Stress strain experimental analysis of geopolymer concrete

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Abstract. The mechanical properties and Modulus of Elasticity (MoE) of fly ash and Ground Granulated Blast Furnace Slag (GGBS) based Geopolymer Concrete (GPC) are presented in this paper. It has been used the eight molarity concentrations of Sodium Hydroxide and alkaline liquid ratio with the ratio of 2.50. We have analyzed the stress-strain characteristics and flexural, compressive and split tensile strengths for the GPC20, GPC40 and GPC60 grades. The experimental analysis was performed on the 150×150×150mm cubes and 100×100×500mm prisms and 150×300mm cylindrical GPC specimens. Testing has been performed and noted that the superior mechanical characteristics and evaluated stress-strain relationships of flyash and GGBS based GPCs in ambient curing environment. The MoE has been varied due to the increase in GPC grade. Finally, we have proposed the equation for determining the MoE which depends on compressive strengths GPC.

1. Introduction

The requirement for concrete as a building material has seen a consistent increment in usage owing to in situ adaptability, ease of usage, durability, fire resistance, and high strength. However, cement, the binders of aggregate in concert is expensive and causes pollution during the manufacturing process. Researchers attempted to produce substitutes for cement like cement-free concrete. It consists of replacement of cement by GGBS and flyash where these are the byproducts generated from iron and coal industry [1]. In general, it is produced using waste materials like “fly ash and GGBS” with the alkaline solutions, which is the polymerization processing that differ from OPC concrete. While GGBS consists of calcium along with silica, alumina and has pozolanic properties, which is more suitable for geopolymer concrete material, fly ash has more amounts of alumina and silica. Silica, alumina and calcium are added to the alkaline activator solution that forms the binding-responsible aluminosilicate hydrate gel and calcium silicate hydrate gel.

In the synthesis of geopolymers, there are two types of essential raw materials, solids containing aluminosilicate and alkali-silicate solution. In alkali-silicate medium, aluminosilicate solids function as sols. A sol-gel matrix is formed by sol-liquid and is usually done in sol-gel methodology. The commonly used kaolinite and calcined kaolinite or metakaolinite are the sources of aluminosilicate. Others include natural aluminosilicate minerals and industrial waste-based materials, such as blast furnace slags and fly ashes. Dali Bondar et al. [1] has suggested that for geopolymeric concrete generation, no temperature higher than 750 degrees centigrade is ever required. Alwis Deva Kirupa & Sakthieswaran [2] Five to eight percent of the world's synthetic Greenhouse gas outflows are from the cement industry itself. The ozone harming substance outflows are diminished by 80% in GPC by
replacing the customary portland bond producing, as it does not include carbonate consumes. Researchers have fundamentally analyzed the different parts of their suitability as binder system.

Pradip Nath [3] studied Geo polymer which attains strength by activating alkaline solution and calcined materials at elevated temperature, and it provides a 3-D polymeric chain and ring structures entailing Si-O-Al-O bonds. The alkali activation of waste substances has ended up a vital vicinity of studies in lots of laboratories due to the fact that it is far viable to apply these substances to synthesize cheaper and ecologically sound cement like construction materials. Sourav Kr. Das et al. [4] has higher fineness of fly ash gives better compressive strength because of more surface area with more Si-Al bond for polymerization. A higher ratio of Na$_2$O and SiO$_2$ gives better strength. The ratio was 2.5. Generally, heat cured GPC gives higher strength but it can be obtained at ambient temperature by replacing fly ash content by GBFS. GPC can be used for rehabilitation and retrofitting works because of its excellent properties. The property of very early attainment of strength helps to use it in road works. Song et al. [5] found GPC is a fine substitution for conventional cement concrete which is advantageous over the problems related to cement manufacturing and disposal of fly ash/ GGBS in a sustainable manner by reducing problems to environment and this makes the GPC eco-friendlier than the conventional cement.

Amit Rai et al. [6] investigated FRC or Fiber strengthened cement, it is a reinforced blend of concrete with randomly circled little strands where at the season of blending filaments are scattered and circulated randomly in the concrete. FRC is having a remarkable flexural-rigidity, protection from spitting, impact resistance, brilliant permeability and furthermore frost protection. The filaments utilized as a part of FRC have numerous benefits; these can expand the toughness, protection from plastic shrinkage breaking of the mortar and shock protection. Steel strands utilized can expand the structural quality to decrease heavy steel requirements and furthermore solidify defrost protection of the concrete is improved. Crack widths are decreased by enhancing the strength. Impact resistances are enhanced by including Polypropylene and Nylon fibres.

Kamal Neupane et al. [7] directed to decide the mechanical and building properties of different evaluations of GPC contrasting against a similar review of conventional portland cement concrete of same evaluations. Interrelationships between various mechanical properties of portland bond concrete, for example, compressive strength and uniaxial rigidity, compressive quality and flexural elasticity and so on are checked and characterized in AS3600. Uniaxial elastic and flexural rigidities achieved by GPC are higher than the recommended value by AS 3600 for a similar grade of concrete. However, modulus of elasticity is observed to be relatively equivalent with the computed incentive from AS 3600 and similar grade of OPC concrete.

Kumaravell & Thirugnanasambandam [8] found that the outflow of C0$_2$ causes pollution during the manufacturing of OPC. The by product from coal industry, i.e. fly ash, is rich in silicate and alumina which responds with alkaline solution for create alumina silicate gel that ties the aggregate to deliver a decent concrete. With the ascent in fly ash fineness, the compressive quality surges, and in this way reduces the porosity. The bars are casted at a length of 3000mm and static load is connected up to failure. Contrasting with theoretical results aftereffects of the heap removal reaction of the geopolymer solid beams and control beams are prepared. For GPC pillars, the deflection at various stages including service load and peak load was high. The conclusions from the trials completed on the flexural behavior of the reinforced concrete bars and customary Portland bond solid beams are,

1. The slump estimation of GPC is 130mm without the expansion of water and the compressive quality of cement concrete and GPC shapes obtained as 23.5 N/mm$^2$ and 26.36 N/mm.
2. RCC and GPC bars are having relatively comparative curvature in the load deflection characteristics. The service load for RCC pillar is 12.5KN, it is marginally higher here with 15 KN.
3. The extreme load limit of GPC beam is 16.27%, which is higher than that of RCC beams.
4. The crack patterns and failure for GPC bars are like those of the RCC beams.

Annapurna et al. [9] did examination work on GPC and reported in the present paper is a stage forward toward the path to empower the improvement of GPC for its wide application in development
industry. The present paper portrays trial work and scientific work relating to Finite Element Analysis utilizing ANSYS programming to simulate the flexural conduct of Reinforced Geo Polymer Concrete Beams. The standard test examples viz., cube, cylinder and prism were casted to study compressive strength, flexural quality, stress strain conduct, and Poisson's ratio. These properties are fused for demonstrating the flexural behavior of Reinforced GPC Beams utilizing ANSYS programming, which will simulate the load deflection behavior, crack pattern, extreme load and so on. The Finite Element Analysis included demonstrating of geo polymer composite reinforced concrete beams with the measurements and properties comparing to beams tried experimentally in the research center. By taking the benefit of the symmetry of the bar and loading, one fourth of the full beam was utilized for finite element modeling. This approach reduces computational time and computer disk space prerequisites essentially. The accompanying conclusions were drawn from the exploration:

a. At different phases of cracking except, at the crack theoretical model overestimates the heaps in the scope of 13 to 15%.

b. The theoretical model estimates the load at conclusive break inside satisfactory limit of - 3%.

c. At diverse phases of cracking except at failure, the practical model overestimates the redirection in the scope of 6 to 14%, thus enabling the utilization of practical model for prediction of deflection.

The information displayed by Vidivell & Mageswari [10] in this paper demonstrates that there is awesome potential for use of fly ash in concrete in several structures. It has been presumed that 20% fly ash remains could be joined as cement substitution in concrete. Since the solid examples containing 10% and 20% fly ash were analyzed by SEM represent to thick microstructure which expands the strength in concrete.

From the survey of existing literature it reveals that good research work was carried out for the use of inorganic geopolymers (Abraham, Arumairaj et al. Celik, Yilmaz et al. Reddy, Dinakar et al.) [26]-[28]. They have been utilized in aerospace (Khan, Hameed Sultan et al.) [29], non-ferous foundaries (Vázquez-Rodríguez, Valadez-Ramos et al.) [30] and metallurgy, civil engineering (Bai and Colombo, Dutta and Robi [32] and plastic industries. The synthesis and applications of geopolymers are explained in many research works (Ding, Chang et al. De Rossi, Simao et al., Guo, Ma et al.) [30]. Geopolymer cement is the environmentally friendly cement (Maddalena, Roberts et al. Gettu, Patel et al. [33]. Geopolymerization is a geo-synthesis which depends upon the aluminum ion ions to bring crystallographic and chemical change in the silica backbone (Rao et al.) [10]. The geopolymer cement is an alternate for convensional ordinary Portland cement (Pimraksa, Chindaprasirt, Singh, Tan ) [31]. It minimizes the CO₂ emission (Suwan, Hanjitsuwan et al. Verma and Kumar). It uses the waste material i.e. fly ash that acts as binder which is abundant and environment friendly (Dutta and Robi, Srivastava, Srivastava et al.) [32], [33].

Alkali activated cements have been in use from 1940’s (Roy). However, the use of alkalis in achieving pozzolonic action in materials can be traced to ancient times also. The industrial revolution and increased use of steel by mankind led to production enormous quantity of blast furnace slag. Hence slag cements gained popularity and alkali activation of slag led to formation of zeolite like materials which are more durable when compared to calcium silicate hydrate. In common terms alkali activation can be defined as a chemical process that transforms glassy structures into very compact well-cemented composites.

Rashad (2013 & 2014) reviewed various work carried out on the effect of different additives on workability of alkali activated slag and fly ash. It was found that sodium lignosulfonate or sulfonated naphthalene based superplasticizers failed to improve the workability, whereas polycarboxylate and vinyl copolymer based superplasticizers improved the workability to an extent of alkali activated slag. However, Superplasticizer of lignosulphonates-based improved the workability of alkali activated fly ash.Vijai et al (2015) conducted studies on fiber reinforced geopolymer concrete composite beams. Steel rebars, various types of fibers such as steel, polypropylene and glass fibers in different volume fractions were incorporated. Experimental results were compared with Nonlinear finite element analysis.
From the literatures it is clear that geopolymer concrete can be used as structural concrete. However, few modifications are needed in order to incorporated the difference in fresh property behaviour such as viscosity, properties controlling setting time etc. At present there are few structural grade applications of geopolymer concrete around the world. It is thought worthwhile to mention these examples here, since, it would be a great source of confidence and encouragement for researchers and engineering community to look up to geopolymer concrete as a promising future material. Another important practical application that has been carried out is the runway at Brisbane west wellcamp airport. The geopolymer concrete mix achieved a specified flexural strength of 4.8 MPa. Again a combination of GGBS and Fly ash was used. More than 30,000 cubic meters of geopolymer concrete was used in this project.

Geopolymer being a vast and current field of research, ample of literatures are available. A trend can be traced in the type of literatures published by various authors across times. Initial literatures were focused on understanding the geopolymer mechanism, the chemistry and microstructural analysis of geopolymers. Later the attention shifted to applications of geopolymers. Among various applications, utilization of geopolymers as binders in concrete has emerged as a promising area. Hence literatures on geopolymer concrete can be found from 1990’s. Prof. B. V. Rangan of Curtin university, Australia was probably the first person to work and publish on fly ash based geopolymer concrete. Later several researchers started working of geopolymer concrete. The geopolymer concrete technology has reached a stage where people have started applying it in the field. Few structures that are currently built and being used have been documented here. The next stage of geopolymer concrete can be attributed to making geopolymer concrete user friendly, developing design guidelines and further in situ applications, towards this, researchers have started working towards blending of source materials for geopolymer concrete.

The literatures clearly indicate the opportunities geopolymer technology and geopolymer concrete in particular offers to the future in civil engineering. It also indicated the broad database that needs to be developed on various properties of geopolymers in order to arrive at design parameters and methods (proportioning, structural designs).

2. Materials and Methods

2.1 Binder
Flyash was collected from the Thermal Power Station and GGBS collected from Cement factory were used for the experimental work; its chemical compositions are expressed in Table1. The specific gravities of Fly ash and GGBS are given by 2.17 and 2.90.

| Compositions | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | SO$_3$ | CaO | MgO | Na$_2$O | LOI |
|--------------|--------|-------------|-------------|-------|-----|-----|--------|-----|
| Fly ash      | 60.110 | 26.530      | 4.250       | 0.350 | 4.0 | 1.250 | 0.220  | 0.880 |
| GGBS         | 34.060 | 20          | 0.80        | 0.90  | 32.60 | 7.890 | NIL    | NIL  |

2.2. Aggregate
River sand was used as the fine aggregate (FA). Crushed rock was used as a coarse aggregate (CA). The specific gravities of FA and CA are 2.58 and 2.70 with fineness moduli of 2.70 and 6.360 [11]

2.3. Alkaline Activator Solution
A mixture of Na$_2$SiO$_3$ and NaOH at a mass ratio of 2.50 was used. NaOH was acquired from chemical factories in a pellet form and Na$_2$SiO$_3$ in a liquid form. A NaOH solution was used with a concentration of 8M. The Na$_2$SiO$_3$ solution was used with a chemical composition of Na$_2$O=8.5%, SiO$_2$=26.5%, $H_2$O= 65% by mass. The Na$_2$O/SiO$_2$ (molar ratio) of this solution is 0.60.

2.4. Superplasticizer
CONPLAST SP 430, obtained from Chemical factories, was used as a superplasticizer (SP) which improves the workability of the mixture. The dosage of SP shown in Table 2 is as per the weight of the binder.

2.5. Experimental analysis

The experimental study consists of properties of ambient cured fly ash and GGBS-based GPC. For GPC20, GPC40 and GPC60, the mechanical properties and MoE were calculated. The MoE was measured for cylinder specimens with a diameter of 150 mm and a height of 300 mm. In order to determine their MoE and their corresponding mechanical properties, 3 cubes of 150×150×150mm, 6 cylinders of 150mm diameter and 300mm height, and 3 prisms of 100×100×500mm were cast for each combination. The proportions of the mix are shown in Table 2. The proportion of the mix taken from literature [10] is as follows.

Table 2: Mix The Geo-polymer Concrete Proportions

| Mix   | Fly ash | GGBS | Fine Aggregate | Coarse Aggregate | Alkaline So. | Na2SiO3 | NaOH | SP(*) |
|-------|---------|------|----------------|------------------|--------------|---------|------|-------|
| GPC20 | 252     | 108  | 774            | 1090.80          | 198          | 141.42  | 56.57 | 3     |
| GPC40 | 270     | 180  | 760            | 972              | 248          | 177.15  | 70.85 | 4     |
| GPC60 | 260     | 260  | 717.60         | 915.20           | 286          | 204.28  | 81.72 | 5     |

All units are in kg/m³

Preparation of specimens from the GPC

The weight of the concrete ingredients was batched according to the proportions of the mix shown in Table 2. Initially, in the “Hobart mixer" for 3mins, the CA and FA's are dry blended. For around 3 minutes, the binder is applied to the aggregater and combined; the prepared alkaline is mixed along with the SP. To obtain the homogeneous mixture, it is blended for 4mins.

Testing

The GPC MoE was calculated from the "stress-strain curve as a stress to strain ratio up to the elastic limit (secant module)". Testing was achieved using a Tinius-Olsen machine with a 2000kN capacity. The MoE for the geopolymer cylindrical specimen is calculated with the procedure specified in ASTM standards. The following equation was used to estimate the MoE of the geopolymer cylindrical specimen [10][11].

3. Result and Discussion

3.1. Workability of GPC

The workability of the geopolymer concrete for the different mixtures is given in Table 3. This might be due to faster polymerization at a higher GGBS content, which results in decreased workability [15]-[18].

Table 3: Work ability of GPC

| GPC   | Binder Proportions (Binder: FA: CA: Alkaline solution) | Slump(mm) |
|-------|--------------------------------------------------------|-----------|
| GPC20 | 1:2.15:3.05:0.55                                       | 122       |
| GPC40 | 1:1.69:2.16:0.50                                       | 110       |
| GPC60 | 1:1.38:1.76:0.50                                       | 78        |

3.2. Mechanical properties

The compressive, flexural and split tensile strengths were determined after 28days of curing, and the obtained results are expressed in Table 4. The values in Table 4 are the averages of the three specimens.

Table 4: Mechanical Properties of GPC.

| GPCMix | Binder Content (kg/m³) | Compressive Strength (MPa) | Split Tensile Strength (MPa) | Flexural Strength (MPa) |
|--------|------------------------|----------------------------|----------------------------|-------------------------|

5
For the compressive strengths of 20 MPa (GPC20), the fly ash and GGBS proportions were selected in a ratio of 70:30. For the GPC40 and GPC60, the fly ash and GGBS proportions were 60:40 and 50:50 respectively. As seen in Table 4, the increase in compressive strength is due to the increase in the binder content and the increase in the GGBS content. With higher binder content, a greater amount of alkaline solution is available for polymerization, which results in the increased concrete strength [18], [19], [20], [21]. Split tensile and flexural strength testing is conducted to assess the tensile strength of concrete. The flexural strength of the GPC samples was determined by loading at two points perpendicular to the loads with the longitudinal axes [22],[23]. The split tensile and flexural strengths of the GPC specimens cured under ambient conditions are shown in Table 4. The results concluded that with an increase in the slag content, the split tensile and flexural strength of the GPC increased. With the inclusion of GGBS in the binder, the tensile strength output rate improved dramatically. Compared with that of fly ash, the slag reaction is stronger, resulting in a higher strength [24].

With the rise in the compressive strength of the GPC, a similar increase is seen in its corresponding split tensile and flexural strength. The results obtained showed that as in the case of fly ash-based geo-polymer concrete, GPC mixes with GGBS and fly ash as a binder show strong mechanical properties under ambient curing conditions without the need for heat curing [25]. Our results are in line with [13]. With the increase in the compressive strength of the GPC, its corresponding split tensile and flexural strength is seen to increase in a similar manner. The results obtained indicated that the GPC mixes with GGBS and fly ash as a binder indicate good mechanical properties under ambient curing conditions without the requirement for heat curing as in the case of fly ash-based geo-polymer concrete [25]. Our findings are in agreement with (Siddique, 2007) [13].

### 3.3. Modulus of Elasticity

The stress-strain curves of the geopolymer concrete tested under compression are represented in Figure 1, and the MoE results are expressed in Table 5.

![Stress-Strain Curve of geo-polymer concretes](image.png)

**Fig. 1. Stress-Strain Curve of geo-polymer concretes**

Figure 1 shows that as the compressive intensity increased, the overall stress was improved. And the decrease in the overall strain was observed with the rise in the strength of compression. More ductile than GPC40 and GPC60, GPC20 is The comparable graph was found to a certain degree in the stress-strain activity of the GPC40 and GPC60.

### Table 5: MoE of the GPC mixes.

| GPCMix | MoE (GPa) | Stiffness (N/mm²) |
|--------|----------|------------------|
| GPC 20 | 10.586   | 7676             |
| GPC 40 | 14.110   | 15342            |
| GPC 60 | 21.212   | 20907            |
The GPC MoE is proportional to the GPC compressive strengths, but the GPC elastic modulus for equivalent compressive strengths is comparatively lower than the OPC concrete. With the compressive strengths rising from 20MPa to 40MPa, the MoE increased by 33%. The MoE increased by 50 percent with the rise in compressive intensity from 40MPa to 60MPa.

Based on the compressive strength of concrete for fly ash and GGBS-based geo-polymers, an equation is proposed for measuring the MoE from the experimental results. With an increase in the MoE and compressive forces of the concrete, the stiffness increases. This may be attributed to an improvement in the paste's volume, which resulted in the concrete's improved homogeneity (a decline in the voids) by increasing its compressive strength and stiffness. "An increase in GGBS content raises the compressive strength while lowering the stiffness at the same time." When the compressive strength increases from 20MPa to 40MPa, the stiffness also increases by 100 percent, and the stiffness increases by 36 percent as it increases from 40MPa to 60MPa.

4. Conclusion
From this research work, it is noticed that if GGBS increases then the compressive strength of blend increases whereas workability reduces. By replacing the flyash with GGBS is obtained that a suitable option for oven curing. The maximum strain decreases with the increment of compressive strengths of GPC, and the post peak behavior changes from ductile to brittle failure. Also MoE increases with the compressive strengths. We have proposed a equation for evaluating the MoE based on the compressive strengths. Also, stiffness of GPC increases with the compressive strengths.

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