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***Research paper***

# Parametric study of flyash based geopolymer concrete

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**Abstract**

With the growth of civilization the demand of cement concrete is increasing rapidly which increase the production of cement and abolishing the natural source of limestone. Also contributing a lot to the global warming by generating huge amount of carbon-di-oxide. Therefore the present study concentrate on the production of concrete using the geopolymerization technology which replaces cement fully by fly ash, a waste material and alkali solution. India is presently producing approximately 190 million tons of fly ash every year from moreover 145 power plants. Present research is focused on the different parameters which are curing temperature, ratio of sodium silicate to sodium hydroxide, molarity of sodium hydroxide, curing type and the results have been studied and discussed. Previous works emphasis that only the use of fly ash as the base material confine the concrete to be heat cured which limits the applicability of geopolymer concrete to cast-in-situ conditions. So some proportion of flyash is replaced by ground granulated blast furnace slag (GGBFS) and the effect on compressive and tensile strength is observed. Ambient temperature dry curing was done without any water when some proportion of fly ash was replaced by GGBFS. The ratio of sodium silicate solution to sodium hydroxide solution by mass was kept fixed at 2.5 and the concentration of sodium hydroxide was kept 14M. The ratio of flyash to alkali solution was kept 0.35 & 0.40. Replacing 40% of Flyash by GGBFS and keeping the concentration of NaOH as 14M at ambient temperature, the compressive strength encountered was 40 MPa.

***Keywords:*** *Compressive strength, flyash, geopolymer concrete, GGBFS, sodium hydroxide, sodium silicate.*

## 1. Introduction

The use of conventional concrete is increasing rapidly now-a-days. The conventional concrete uses cement as the main binding and strength generating material but the production of cement is exothermic and produces a huge amount of heat. Almost 0.9 tone of $CO_2$produced for every 1tons of cement production, which not only reduces the natural resource of lime stone but also contributing a lot to the global warming. Whereas production of geopolymer concrete reduces the emission of $CO_2$ by almost 5 times [1]-[2]. The concept of Geopolymer was first mentioned by Prof. J.Davidovits in 1978. The Geopolymerization process creates a 3D inorganic chain by a fast chemical reaction between the aluminosilicates in the presence of alkali solution. Three steps are involved for the full geopolymerization process. First the Si and Al are freed from the material, then the orientation or condensation of precursor ions into monomers takes place and lastly the polymeric structures are formed by setting or polycondensation of monomers into polymers[3]. Type of polymers includes poly(sialate), poly(sialate-siloxo) and poly(sialate-disiloxo)[4]. The chemical reaction behind geopolymerization is as follows:

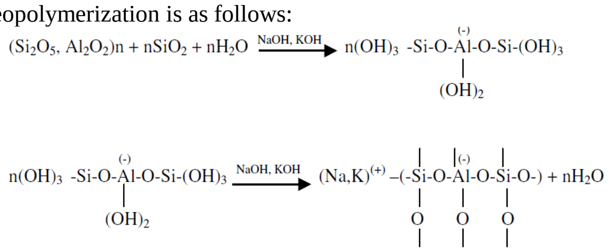


**Figure 1:** Chemical reaction behind geopolymerization

Low calcium flyash based geopolymer concrete uses flyash and alkaline solution (rich in Silica and Alumina) as binding agent. The flyash available in India are mostly low calciumbased which when used in geopolymer concrete shows a good result in terms of compressive strength, fire resistance and chemical attack in previous researches. Geopolymer is an inorganic polymer made up of aluminium and silica. It is an alumina-silicate chain formed by the activation of natural resources having alumina and silica as their ingredients or by-products like flyash, ground granulated blast furnace slag with alkaline solution. Previous researches have significantly shown a good result when a molarity of sodium hydroxide solution in the range of 10M to 16 M with the flyash to alkali activator ratio in the range of 2.5 to 3.3 are used [5]. In the heat curing environment the geopolymerization process takes place but practically due to this reason geopolymer concrete is mostly limited to prefabricated members. Initial heat curing with moisture makes the polymerization process faster. Due to this drawback, present study incorporates Ground Granulated Blast Furnace Slag (GGBFS) with flyash,as a partial replacement of flyash and the curing is done at room temperature. As Class F grade flyash(low in calcium content) is used here, so some portion of GGBFS increases the calcium content and polymerization takes place in the alkaline atmosphere and thus the Si-O-Al-O bonds are formed.

## 2. Materials used

### 2.1. Flyash

The flyash was obtained from a thermal power plant located at Bikaner, Rajasthan having a grade of class F. Mostly in Indian condition the coals available are of anthracite or bituminous condition which creates class F flyash having a low calcium oxide (CaO < 7%) content.

### 2.2. Ground granulated blast furnace slag

The GGBFS used in this study are also taken from a nearby steel melting shop located at Dehradun, India. It is mainly glassy and granular in structure but for the use in geopolymer concrete it was grinded to powder form. Generally the CaO content of GGBFS lies in the range of 35-50%.

### 2.3. Sodium hydroxide

The sodium hydroxide solids were obtained in pellet form (3 mm), with a specific gravity of 2.130, 98% purity from Loba Chemie, Maharashtra, India. It was then dissolved in water to form a solution manually.

### 2.4. Sodium silicate solution

The sodium silicate solution was also obtained from Loba Chemie, Maharashtra, India of laboratory grade. The chemical composition of the sodium silicate solution was $Na_2O$ = 8%, $SiO_2$= 24% and water = 68% by mass.

### 2.5. Aggregates

The aggregate used in this study was purchased from a local vendor of Jaipur, Rajasthan having the size of 20 mm and 10 mm down. The fine aggregate used in this study was fine sand. Coarse aggregates of 20mm and 10mm down are mixed in a ratio of 1:1. The final fineness modulus was of 4.7. Both of the aggregates are of surface dry condition and conform to the Indian Standard specifications (IS: 383-1970).

## 3. Experimental programme

During the experiment author's main focus was to see the effect of GGBFS on strength generation without heat and water curing when used as a base material, partial replacement of fly ash. The ratio of sodium silicate to sodium hydroxide solution was kept constant at 2.5 but the amount of fly ash replacement by GGBFS was changed to 10%, 20%, 30% & 40%. The ratio of $SiO_2$ to $Na_2O$ was kept 3 in the sodium silicate solution. The ratio of alkali solution to flyash was taken as 0.35 and 0.40 only. The molarity of sodium hydroxide solution was kept constant at 14M for this study. The sodium hydroxide solution was made by dissolving the pellets in water at room temperature to obtain a certain molarity. In the time of curing no water is used but to make the solution some percentage of water was used which somewhat gives importance in the formation of C-S-H gel during the ultimate strength generation. Sodium hydroxide and sodium silicate solutions are mixed approximately 24 hours prior to use in the concrete mixture. Initially the fly ash and GGBFS are mixed in dry condition and after getting a uniform mixture the alkaline solution was poured and it was mixed for another 4-5 minutes. The freshly mixed geopolymer concrete was light grey in colour due to the presence of high amount of CaO in GGBFS and the appearance was shiny. It was very much cohesive in nature with low workability. The workability was measured using the slump test method and the value encountered lied in the range of 60-100 mm. Due to high cohesiveness the mixture started losing it plasticity within a maximum time of 10-15 minutes of mixing. So the placing, compaction and finishing work were carried out fast. The compaction was done by table vibration process for 15 seconds and the specimen was left in sunlight for the fast initiation of polymerization process. After 24 hours of placing, it was remolded and again the specimens were kept in sunlight for 28 days and compression and tensile test results are obtained at regular interval of 3, 7 & 28 days.

The composition of flyash and GGBFS was obtained by XRF analysis. The analysis results and the mix proportions are shown in the below table:

**Table 1:** Chemical Composition of Flyash & GGBFS

| Oxides | Flyash | GGBFS |
|---|---|---|
| $SiO_2$ | 53.36 | 35.26 |
| $Al_2O_3$ | 26.49 | 13.81 |
| $Fe_2O_3$ | 10.86 | 0.87 |
| CaO | 1.34 | 38.27 |
| $Na_2O$ | 0.37 | 0.35 |
| $K_2O$ | 0.80 | 0.3 |
| $TiO_2$ | 1.47 | 0.47 |
| MgO | 0.77 | 4.64 |
| $P_2O_5$ | 1.43 | 0.05 |
| $SO_3$ | 1.70 | 3.76 |
| LOI | 1.39 | 2.34 |

The mixing was done in a pan mixer and the mixing details are as follows:

**Table 2:** Details of Mix Proportions (Kg/m$^3$)

| Sl. No | Flyash | GGBFS | Sodium Silicate Solution | Sodium Hydroxide Solution | Molarity | Curing Type | Alkali Solution/ Flyash |
|---|---|---|---|---|---|---|---|
| 1 | 500 | 00 | 105 | 70 | 14 | Ambient | 0.35 |
| 2 | 450 | 50 | 94.5 | 63 | 14 | Ambient | 0.35 |
| 3 | 400 | 100 | 84 | 56 | 14 | Ambient | 0.35 |
| 4 | 350 | 150 | 73.5 | 49 | 14 | Ambient | 0.35 |
| 5 | 300 | 200 | 63 | 42 | 14 | Ambient | 0.35 |
| 6 | 500 | 00 | 95 | 80 | 14 | Ambient | 0.40 |
| 7 | 450 | 50 | 85.5 | 72 | 14 | Ambient | 0.40 |
| 8 | 400 | 100 | 76 | 64 | 14 | Ambient | 0.40 |
| 9 | 350 | 150 | 66.5 | 56 | 14 | Ambient | 0.40 |
| 10 | 300 | 200 | 57 | 48 | 14 | Ambient | 0.40 |

## 4. Results & discussion

In this study mainly two types of parameters are considered i.e. alkali solution to flyash ratio and percentage of GGBFS addition. For the initial five types of mixes the replacement of fly ash by GGBFS was increased from 0% to 40% by taking 10% interval and keeping the alkali solution to flyash ratio as 0.35. In the remaining five mixes the ratio of alkali solution to flyash was kept constant at 0.4 and again the replacement of flyash by GGBFS was increased from 0% to 40% in the same manner mentioned previously.

### 4.1. Workability

While considering the workability of the fresh mix, slump cone test was conducted. As the mix was very much cohesive the workability was moderate and resulted in the range of 60 mm to 100 mm. It was observed that with the increase of GGBFS content, the slump value decreases due to the higher presence of CaO. As water was not added externally throughout the process of geopolymer concrete manufacturing which maybe one of the reasons of low workability. With the higher ratio of alkali solution to flyash of 0.40 author observed higher workability in comparison to the ratio of 0.35, this maybe for the higher quantity of alkaline solution which contributes a little higher quantity of water to the same mix proportions.

### 4.2. Compressive & Tensile Strength

In this study author's main objective was to obtain a moderate compressive strength in ambient temperature condition for which no heat or humidity with heat curing was done. In India average high temperature in most of the parts of the country lies in between 32$^0$C to 35$^0$C throughout the year and states like

Rajasthan, Maharashtra, Karnataka, Andhra Pradesh, etc. face a huge water scarcity, so proper curing was not possible and renovation works of structures occurs frequently. So all the casted cubes and beams of size 150mm x 150mm x 150mm and 100mm x 100mm x 500mm respectively were left to unshaded place for the direct contact of sunlight for the entire period of 28 days.

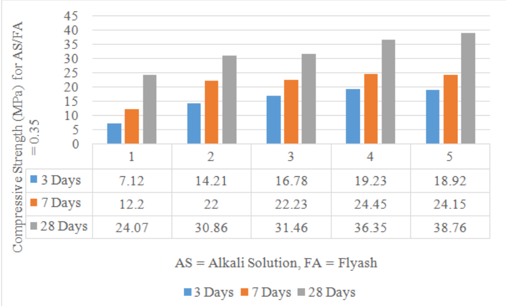


**Figure 2:** Compressive strength of five different mixes at AS/FA = 0.35

From fig.2 it was observed that with the increment in the replacement of flyash by GGBFS (upto 40%) the 28 days compressive strength increases from 24.07 MPa to 38.76 MPa which is almost 61% increment. This is due to the higher quantity of CaO in GGBFS which helps in the formation of C-S-H gel results in proper binding [6] in addition to the Si-O-Al bonds.

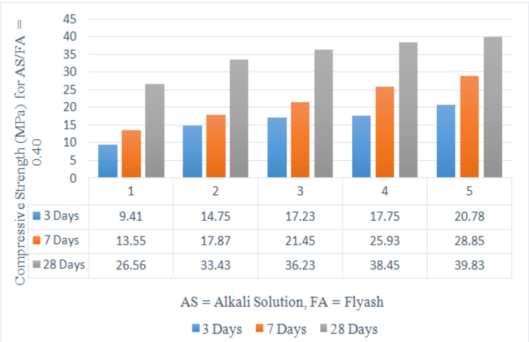


**Figure 3:** Compressive strength of five different mixes at AS/FA = 0.40

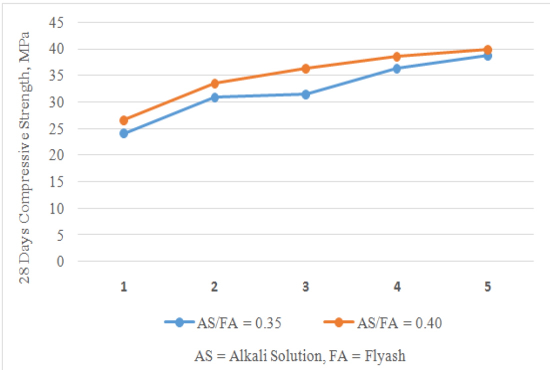


**Figure 4:** Compressive strength of five different mixes at different AS/FA ratio

From fig.4 it was observed that with the higher AS/FA ratio the compressive strength of Geopolymer concrete increases on each and every aspect. This is due to the reason that with high ratio value the mix will be getting higher alkaline solution resulting in higher quantities of Si, Al atoms. These atoms will increase the compressive strength with higher number of Si-O-Al bonds. This results in the increment in the compressive strength [7]-[9].

But it was also observed that with the increment in the AS/FA ratio from 0.35 to 0.40, the compressive strength increased from 38.76 MPa to 39.83 MPa in 28 days which is just approximately 3% increment rather than the initial increment of strength during the 3 days' and 7 days' time for mix-5 which was much higher and was of 9.83% & 19.46% respectively. In previous researches it was observed that in geopolymer concrete initial strength gain is very fast due to heat curing.This heat curing accelerates the rate of formation of polymers which is one of the factor for the initial strength gain. But in this condition the initial strength gain was good due to the addition of GGBFS as no heat curing was done.

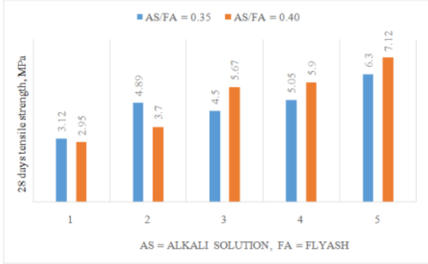


**Figure 5:** 28 Days Tensile strength of five different mixes at different AS/FA ratio

Tensile strength of all the 10 mixes are shown in fig. 5. The size and shape of coarse aggregate play a vital role on the flexural strength of concrete and it has been observed that the max tensile strength of 7.12 MPa was obtained at the AS/FA ratio of 0.40.

## 5. Conclusion

Inclusion of GGBFS in flyash based geopolymer concrete gives a huge impact on the compressive and tensile strength generation in ambient curing condition. Ten different mixes were developed by changing the GGBFS content (from 10% to 40%), as a partial replacement of flyash. Also the Sodium Silicate to Sodium Hydroxide ratio, Molarity of Sodium Hydroxide and $SiO_2$ to $Na_2O$ ratio was kept constant at 2.5, 14 and 3.0 respectively which finally gives a maximum of 39.83 MPa compressive strength and 7.12 MPa tensile strength. As there was no such dominating variation in final strength in between the 0.35 and 0.40 ratio value of sodium silicate to sodium hydroxide so both of the ratio can be utilized for future researches. The higher percentage of CaO content of GGBFS helps in formation of compressive and tensile strength in ambient curing condition which will increase the use of geopolymer concrete for cast-in-situ condition and will show a direct positive impact on our environment by reducing the use of OPC and curbing the quantity of $CO_2$ emission in environment and will create a green concrete evolution.

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