Analytical Study on Flexural Behaviour of Reinforced Geopolymer Concrete Beams by ANSYS

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Abstract. The present investigation embodies the flexural behavior of Reinforced Geopolymer Concrete (RGPC) beams with different percentages of GGBS and Metakaolin cured under ambient temperature with 10 molar NaOH. Twelve reinforced concrete beams of size 700 mm x 150 mm x 150 mm were tested. The beams were tested under two point bending system over an effective span of 700 mm. The behavior was studied with reference to ultimate load. The results were found to be similar to that of conventional cement concrete reinforced beams.

1. Introduction
The construction industry forms an important role of the Indian economy. Utilization of the industrial by-products in the construction industry becomes an important route for construction cost reduction and safe disposal of the industrial wastes [1].

In this regard, direct use of GGBS and flyash with alkali activation to produce geopolymer cements are used to manufacture special concretes for construction [2, 3]. The internal energy which is used for the manufacture geopolymer cements are very less than the Ordinary Portland cement based concrete (OPCs), which is directly effected on the greenhouse gases [3]. In some severe environmental conditions where OPCs are not so durable and the development of new and alternative concrete like geopolymer concrete is in need.

As we know that the production of cement gives more pollution to the environment and in the other hand depletion of natural resources is also happening. In the last 4 decades requirement and production of cement around the globe are increasing due to rapid growth in population. As the demand for electricity increases, the electricity produced from thermal power plants also increases. Simultaneously the waste i. e. Fly ash production increases, which may cause more disposal and environmental problems [4].

As the constructions increase the utilization of concrete increases in which Ordinary Portland Cement (OPC) is used as a primary binder. As a civil engineer we very much knew about the problems related to environmental issues in the production of cement. The amount of carbon dioxide releases into the atmosphere is equal to the production of cement and also it is well known that the energy required for the production of cement is high which consumes more fossil fuels [4,5]. When the cement is partially replaced in the presence of water and cured at ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process to form the C-S-H gel. The development and
application of high volume fly ash in concrete, which enabled the replacement of cement up to 60% by mass of concrete [4].

The extensive research works carried out for several years to corroborate the potential of geopolymer concrete as a potential construction material [2, 3, 6 - 10]. The development of alternative concretes like geopolymer concrete is of great relevance to India, where large quantities of industrial wastes are being generated by the industries [1].

The use of geopolymer concrete is slowly increasing, especially for chemical resistant structures in industries and research to extend the variety of applications. In fact, a considerable amount of experimental work has been already carried out in Australia, US and Spain. Several investigators have proposed suitable source materials for geopolymer concrete production, their processing, mix design, mechanical properties, and durability aspects [11 – 13].

The inorganic binder with alumina and silica containing materials in geopolymer concrete is more durable. But, like conventional reinforced concretes, the geopolymer concrete also needs to be reinforced with steel bars for structural engineering applications. Hence, the investigations on the behaviour of Reinforced geopolymer concrete were undertaken.

This paper considers reinforced geopolymer concrete beams with different percentages of GGBS and Metakaolin produced by ambient temperature curing. The geopolymer concrete beams based on ordinary portland cement were also prepared and tested for comparison. A total of eleven beams consisting of geopolymer concrete mixes and one ordinary portland cement mixes were tested. Performance aspects such as load carrying capacity and deflections at different stages were studied. The paper compares the performance of geopolymer concrete beams with ordinary portland cement Concrete beams.

2. Materials and Method
2.1 Materials
Ordinary Portland cement conforming to IS 12269, fine aggregates, coarse aggregates and potable water were used for the control OPC test specimens. The geopolymer concrete was obtained by mixing different combinations of GGBS, Metakaolin, fine aggregates, coarse aggregates and alkaline activator solution (AAS).

GGBS (ground granulated blast furnace slag) from JSW Cements conforming to IS 12089 were used. River sand available in Vijayawada was used as fine aggregates. They were tested as per IS 2386. In this investigation, locally available granite crushed stone aggregates of maximum size 10mm and down was used and characterization tests were carried out as per IS 2386.

The properties of the materials used are shown in Tables 1 to 6. Potable water was used for the OPC and distilled water was used for the geopolymer concretes. High strength deformed steel bars with 0.2% proof stress of 500 MPa and nominal diameters of 8mm, 10mm and 12mm were used as reinforcements in beams are shown in Table-7.

The alkaline activator solution (AAS) used in geopolymer concrete mixes was a combination of sodium silicate solution (SiO$_2$/Na$_2$O=2.5), 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 GGBS and provide a highly alkaline liquid medium for condensation polymerization reaction. The sodium hydroxide was taken in the form of flakes of approximately 2.5 mm in size. The sodium hydroxide (NaOH) solution with required concentration was prepared by dissolving the computed amount of sodium hydroxide flakes in distilled water.

The NaOH solution and sodium silicate solution were prepared separately and mixed together at the time of casting. Since a lot of heat is generated when sodium hydroxide flakes react with water, the sodium hydroxide solution was prepared 24 hours before casting. It should be noted here that it is essential to achieve the desired degree of workability of the geopolymer concrete, concrete mix amount of superplasticiser is added in geopolymer concrete and the properties are shown in Table-8. However, excess water can result in the formation of pore network, which could be the source of low strength and low durability.
Table 1. Physical properties of Metakaolin

| Parameter                  | Value       |
|----------------------------|-------------|
| Colour                     | Pink        |
| Pozzolan Reactivity mg Ca (OH)² / gm | 900         |
| Average Particle size      | 1.4 micron  |
| Brightness (ISO)           | 75 ± 2      |
| Bulk Density (Gms / Ltr)   | 320 to 370  |
| Specific Gravity           | 2.5         |

*Data taken from the product brochure of the supplier

Table 2. Chemical properties of Metakaolin

| Parameter        | Value       |
|------------------|-------------|
| Al₂O₃            | >39.0 %     |
| Fe₂O₃            | <0.8%       |

Table 3. Physical properties of GGBS

| Parameter                  | GGBS       | IS : 12089 – 1987 |
|----------------------------|------------|-------------------|
| CaO                        | 37.34%     | ---               |
| Al₂O₃                      | 14.42%     | ---               |
| Fe₂O₃                      | 1.11%      | ---               |
| SiO₂                       | 37.73%     | ---               |
| MgO                        | 8.71%      | Max. 17%          |
| MnO                        | 0.02%      | Max. 5.5%         |
| Sulphide Sulphur           | 0.39%      | Max. 2%           |
| Loss of Ignition           | 1.41%      | ---               |
| Insoluble Residue          | 1.59%      | Max. 5%           |
| Glass Content (%)          | 92%        | Min. 85%          |

*Data taken from the product brochure of the supplier

Table 4. Physical properties of coarse aggregate

| Sieve size (mm) | Requirement as per IS: 383-1970 | Percentage passing |
|-----------------|----------------------------------|--------------------|
| 12.50           | 100 %                            | 100 %              |
| 10.00           | 85 - 100 %                       | 94.62 %            |
| 4.75            | 0 - 20 %                         | 15.40 %            |
| 2.36            | 0 - 5 %                          | 2.89 %             |

Specific gravity: 2.74
Water Absorption %: 0.33
Aggregate Impact Value: 12.65
Bulk Density (kg/m³): 1660
Flakiness: 13%
Elongation: 12%
**Table 5.** Physical properties of fine aggregate

| I. S. Sieve (mm) | Percentage passing through I.S. Sieve |
|-----------------|-------------------------------------|
| 10              | 100                                 |
| 4.75            | 99.6                                |
| 2.36            | 99                                  |
| 1.18            | 92.6                                |
| 600 micron      | 48.6                                |
| 300 micron      | 8.2                                 |
| 150 micron      | 2                                   |

Zone II as per IS 383

Fineness modulus = 2.2
Specific Gravity = 2.50
Bulk Density = 1625 Kg/m³
Silt Content = 0.25%

**Table 6.** OPC 53 grade cement

| S. No. | Name of the test                        | Req. as per IS: 12269 - 1987 | Test results                  |
|--------|-----------------------------------------|------------------------------|-------------------------------|
| 1      | Standard Consistency                    | ---                          | 31%                           |
| 2      | Setting time of Cement in minutes       |                              |                               |
| 2      | Initial setting time                    | Not less than 30 min         | 105 minutes                   |
| 2      | Final Setting time                      | Not more than 10 hrs         | 255 minutes                   |
| 3      | Specific gravity                        | ----                         | 3.15                          |
| 4      | Soundness of Cement                     | Not more than 10 mm          | 2 mm                          |
| 5      | Fineness of Cement                      | Not more than 10 %           | 3 %                           |
| 6      | Compressive strength                    | 7 days                       | Not less than 27.0 N/mm²      | 29.74                        |
| 6      |                                          | 28 days                      | Not less than 37.0 N/mm²      | 39.55                        |
| 6      |                                          |                              | Not less than 53.0 N/mm²      | 57.42                        |

**Table 7.** Properties of steel

| S. No. | Diameter of the specimen (mm) | Area as per weight (mm²) | Weight of the specimen (Kg./m) | Yield stress (N/mm²) | Ultimate Stress (N/mm²) | Percentage elongation |
|--------|------------------------------|--------------------------|--------------------------------|----------------------|-------------------------|-----------------------|
| 1      | 8                            | 50.32                    | 0.396                          | 552.28               | 576.29                  | 25                    |
| 2      | 10                           | 73.64                    | 0.619                          | 595.36               | 698.90                  | 26                    |
| 3      | 12                           | 113.25                   | 0.887                          | 594.06               | 896.84                  | 24                    |

**Table 8.** Properties of GLENIUM B233* superplasticiser

| Property                        | Value                  |
|--------------------------------|------------------------|
| Specific gravity               | 1.09                   |
| Chloride ion content           | Less than 0.2%         |
| Recommended Dosage             | 0.5 to 1.5 liter per 100kg of cementsations material |
| pH                             | 7±/-1                  |
| Aspect                         | Yellowish free flowing liquid |

*Data taken from the product brochure of the supplier*
Table 9. Mix proportions of GEOPOLYMER CONCRETE

| Materials used | Cementitious materials | Fine aggregate | Coarse aggregate | Sodium hydroxide | Sodium silicate | Superplastiser |
|----------------|------------------------|----------------|-----------------|------------------|-----------------|----------------|
| Quantity of materials in kg/m³ | 414 | 660 | 1136 | 53 | 133 | 8.28 |

Table 10. Mix proportions of cement concrete

| Cement (Kg) | Water (Kg) | Crushed sand (Kg) | C.A (Kg) 10 mm | Mix proportion | W/C | Slump (mm) |
|-------------|------------|-------------------|----------------|----------------|-----|------------|
| 452         | 186        | 625               | 1090           | 1: 1.38 : 2.41 | 2.41| 55         |

Table 11. Combinations of GGBS and Metakaolin

| Mix ID | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 |
|--------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| Metkaolin (%) | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10  | 0   | 100% OPC |
| GGBS (%) | 0  | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90  | 100 |

2.2 Mix Proportions

Unlike Ordinary Portland cement concretes, geopolymer concretes are a new class of construction materials and therefore no standard mix design approaches are available for geopolymer concretes. While Rangan and Hardjito have presented certain guidelines for fly ash based geopolymer concretes, some of the trials carried out using these procedures indicated that the workability and strength characteristics of such mixes were not satisfactory. Such a thing is possible because geopolymer concrete involves more constituents in its binder (viz., GGBS, Metakaolin, sodium silicate, sodium hydroxide and water), whose interactions and final structure and chemical composition are strongly dependent on the source of the materials and their production process [1].

Therefore, the chemistry and microstructure of geopolymer concrete is more complex and is still a matter of research, whereas the chemistry of cement and its structure and chemical composition are well established due to extensive research carried out over more than a century. While the strength of cement concrete is known to be well related to its water cement ratio, such a simplistic formulation may not hold good for geopolymer concretes. Therefore, the formulation of the geopolymer concrete mixtures was done by trial and error basis. Numerous trial mixes were cast and tested for compressive strength at the end of 28 days. The primary objective of performing the trial and error procedure was to obtain a range of compressive strength at the end of 28 days. The proportions and composition of GPS and AAS were so decided that the test specimens cast were demoulded after 24 hours of in mould curing and the required strength could be realized. In order to compare the results of tests conducted using geopolymer concrete, additional conventional concrete mixes, prepared with OPC and designed as per IS 10262 - 2009 The details of the mix proportions are given in Tables 9 & 10. The combinations of the geopolymer concrete mixes are shown in Table-11.

2.3 Mix Design of Geopolymer Concrete

In the design of geopolymer concrete, coarse and fine aggregates together were taken as 75% of 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 30.8% of the total aggregates.
From the past literatures it is clear that the average density of Cementitious materials based geopolymer concrete is similar to that of OPC concrete (2400kg/m$^3$) [15]. Knowing the density of concrete, the combined mass of alkaline liquid and cementitious materials can be arrived. By assuming the ratios of alkaline liquid to cementations materials as 0.45, mass of metakaolin and mass of alkaline liquid was found out. To obtain mass of sodium hydroxide and sodium silicate solutions, the ratio of the sodium silicate solution to the sodium hydroxide solution was fixed as 2.5. Extra water (other than the water used for the preparation of alkaline solutions) used respectively to achieve workable concrete [16, 17]. Sodium hydroxide of 10 Molar concentration is used in the present study.

2.4 Strength characteristics of the mixes

Figure 1. Geometry of the beam specimen

The beam specimens were 150 mm wide and 150 mm deep in cross-section. They were 700 mm in length and simply supported over an effective span of 660 mm. The clear cover of the beam was 20 mm. The geometry of the beam specimen is shown in Figure 1.

High yield strength deformed steel bars of diameter 8 mm, 10 mm and 12 mm were used as the longitudinal reinforcement in the specimens. Two legged vertical stirrups of 8 mm diameter at a spacing of 120 mm centre to centre were provided as shear reinforcement a day before casting [1, 14].

2.5 Preparation of specimens

Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the hardening concrete. The concrete was placed in the moulds in three layers of equal thickness and each layer was vibrated until the concrete was thoroughly compacted. Along with beam casting, three numbers of 150 mm cubes were cast to determine the 28 day compressive strength. Specimens were demoulded after 24 hrs [1]. The OPC beams were water cured for a period of 28 days while the geopolymer concrete beams were cured in ambient condition, in the laboratory for a period up to 28 days after casting. After curing, the test specimens were tested for compressive strength and structural behaviour.

3. Modelling with ANSYS

For the evaluation of structures the procedure which is given by Neha et al. (2014) was followed to get an accurate prediction of various component response subjected to different loading conditions finite element analysis is used. To evaluate the response of the concrete, FEA is a numerical analysis method that divides the entire structural member into a number of small parts and then the loading conditions is applied. Because of advancement in engineering and computer knowledge the use of FEA technique is increasing day by day. At a set of nodal points the finite number of degrees of freedom characterized to find the response of each element of an unknown function. In the state of being real, all the problems are non linear. Hence, it is an effective tool to obtain exact solution for non linear analysis. To find the potential of high load carrying capacity of the components through redistribution, shear strength and tensile strength by taking the exact behavior of the material into consideration the method of non – linear analysis is used. The behavior of reinforced concrete beams is complex for non linear analysis is due to various parameters. Material non-linearity or geometry are the main causes for nonlinearity. Either one of them or both are the reasons in the structure to form nonlinearity. Non-
linear stress strain relationship of material discusses about material non-linearity and hence modulus of elasticity is not a distinctive value. The loading in deformable bodies and slender members such as columns are changed due to the geometry of the body. In such case, geometric nonlinearity is encountered. So many researchers are made attempts to predict the behavior of the members by using ANSYS. The mesh density, properties of concrete, tolerance values, etc. is the main values which will effect on the convergence and accuracy of the solution. The Finite Element Method translates partial differential equation problems into a set of linear algebraic equations.

3.1 Material Properties
In the ANSYS there is a liberty to change engineering data modules. The engineering data for the new material can be input or edited. Geopolymer Concrete and Fe 500 grade of steel is chosen for all the beam specimens. Material properties of geopolymer concrete and steel were given. In the longitudinal direction, 3 numbers of 12 mm diameter rods were used in the tension side and 2 numbers of 10 mm diameter rods were used in the compression side. 8 mm stirrups at 136 mm c/c were used in the transverse direction. The steel it is taken as an elastic-perfectly plastic material and identical for the finite element models in tension and compression. The ANSYS model of the beam specimens with reinforcement is shown in Figure 2.

![Figure 2. Modeling of the beam](image1)

![Figure 3. Reinforcement in the beam](image2)

![Figure 4. Meshing in the beam](image3)

3.2 Finite Element Discretization
A model in finite element analysis requires meshing. Mesh density is an important step in finite element modeling. An average number of elements are used in a model to obtain the results. This is practically achieved that the negligible effect on the result is formed due to the mesh density. The nodes in the concrete portion and the width and length of the element in the plates to be consistent
with the model are properly set. To make it as a single entity the numbering control commands are used to merge all the items. To get the accurate result very fine size of mesh is used. The meshed model of the beam specimen is shown in Figure 4.

4. Results and Discussions
The deflected shapes of the specimens analysed using ANSYS are shown in Figure 5. It is observed that specimens with 100% GGBS has the maximum deflection when compared with other specimens.

![Figure 5. Total Deformation of the RGPC beam](image)

The load-deflection relationships until failure are obtained and compared with the experimental results for RGPC are obtained from the analysis.

| Mix ID | $\Delta_{\text{Exp}}$ (mm) | $\Delta_{\text{Ansys}}$ (mm) | $\Delta_{\text{Exp}}/\Delta_{\text{Ansys}}$ |
|--------|-----------------|-----------------|-----------------|
| M1     | 1.91            | 1.65            | 1.16            |
| M2     | 2.12            | 1.85            | 1.15            |
| M3     | 2.36            | 2.08            | 1.13            |
| M4     | 2.48            | 2.2             | 1.13            |
| M5     | 2.57            | 2.36            | 1.09            |
| M6     | 2.89            | 2.63            | 1.10            |
| M7     | 3.00            | 2.85            | 1.05            |
| M8     | 3.09            | 2.98            | 1.04            |
| M9     | 3.24            | 3.15            | 1.03            |
| M10    | 3.35            | 3.25            | 1.03            |
| M11    | 3.47            | 3.38            | 1.03            |
| OPC    | 3.45            | 3.058           | 1.13            |

5. Conclusion
This study intended to investigate the possibilities of performing nonlinear finite element analysis of reinforced concrete structures using the ANSYS concrete model. The results obtained from finite element models developed by ANSYS software indicated similar deflections when compared with the experimental and analytical results of RGPC and OPC.

6. References
[1] Dattatreya J. K., Rajamane N. P., Sabitha D., Ambily P. S., Nataraja M. C. 2011. Flexural behaviour of reinforced Geopolymer concrete beams. *International Journal of Civil and Structural Engineering*. 2(1): 138-159.
[2] Davidovits J. 1991. Geopolymers: inorganic polymeric new materials. *Journal of Thermal Analysis*. 37: 1633-1656.
[3] Duxson P., Fernández Jiménez A, Provis J L, Lukey G C, Palomo A, Van Deventer. 2007. Geopolymer Technology, *The current state of the art. Journal of Material Science*. 42(9): 2917-2933.
[4] A. Sofi, B. R. Phanikumar. 2015. An experimental investigation on flexural behaviour of fibre-reinforced pond ash-modified concrete. *Ain Shams Engineering Journal*. 6: 1133-1142.
[5] Chun LB, Sung KJ, Sang KT, Chae ST. 2008. A study on the fundamental properties of concrete incorporating pond-ash in Korea. 3rd International conference on the sustainable concrete technology and structures sustainable concrete technology and structures in local climate and environmental conditions, Vietnam. pp. 401-408.

[6] Hardjito D. and Rangan B.V. 2005. Development and properties of low calcium fly ash based geopolymer concrete, Research report GC1, Curtin University of Technology, Perth, Australia.

[7] Bakharev T. 2005. Geopolymeric materials prepared using Class Fly ash and elevated temperature curing, Cement and Concrete Research, 35: 1224-1232.

[8] Palomo A., Grutzeck M.W., Blanco M.T. 1999. Alkali activated Fly Ashes: Cement for the Future, Cement and Concrete Research, 29: 1323-1329.

[9] Van Jaarsveld J.G.S., van Deventer J.S.J., Lukey G.C. 2002. The effect of composition and temperature on the properties of fly ash and kaolinite based geopolymers. Chemical Engineering Journal, 89(13): 63-73.

[10] Sofi D., Van Deventer J.S.J., Mendis P.A., Lukey G.C. 2006. Engineering properties of inorganic polymer concretes (IPCs), Cement and Concrete Research, 37: 251-257.

[11] Wallah S.E., Rangan B.V. 2006. Lowcalcium fly ash based geopolymer concrete: long term properties. Research report GC2, Curtin University of Technology, Perth, Australia.

[12] Bakharev T. 2005. Durability of geopolymer materials in sodium and magnesium sulfate solutions, Cement and Concrete Research, 35(6): 1233-1246.

[13] Bakharev T. 2005. Resistance of geopolymer materials to acid attack, Cement and Concrete Research, 35(4): 658-670.

[14] B. Sarath Chandra Kumar, K. Ramesh and P. Poluraju. 2017. An experimental investigation on flexural behavior of GGBS and metakaolin based geopolymer concrete, ARPN journal of engineering and applied sciences, 12 (7), 2052-2062.

[15] Gabriel Varga. The Structure of Kaolinite and Metakaolin. Epitoanyag, 2007, 59, 6-9.

[16] K. Vijai, R. Kumutha and B. G. Vishnuram, Experimental Investigations on Mechanical Properties of Geopolymer Concrete Composites, Asian Journal of Civil Engineering (Building and Housing), 2012, 13 (1), 89-96.

[17] Suresh G. Patil and Manojkumar, Factors Influencing Compressive Strength of Geopolymer Concrete, International Journal of Research in Engineering and Technology, 2013, 372-385.

Acknowledgements
The authors wish to gratefully acknowledge the support of KaoMin Industries regarding Metakaolin supply and JSW Cements for the supply of GGBS and also the help of the Head of the department and Structural engineering laboratory staff of Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A. P., India, is gratefully acknowledged.