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# Strength Studies of Geopolymer Mortar Using Fly Ash and GGBS

St Vikram, Dr. V. Sreevidya
*Post Graduate, Structural Engineering,*
*Sri Krishna, College of Technology, Coimbatore*
*Associate Professor, Civil Department,*
*Sri Krishna, College of Technology, Coimbatore*

**Abstract:** Global warming is a threatening issue nowadays and cement industry also contributes to CO2 emissions. This necessitates for the alternative construction materials to lessen the carbon emis- sion, and to carry out sustainable development. A greener alternative to portland cement is utilizing the industrial by-products such as fly ash, ground granulated blast furnace slag which are pozzolonic in nature .The development of geopolymer mortar is an important step towards the production of eco- friendly materials. This paper presents the mechanical properties with emphasis on compressive strength and tensile strength of geopolymer mortar at ambient and heat curing for construction of a geopolymer cabinet.
**Index Terms:** Fly Ash, Geopolymer , Sodium hydroxide , Sodium Silicate, GGBS

## I. Introduction

Production of cement causes a large volume of carbon dioxide CO2 emission causing temperature rise, global warming. It is estimated that one tonne of cement approximately requires about 2 tonnes of raw materials (Limestone and Shale) and release about 0.87 tonne of carbon dioxide and about 3 kg of nitrogen oxide. Production of cement causes greater impact in environment causing changes in land-use patterns and local water contamination as well as air pollution. Fugitive CO2 emissions also pose huge threat to the environment. The cement industry does not fit in sustainable development due to raw materials used for the production does not recycle and are non-renewable. The waste material or by-product from the industry which can be utilized for reduction of carbon dioxide CO2 emission. Emphasis on energy conservation and environmental protection has been increased in recent times which have led to the investigation of alternatives to customary building materials and technologies.

Thus, the material or by product of an industry could be used in cement production thereby lessening carbon foot print. Inorganic polymer or organic polymer composites possess the potential to form a substantial element to form an environment friendly and sustainable constructional building material which produces lower greenhouse footprint when compared to the traditional concrete.

In early 1950s a concrete material was developed originally named as soil silicate concretes and soil cement which are nowadays known as geopolymer concrete. Geopolymer concrete is alternative material of conventional cement concrete, which is made up of different combinations of materials like fly ash, bottom ash, blast furnace slag, ground granulated blast furnace, rice husk ash, silica fume, metakaolin, volcanic tuffs, mine tailings, zeolites, silvers trim, silicates and alkali-activated solutions such as Sodium silicate-Na2SiO3 and Sodium hydroxide-NaOH / Potassium silicate-K2O3Si and potassium hydroxide-KOH). The term geopolymer is a family of mineral binder and chemical compositions which is similar to zeolites but with an amorphous microstructure. The polycondensation of silica/alumina precursors present in the polymers is the important mechanism which helps to gain its structural strength.

The geopolymer mortar has two limitations such as the delay in setting time and the necessity of heat curing to gain strength. These two limitations of geopolymer concrete mix was eliminated by replacing 10% of fly ash by OPC on mass basis with alkaline liquids resulted in Geopolymer Concrete Composite (GPCC mix) [5] The present paper work is aims to study the compressive strength characteristics of geopolymer concrete using fly ash and GGBS which are producing at ambient temperature conditions without water curing. Also aims to eliminate the necessity of heat curing of concrete.

GGBS, Fly ash are among the solid wastes that are gener- ated by the industries. Thus they are considered as a pollutant or the wastes that they are very cheap and easily available and so they can be used as a full or partial replacement to cement. In this project the replacement Portland cement with natural sand,GGBS and Fly Ash can be executed and considered as economical alternative.

## II. Materials Used

**1) Fly ash**

Fly ash is a by a product of coal combustion in the generation of thermal industry. Fly ash is a fine powder recovered by electrostatic precipitation from the gases of burning coal during the production of electricity in thermal power plants. It is available abundantly worldwide. Presently, as per the Indian Ministry of Environment & Forest Figures, only a little percentages of fly Ash is being used in manufacturing cements, construction concrete, block tiles and some are disposed off in landfills and embankments but a huge amount of fly ash is unutilized.

There are two major classes of fly ash on the basis of chemical composition from the types of coal burned are
Class F
Class C

The composition of fly ash obtained from Mettur power plant is shown in Table 1

TABLE I
COMPOSITION

| Constituents | Percentage of content (%) |
|---|---|
| SiO2 | 46.2 |
| Al2O3 | 26.4 |
| Fe2O3 | 10.7 |
| CaO | 7.60 |
| SO2 | 1.80 |
| LOI | 0.20 |

**2) Geopolymer**

The term geopolymer was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure. Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calcium- silicate-hydrates (CSHs) for matrix formation and strength, but utilise the polycondensation of silica and alumina precursors to attain structural strength. Two main constituents of geopolymers are: source materials and alkaline liquids. The source materials should be alumino-silicate based and rich in b o t h silicon (Si) and aluminium (Al). They could be by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. Geopolymers are also unique in comparison to other aluminosilicate materials (e.g. aluminosilicate gels, glasses, and zeolites). The concentration of solids in geopolymerisation is higher than in aluminosilicate gel or zeolite synthesis.

**3) Ground Granulated Blast Furnace Slag (GGBS)**

Granulated blast furnace is a by product from the blast slag in a solid waste discharged in iron and steel industry. This granulated slag is then dried and ground to a fine powder. The primary constituents of slag are lime (Cao) and Silica (Sio2). The main components of the GGBS are Cao - 40%, Sio2 35%,Al2o3 13%,Mg 8%. It can be used in replace +as much as80% of Portland cement used in concrete.Cement also contains these constituents. GGBS has better water impermeability characteristics as well as improved the resistance to corrosion and sulphur attack.As a result service life of structure is enchanged and the maintenance cost is reduced.

**4) Water**

In the present investigation, potable water was used.

**5) Fine Aggregate**

The properties of river sand used are shown in Table 2.

TABLE II
PROPERTIES

| Properties | Values |
|---|---|
| Specific gravity | 2.6 |
| Fineness modulus | 2.85 |

**6) Sodium Hydroxide**

Generally sodium hydroxides are available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. For an economical geopolymer concrete , it is recommended to use the lowest cost possible i.e. up to 94% to 96% purity.In this investigation the sodium hydroxide pellets of 12 molar concentrations were used, whose physical property and chemical property are shown in Table 3 and 4.

Table III
Properties Of Sodium Hydroxide Specific Gravity

| Colour | Colour less |
|---|---|
| 20% | 1.22 |
| 30% | 1.33 |
| 40% | 1.43 |
| 50% | 1.53 |

Table IV
Chemical Properties Sodium Hydroxide

| | | |
|---|---|---|
| Assay | 97% | Min |
| Carbonate(Na2CO3) | 2% | Max |
| Chloride (Cl) | 0.01% | Max |
| Sulphate (SO2) | 0.05% | Max |
| Lead (Pb) | 0.001% | Max |
| Iron (Fe) | 0.1% | Max |
| Zink (Zn) | 0.02% | Max |

**7) Sodium silicate**

Sodium silicate also known as water glass or liquid glass, available in liquid (gel) form. In present investiga- tion sodium silicate 2.0 is used. The chemical properties and the physical properties of the silicates are given the manufacturer is shown in Table 5. Escape special TeX symbols.

## III. Mix Proportion

The geopolymer mortar is prepared in F/B ratio of 0.42 with a mixture of flyash of about 60 % along with GGBS of about 40 %: sand ratio as 1:2. The molar concentration of NaOH is 12M. Ratio of NaOH: Na2SiO3 is taken as 2.5.

Table V
Physical and Chemical Properties Sodium Silicate

| | |
|---|---|
| Chemical Formula | Na2O x SiO2 (Colour less) |
| Na2O | 15.9% |
| SiO2 | 31.4% |
| H2O | 52.7% |
| Appearance | Liquid (Gel) |
| Colour | Light Yellow Liquid (gel) |
| Boiling Point | 102 C for 40% aqueous solution |
| Molecular Weight | 184.04 |
| Specific Gravity | 1.6 |

## IV. Preparation of Liquids

The sodium hydroxide (NaOH) solids were dissolved in water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar(M). For instance, NaOH solution with a concentration of 12M consisted of 12x40 = 480 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 444 grams per kg of NaOH solution of 12M concentration. Similarly, the mass of NaOH solids per kg of the solution for 10M concentration was measured as 404 grams. The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior to use to prepare the alkaline liquid. On the day of casting of the specimens, the alkaline liquid was mixed together with the super plasticizer and the extra water (if any) to prepare the liquid component of the mixture.

## V. Preparation of Mortar

The fly ash along eith and the fine sand were first mixed together in for about 3 minutes. The liquid component of the mixture was then added to the dry material sand the mixing continued for further about 4 minutes to manufacture the fresh mortar. The fresh mortar was cast into the moulds immediately after mixing and compacted by vibrating the moulds for 20 seconds on a vibrating table. Cubes and cylinders were cast for study of compressive strength and split tensile strength respectively.

## VI. Curing

Curing for the specimens adopted is of two types.

- Ambient curing In ambient curing the specimens are cured in ambient conditions i.e. at room temperature in laboratory conditions.
- Heat curing There are two types of heat curing viz. are steam curing and dry curing. Dry curing was adopted. In heat curing the specimens are heat cured at 600C for 24hrs in laboratory oven and then left in ambient conditions. Mortar cubes of 7x7x7 cm were cast with a ratio of fly ash and ggbs to sand 1:2. After casting the specimen were cured by ambient as well as heat curing. The compressive and tensile strength test was performed at 7, 14, 28 days.

## VII. Strength Tests

- Compressive Strength Test Compressive strength test is a mechanical test measuring the maximum amount of compressive load a material can bear before fracturing. Due to compression load, the cube or cylinder undergoes lateral expansion owing to poisons ratio effect.

$$CompressiveStrength = \frac{Maximum\ load}{C/S\ Area\ of\ the\ cube} N/mm$$

- Splitting Tensile Test

The splitting test is simple to perform and gives more uniform results than other tension tests. Strength determined in the splitting test is believed to be closer to the true tensile strength. Splitting strength gives about 5 -12% higher value than the direct tensile strength.

$$Split\ Tensile\ Strength = \frac{2P}{\pi LD}$$

where
P = Compressive Load in kN
L =Length in mm, D=Diameter in mm

## VIII. Benefits of Geopolymer Concrete

Geopolymer is better than normal concrete in many as- pects such as compressive strength, exposure to aggressive environment, workability and exposure to high temperature. Geopolymer concrete has several economic benefits over conventional Portland cement concrete. Geopolymer concrete is cost effective against the conventional Portland cement concrete which has similar performance.

It acts as a low-carbon and lesser energy consumption material and is a better alternative to traditional cement concrete and also reduces the carbon dioxide $CO_2$ emission and other environmental pollutions. Rock based geopolymer achieves 59 % of energy needs whereas slag based geopolymer achieves 43% reduction in energy needs than a conventional concrete. Carbon emissions are also lower in geopolymer where reduc- tion in 80% and 70 % of carbon emission is achieved for rock based and slag based geopolymer respectively.

Further the recent research focuses on the low drying shrink- age, low creep, resistance of sulfate attack or acid attack, acid resistance and fire resistance which may yield additional economic benefits while utilizing geopolymer concrete in infrastructure applications. The main benefits of geopolymer concrete over conventional concrete are

- High compressive strength
- High abrasion resistance

- Rapid setting and quick hardening
- Fire resistance (up to 1000oC)
- Less emission of toxic fumes under heating
- High resistance to different acids and salt solutions attacks
- Less deleterious alkali-aggregate reactions
- Low shrinkage and thermal conductivity
- High surface resistance etc.,

## IX. Results and Discussions:

The variation of load and compressive strength for heat and ambient cured samples at 7, 14 and 28 days respectively are shown in Table 6 and 7.

Table VI
Load at Failure for Compressive Strength

| | Load at Failure (kN) | | |
|---|---|---|---|
| | Ambient curing | | |
| Days of curing | 7 | 14 | 28 |
| Cube (7cm x 7cm x 7cm) | 103.8 | 126.4 | 184 |

Table VII
Compressive Strength for Ferro- Geopolymer Mortar

| | Load at Failure (kN) | | |
|---|---|---|---|
| | Ambient curing | | |
| Days of curing | 7 | 14 | 28 |
| Cube (7cm x 7cm x 7cm) | 21.2 | 25.8 | 37.4 |

Table VIII
Split Tensile Load at Failure

| | Load at Failure (kN) | | |
|---|---|---|---|
| | Ambient curing | | |
| Days of curing | 7 | 14 | 28 |
| Cube (7cm x 7cm x 7cm) | 14.9 | 19 | 28.2 |

Table IX
Split Tensile Strength for Ferro- Geopolymer Mortar

| | Load at Failure (kN) | | |
|---|---|---|---|
| | Ambient curing | | |
| Days of curing | 7 | 14 | 28 |
| Cube (7cm x 7cm x 7cm) | 1.9 | 2.5 | 3.6 |

## X. Conclusion

Geopolymer concrete offers environmental friendly and protects the natural resource by utilizing the waste/by-products from the industry which is harmful of the environment con- verted into value added construction building materials. This paper presents the overview of geopolymer materials, char- acterizations, different testing, code for testing and economic benefits, instead of the traditional Portland cement to make concrete. Geopolymer concrete has several excellent benefits like high compressive strength, simple guidelines for mix design and high fire resistance which is suitable for the structural applications.

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