Flexural behaviour of cement added geopolymer concrete

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Abstract: This work aims to improve the flexural behaviour of Geopolymer Concrete (GPC). GPC is an ecofriendly concrete in which Ordinary Portland Cement (OPC) is completely replaced by pozzolanic materials i.e. Fly Ash or GGBS or Rice Husk Ash and activated alkaline solutions like NaOH or K2O and Na2SiO3 to act as a binder in the concrete mix. GPC having its own advantages over the OPC concrete, like faster setting time, early age strength and also GPC is a good alternative material for OPC to control the emission of green house gases. But GPC required heat curing. This problem was overcome with partial replacement of fly ash by lime or GGBS or cement. In this study, 2 to 6% of fly ash was replaced by cement or GGBS in GPC. Among the above combination, partial replacement of Fly Ash by cement in GPC shows better performance in mechanical properties of GPC. A comparative study of flexural behaviour of beam with RCC, Geopolymer Concrete beam with 6% replacement of GGBS in fly ash (GGPC) and Geopolymer Concrete beam with 6% replacement of cement in fly ash (CGPC) has been done. The test results revealed that CGPC beam shows better results in compressive strength as well as in flexure and setting time is also reducing considerably when compare with GGPC. CGPC beam shows that less amount of deflection and greater moment of resistance than that of GGPC beam.

1. Introduction
Globe is suffering with plenty of problems; those problems may be by human mistake or naturally. Global warming is one of the most important problems and it is challenging to the developed and developing countries. Industrial effluents like CO₂, HFCs and N₂O are responsible for Global warming. Cement industry is one of the chief sources for the emission of CO₂ that contributes to the Global warming. At the time of incineration of cement large amount of CO₂ is releasing into the atmosphere and approximately one ton CO₂ emits in the production of one ton of cement [1,2]. In this way cement industry is releasing around 1.65 billion tones of green house gases across the world [2-4].
This emission may be increased to 50% by the year 2020 [5-6], which shows a significant effect on the temperature rise. In this concern cement is replaced by earth materials to bind the concrete ingredients.

The word geopolymer is coined by a French scientist, Joseph Davidovits in the year 1991 [7]. Geopolymer Concrete (GPC) is an efficient material to reduce the effect of green house gases in the environment [8]. GPC is an innovative material for the development of infrastructure without affecting environment and also an alternative material for Ordinary Portland Cement (OPC) concrete. GPC plays a major role in green concrete technology by eliminating cement and utilizing waste materials such as fly ash and blast furnace slag. Geopolymer is developed from the earth materials (NaOH and Na$_2$SiO$_3$) when polymerization developed between the solution and base material. The basic polymerisation process can be explained with three distinct activation levels: (a) destruction-coagulation; (b) coagulation-condensation; and (c) condensation-crystallisation. Alumino- Silicate is the source material to develop polymerisation. The developed polymers are inorganic type polymers, and these polymers are developed at moderate to high temperature (60°C-80°C). Polymer chain length is increased with addition of Silicate molecules. These polymerised long chains are finally developing the bonding between the ingredients of concrete. The rate of polymerization depends on various factors such as the chemical composition of the Fly Ash or GGBS and the alkaline liquid, curing type and relative humidity. Generally, the polymerization is accelerated at higher temperature than ambient, normally at 60-80°C is good for the development of geopolymerization. So many studies had performed [9-11] to find out the influence of fly ash in geopolymerization as a source material. The results revealed that, Class F type fly ash (low calcium) based geopolymer concrete shows excellent mechanical and durability properties, when it was cured in oven at high temperature. Due to this reason geopolymer concrete applications are limited to precast concrete members only. So to avoid this problem Geopolymer concrete is made with small amount of additives with low calcium fly ash to make it ambient cured concrete [12].

The primary objective of this work is to improve the flexural behaviour of GPC by using different additive materials with couple advantage of the reduction in the emission of green house gases and to bring the concrete to ambient curing condition.

2. Materials and methodology
In this research different types of material are used i.e. Fly Ash (Class F), Alkaline liquids (NaOH and Na$_2$SiO$_3$) Cement, GGBS and Aggregates.

2.1 Fly Ash
Fly ash is a by product, produced from the thermal power plants by the combustion of anthracite or bituminous coal for the generation of power. Generally fly ash is classified into two categories based on calcium and silicate content, low calcium fly ash contains around 60% of silicate content. This high silicate content fly ash called as low calcium fly ash or class F fly ash as per ASTM code. Fly ash particles are very fine as per IS code 3812:2003 and are typically spherical and rounded. The diameter of Fly Ash particles is ranging in between 1μm to 150 μm. In this research work class F Fly Ash (Low-Calcium) is used, which is obtained from Rayalaseema Thermal Power Project, which is a coal based plant promoted by Andhra Pradesh Power Generation Corporation at Cuddapah district in Andhra Pradesh state, India.

2.2 Alkaline liquids
The alkaline liquids are forming soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquids used in geopolymerization are a combination of sodium hydroxide (NaOH) and sodium silicate (Na$_2$SiO$_3$).Alkaline liquid plays an important role in the polymerization process and it is responsible for binding. In this study, to activate the fly ash, a combination of sodium hydroxide and sodium silicate was chosen as the alkaline liquid. Geopolymer substances are extracted from earth origin, hence no by products are developed during processing of these materials. 99% purity of NaOH was used in this work.
2.3 Coarse Aggregate
Coarse aggregates conforming to IS: 383-1970 is used in the present research work. The granite crushed angular shaped coarse aggregate was obtained from the local crushing plant. It has a specific gravity of 2.762; fineness modulus is 3.717 and bulk density of 1680 kg/m$^3$.

2.4 Fine Aggregate
Fine aggregates conformed to the IS: 383-1970 is used in the present research work. River sand was used as fine aggregate and it has a specific gravity of 2.63, fineness modulus of 2.86 and conforming to grading zone -2.

2.5 Cement
Ultra Tech OPC 53 grade cement conforming to code IS: 12269-1987 (specific gravity of cement 3.1, initial setting time of 46 minutes and final setting time of 184 minutes) was used in this study.

2.6 Ground Granulated Blast Furnace Slag
Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. GGBS which is locally accessible in Gadivemula, close to Kurnool area from JSW cement production line. GGBS is tested according to the code IS: 4032-1985.

Chemical composition of fly ash, cement and GGBS are shown in Table.1

| Oxide   | CaO  | Al$_2$O$_3$ | Fe$_2$O$_3$ | SiO$_2$ | MgO  | SO$_3$ | Na$_2$O | LOI  |
|---------|------|-------------|-------------|---------|------|--------|---------|------|
| Fly ash | 3.20 | 30.6        | 1.50        | 61.12   | -    | 0.30   | 1.35    | 0.79 |
| Cement  | 63.60| 4.70        | 2.70        | 21.9    | 2.60 | 2.50   | 0.50    | 2.00 |
| GGBS    | 37.34| 14.42       | 1.11        | 37.73   | -    | 3.62   | 0.31    | 1.41 |

2.7 Methodology
Geopolymer is an inorganic polymer, which is produced from a range of alumino-silicate materials reacted by alkaline solutions. In highly alkaline and mild temperature conditions, solid alumino silicate oxides react with alkali metal silicate solutions to yield amorphous to semi crystalline polymer structures which consist of Si–O–Al and Si–O–Si bonds. Under alkaline conditions, geo – polymerization process occurs at significantly high rate resulting in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows:

\[ M_n (\text{SiO}_2)_{z} \text{AlO}_2\text{nH}_2\text{O} \]

Where “z” is 1, 2 or 3 or higher up to 32; “M” is a monovalent cation such as Na$^+$ and K$^+$, and “n” is a degree of polycondensation.

Geopolymers are prepared through a condensation reaction between the tetrahedral aluminosilicate units and alkali metal ions, equivalent to the charge related with tetrahedral Aluminum. In general, Geopolymers are prepared from two-part mix comprised of solid alumino silicate materials and alkaline solution (often soluble silicate). The Geopolymer concrete design renders an alternative solution for production of conventional concrete. Geopolymer concrete is environmental friendly and also reduces release of CO$_2$. Geopolymerization is the process of combining small molecules known as oligomers into a covalently bonded network. They are classified based on the ratio of Si/Al in their structures:

a) Poly (Sialate) (-Si-O-AL-O-)
b) Poly (sialate-siloxo) (-Si-O-Al-O-Si-O-)
c) Poly (sialite - disiloxo) (-Si-O-Al-O-Si-O-Si-O-).

Sialate is an abbreviation for silicon-oxoaluminate. Polysialates are chain and ring polymers with Si$^{4+}$ and Al$^{3+}$ in IV-fold coordination with oxygen and range from amorphous to semi-crystalline. The schematic formation of Geopolymer material with three dimensional polymeric chains and ring structure consisting of Si-O-Al-O bonds was shown in equations (I) and (II).

$$\text{n(Si}_2\text{O}_5\text{Al}_2\text{O}_2) + 2\text{nSiO}_2 + 4\text{nH}_2\text{O} + \text{NaOH or KOH} \rightarrow \text{Na}^+\text{n(OH)}_3\text{Si-O-Al-O-Si-OH)}_3 \quad (I)$$

(Si-Al materials)

$$\text{n(OH)}_3\text{Si-O-Al-O-Si(OH)}_3 + \text{NaOH or KOH} \rightarrow (\text{Na}^+, \text{K}^+\text{(-Si-O-Al-O-Si-O-)} + 4\text{nH}_2\text{O} \quad (II)$$

(Geopolymer backbone)

H$_2$O molecules are not involved in any chemical reaction of Geopolymer concrete and instead water is expelled during curing and subsequent drying.

3. Experimental Programme

3.1 Mix Design of Geopolymer Concrete

Generally there is no standard mix design procedure available for geopolymer concrete. Geopolymer concrete mix design is completely based on source materials and alkaline liquids. Compressive strength of GPC increases with increase in molarity. Geopolymer mix design procedure is affected by many parameters. Alkaline liquids and curing conditions are most influence parameters on the mechanical strength properties of GPC. The following ratios of various ingredients of geopolymer concrete are selected from the literature reviews on geopolymer concrete and from the experience gained during the experimental trials.

- Ratio of alkaline liquid to fly ash is 0.45
- Ratio of the sodium silicate solution to sodium hydroxide solution is 2.0
- Molarity of NaOH is 10M
- Percentage of aggregates (coarse and fine) in the total mix is around 70–80.

Geopolymer liquids were prepared one day before casting the geopolymer concrete. Sodium hydroxide (NaOH) of 10M was diluted in water (molecular weight of NaOH is 40, so 400 grams of NaOH was added in one litre of water) and this mix was added to sodium silicate solution before 24 hours, because this process is exothermic. Fly ash and aggregates were mixed together for 3 minutes,
and then geopolymer liquids were added to mix and again mix for 3 minutes and placed in the moulds. Mix design details for various mixes are shown in Table 2.

### Table 2. Mix proportions for various mixes.

| Mix No. | Mix designation | Flyash (kg/m³) | Cement (kg/m³) | GGBS (kg/m³) | F.A (kg/m³) | C.A (kg/m³) | % age replaced | Curing |
|---------|-----------------|----------------|----------------|--------------|-------------|-------------|----------------|--------|
| 1       | GPCO (Control mix) | 413.79         | -              | -            | 540         | 1260        | 0              | 60°C, 48h Oven |
| 2       | GPC-0           | 413.79         | -              | -            | 540         | 1260        | 0              | Ambient         |
| 3       | CGPC-2         | 405.51         | 8.28           | -            | 540         | 1260        | 2              | Ambient         |
| 4       | CGPC-4         | 397.24         | 16.55          | -            | 540         | 1260        | 4              | Ambient         |
| 5       | CGPC-6         | 388.96         | 24.83          | -            | 540         | 1260        | 6              | Ambient         |
| 6       | GGPC-2         | 405.51         | -              | 8.28         | 540         | 1260        | 2              | Ambient         |
| 7       | GGPC4          | 397.24         | -              | 16.55        | 540         | 1260        | 4              | Ambient         |
| 8       | GGPC-6         | 388.96         | -              | 24.83        | 540         | 1260        | 6              | Ambient         |

Three reinforced beams of size 150x180x1350mm were casted. RCC beam casted according to IS: 10262-2009 for M20 grade of concrete. Second beam was casted with 6% cement replaced in fly ash of GPC. Third beam was casted with 6% GGBS replaced in fly ash of GPC. Reinforcement provided in all three beams was designed as per IS: 456-2000. The reinforcement details of beam is shown in the Figure 1.

![Figure 1: Reinforcement details of Beam.](image)

CGPC and GGPC beams were cured at ambient temperature; Reinforced concrete beam was cured for 28 days in water. After 28 days, beams were tested as simply supported beams under four point loading at L/3 from either supports with effective span of 1150mm, under loading frame of 100 tons capacity. The testing arrangement of beam under loading frame is as shown in Figure 2.
Compressive and tensile Strains were measured at top and bottom of the beam by using strain measuring gauges (resistance 120± 0.3%, Gauge factor-2.1, Foil type, size-5mm and 10mm). Deflection of beams was measured with the help of LVDT (Linear Variable Differential Transformer) attached at middle centre of bottom of the beam. Load was applied with the servo control system with loading rate of 0.02kN per sec. Beams were tested up to the failure load.

4. Results and discussions

Three beams were tested under loading frame to evaluate the flexural behaviour of concrete. LVDT was used to measure the deflection of beam and strain gauges were used to measure the compressive strain at top ($\varepsilon_c$) and tensile strain at bottom ($\varepsilon_t$) of the beams. Based on the experimental data, load vs. deflection and moment vs. curvature were drawn and shown in Figure 4 and Figure 5.

4.1 Load vs. deflection of RCC, CGPC and GGPC Beams

Load values and corresponding deflection values were taken from loading frame data and graph was plotted for Load vs. Deflection. Load carrying capacity of CGPC and GGPC beams are less than that of RCC beam. But load carrying capacity of CGPC beam is more than that of GGPC beam. First crack was observed at 15.1 kN load in RCC beam, at 13.4 kN load in CGPC beam and at 10.5 kN load in GGPC beam. At earlier stage of loading response of all beams for deflection is almost similar, but when the load is increasing geopolymer based beams were responding rapidly, but CGPC shows less deflection than that of GGPC. Maximum deflection was observed in GGPC beam. CGPC beam shows better stiffness (load/deflection) as compared with GGPC. Crack pattern is almost similar in all the three beams as shown in Figure 3.
4.2 Moment vs. Curvature of RCC, CGPC and GGPC Beams

Strain gauge readings and corresponding load values are collected from the loading frame data. Moment is evaluated from two point load and Curvature is calculated from Compressive and tensile strain values by using the following formula.

\[
\text{Curvature } (\phi) = \left( \varepsilon_c + \varepsilon_t \right) / d
\]

Moment resisting capacity of RCC beam is more than that of CGPC and GGPC beam. But Moment resisting capacity of CGPC beam is more than that of GGPC beam. Earlier stage of loading moment resisting capacity is almost similar to each other, but when the load is increasing resting capacity is more in RCC and then follows by CGPC and GGPC.

Figure 4. Load vs. deflection of RCC, CGPC and GGPC Beams.

Figure 5. Moment vs. Curvature (\(\phi\)) of RCC, CGPC and GGPC Beams.
5. Conclusions

This study has concluded that at 6% of replacement of cement in fly ash of GPC yields the better results in flexural strength of beams. Percentage of cement replacement in fly ash of GPC increases the strength of concrete. Setting time of CGPC was much lesser than GGPC. Workability is reducing to the corresponding increase of replacement in fly ash of GGPC by cement. Load carrying capacity of CGPC beam is more than 8% as compared to GGPC beam. Deflection of GGPC beam is more than 10.7% that of CGPC beam. Stiffness of CGPC beam is more than that of GGPC beam.

Both CGPC and GGPC beams are more ductile than RCC beam. From load vs. deflection graph, we can conclude that energy absorption is more in CGPC and GGPC beam as compared with RCC beam.

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