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# BEHAVIOUR OF GFRP- GEOPOLYMER CONCRETE COLUMNS UNDER AXIAL LOADING

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**Abstract**:

Ordinary Portland Cement (OPC) has been traditionally used as the binding agent in concrete. Geopolymer binders offer a possible solution for several problems that facing the current cement industry. Geopolymer, also known as inorganic polymer, is one such material that uses by-product material such as fly ash instead of cement. Recent research has shown that fly ash based geopolymer concrete has suitable properties for its use as a construction material. The G30 specimens were prepared in 8 molarity,10 molarity and 12 molarity of sodium hydroxide concentration. Specimens of low calcium fly ash based reinforced polymer concrete and specimens of ordinary Portland cement reinforced concrete were cast. Specimens from each molarity fly ash based reinforced polymer concrete and ordinary Portland cement reinforced concrete were wrapped with double layer of GFRP sheets. This paper investigates the suitability of glass fiber reinforced polymer (GFRP) sheets in strengthening of fly ash based polymer members under compression. And it is also presents the behavior of geopolymer concrete columns under axial bending.

**Keywords**: Axial Loading, Columns, Fly Ash, Geopolymer Concrete, Compressive Strength, GFRP Wrapping Sheets.

## 1. INTRODUCTION

Concrete is a versatile construction material and is being used worldwide. But the greenhouse gas (CO2) produced during its manufacturing process causes environmental impact. The demand of cement is increasing with the increase of population and the subsequent increase in the use of concrete as a construction material. OPC has been traditionally used as the binding agent in concrete. About one ton of carbon dioxide is emitted into the atmosphere in the production of one ton of cement. The present world is looking for alternative environmentally friendly binders to help reduce the increasing trend of global warming and climate change. The worldwide consumption of concrete is estimated to increase due to the increase of infrastructure especially in countries such as India and China. Emission of greenhouse gases such as CO2 and N2O is a major contributing factor for global warming. It is reported that the production of cement contributes about 5–7% of CO2 emissions globally while in 2008, Australia reported 1.3% of greenhouse gas emissions are due to the production of cement.

Flyash based polymer binders have emerged as the best possible alternatives for cement binders for applications in concrete industry reducing the environmental deterioration. A base material such as fly ash that is rich in Silicon (Si) and Aluminum (Al) is reacted by an alkaline solution to produce the geopolymeric binder. The base material for geopolymerisation can be a single material or combination of various materials. Source materials such as low calcium fly ash, high calcium fly ash, and slag can be used to make geopolymer.


Fig.1 Snapshot of flyash

Although different source materials are used to manufacture geopolymer, basically the reaction of the source materials with an alkaline solution results in a compact well cemented composite. The coal-fired power stations generate fly ash as a by-product. Use of fly ash in geopolymer concrete will help reduce the carbon footprint of concrete. The results of recent studies have shown the potential use of fly ash based geopolymer concrete as a construction material. It is generally agreed that the production of Portland cement clinker is expensive and ecologically harmful. The emissions generated by Portland cement productions are principal contributors to the greenhouse gas (GHG) effect. For instance, the production of Portland cement for concrete accounts for an estimated 5 percent of global anthropogenic carbon dioxide. Recent estimates of the emissions from cement production reveals that 377 million metric tons of carbon was generated in 2007; this indicates that emissions have more than doubled since the mid-1970s from fossil-fuel burning and cement production. Whilst measures may be undertaken to reduce the generation of carbon dioxide from cement kilns, carbon dioxide emission is still in the order of 600 kg of carbon dioxide per ton of cement of which 400 kg per ton is the result of the calcination of limestone. The United Nations Intergovernmental Panel on Climate Change (IPCC) has identified the unmindful pumping of CO2 into the atmosphere is the main culprit for the climate change and highlighted that the "largest mitigation potentials are in the steel, cement and pulp and paper industries…". Carbon emission data is alarming; the 2007 carbon emission estimate was an all-time high and a 1.7 percent increase from the previous year alone. The highest average growth rates in industrial-sector CO2 emissions are projected for developing countries. As one such rising economy, India has an international obligation of reducing CO2 emissions.

S. Nagan and S. Karthiyaini observed that that the bonding of fly ash based polymer paste and aggregates is very strong and cohesive. The ultimate load capacity of G30 grade fly ash based polymer concrete columns is much higher than the M30 grade of control columns and also exhibits weaker shear failure.

Muhammad M Rahman and Prabir K Sarker carried out visual inspection, no change in appearance was observed in the columns and cylinders after direct exposure to sun and rain in varying weather conditions for more than one year. This showed the soundness of geopolymer concrete as a structural material in varying weather conditions. The general load-deflection and failure behaviors of the columns were similar to those usually exhibited by OPC concrete columns with biaxial bending.

Prabir Kumar Sarker said that bond performance of GPC is better than that of OPC concrete. Pull out loads increase with increasing embedment length, but the average bond strength decreases due to the splitting failure mode because of the nonlinear distribution of the bond along the embedment length.

Weena Lokuge and Warna Karunasena observed that increased heat curing time enhanced the unconfined compressive strength of fly-ash-based geopolymer concrete. They investigated that GFRP confinement gives better ductility levels than CFRP confinement for all the mixes of geopolymer concrete. Dr. C. AntonyJeyasehar Dr. M. Salahuddin were manufactured the Geopolymer concrete with low calcium fly ash with different molarities of NaOH. The geopolymer concrete with steam curing at 750C increases the strength by 35-50 percent when compared to geopolymer concrete without steam curing. They stated that the strength of geopolymer bricks can be brought to the level of ordinary bricks by using lower molar solutions of NaOH

Biruk Hailu Tekle, Amar Khennane, and Obada Kayali said that bond performance of GPC is better than that of OPC concrete. Pull out loads increase with increasing embedment length, but the average bond strength decreases due to the splitting failure mode because of the nonlinear distribution of the bond along the embedment length.

Fig.2 Snapshot of sodium hydroxide pellets

## 2. GEOPOLYMER PRODUCTION

### Mixture Proportions of Geopolymer Concrete

The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminium oxides in the low-calcium fly ash reacts with the alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, fine aggregates, and other un-reacted materials together to form the geopolymer concrete. As in the case of Portland cement concrete, the coarse and fine aggregates occupy about 75 to 80% of the mass of geopolymer concrete. The influence of aggregates, such as grading, angularity and strength, are considered to be the same as in the case of Portland cement concrete [Lloyd and Rangan, 2009]. Therefore, this component of geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete.

Studies have been carried out on fly ash-based geopolymer concrete. The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste. Research results [Hardjito and Rangan, 2005] have shown the following:

- Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of geopolymer concrete.
- Higher ratio of sodium silicate solution-to-sodium hydroxide solution ratio by mass, results in higher compressive strength of geopolymer concrete.
- The slump value of the fresh geopolymer concrete increases when the water content of the mixture increases. Superplasticizers may assist in improving workability.
- As the H2O-to-Na2O molar ratio increases, the compressive strength of geopolymer concrete decreases.

As can be seen from the above, the interaction of various parameters on the compressive strength and the workability of geopolymer concrete is complex. In order to assist the design of low-calcium fly ash-based geopolymer concrete mixtures, a single parameter called „water-to-geopolymer solids ratio" by mass was devised. 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 water used in the making of the sodium hydroxide solution, and the mass of extra water, if any, present in the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids used to make the sodium hydroxide solution, and the mass of solids in the sodium silicate solution (i.e. the mass of Na2O and SiO2).

Tests were performed to establish the effect of water-to-geopolymer solids ratio by mass on the compressive strength and the workability of geopolymer concrete. the compressive strength of geopolymer concrete decreases as the water-to-geopolymer solids ratio by mass increases. This test trend is analogous to the well-known effect of water-to-cement ratio on the compressive strength of Portland cement concrete... The proportions of two different geopolymer concrete mixtures used in laboratory studies are given in Table1. The details of numerous other mixtures are reported elsewhere

Table 1. Geopolymer Concrete Mixture Proportions

| **Material** | **Mixture 1 (kg/m$^3$)** | **Mixture 2 (kg/m$^3$)** | **Mixture 3 (kg/m$^3$)** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **Coarse Aggregate** | 1294 | 1294 | 1294 |
| **Fine Aggregate** | 554 | 554 | 554 |
| **Fly Ash** | 408 | 408 | 408 |
| **Sodium silicate solution** | 103 | 103 | 103 |
| **Sodium hydroxide solution** | 8M | 10M | 12M |

With regard to alkaline liquid-to-fly ash ratio by mass, values in the range of 0.30 and 0.45 are recommended. Based on the results obtained from numerous mixtures made in the laboratory over a period of six years, the data given in Table 2 are proposed for the design of low-calcium fly ash-based geopolymer concrete. Note that wet-mixing time of 4 minutes, and steam-curing at 60C for 24 hours after casting are proposed.

The design data given in Table 2 assumes that the aggregates are in saturated-surface-dry (SSD) condition. In other words, the coarse and fine aggregates in a geopolymer concrete mixture must neither be too dry to absorb water from the mixture nor too wet to add water to the mixture. In practical applications, aggregates may contain water over and above the SSD condition. Therefore, the extra water in the aggregates above the SSD condition must be estimated and included in the calculation of water-to-geopolymer solids ratio given in Table 2. Mixes with aggregates not prepared to SSD condition have been found to produce geopolymer with high compressive strength and good workability. The design data given in Table 2 assumes that the aggregates are in saturated-surface-dry (SSD) condition. In other words, the coarse and fine aggregates in a geopolymer concrete mixture must neither be too dry to absorb water from the mixture nor too wet to add water to the mixture. In practical applications, aggregates may contain water over and above the SSD condition. Therefore, the extra water in the aggregates above the SSD condition must be estimated and included in the calculation of water-to-geopolymer solids ratio given in Table 2. Mixes with aggregates not prepared to SSD condition have been found to produce geopolymer with high compressive strength and good workability.

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Table 2: Data for Design of Low-Calcium Fly Ash-Based Geopolymer

| Water-to-geopolymer solids ratio, by mass | Workability | Design compressive strength (MPa) |
|---|---|---|
| 0.16 | Very Stiff | 60 |
| 0.18 | Stiff | 50 |
| 0.20 | Moderate | 40 |
| 0.22 | High | 35 |
| 0.24 | High | 30 |

## 3. EXPERMENTAL TEST RESULTS AND DICUSSION

### 3.1Test on fresh concrete

The fresh fly ash-based geopolymer concrete was light in color and shiny in appearance (fig 3.5). The mixtures were usually cohesive. The workability of both geopolymer and traditionally vibrated concrete were measured by means of the conventional slump test

Table 3 shows the varies slump value

| S.NO | Slump Value | Molarity Range |
|---|---|---|
| 1 | 156 | 8M |
| 2 | 158 | 10M |
| 3 | 162 | 12M |

Fig.1. Slump value of different molarity

### Compressive Strength Test

Compressive strength of concrete is defined as the load, which causes the failure of a standard specimen. (Ex. 150 mm cube according to IS) divided by the area of cross section in uniaxial compression under a given rate of loading. The test of compressive strength should be made on 150mm size cubes. Nine specimens were used for compression testing for each batch of mix, each to check 7days, 14days and 28days compressive strength of concrete. Clean and surface dried specimens were placed in the testing machine. The platen was lowered and touched the top surface of the specimen, the load was applied gradually and maximum load was recorded.

Table 4 Compressive strength of various mixes

| S.NO | Mix | Compressive Strength in N/mm$^2$ | | |
|---|---|---|---|---|
| | | 7$^{th}$ day | 14$^{th}$ day | 28$^{th}$ day |
| 1 | RGCSS-1 | 31.26 | 36 | 41.04 |

| | | | | |
|---|---|---|---|---|
| 2 | RGCSS-2 | 39.17 | 40.63 | 45.76 |
| 3 | RGCSS-3 | 46.12 | 53.63 | 57.63 |

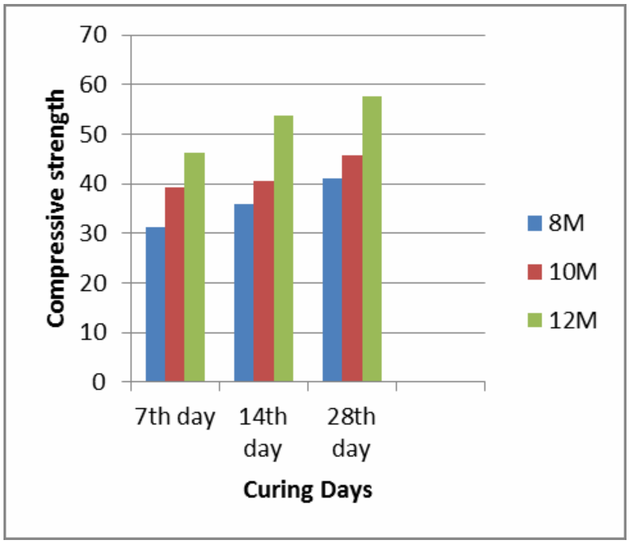


Fig.2. Compressive Strength of various geopolymer mixes

**Split Tensile Strength Test**

The determination of the splitting tensile strength of cylindrical concrete samples such as molded cylinders and drilled cores is outlined in this procedure. A diametric compressive load will be applied along the length of the sample at a continuous rate until failure occurs. This loading induces tensile stresses on the plane containing the applied load, causing tensile failure of the sample. The splitting tensile strength will be determined by dividing the maximum applied load by the appropriate geometrical factors.

Table 5 Split tensile strength of cylinders

| S.NO | Mix | Tensile Strength in N/mm$^2$ | | |
|---|---|---|---|---|
| | | 7$^{th}$ day | 14$^{th}$ day | 28$^{th}$ day |
| 1 | RGCSS-1 | 5.34 | 8.98 | 10.39 |
| 2 | RGCSS-2 | 7.59 | 9.20 | 12.43 |
| 3 | RGCSS-3 | 10.56 | 10.94 | 11.40 |

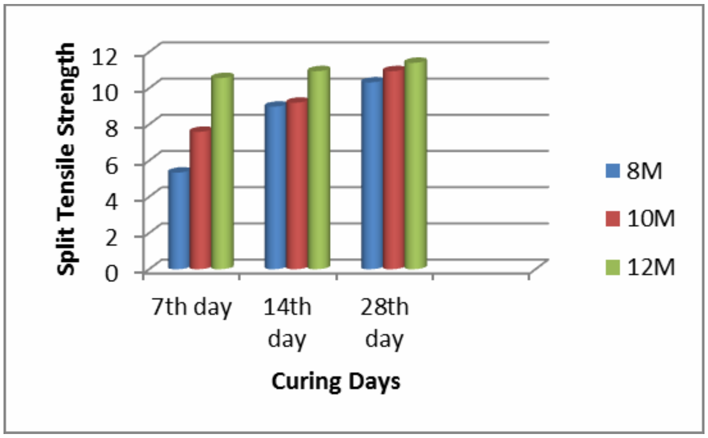


Fig.3. Split tensile strength of various geopolymer mixes

**4. Instrumentation and Testing Procedure**.

All specimens were tested in a compression testing machine of capacity2000 KN. The specimens were loaded into the testing frame until failure point and exerted under axial compression. All the columns were tested under similar conditions.

**5. COMPRESSIVE STRENGTH OF COLUMN**

Compressive strength is one of the most important properties of concrete. Failure of concrete under compression is a mixture of shear failure and crushing. The compressive strength varies as a function of both cement paste and fibers. Higher binder ratio gives higher compressive strength.

**5.1Mix proportions of concrete**

Mix design for M30 were prepared as per IS 10262-2009 with minimum water cement ratio to obtain maximum compressive strength.

Casting of concrete with adequate amount of each ingredient and with different percentage of glass fiber was done for compressive strength

Table.6. Compressive strength of control specimen and GFRP Specimens at 28$^{th}$ day

| S.NO | Specimen details | Failure load(KN) | Compressive strength (MPa) |
|---|---|---|---|
| 1 | CS-1 | 420 | 26.22 |
| 2 | CS-2 | 426 | 28.72 |
| 3 | RGCCS(8M)-1 | 852 | 44.44 |
| 4 | RGCCS(10M)-2 | 860 | 46.22 |
| 5 | RGCSS(12)-3 | 862 | 48.12 |

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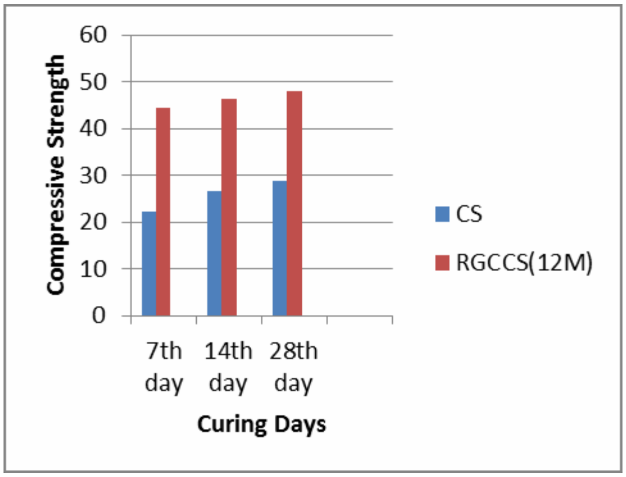


Fig.4. Compressive strength of control specimen and RGCCS

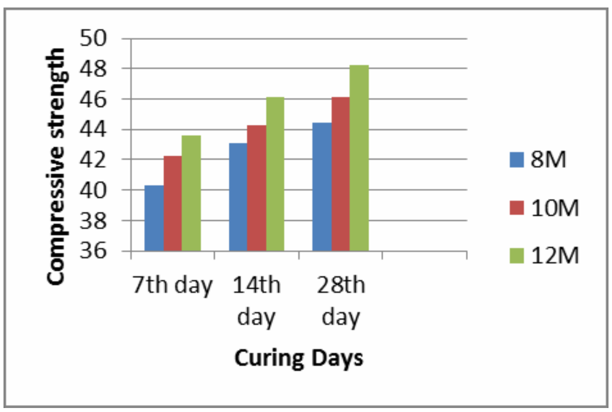


Fig.5. Compressive strength of various molarities of RGCCS

**6. C0NCLUSION**

Based on the above study the following results are obtained Wrapping of GFRP sheets with columns increasing the compressive strength of columns. It also showed that wrapping layers increases the level of confinement. Load carrying capacity of control specimens is less than when compared to geopolymer fiber reinforced polymer columns Use of GFRP in concrete compression members produces an increase in strength. Fly ash based Polymer concrete columns and ordinary concrete columns, it can be concluded that the bonding of fly ash based polymer paste and aggregates is very strong and cohesive. The constituents of GFRP include high-quality corrosion resistant vinyl ester resin that increases the lifespan of a concrete structure

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