Research on shear strength of geopolymer concrete by using fly ash

Sachin A. Daur\textsuperscript{1a}, Madhulika Sinha\textsuperscript{2b}

\textsuperscript{1}Construction Management @P H C E T Engineering College, Rasayani, New Mumbai, India
\textsuperscript{2}Professor @P H C E T Engineering College, Rasayani, New Mumbai, India.

Email: \textsuperscript{a}sachindaur13@gmail.com; \textsuperscript{b}madhulikas@mes.ac.in

Abstract: Cement is one of the most important construction materials. Cement is a backbone of civil engineering work. Development of whole world depends upon increasing infrastructure. For which cement is very necessary. Manufacturing of cement produce huge amount of carbon di-oxide and other greenhouse gases which is hazardous to the environment causes pollution. Hence it is very necessary to develop alternative binding material instead of cement for construction. Many researchers contribute their work on replacement of cement in concrete.

Keywords: Geopolymer, Fly ash, Alkaline solution, Compressive strength, Shear strength.

1. Introduction

Ash-based geopolymer concrete is a major change in the construction and concrete industry in the use of Portland cement and 100% cement material is an industrial product, i.e., fly ash. The adoption of fly-based concrete is an efficient use of the world's largest ash-filled flies as a result of coal-fired power plants.

In structural and mechanical engineering, the shear strength of a component is important in designing the size and materials to be used in the construction or construction of the component. In a reinforced concrete line, the main purpose of reinforcing bar stirrups is to increase the shear strength.

Cement is one of the most widely used materials in the world. It is an important ingredient in producing concrete. Over the past decades, more research has been done to replace cement in concrete even with debris and industrial products such as ash ash (FA) and ground granulated blast furnace slag (GGBS) to reduce the amount of greenhouse gases associated with cement production. In addition, the use of waste and industrial effluents will reduce the use of non-renewable natural resources in construction that makes concrete sustainable. The use of fly ash in the concrete industry not only has a positive impact on the environment but also enhances the resilience and economy of concrete production. However, many previous studies limit the use of additional cement materials to about 30% of cement content [1]. The whole development of a country depends on the amount of energy production and consequently its use as energy. Our country, India needs a lot of energy resources to meet the expectations of its people and its goal of becoming a developed nation by 2030. Mineral fuel plays an important role in meeting the demand for electricity generation. Coal is considered one of the major energy sources the world's richest fossil fuels. Globally, India ranks third in the world in terms of coal production and has the fourth largest coal-fired power plant (197 billion tons). It is estimated that 75% of India's total energy source is thermal when half of the coal is about 90%. About 600 million tons of coal is produced worldwide each year, with Fly ash generation estimated at 500 MT (60-78%) of total ash production [2].

1.1 The need to learn

1. Find another OPC method in concrete.
2. Produce a strong infrastructure that is able to design a life that is measured for hundreds of years.
3. Reduce CO2 emissions and produce eco-friendly concrete mix.
4. Protect water sources and areas above freshwater by removing fly ash dumps.
5. Producing a product that works well for the price.
6. Producing higher strength concrete than standard Portland cement concrete.

1.2 Purpose and performance of the work
1. Production of ash-based geopolymer concrete with varying percentage of GGBS.
2. To study the effect of GGBS ‘expansion on its new and stronger geopolymer concrete features.
3. Testing the compressive strength and shaving power of geopolymer concrete with various percentages of GGBS.
4. Determining the total percentage of fly ash and GGBS in the result.

2. Book responsibility:
The purpose of this section is to review the previous work on geopolymer concrete by paying particular attention to material structures and their structural behavior.

2.1 B. Laxman Raju et al. [1] investigated the “Interface Shear of Fly ash and GGBS Based Geopolymer Concrete” This article presents an experimental study conducted to determine the shear strength of geopolymer concrete. In addition, it was proposed to evaluate the validity of existing statistics such as Birkeland and Birkeland, Mattock and the Design ACI 318 code, developed by standard Portland concrete to measure the shear volume of geopolymer concrete. Push off Samples were used to study the shear strength at the interface. Both reinforced concrete samples and reinforced concrete samples were used for the investigation. It was noted that the shear strength of geopolymer concrete is higher than that of OPC concrete. The presence of reinforced transversely shear plane produced an increase of about 29% against shear resistance against slipping.

2.2 Satyajit Kumar et al. [2] Discuss “The investigation of fly ash polymer composite” Industrial waste, such as ashes that cause environmental problems, is widely used as a building material due to its low cost and easy availability. But the main disadvantage of these bricks is their low strength. Therefore, more research is being done to increase the strength of these bricks. Current research work is under way to develop a new systematic process of producing composite ashes that will have high compression strength. Here fly-ash is mixed with Cold setting resin in different proportions and water is treated at different temperatures to find a solution in the brick industry. Pressure strength, durability, water absorption, density and thermal performance of fly ash-resin powders obtained under the best test conditions are 11.24 Mpa, 47.37HV, 19.09% 1.68 g / cm3, and 0.055 W / mK respectively. Slide behavior is also under investigation. The structural correlations of these compounds are studied using X-ray diffraction, FTIR analysis and scan electron microscopy.

2.3 Benny Josef et al. [3] learned from "Interface shear strength of fly ash based geopolymer concrete." This current paper and experimental study conducted to evaluate the impact of composite content on the shear strength of a geopolymer concrete connector and compare it with that of standard Portland cement concrete. In addition, it is proposed to consider the suitability of the existing OPC concrete figures to assess the shear capacity of the geopolymer concrete. A push-off template was used to study the shear strength of the interface. Both reinforced and non-reinforced concrete were used in the study. It has been observed that the shear strength of geopolymer concrete is lower than that of OPC concrete and that the combined content of less than 65% in geopolymer concrete leads to a significant reduction in shear volume. A 50% reduction in value has been proposed to predict the shear strength of the geopolymer concrete.
2.4 U-Subhash V. Patankar et al. [4] Discuss “The mixed design of fly ash based geo-polymer” Geopolymer is a new development in the concrete world where cement is completely replaced by pozzolanic materials such as fly ash and is activated by highly alkaline solutions to act as a bond in concrete mixing. In order to select the appropriate ingredients for geopolymer concrete to achieve the desired strength in the required performance, exploratory research has been conducted to plan the geopolymer concrete and the composite design process is proposed on the basis of quantity and fineness of fly ash, sum of water, grated finely ground aggregate, and fine to total aggregate proportion. Sodium silicate solution containing Na2O = 16.37%, SiO2 = 34.35% and H2O = 49.28% and sodium hydroxide solution with 13M concentration were maintained throughout the study. A water-to-geopolymer binder scale of 0.35, an alkaline-to-fly ash level of 0.35 and a sodium silicate-to- sodium hydroxide ratio of 1.0 were concentrated on the basis of performance and pressure cube pressure. The performance of the geopolymer concrete is measured by the use of a flow table and 150mm side cubes are cast and tested for compression strength after the specified heating time of the oven. The oven temperature is maintained at 60 °C for 24 hours duration and tested 7 days after heating. It is recognized that performance results and pressures are closely related to the required level of performance and pressure. Therefore, the proposed method is used to design a standard and standard geopolymer concrete.

2.5 Rohit Zende et al. [5] read "research on fly ash and GGBS-based geo-polymer concrete under ambient concrete" Construction has been the most important human activity since mediaeval time. Concrete is widely used and reliable building materials. Some of the challenges in the construction industry are global warming and a shortage of building materials. One of the ways to change concrete materials is the use of geo-polymer which helps to apply a very small amount of cement to the concrete. This project deals study of the mechanical properties of geopolymer concrete with different mixes. In this study, Geopolymer concrete is produced by fly ash and sodium hydroxide and sodium silicate are used as binder. Fly ash is replaced by GGBS by 25%, 50% and 75% to improve various concrete structures. In this project, compound formation was performed at 11M and 13M sodium hydroxide concentration. A solution of 2.5 alkaline activator and an alkaline solvent fluid 0.40 was selected for this study. Template size 150x150x150mm cubes, 150x300mm cylinders and 500x100x100mm prisms are made and geo-polymer concrete templates are treated at ambient temperature for 7 days and 28 days. The treated specimens are then tested for compressive strength, dividing force and consecutive bending strength.

3. Experimental work and methodology:
3.1 Material used:
For the preparation of fly ash based geo-polymer concrete following ingredients are used as shown in figure 1.

3.1.1 Fly ash:
In this project work fly ash as shown in figure 2 was obtained from Sofia Thermal Power Plant Nandgao Khandeshwar, Amravati district, Maharashtra state. The unprocessed fly ash having specific gravity of 1.84 calculated from pycnometer test. Chemical composition of fly ash which is use as a binder in geo-polymer concrete as shown in table 1.

3.1.2 Ground granulated blast slag (GGBS):
Ground-granulated blast-furnace slag (GGBS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from blast furnace in water or steam, so produce a glassy, granulated product
that is then dried and ground into a fine powder as shown in figure 3. Ground- granulated blast furnace slag is highly cementitious and high in CHS (calcium silicate hydrates) which is a strength enhancing compound which improves the strength, durability and appearance of the concrete.

GGBS is purchase from Magma iron Pvt. Ltd. Nagpur. It is stored in tight bags. The GGBS having specific gravity 2.88. Physical properties and chemical properties of GGBS are given in table 2 and table 3 respectively:

Table 1. Chemical composition of Fly ash

| Sr. No. | Characteristics      | Fly ash (% wt.) |
|---------|----------------------|-----------------|
| 1       | Silica               | 55-65           |
| 2       | Aluminium oxide     | 22-27           |
| 3       | Iron oxide           | 5-7             |
| 4       | Calcium oxide        | 5-7             |
| 5       | Magnesium oxide      | <1              |
| 6       | Titanium oxide       | <1              |
| 7       | Phosphorous          | <1              |
| 8       | Sulphates            | 0.1             |
| 9       | Alkali oxide         | <1              |
| 10      | Loss of ignition     | 1-1.5           |

Figure 2. Fly ash

Table 2. Physical properties of GGBS

| Sr. No. | Test conducted                                      | Test result | Test method            |
|---------|-----------------------------------------------------|-------------|------------------------|
| 1       | Specific gravity                                    | 2.88        | IS 1727-1967           |
| 2       | Fineness- specific area in m²/Kg by Blaine's permeability | 320         | IS 1727-1967           |
| 3       | Residue on 45 microns                               | 3           | IS 1727-1967           |
| 4       | Residue on 90 microns                               | 7           | IS 1727-1967           |

3.1.3 Fine Aggregate
Natural sand obtained from Wardha River was used as fine aggregate which was passing through 4.75 mm IS sieve is use in this project.
1. Specific gravity of fine aggregate is 2.62.
2. Sieve analysis was conducted to the fine aggregate.
3. Water absorption for the fine aggregate is 1%.
4. Fineness modulus for fine aggregate is 3.02.
5. Specific gravity of fine aggregate is 2.62.
6. Sieve analysis was conducted to the fine aggregate.
7. Water absorption for the fine aggregate is 1%.
8. Fineness modulus for fine aggregate is 3.02.

Physical properties of Fine aggregate are as shown in table 4.

Table 3. Chemical properties of GGBS

| Sr. No. | Test conducted                        | Test result | Requirements as per IS 12089-1987 |
|---------|---------------------------------------|-------------|----------------------------------|
| 1       | Insoluble residue (max)%              | 0.23        | 5                                |
| 2       | Manganese oxide (max)%                | 0.29        | 5.5                              |
| 3       | Magnesium oxide (max)%                | 6.06        | 17                               |
| 4       | Sulphide Sulphur (max)%               | 0.58        | 2                                |
| 5       | Glass content %                       | 96          | Min 85.0                         |
| 6       | (CaO+MgO+1/3Al2O3)/(SiO2+2/3Al2O3)    | 1.14        | ≥1.0                             |
| 7       | (CaO + MgO + Al2O3)/SiO2             | 1.1         | ≥1.0                             |

Table 4. Physical properties of Fine aggregate

| Sr. No. | Characteristics | Result |
|---------|-----------------|--------|
| 1       | Aggregate type  | Natural|
| 2       | Specific gravity| 2.62   |
| 3       | Fineness modulus| 3.02   |
| 4       | Water absorption| 1%     |

Table 5. Sieve analysis on fine aggregate

| Sr. No. | Sieve size | Weight Retained | Cumulative weight retained (kg) | Weight passing (%) | Percentage weight retained (%) |
|---------|------------|-----------------|---------------------------------|---------------------|--------------------------------|
| 1       | 10mm       | 0               | 0                               | 1                   | 100                            |
| 2       | 4.75mm     | 0               | 0                               | 1                   | 100                            |
| 3       | 2.36mm     | 0.1195          | 0.1195                          | 0.8805              | 88.05                          |
| 4       | 1.18mm     | 0.3255          | 0.445                           | 0.555               | 55.5                           |
| 5       | 600 micron | 0.192           | 0.637                           | 0.363               | 36.3                           |
| 6       | 300micron  | 0.2055          | 0.8425                          | 0.1575              | 15.75                          |
| 7       | 150micron  | 0.137           | 0.9795                          | 0.0205              | 2.05                           |
| 8       | Pan        | 0.0215          | -                               | -                   | -                              |
| 9       | Total      | 1.00            | 3.0235                          |                     | 3.0235                         |

Fineness modulus of fine aggregate = Cumulative weight retain / Sum of weight retain = 3.0235/1.00 = 3.0235.
3.1.4 Coarse aggregate:
The material which is retained on BIS test sieve number greater than 4.75mm IS sieve size of aggregate is termed as coarse aggregate. The broken stone is generally used as a stone aggregate. Locally available coarse aggregate having maximum size of 20mm are used and minimum size of 12 mm are used as a coarse aggregate. The aggregate used, having rounded shape and are smooth. Specific gravity of coarse aggregate calculated by pycnometer apparatus is obtained 2.71. Water absorption test carried out in lab on coarse aggregate and it is obtained 2%. Sieve analysis was carried out to find fineness modulus of coarse aggregate as shown in table 6 and obtained fineness modulus is 2.7045.

| Sr. No. | Sieve size | Weight Retained | Cumulative weight retained (kg) | Weight passing (%) | Percentage weight retained (%) |
|---------|------------|-----------------|---------------------------------|--------------------|--------------------------------|
| 1       | 20mm       | 0.53            | 0.053                           | 9.947              | 99.47                          |
| 2       | 16mm       | 3.536           | 3.609                           | 6.391              | 63.91                          |
| 3       | 12.5mm     | 2.809           | 6.418                           | 3.582              | 35.82                          |
| 4       | 10mm       | 0.7515          | 7.1695                          | 2.8305             | 28.3                           |
| 5       | 4.75mm     | 2.626           | 9.7955                          | 0.2045             | 20.45                          |
| 6       | Pan        | 0.288           | -                               | -                  | -                              |
| 7       | Total      | 10              | 27.045                          | -                  | -                              |

Fineness modulus of coarse aggregate = Cumulative weight retain / Sum of weight retain = 27.045/10 = 2.7045.

Physical properties of coarse aggregate are tabulated in Table 7 are as follows:

3.1.5 Sodium Silicates:
The sodium silicate was purchased from Rajas chemicals Khamgao at 30Rs per kg. A sodium silicate used in this project content Na₂O=9%, SiO₂=29%, Water=63%. Physical and chemical properties of liquid sodium silicate gel are as follows:

| Chemical formula: | Na₂O* SiO₂*H₂O |
|-------------------|----------------|
| Appearance:       | Jelly          |
| Color:            | Colorless      |
| Molecular weight: | 184-254 g/mole |
| Molar ratio:      | 1:28           |
| Specific gravity: | 1.5            |
| Baume:            | 50             |
| Na₂O:             | 5.45%          |
| SiO₂:             | 31%            |
| Total solids:     | 49.50%         |
| pH:               | 12.6           |

Table 7. Physical properties of coarse aggregate
| Sr. No. | Characteristics | Result                  |
|---------|-----------------|-------------------------|
| 1       | Aggregate type  | Crushed stone           |
| 2       | Maximum size of aggregate | 20               |
| 3       | Specific gravity | 2.71                      |
| 4       | Shape of aggregate | Rounded and smooth |
| 5       | Fineness modulus | 2.7045                        |
| 6       | Water absorption | 2%                           |
3.2 Methodology

3.2.1 Mix design of geo-polymer concrete:
Geo-polymer is a new development in the world of concrete in which cement is totally replaced by pozzolonic materials like fly ash and activated by highly alkaline solutions to act as a binder in the concrete mix. For the selection of suitable ingredients of geo-polymer concrete to achieve desire strength at required workability, an experimental investigation has been carried out for the gradation of geo-polymer concrete and a mix design procedure is proposed on the basis of the quantity of fineness of fly ash, quantity of fly ash, quantity of water, grading of fine aggregate, fine to total aggregate ratio. Sodium silicate with Na2O=9%, SiO2=29%, Water=63% and Sodium hydroxide solution having 11M concentration were maintained constant throughout the experiment.

The primary difference between geo-polymer concrete and Portland cement is the binder. To form geo-polymer-paste alkaline activator solution used to react with silicon and Aluminium oxides which are present in fly ash and GGBS. This alkaline activator solution helps to bind coarse aggregate and fine aggregate to form geopolymor mix. The fine and coarse aggregate occupy nearly 75% to 80% mass of geo-polymer concrete according to literature survey as geo-polymer concrete does not have any specific mix design. The fine aggregate was taken as 30% of total aggregate. The density of geo-polymer concrete is taken 2400Kg/m3. The workability and strength of concrete are influence by properties of materials that make geo-polymer concrete. Fly ash is replaced by GGBS in range of 20%, 40%, 60%, and 80%. The ratio of Sodium silicate to sodium hydroxide is 2.5 and is kept constant throughout this study. The ratio of alkaline activator to fly ash is 0.40 kept constant. In this project work we used 11M NaOH solution.

3.2.2 Preparation of alkali solution
Alkaline activation is a chemical process in which a powdery aluminosilicate such as fly ash is mixed with an alkaline activator to produce a paste capable of setting and hardening within a reasonably short period of time.

The role of alkali activator solution is to dissolve the reactive portion of source materials Si and Al present in fly ash and provide a high alkaline liquid medium foe condensation. The alkaline activator plays an important role in geo-polymer concrete. Alkaline activator plays a fundamental role in the hydration of binders. Due to their characteristics, mortars and alkaline activated concretes can show higher mechanical resistance result than those obtained by a concrete made with OPC. The preparation of solution is done by dissolving sodium hydroxide in water. The concentration of sodium hydroxide changes with molarity. The quantity of sodium hydroxide solution with a concentration of 11M is calculated. The mass of NaOH solids in solution varied depending on the concentration of the solution express in terms of molar, M. The NaOH solution with concentration of 11M consisted of 11*40=440gm of NaOH solids per liter of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 306gm per kg of NaOH solution of 11M concentration. The sodium hydroxide added to the water and stirred about fifteen minutes to gel cool down. Then sodium silicate is added to the solution. This solution is used after 24 hours of its preparation.

3.2.3 Materials
In the proposed mix proportioning method, low calcium processed fly ash of thermal power plant was used as source material. The laboratory grade sodium hydroxide in flake form (98 % purity) and sodium silicate (38 % solids) solutions are used as alkaline activators. Locally available river sand is used as fine aggregate and locally available less than 20 and greater than 12.5 mm sizes crushed basalt stones are used as coarse aggregates.

3.2.4 Parameters considered for Mix Proportioning of Geopolymer Concrete
For the development of fly ash based geopolymer concrete mix design method, detailed investigations have been carried out and following parameters were selected on the basis of workability and compressive strength.
3.3 Method proposed for mix proportioning
Based on the experimental investigation carried out in the present study the following mix proportioning method is proposed. Subhash V. Patankar discuss on “Mix design of fly ash based geopolymer concrete” following mix design steps are taken from his research [4].

Table 8. Water content per cubic meter of concrete.

| Sr. No. | Degree of workability | Flow in percentage | Quantity of water required in Kg/m³ | Fineness of fly ash in m²/kg |
|---------|-----------------------|-------------------|------------------------------------|-----------------------------|
|         |                       |                   |                                    | <300 | 300–400 | 400–500 | >500 |
| 1       | Low                   | 0–25              | 80                                 | 85  | 100     | 110     |
| 2       | Medium                | 25–50             | 90                                 | 95  | 110     | 120     |
| 3       | High                  | 50–100            | 100                                | 110 | 120     | 135     |
| 4       | Very high             | 100–150           | 120                                | 130 | 140     | 160     |

3.3.1 Data Required for Mix Design
1. Characteristic compressive strength of Geopolymer Concrete (f<sub>ck</sub>)
2. Fineness of fly ash in terms of specific surface in m²/kg
3. Workability in terms of flow
4. Oven curing (heating) 60 °C for 24 hr and tested after 7 days.
5. Fineness modulus of fine aggregate
6. Water absorption and water content in fine and coarse aggregate

3.4 Design steps
1. Selection of quantity of fly ash: From Rohit Zende [5] quantity of fly ash is taken to be 394.28 Kg/m³ at solution to fly ash ratio is 0.40.

2. Calculation of the quantity of alkaline activators:
Calculate the quantity of alkaline activators considering:
Solution/Fly ash ratio by mass = 0.4,
i.e., Mass of (Na₂SiO₃ + NaOH) / Fly ash = 0.4 Mass of (Na₂SiO₃ + NaOH) / 394.28 = 0.4 Mass of (Na₂SiO₃ + NaOH) = 157.712 kg/m³.
Take the sodium silicate-to-sodium hydroxide ratio by mass of 2.5 [5]
Mass of sodium hydroxide solution (NaOH)= 45.06 kg/m³ Mass of sodium silicate solution (Na₂SiO₃) = 112.65 kg/m³

3. Calculation of total solid content in alkaline solution:
Solid content in sodium silicate solution = (38/100) x 112.65 = 42.807 kg/m³
Solid content in sodium hydroxide solution = (38.50/100) x 45.06 =17.34 kg/m³ Total Solid content in both alkaline solutions = 60.140Kg/m³

4. Selection of water content: For medium degree of workability and fineness of fly ash of 394.28 m²/kg, water content per cubic meter of geopolymer concrete is selected from Table 8 Water content = 95 kg/m³.
5. Adjustment in water content:
For sand conforming to grading-I, correction in water content is taken from Table 9. Adjustment in
water content = -1.5%.
Total quantity of water required = 95 - (1.5/100) x 95 = 93.575 kg/m³
Water content in alkaline solutions = 157.712 - 60.140 = 97.572 kg/m³.
As required water present in alkaline solution therefore no need to add extra water in concrete.

6. Calculation of Fine and Coursed aggregate content
Total aggregate content = (Wet density of GPC) - (Quantity of fly ash + Quantity of both solutions + extra water; if any).

$$= 2400 - (394.28 + 157.712 + 0)$$
$$= 1848.008 \text{ Kg/m}^3$$

Sand content = [Fine to total aggregate content in %] x [Total quantity of all in aggregate]

$$= [30 / 100] \times 1848.008$$
$$= 554.4 \text{ Kg/m}^3$$

Coarse aggregate content = [Total quantity of all in aggregate] - [Sand content]

$$= 1848.008 - 554.4$$
$$= 1293.608 \text{ Kg/m}^3$$

Quantity of materials required per cubic meter of geopolymer concrete is shown in Table 9.

### Table 9. Mix design for geo-polymer concrete.

| Sr. No. | Designation of mix | Replacement of fly ash with GGBS (%) | Fly ash (Kg/m³) | GGBS (Kg/m³) | Fine aggregate (Kg/m³) | Coarse aggregate (Kg/m³) | Alkaline solution NaOH (Kg/m³) | Na₂SiO₃ (Kg/m³) |
|---------|---------------------|--------------------------------------|----------------|--------------|------------------------|-------------------------|-----------------------------|----------------|
| 1       | M1                  | 00                                   | 394.28         | 00           | 554.4                  | 1293.6                  | 45.06                       | 112.65         |
| 2       | M2                  | 20                                   | 315.42         | 78.856       | 554.4                  | 1293.6                  | 45.06                       | 112.65         |
| 3       | M3                  | 40                                   | 236.57         | 157.712      | 554.4                  | 1293.6                  | 45.06                       | 112.65         |
| 4       | M4                  | 60                                   | 157.71         | 236.568      | 554.4                  | 1293.6                  | 45.06                       | 112.65         |
| 5       | M5                  | 80                                   | 78.856         | 315.424      | 554.4                  | 1293.6                  | 45.06                       | 112.65         |

3.5 Experimental method
In figure 4, showing a rough idea about experimental procedure of project carried out in lab.
3.5.1 Preparation of alkaline activator solution:
The alkaline activator is produced first before 24 hours of mixing. First Sodium Hydroxide of required molarity was prepared first manually as follows: 1. Take a required quantity of solid sodium hydroxide in a glass beaker which having 98% purity, 2. Add a water into the beaker that exactly make a 1 Lit solution, 3. Stir well that mixture about 4 to 5 minutes, 4. Keep this Jar for some time to become a cool, and 5. After preparing 11M Sodium Hydroxide solution add a Sodium silicate liquid into that
solution as shown in figure 5. Stir this solution up to 4 to 5 minutes and keep it away up to 24 hours before mixing. 

### 3.5.2 Mixing:

Different weight of percentage of fly ash (100%, 80%, 60%, 40%, and 20%) with (0%, 20%, 40%, 60%, and 80%) of Ground granulated blast slag was taken for geopolymer concrete mix M1, M2, M3, M4, and M5 respectively. Now weight the required quantity of Coarse and fine aggregate for mix. Before mixing all coarsed and fine aggregate were completely in dry state as shown in figure 6.

Different quantity of fly ash, GGBS along with alkali activator and aggregate were mix properly in a mixer are as follows:

1. Weight all quantity of mix properly on a digital weight machine first as shown in figure 7.
2. Separate all material properly such as we can handle it easily.
3. First add course and fine aggregate in to the mixer.
4. Mix it 2 to 3 minutes in a mixer properly. Keep in mind aggregate are completely in dry state.
5. Add Fly ash and GGBS in to the aggregate.
After fly ash and aggregate mix properly in to the mixer then add alkaline activator in a mix. Mix it properly up to next 5 minutes as shown in figure 8. Add water if required otherwise water is already present in alkaline activator.

3.5.3 Compacting:
Properly mix Geo-polymer concrete is then poured first in slum cone test apparatus to check workability of geo-polymer concrete. After completing slum cone test concrete in poured into the moulds of casting into the lab. A (100 X 100 X 100) mm size moulds are used for compressive strength test. Concrete is placed in three layers and tamping is done for each layer by giving more than 25 blows, in order to get fully compacted geopolymer concrete specimens. Then the top surface is well finished. The sizes of the moulds used are cube (100 X 100 X 100) mm for compressive strength and ‘L’ shape moulds of [(150X150X150) - (60X90X150)] were used as shown in figure 9 for calculating shear strength of geo-polymer concrete.

For each mix six (100 X 100 X 100) mm size moulds were cast from which three for 7 days compressive test and three for 28 days compressive test and three ‘L’ size moulds of size [(150X150X150) mm - (60X90X150)] mm specially prepared moulds by adding (60X90X150) mm wooden block in standard (150X150X150) mm size moulds are cast for shear strength test as shown in figure 10. At the time of casting precaution is taken for casting those moulds such as exact “L” shape specimen obtained after demolding.

After 24 hours all the cubes are de-moulded and kept for curing at room temperature. As geo-polymer concrete content alkaline activator this activator produces a polymerization reaction with binder present in concrete.

To produce a polymerization reaction in concrete to get strength to geopolymer concrete does not required water for curing. Geo-polymer concrete required temperature curing for getting strength. But it is not possible to cure geo-polymer concrete at site for temperature curing hence, we do work on curing of geo-polymer concrete at ambient temperature. Hence, after demolded cubes are placed at room temperature for curing.

After 7 and 28 days later take compressive strength test of concrete and after complete gaining of concrete strength after 28 days perform shear strength of geopolymer concrete and result are noted.
For calculating shear strength, a specific ‘L’ shape cubes are prepared having dimensions [(150X150X150) - (60X90X150)]mm are cast in lab by providing (60X90X150) mm wooden block in (150X150X150) mm size cube on its one side as shown in figure 3.10.

Shear strength test assembly is kept on compressive test machine and apply load on shear block. Note the reading exactly on what amount of load the shear test specimen broken or crack on shear failure. Load obtained in test is not your final reading. The load obtained is divided into two equal parts due to shear force as shown in fig. 3.10.

Shear strength can be calculated by using formula:

\[
\text{Shear strength} = \frac{\text{Failure load}}{\text{Area}}
\]

Where, \( \text{Failure load} = \frac{\text{Applied load}}{2} \).

4. Result and discussion:

4.1 Determination of compressive strength

The compression test on cubes were conducted according to Indian standard specification (IS: 516-1959). After 28 days of casting cubes are taken for compressive strength test on compression testing machine in lab. Figures and tables show the compressive strength readings.

Compressive strength results of Geopolymer concrete at 7 and 28 days are as shown in table 10 and table 11 respectively. Graphical representation of compressive strength verses replacement of fly ash is as shown in figure 4.2. In this graph compressive strength values taken on Y-axis and replacement of fly ash with GGBS taken on X-axis.

| Sr. No. | Designation of mix | Compressive strength at 7 days of cube 1, 2 & 3 (Mpa) | Average compressive strength at 7 days (Mpa) |
|---------|-------------------|-----------------------------------------------------|-----------------------------------------------|
| 1       | M1                | 7.30, 6.75, 7.16                                     | 7.07                                          |
| 2       | M2                | 14.93, 16.82, 16.20                                  | 15.98                                         |
| 3       | M3                | 20.48, 17.56, 21.31                                  | 19.78                                         |
| 4       | M4                | 24.34, 20.11, 24.38                                  | 22.94                                         |
| 5       | M5                | 20.36, 24.62, 27.36                                  | 24.11                                         |
Table 11. Compressive strength of geo-polymer concrete at 28 days at ambient temperature.

| Sr. No. | Designation of mix | Compressive strength at 28 days of cube 1, 2 & 3 (Mpa) | Average compressive strength at 28 days (Mpa) |
|---------|--------------------|------------------------------------------------------|-----------------------------------------------|
| 1       | M1                 | 10.21, 8.28, 11.16                                    | 9.88                                          |
| 2       | M2                 | 31.20, 33.69, 28.41                                   | 31.10                                         |
| 3       | M3                 | 33.73, 30.10, 35.63                                   | 33.15                                         |
| 4       | M4                 | 30.67, 36.42, 38.73                                   | 35.27                                         |
| 5       | M5                 | 43.16, 41.81, 38.26                                   | 41.07                                         |

Graph shows that as percentage of GGBS increase in concrete then compressive strength at 7 days increases polynomials over percentage replacement of fly ash by GGBS. Curve show that there is an up down or fluctuation in increment of compressive strength. Compressive strength of concrete at 28 days also shows polynomial curve means there is increment in compressive strength as GGBS increases in concrete but there are more fluctuations are between them. From above result and literature survey we can say that as percentage of GGBS increases in fly ash based geo-polymer concrete then its compressive strength increases [7].

4.2 Determination of shear strength

Due to covid-19 disease lockdown in India country all labs are closed therefore I unable to perform shear strength test. Therefore, from literature survey I found some results of shear strength of fly ash based geopolymer concrete. From literature survey it has been evaluate that shear strength from different standard codes and publisher gives a formula about shear strength of plain concrete in terms of compressive strength.

American concrete institute (ACI) committee 318 (2002) publish a building code requirement for structural concrete (ACI 318-02) mention shear strength formula for general plain concrete in chapter 22 are as shown in equation 1,

\[ VC = 0.166\sqrt{f_{ck}} \]  \hspace{1cm} \text{..equation 1}  

Where, \( VC \) = Shear strength of concrete in Mpa, \( f_{ck} \) = Characteristic compressive strength in Mpa.

In designer’s handbook of Eurocode-2 part 1.1, Design of concrete structures, Telford, London (1995) provides a formula for shear strength of plain concrete mention below in equation 2.

\[ TRD = (0.25f_{ck}0.05)/Y \]  \hspace{1cm} \text{..equation 2}  

In designer’s handbook of Eurocode-2 part 1.1, Design of concrete structures, Telford, London (1995) provides a formula for shear strength of plain concrete mention below in equation 2.
Where, $T_{RD} =$ Shear strength of concrete in Mpa, $0.25f_{ck}$, $0.05 =$ Formula for 5% fractile tensile strength $= 0.7 f_{ctm}, f_{ctm} =$ Mean tensile strength $= 0.3 (f_{ck})^{0.67}, Y_C =$ Factor of safety $= 1.5$.

In Canadian standard association (CSA) technical committee on reinforced concrete design (1994), Design of concrete structure A23.3-94 gives a formula for shear strength of plain concrete mention in equation 3.

$$V_C=0.2\sqrt{f_{ck}}$$ ..equation 3

Where, $V_C =$ Shear strength of concrete in Mpa, $f_{ck} =$ Characteristic compressive strength in Mpa.

Shear strength values of fly ash based geo-polymer concrete according to above formulae with reference to compressive strength of fly ash based geo-polymer concrete are as shown in table 12.

### Table 12. Shear strength of concrete

| Sr. No. | Designation of mix | Compressive strength at 28 days (Mpa) | Shear strength of concrete on the basis of compressive strength (Mpa) | Average shear strength (Mpa) |
|---------|---------------------|--------------------------------------|---------------------------------------------------------------------|-----------------------------|
|         |                     |                                      | ACI                               | CSA                         | EUROCODE -2                      |
| 1       | M1                   | 9.88                                 | 0.52                              | 0.63                        | 0.64                              | 0.59                           |
| 2       | M2                   | 31.10                                | 0.92                              | 1.11                        | 1.40                              | 1.14                           |
| 3       | M3                   | 33.15                                | 0.95                              | 1.15                        | 1.46                              | 1.18                           |
| 4       | M4                   | 35.27                                | 0.98                              | 1.19                        | 1.52                              | 1.23                           |
| 5       | M5                   | 41.07                                | 1.06                              | 1.28                        | 1.69                              | 1.34                           |

From table 12 we got a values of shear strength of geo-polymer concrete on the basis of different standard codes i.e., ACI, CSA, EUROCODE-2. From those values we take an average shear strength of all three values as a shear strength of geopolymer concrete. From above table we can say that as percentage of GGBS increases in geopolymer concrete shear strength of concrete also increases. When percentage of fly ash is 100% in geo-polymer concrete, we got 0.59 Mpa shear strength then as we increase GGBS percentage then shear strength increases for mix M2, M3, M4 & M5 is 1.14 Mpa, 1.18 Mpa, 1.23 Mpa and 1.34 Mpa respectively.

A Compressive strength verses shear strength of geo-polymer concrete variation showing graph is as shown in figure 13. A graph represents compressive strength of concrete in Mpa on X- axis and shear strength of concrete in Mpa on Y axis. In this graph blue line represents shear strength by ACI, dark red line represents shear strength by CSA, green line shows shear strength by using Eurocode-2 and from all this black line shows average shear strength geo-polymer concrete calculated from above code.

Above graph of compressive strength and shear strength shows there is a linear variation in shear strength with respect to compressive strength. From above graph we can say that as compression strength of concrete increases by day wise then there is also increment in shear strength of concrete.
5. Summary:
The use of geopolymer technology as a construction material in pre-cast industry applications like railway sleepers, sewer pipes, culverts and other prestressed concrete building components has been an increase in order to meet the demand of reducing the greenhouse gas emissions for sustainable development. This has led to an emphasis on information regarding the structural behavior and performance of fly ash-based Geopolymer concrete under aggressive Environments. However, a systematic compilation of the available information in literature clearly shows that the comprehensive investigation on the mix design procedure for High strength grade geopolymer concrete is almost nonexistent leading to uncertainty regarding its applicability. This made the author to study the development of unprocessed fly ash based geopolymer concrete and its behavior under ambient temperature.

As a preliminary investigation, studies were carried out to optimize the parameters affecting the properties of geopolymer concrete. Using the optimized parameters such as Alkaline liquid to fly ash ratio, ratio of Sodium silicate to sodium hydroxide, curing time, Curing temperature, Sodium hydroxide concentration, the Addition of extra water. The mix design was developed for geo-polymer concrete. Mechanical properties such as compressive strength, shear strength is determined in ambient temperature.

The outcome of the study shows the geo-polymer concrete is best replacement for the ordinary Portland cement and as the GGBS percentage increases in concrete increases strength properties and workability of concrete.
6. References:

[1]. B.Laxman Raju, L.Sudheer Reddy, Sumanth Kumar B “Interface Shear of Fly ash and GGBS Based Geopolymer Concrete” IJTIMES, ISSN: 2455-2585 Volume 5, Issue 04, April-2019.

[2]. Satyajit kumar "Investigation of fly ash polymer composite" Rourkela national technology center.

[3]. Benny JOSEPH, George Mathew “interface shear strength of fly ash based geopolymer concrete” International Journal of Engineering, 2013.

[4]. Subhash V. Ptankar “Mixed design of fly ash based geo-polymer” Conference paper2014 https://www.researchgate.net/publication/275340304.

[5]. Rohit Zende, Mamtha A. “Study On Fly Ash and GGBS Based Geopolymer Concrete under Ambient Curing” JETIR (ISSN-2349-5162), July 2015, Volume 2, Issue 7.

[6]. Dhanabal G., Drs. V. Sreevidya “Shear Power Features of Self Compacting Geopolymer Concrete Cast at Different Ages” International Journal of Recent Engineering and Management Research (IJLEMR) ISSN: 2455-4847, April 2019.

[7]. J. Guru Jawahar, D. Lavanya, C. Sashidhar “The effectiveness of fly ash and GGBS based on geopolymer concrete in the acid environment” International Journal of Scientific Research and Development (IJRSI), Volume III, Issued August 8, 2016.

[8]. B.H. Win "Properties of fly ash based geopolymer mortar", International Journal Of Engineering Research & Technology, vol.4, issue 07, July-2015.

[9]. Shaikh Usman "Energy lessons in geo-polymer concrete using fly ash and quarry dust", pace center of technology and science, vallur, 2015-2017.

[10]. Tanveer Singh Bains, Khushpreet Singh “Experimental Study on Geopolymer Concrete using Fly Ash, Bagasse Ash and Metakaolin with Pet Fiber”.

[11]. International Journal of New Technology and Engineering Evaluation, Issued May 7, 2019.