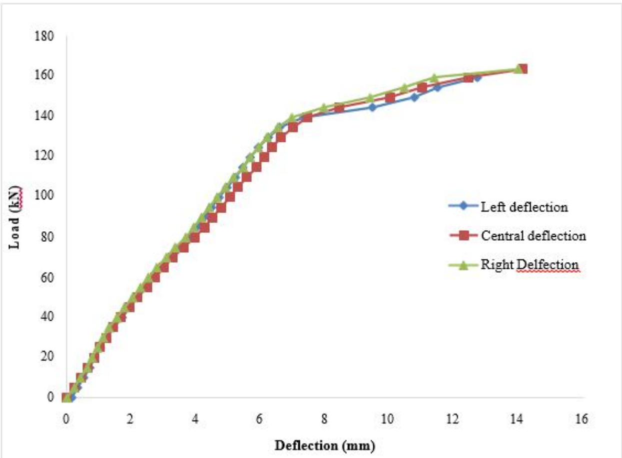

Figure 6.6: Load vs deflection of BR - 1

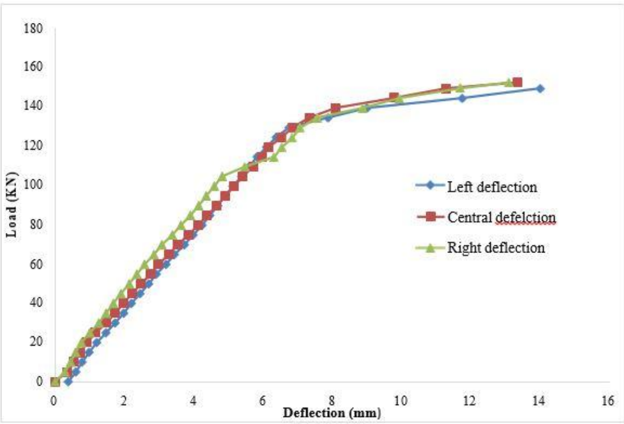

Figure 6.7: Load vs deflection of BR – 2

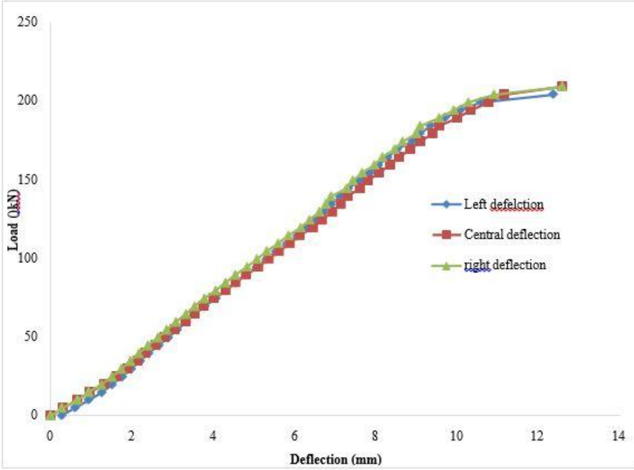

Figure 6.8: Load vs deflection of OR – 1

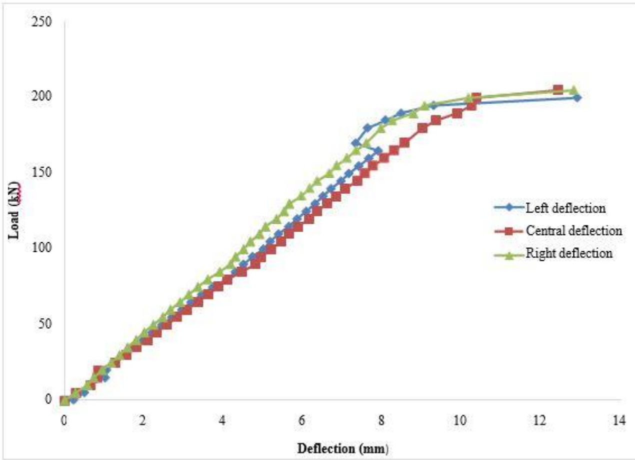

Figure 6.9: Load vs deflection of OR - 2

6.7 Analytical Results of Rgpc Beams

In analysis, the total load applied to the finite element model is divided into a series of load increments called load steps. The static loading condition has been applied to the beam in the present analytical study. After the completion of each incremental loading condition the solution is recorded. Giving the number to load steps and the time to complete the increment, ANSYS carries out the analysis of the beam based on the inputs and gives the solution in terms of longitudinal displacements of the beam at certain load and also the crack pattern if any under the provided set of incremental loads.

6.8 Comparision of Experimental and Analytical Results

Based on all the experiment and analysis carried out throughout this paper, the comparative results of the OPC beam, GPC beam and ANSYS model of GPC beam are as shown in the Table 6.8 and graph (Figure 6.18). The graph explains the comparative result of the load-deflection of the balanced reinforced beam under similar load conditions.

Table 6.2: Comparison of experimental and analytical results of balanced-section

GPC	First crack		Second crack		Third crack		Ultimate load	
	Load (kN)	Def. (mm)	Load (kN)	Def. (mm)	Load (kN)	Def. (mm)	Load (kN)	Def. (mm)
Experimental	44.85	1.93	64.78	3.0	109.63	5.57	164	14.12
Analytical	24.9	1.07	49.83	2.3	74.75	3.716	163.4	14.11

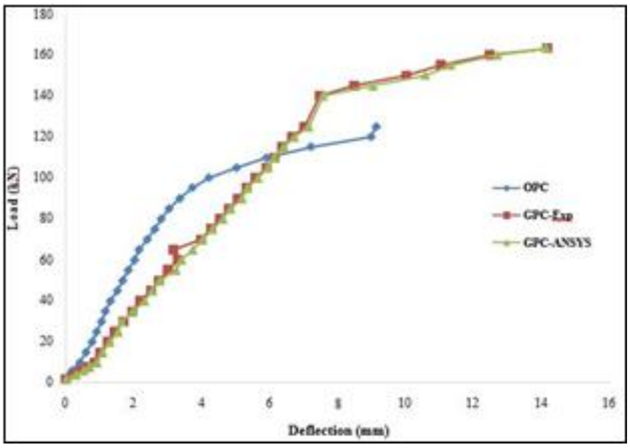

Figure 6.10: Comparative load vs deflection curve

7. Conclusion

In this chapter conclusions and scope for future are been projected from the entire investigation carried out. These conclusions include all the results comprising both analytical and experimental. The analytical model is done using ANSYS 16.0 using relative experimental data.

7.1 Conclusions

Based on the experimental and analytical studies carried out in the present thesis taking M30 grade concrete and Fe500 grade steel, following conclusions can be drawn:

1) As there are no particular codes available for GPC mix design, it is assumed that the provisions made in the IS: 456-2000 will also hold good for the reinforced geopolymer concrete beams. And the geo-polymer concrete beams that are been designed with different percentages of steel behave similar to that of the ordinary Portland cement concrete reinforced beams.
2) At various stages of cracking except, at the final crack theoretical model under- estimates the loads by 44%, 30% and 27% for first, second and third crack conditions respectively over the experimental results.
3) At various stages of cracking except, at the final crack theoretical model under- estimates the deflections by 44.5%, 23% and 33% for first, second and third crack conditions respectively over the experimental results.
4) The theoretical model estimates the load at final crack within acceptable limit of -0.5%.
5) The failure patterns of the GPC beams both experimental and analytical are much similar and also produce 95% symmetrical deflections.
6) The Load-deflection curves of OPC and GPC beams are convergent.
7) Based on the comparative studies carried out between the OPC beams and GPC beams both analytical and experimental, they are 85% similar in load and deflection.

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