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# Study on Influence of Various Factors on the Properties of Geopolymer Concrete Produced from Industrial By-Products

**Kollu Kanaka Durga Vara Prasada Rao[1], Munduru Raghavendra Rao[2]**

*[1]First Professor & HOD, [2]PG Student*
*Department of Civil Engineering,*
*VIKAS COLLEGE OF ENGINEERING&TECHNOLOGY, NUNNA, VIJAYAWADA.*

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**Abstract -**Large amounts of carbon dioxide and other gases are produced during the Portland cement manufacturing process. When these gases are released into the atmosphere, pollution results, which leads to environmental deterioration. For environmental sustainability, it is crucial to find a viable alternative solution to lessen the environmental damage caused by the usage of Portland cement. Conversely, fly ash, a waste product of coal-based thermal power plants, is widely accessible but presents disposal challenges. Using a cementitious substance like fly ash instead of Portland cement in concrete has advantages for the environment. In order to create geopolymer concrete, a new sustainable concrete, all of the cement is replaced with fly ash that has been treated and chemically activated using alkaline solutions containing sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$). This thesis examines how the compressive strength of fly ash-based geopolymer concrete is affected by a number of variables, including the ratio of alkaline liquid to fly ash, the molarity of NaOH, the curing temperature, and the curing hours. The foundational ingredient for creating geopolymer concrete is fly ash, which is activated by an alkaline solution of sodium hydroxide and sodium silicate. The present investigation employed the following test variables: the molarities of sodium hydroxide (NaOH) 12M, 4M, 16M, and 18M; the ratio of NaOH to sodium silicate ($Na_2SiO_3$) 2.5; and the alkaline liquid to fly ash ratios of 0.35, 0.40, 0.45, and 0.50. It is also absorbed that compressive strength is remarkably affected by the curing hours and curing temperature. When curing temperature is increases, the compressive strength is also increases and it requires less curing period to gain the higher strength.

**Key Words:** Fly ash, geopolymer concrete, alkaline liquid, density, compressive strength.

## 1. INTRODUCTION

One of the main causes of greenhouse gas emissions, such as carbon dioxide, is the production of cement. The growing demand of the building industry is driving a daily growth in the output of Portland cement worldwide. The primary component used to make concrete is cement. But the production of cement requires large amount of raw material. During the production of cement burning of lime stone take place which results in emission of carbon dioxide ($CO_2$) gas into the atmosphere. There are two different sources of $CO_2$ emission during cement production. Combustion of fossil fuels to operate the rotary kiln is the largest source and other one is the chemical process of burning limestone.

One tonne of $CO_2$ is released into the atmosphere for every tonne of cement produced. The manufacture of cement is thought to be responsible for around 7% of all carbon dioxide emissions, necessitating the use of more environmentally friendly alternatives to Portland cement for binder.

The waste residue known as fly ash, which is produced when coal is burned in thermal power plants, is widely accessible worldwide. Over 100 million tonnes of fly ash are produced in India each year. Just 17 to 20% of this is used for soil stabilisation or in concrete.

Most of the fly ash is disposed off as a waste material that coves several hectors of valuable land. As fly ash is light in weight and easily flies, this creates severe health problems like asthma, bronchitis, and so forth. There are environmental benefits in reducing the use of Portland cement in concrete, and using a by-product material, such as fly ash as a substitute. With silicon and aluminium as the main constituents, fly ash has great potential as a cement replacing material in concrete. For every ton of fly ash used in place of Portland cement saves about a ton of carbon dioxide emission to the atmosphere .

Davidovits proposed a new term geopolymer in 1978 to represent the mineral polymers resulting from geochemistry. Geopolymers are members of the family

of inorganic polymers in which the mineral molecules are linked with covalent bond. Geopolymers are produced by source materials or by-product of geological origin that is rich in silica and alumina like fly-ash when react with alkaline solution at elevated temperature.
The chemical reaction that takes place in this case is polymerization, so this binder is called geopolymer. Geopolymer concrete is a new type of concrete in which cement is fully replaced by the pozzolanic materials that is rich in Silicon (Si) and Aluminium (Al) like fly ash. It is activated by highly alkaline liquids to produce the binder which binds the aggregates in concrete when subjected to elevated temperature. The concrete made with such industrial waste is eco-friendly and so it is called as "Green concrete

The chemical composition of the geopolymer material is similar to zeolitic materials, but the microstructure is irregular. The polymerization process involves a fast chemical reaction under alkaline condition on Si-Al minerals, those results in a three-dimensional polymeric chain and ring structure existing of Si-O-Al-O bonds.

When the chemical reaction that creates geopolymers takes place, water is released. The discontinuous nanopores that are left in the concrete by the water that is released from the geopolymer concrete during the rest, oven curing, and further drying periods improve the concrete's performance. Water gives a geopolymer combination its workability during handling; it has no bearing on the chemical reaction that occurs.

Alkaline liquids and source materials are the two primary components of geopolymers. Fly ash, silica fume, slag, rice husk ash, GGBS, red mud, and other by-product minerals can all be utilised as source materials.

A mixture of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate is the most widely utilised alkaline liquid in geopolymer concrete.

It's crucial to combine the two solutions to create the alkaline liquid at least 24 hours before use. The molarity of a solution determines the mass of NaOH solids in that solution.

Benefits of Geo-Polymer Concrete

- High early compressive strength gain
- Good abrasion resistance
- Rapid controllable setting and hardening
- Fire resistance up to 1000 degree centigrade and no emission of toxic fumes when heated
- High level of resistance to a range of different acids and salt solutions
- Low thermal conductivity and low shrinkage
- Impermeable like normal OPC concrete
- Bleed free
- High surface definition that replicates mould patterns

To study the effect of factors like Molarity, alkaline liquid to fly ash ratio, curing hour and curing temperature that affects the compressive strength of fly ash based geopolymer concrete.

## 2. EXPERIMENTAL WORK

### Materials Used

Fly Ash

In this study, fly ash (ASTM Class F) obtained from Rosa Thermal Power Station Shahajahanpur was used. The chemical and physical properties of fly ash shown below in table 2.1 and 2.2 respectively.

**Table-1**: Chemical Properties of Fly Ash

| **Parameter** | **Value (%)** | **Class- F Fly ash (ASTM C-618)** |
|---|---|---|
| Silicon dioxide ($SiO_2$) | 56.31 | 46-60 |
| Alumina ($Al_2O_3$) | 31.82 | 21-28 |
| Iron oxide ($Fe_2O_3$) | 4.77 | 5-9 |
| Calcium oxide (CaO) | 2.33 | 0.5-8 |
| Magnesium Oxide (MgO) | 1.09 | 0.2-4 |
| Sulphur trioxide ($SO_3$) | 0.16 | 0-0.4 |
| Sodium oxide ($Na_2O$) | 0.042 | 0-0.3 |
| Potassium oxide ($K_2O$) | 0.013 | 0-0.2 |
| Titanium ($TiO_2$) | 2.01 | 1-2.1 |

**Table-2**: Physical Properties of Fly Ash

| **Characteristics** | **Observed Value** |
|---|---|
| Specific Gravity | 2.18 |
| Fineness(m2/kg) | 340 |
| Lime reactivity(N/mm2) | 4.8 |
| Loss on Ignition(% by mass) | 0.70 |
| Soundness by auto-cleave method | 0.12 |

**Alkaline Solution**

The combination of sodium silicate to sodium hydroxide was used as alkaline solution in the present study and the ratio of both was maintained to 2.5 throughout the study. The solution was prepared one day prior to be used.

Sodium Hydroxide Generally NaOH is available in market in pellets or flakes form with 96% to 98% purity where the cost of the product depends on the purity of the material. Sodium hydroxide in pellet form was used in this work of 97% purity. The solution of NaOH was formed by dissolving it in deionised water for the molarity of 12M, 14M, 16M & 18M. The NaOH solution was prepared 24 hours before casting of specimens.

Sodium Silicate ($Na_2SiO_3$) is also known as waterglass which is available in the market in gel form and also in the solid form. Sodium silicate in gel form was used in this study having 31% of $SiO_2$, 14% of $Na_2O$ & 55% of $H_2O$. The ratio of silicon dioxide ($SiO_2$) and sodium oxide ($Na_2O$) in sodium silicate gel is 2.21.

**Mix Proportioning Details**

The geopolymer concrete was made for sixteen different mix proportion of fly ash, alkaline solution, fine aggregate and coarse aggregate with variation in alkaline liquid to fly ash ratio as 0.35, 0.40, 0.45 & 0.50 for molarities of 12M, 14M, 16M, &18M.

**Table-3**: Mix details of fly ash based geopolymer Concerte

| S.No. | Alkaline sol./Fly ash ratio | Fly ash (Kg/m3) |
|---|---|---|
| Mix-1 Mix-2 Mix-3 Mix-4 | 0.35 | 580 |
| Mix-5 Mix-6 Mix-7 Mix-8 | 0.40 | 580 |
| Mix-9 Mix-10 Mix-11 Mix-12 | 0.45 | 580 |

**Table-4**: Mix details of fly ash based geopolymer Concerte

| Coarse aggregate (Kg/m3) | Sodium hydroxide (Kg/m3) | Sodium silicate (Kg/m3) | Molarity (M) |
|---|---|---|---|
| 1051 | 58 | 145 | 12 14 16 18 |
| 1032 | 66.28 | 165.71 | 12 14 16 18 |
| 1013 | 74.57 | 186.43 | 12 14 16 18 |
| 994 | 82.86 | 207.14 | 12 14 16 18 |

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**Mixing Casting and Curing of Geopolymer Concrete**

In the laboratory, the fly ash and the aggregates was first mixed together in dry state 2-4 minutes to get homogeneous mix. The alkaline solution was mixed with the extra water and this liquid components were added to the mixed aggregate and the mixing continued usually for another 12 - 15 minutes so that binding paste covered all the aggregates and mixture become homogeneous and uniform in colour. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength.

After the mixing is done, the fresh geopolymer concrete was filled in the moulds in three layers with required compaction same as the usual methods used in the case of Portland cement concrete and the specimens are kept on a vibrating table so that to minimize amount of voids present in the fresh concrete. The workability of the fresh concrete was measured by means of the conventional slump test.

For the polymerisation process, the high temperature curing is required in geopolymer concrete. The required temperature may be provided either by oven curing or by steam curing. In the present study, oven curing was used. The GPC cubes were placed in an oven for the period of 12, 18 and 24 hours. After the curing period, the test specimens were left in the moulds for at least 5-6 hours in order to avoid a major change in the environmental conditions. After de-moulding, the concrete specimens were allowed to become air-dry in the laboratory until the day of the compressive strength testing.

**Fig.-1:** Addition of Alkaline Solution

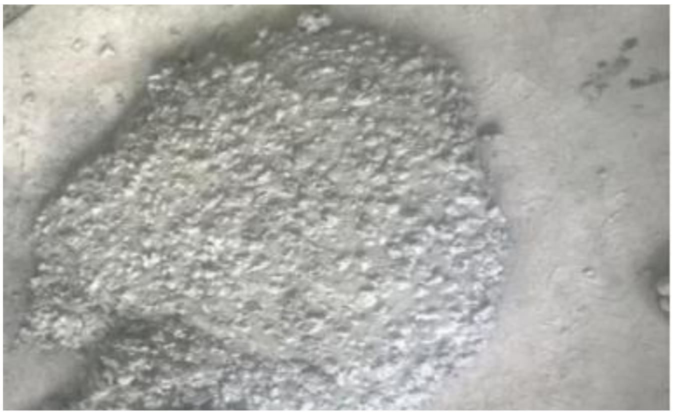

**Fig.-2:** Fresh Geopolymer Concrete

**Testing of Geopolymer Concrete Cubes**

The geopolymer hardened concrete cubes were tested for compressive strength. The compressive strength test was performed according to IS-5160: 1959. Cube specimens of size 150mm × 150mm× 150mm were prepared for each mix. After one day of rest period, they were cured in oven for 12, 18 & 24 hours and were demoded and stored until the day of testing. For specimens with uneven surfaces, capping was used to minimize the effect of stress concentration. The compressive strength reported is the average of three results obtained from three identical cubes.

## 3. RESULTS AND DISCUSSION

**Effect of Molarity and AL (Alkaline Liquid) / Fly-Ash Ratio on the Compressive Strength of GPC**

**Table-5**: Compressive Strength of Alkaline solution to fly ash ratio=0.35

| Mix No. | Molarity (M) | Compressive Strength (MPa) @ 7 days | Average comp. Strength (MPa) |
|---|---|---|---|
| Mix -1 | 12 | 26.60 | 26.30 |
| | | 24.90 | |
| | | 27.40 | |
| Mix-2 | 14 | 29.70 | 31.2 |
| | | 32.90 | |
| | | 30.90 | |
| Mix-3 | 16 | 35.60 | 34.8 |
| | | 32.70 | |
| | | 36.10 | |
| Mix-4 | 18 | 31.70 | 33.9 |
| | | 35.90 | |
| | | 34.10 | |

| | | | |
|---|---|---|---|
| Mix-5 | 12 | 34.80 | 32.1 |
| | | 33.20 | |
| | | 28.40 | |
| Mix-6 | 14 | 36.40 | 36.7 |
| | | 34.60 | |
| | | 39.10 | |
| Mix-7 | 16 | 41.80 | 40.3 |
| | | 38.40 | |
| | | 40.70 | |
| Mix-8 | 18 | 37.90 | 40.8 |
| | | 42.90 | |
| | | 41.70 | |

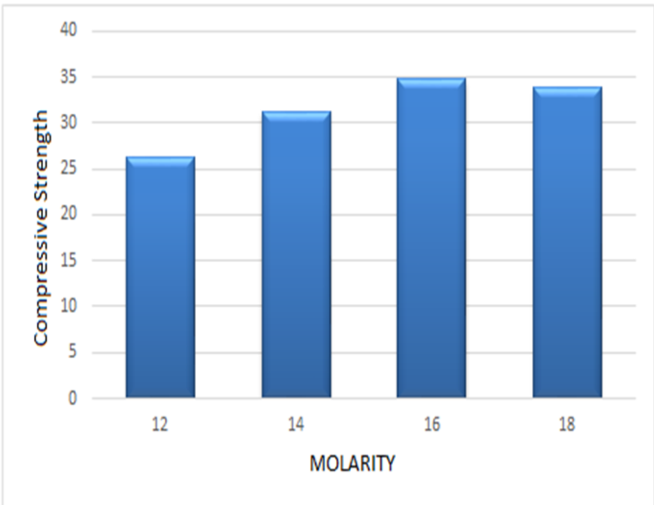


**Fig-3.** Effect of molarity on compressive strength of geopolymer concrete for AL/Fly-ash ratio 0.35

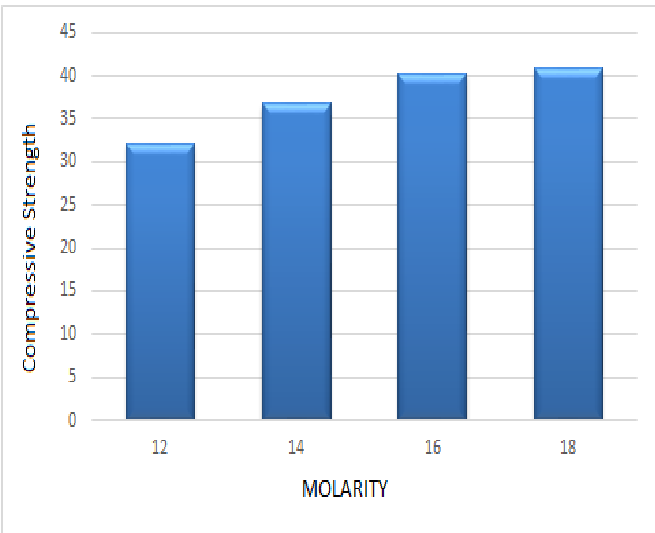


**Fig-4.** Effect of molarity on compressive strength of geopolymer concrete for AL/Fly-ash ratio 0.40

The results indicated that the compressive strength increases with increase in molarity of NaOH solution upto 16M but beyond the molarity 16M, slightly variation in compressive strength is observed for the molarity 18M. Results also show that the compressive strength is increases with increment in alkaline liquid to fly ash ratio but for ratio value beyond 0.45, slightly decrease in compressive strength is observed. It means when this ratio is increases, the water content in the solution is increases which affect the compressive strength.

**Effect of Curing Hour and Curing Temperature on Compressive Strength of GPC**

**Table-6:** Compressive strength of GPC specimens at curing temperature of 90°C

| Mix No. | Curing Tempe-rature (°C) | Curing Period (hours) | Compressive Strength (MPa) | Mean Compressive Strength (MPa) |
|---|---|---|---|---|
| Mix - 11 | 90 | 12 | 38.1 | 38.4 |
| | | | 40.3 | |
| | | | 36.7 | |
| | | 18 | 42.2 | 42 |
| | | | 40.1 | |
| | | | 43.7 | |
| | | 24 | 44.4 | 43.5 |
| | | | 43.2 | |
| | | | 42.9 | |

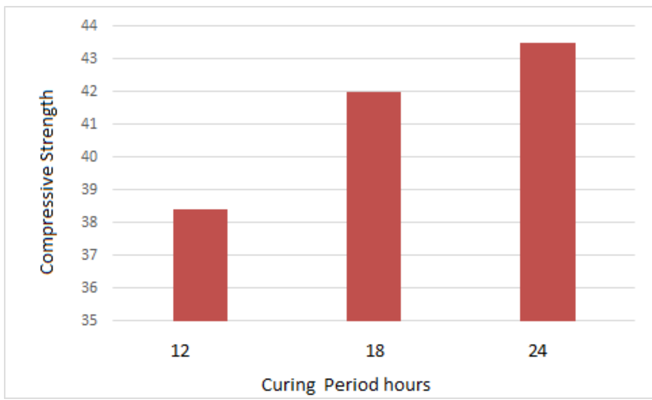


**Fig-5.** Effect of curing hours on compressive strength of GPC for temperature 90°C

The compressive strength of GPC concrete is observed to increases at curing temperatures 75°C and 90°C for 12, 18 and 24 hr of curing period, but when curing is done at 105°C, compressive strength increasing up to 12 hr of curing, after that it start decreasing. Hence it is observed that when curing temperature is increased, it requires less curing hours to gain same compressive strength.

## 4. CONCLUSIONS

The following conclusions are reached in light of the experimental work presented in this study:

1. As the alkaline solution to fly ash ratio rises to 0.45, the compressive strength of geopolymer concrete increases; however, at 0.50, the strength somewhat declines due to the increased water content of the alkaline solution.
2. Up to 16 M, the compressive strength of GPC likewise increases as the concentration of NaOH rises; however, at 18 M, the compressive strength does not significantly change, but the cost of manufacture does.
3. At 75°C, the compressive strength progressively rises as the curing time is extended up to 24 hours.
4. At 90°C temperature, the samples gained 95 % strength at 18 hours of curing, beyond this curing period, minor increment in strength is recorded.
5. Compressive strength of GPC samples at 105°C temperature certain increases up to 12 hours of curing period but it decreases when it cured for 24 hr at 105°C.

The aforementioned discussion has shown that a number of factors influence the geopolymer concrete's compressive strength. In order to obtain the desired benefits from the additional research, it is highly advised that a parametric study of the different factors influencing the compressive strength of the geopolymer concrete be carried out before beginning any additional research on the mechanical characteristics and durability of the material.

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