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Experimental study on Flexural Behaviour of Flyash based Geopolymer Concrete with GGBS

Ashwini. NM[1], Moorthy. NJ [2]

[1]PG student, Civil Engineering Dept, Paavai Engineering College, Namakkal, Tamilnadu, India.
[2]Assistant professor of the Department, Civil Engineering Dept, Paavai Engineering College, Namakkal, Tamilnadu, India.

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ABSTRACT - Concrete is the most abundant manmade material in the world. One of the main ingredients in a normal concrete mixture is Portland cement. The production of cement from industries emits green house gases and CO_2. The production of 1ton of cement emits approximately one ton of $CO_2$and it is responsible for 65% of global warming. In order to reduce the usage of cement, supplementary cementing materials like fly ash and GGBS and instead of water, Alkali solution have been introduced in the name of Geopolymer concrete. Geopolymer concrete is also much more durable that ordinary concrete due to its resistance to corrosion. It is also much stronger than ordinary concrete. Geopolymer concrete is a revolutionary sustainable building material that will pave the way for green building. In this paper an attempt is made to study flexural and elastic properties of geopolymer concrete using low calcium fly ash replacing with GGBS in 5 different percentages as (100% : 0%), (90% :10%), (80% : 20%), (70% : 30%), (60% : 40%). Sodium silicate (103 kg/m^3) and sodium hydroxide of 8 molarity (41kg/m^3) solutions were used as alkaline solution in all 5 different mixes. The investigations were carried for the Compressive strength, Split tensile strength, Flexural strength test on the concrete specimens. The specimens were cured at ambient temperature and tested at 7th and 28th days.

1. INTRODUCTION

1.1 GENERAL

Concrete is one of the most widely used construction material, it is usually associated with Portland Cement as the main component for making concrete. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete.

Production of Portland cement is currently exceeding 2.6 billion tons per year worldwide and growing at 5 percent annually. Portland cement production is a major contributor to carbon-di-oxide emissions as an estimated five to eight percent of all human-generated atmospheric carbon-di-oxide worldwide comes from the concrete industry. The global warming is caused by the emission of greenhouse gases, such as carbon-di-oxide, to the atmosphere by human activities. Among the greenhouse gases, carbon-di-oxide contributes about 65% of global warming. The amount of the carbon dioxide released during the manufacture of Ordinary Portland Cement due to the calcinations of limestone and combustion of fossil fuel is approximately in the order of one ton for every ton of Ordinary Portland Cement produced. In terms of reducing the global warming, the geo-polymer technology could reduce the carbon-di-oxide emission to the atmosphere caused by Cement about 80%.

1.2 GEOPOLYMER CONCRETE

In this work, fly ash-based geopolymer is used as the binder, instead of Portland or any other hydraulic cement paste, to produce concrete. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods.

As in the OPC concrete, the aggregates occupy the largest volume, i.e. about 75-80% by mass, in geopolymer concrete. The silicon and the aluminium in the low calcium (ASTM Class F) fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials.

1.3 APPLICATION OF GEOPOLYMER CONCRETE

- Fire resistance
- Insulated panels and walls
- Foamed Geo-polymer panels for thermal insulation
- Energy low ceramic tiles
- Geo-polymer cement and concrete
  - Precast concrete products like railways sleepers, electrical power poles
  - Protective coatings

- Fire resistance and fire proof composite for infrastructure repair and strengthening.

1.4 ADVANTAGES

- It reduces permeability and gives high life span.
- It is stronger, more resistant to chemicals and corrosion
- It has abundant raw materials resources.
- Eco-friendly to environment and energy saving.
- Low calcium fly ash based Geopolymer concrete has excellent compressive strength and is suitable for structural applications.
- It is most advanced in precast applications due to the relative ease in handling sensitive materials.
- Good volume stability, low thermal conductivity and having high fire resistance.

1.5 FLY ASH

Fly ash is one of the most abundant materials on the Earth. It is also a crucial ingredient in the creation of geopolymer concrete due to its role in the geopolymerization process. Fly ash is a powdery pozzolan. A pozzolan is a material that exhibits cementitious properties when combined with calcium hydroxide. Fly ash is the main byproduct created from the combustion of coal in coal-fired power plants. There are two “classes” of fly ash, Class F and Class C. Each class of fly ash has its own unique properties. Class F fly ash is created from the burning of either anthracite or bituminous coal. This Class of fly ash has little to no self-cementing properties and contains very little calcium oxide (also known as lime). In order to apply Class F fly ash in concrete, it must be combined with some type of cementing agent, such as Portland cement, and must also be combined with an air-entraining admixture. This is not a very economic process if it is going to be made into ordinary concrete. Class C fly ash, on the other hand, is produced through the combustion of lignite or sub bituminous coal. Unlike Class F fly ash, it has self-cementing properties and a much higher lime concentration which makes it ideal for use in ordinary Portland cement based concrete.

Figure 1.1 Fly ash

1.5.1 Properties of Fly ash used for construction are:

- Improving workability without increasing water requirements.
- Increase the pump-ability of concrete.
- Increased life cycle expectancy.
- Resistance to corrosion of concrete reinforcement.
- Resistance to sulphate, acid, salt and alkali-silica reaction attack.
- Increased durability.
- Reduced efflorescence.
- Higher strength.
- Decreased permeability.

The class F fly ash is characterized by high silicon and aluminum contents and low calcium content, and a loss of 0.46.

Table 1.1 Chemical composition of Fly ash

Oxides	Percentage
Sio_2	52.0
Al_2O_3	33.9
Fe_2O_3	4.0
CaO	1.2
K_2O	0.83
Na_2O	0.27
SO_3	0.28
LOI	6.23
SiO_2/Al_2O_3	1.5

1.6 GROUND GRANULATED BLAST FURNACE SLAG

Ground granulated blast furnace slag comprises mainly of calcium oxide, silicon di-oxide, aluminium oxide, magnesium oxide. it has the same main chemical constituents as ordinary portland cement but in different proportions. GGBS is used to make durable concrete structures in combination with ordinary portland cement and/or other pozzolanic materials.

And the addition of G.G.B.S in Geo-Polymer Concrete increases the strength of the concrete and also curing of Geo-Polymer concrete at room temperature is possible. In this project the ground granulated blast furnace slag is obtained from ASTRRA CHEMICALS, CHENNAI.

Fig 1.2 GGBS

The chemical composition of the ordinary Portland cement and the chemical composition of GGBS is compared and discussed below in Table 1.2

Table 1.2 Chemical composition of GGBS

Chemical constitution	Cement (%)	GGBS (%)
Calcium oxide (CaO)	65	40
Silicon di-oxide (SiO_2)	20	35
Aluminum oxide(Al_2o_3)	5	10
Magnesium oxide(MgO)	2	8

1.7 AIM OF THE STUDY

- To find an alternative for the ordinary Portland cement.
- To reduce CO_2 emission and produce eco-friendly concrete.
- To develop a cost efficient product.
- To provide high strength concrete than ordinary Portland concrete.
- To reduce the usage of ordinary Portland cement.

1.8 OBJECTIVE

- To make a concrete without using cement (i.e. Geopolymer concrete).
- To study the different flexural and elastic properties of geo-polymer concrete with percentage replacement of GGBS.
- To evaluate the optimum mix proportion of Geo-polymer concrete with fly ash replaced in various percentage by GGBS.
- To compare the cost variation of geo-polymer concrete with normal concrete.

1.9 SCOPE

- Replacement of cement by fly ash and GGBS can be achieved by utilizing geopolymer matrix which in turn reduces the environmental pollution caused due to the emission of greenhouse gases in cement industries.
- GGBS is one of the abundantly available waste materials from steel industries which are not fully used. Hence the GGBS utilization in this work leads to better solid waste management resulting in sustainable development.
- The incorporation of geo-polymer concrete in construction field has led to the total elimination of cement from concrete which ultimately becomes “GREEN CONCRETE”.
- This research carries out the development of high performance fly ash based Geopolymer concrete with GGBS by examining its flexural and elastic properties.

2. TESTING OF MATERIAL

2.1 Flyash

Fly ash is one of the most abundant materials on the Earth. It is also a crucial ingredient in the creation of geopolymer concrete due to its role in the geopolymerization process.

Table 2.1 Properties of Fly ash

SNo.	Property	Value
1	Specific Gravity	2.44
2	Fineness	227.8 g/m^2
3	Fineness Modulus	5
4	Density	1029.7 Kg/m^3

2.2Fine Aggregates

The fine aggregate used in the project was locally supplied and conformed to grading zone II as per IS: 383:1970. It was first sieved through 4.75mm sieve to remove any particles greater than 4.75mm. Properties of the fine aggregate are tabulated below in Table 2.2

Table 2.2 Physical Properties of fine aggregates.

S.No	Characteristics	Values
1.	Type	Uncrushed (natural)
2.	Specific gravity	2.54
3.	Bulk Density	1668 kg/m^3
4.	Fineness modulus	2.76
5.	Grading zone	Zone II

2.3Coarse Aggregates

Locally available coarse aggregate having the maximum size of (10 - 20mm) were used in this project. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. Properties of the coarse aggregate are tabulated in Table 2.3

Table 2.3 Physical Properties of Coarse Aggregates

S.No	Characteristics	Values
1.	Type	Crushed
2.	Specific gravity	2.6
3.	Bulk Density	1765 kg/m^3
4.	Fineness modulus	6.45
5.	Maximum size	20mm

2.4Alkaline liquid

A combination of alkaline silicate solution and alkaline hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions.

Sodium hydroxide

The sodium hydroxide solids were of a laboratory grade in pellets form with 99% purity, obtained from local suppliers. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets (a small, rounded, compressed mass of a substance of sodium hydroxide)in water.

The mass of sodium hydroxide solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, sodium hydroxide solution with a concentration of 8M consisted of 8x40 = 320 grams of sodium hydroxide solids (in pellet form) per liter of the solution, where 40 is the molecular weight of sodium hydroxide.

Sodium silicate

Sodium silicate solution (water glass) obtained from local suppliers was used. The chemical composition of the sodium silicate solution was Na_2O=8%, SiO_2=28%, and water 64% by mass. The mixture of sodium silicate solution and sodium hydroxide solution forms the alkaline liquid.

2.5 Super plasticizers

Superplasticizers are water reducers which are capable of reducing water contents by about 30 percent. However it is to be noted that full efficiency of superplasticizer can be got only when it is added to a mix that has an initial slump of 20 to 30mm.

Addition of superplasticizer to stiff concrete mix reduces its water reducing efficiency. Depending on the solid content of the mixture, a dosage of 1 to 3 percent by weight of cement is advisable.

In this present investigation, a superplasticizer namely CONPLAST SP 430 has been used for obtaining workable concrete at low w/c ratio. CONPLAST SP 430 complies with BIS: 9103-1999 and BS: 5075 part 3 and ASTM C 494, Type 'B' as a HRWRA. CONPLAST SP 430 is based upon NSF condensates used for this study.

3. MIX PROPORTION

Most of the reported works on geo-polymer material to date were related to the properties of geo-polymer paste or mortar, measured by using small size specimens. In addition, the complete details of the mixture compositions of the geo-polymer paste were not reported.

Palomo et al (1999) studied the geo-polymerization of low-calcium ASTM Class F fly ash (molar Si/Al=1.81) using four different solutions with the solution-to-fly ash ratio by mass of 0.25 to 0.40. The molar SiO_2/K_2O or SiO_2/Na_2O of the solutions was in the range of 0.63 to 1.23. The specimens were 10x10x60 mm in size. The best compressive strength obtained was more than 60 MPa for mixtures that used a combination of sodium hydroxide and sodium silicate solution, after curing the specimens for 24 hours at 65^{o}C. Xu and van Deventer (2000) reported that the proportion of alkaline solution to alumino-silicate powder by mass should be approximately 0.33 to allow the geo-polymeric reactions to occur. Alkaline solutions formed a thick gel instantaneously upon mixing with the alumino-silicate powder. The specimen size in their study was 20x20x20 mm, and the maximum compressive strength achieved was 19 MPa after 72 hours of curing at 35^{o}C with the source material. On the other hand, van Jaarsveld et al (1998) reported the use of the mass ratio of the solution to the powder of about 0.39. In their work, 57% fly ash was mixed with 15% kaolin or calcined kaolin. The alkaline liquid comprised 3.5% sodium silicate, 20% water and 4% sodium or potassium hydroxide. In this case, they used specimen size of 50x50x50 mm. The maximum compressive strength obtained was 75 MPa when fly ash and builders waste were used as the source material.

Following the earlier work of Davidovits (1982) and using calcined kaolin as source material, Barbosa et al (2000) prepared seven mixture compositions of geo-polymer paste for the following range of molar oxide ratios: $0.2<Na_2O/SiO_2<0.48$; $3.3<SiO_2/Al_2O_3<4.5$ and $10<H_2O/Na_2O<25$. From the tests performed on the paste specimens, they found that the optimum composition occurred when the ratio of Na_2O/SiO_2 was 0.25, the ratio of H_2O/Na_2O was 10.0, and the ratio of SiO_2/Al_2O_3 was 3.3. Mixtures with high water content, i.e. H_2O/Na_2O = 25, developed very low compressive strengths, and thus underlying the importance of water content in the mixture. There was no information regarding the size of the specimens, while the moulds used were of a thin polyethylene film.

3.1Experimental Mix

Some of the trials carried out indicated that the workability and strength characteristics of such mixes were not satisfactory. Such a thing is possible because GPC involves more constituents in its binder (GGBS, flyash, Sodium silicate, Sodium hydroxide and water), whose interactions and final structure and chemical composition are strongly dependent on the source of the material and their production process.

TABLE 3.1 Proportion of adding cementitious materials for preparation of Geopolymer concrete

MIX ID	BINDER (%)	
	FLYASH	GGBS
M1	100	-
M2	90	10
M3	80	20
M4	70	30
M5	60	40

TABLE 3.2 Mix proportion value

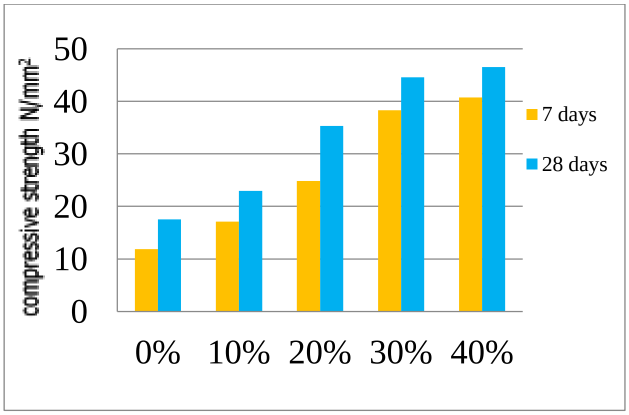
CONSTITUENTS	DENSITY (kg/m³)
Coarse aggregate	1294
Fine aggregate	554
Fly ash	408
Sodium silicate	103
Sodium hydroxide	41
Super plasticizer	6.12

TABLE 3.3 Mix proportion arrived for different combinations for 1 m³ of concrete

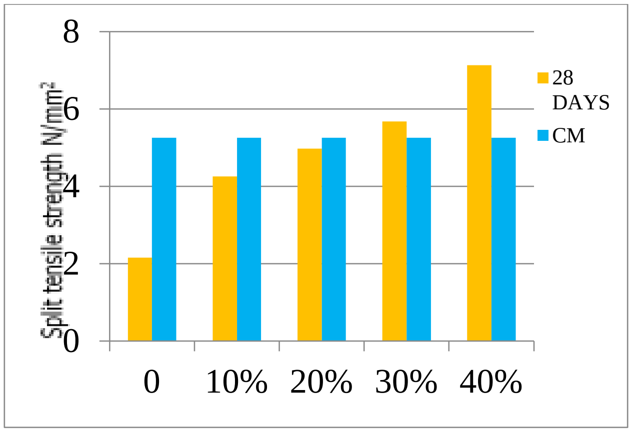
Mix ID	Fly ash (kg/m³)	GGBS (kg/m³)	Sodium hydroxide (kg/m³)	Sodium silicate (kg/m³)	Fine Agg. (kg/m³)	Coarse Agg. (kg/m³)	water (kg/m³)	Super plasticizer (kg/m³)
C	408	-	41	103	554	1294	40.8	6.12
F_{90} G_{10}	367.2	40.8	41	103	554	1294	40.8	6.12
F_{80} G_{20}	326.4	81.6	41	103	554	1294	40.8	6.12
F_{70} G_{30}	285.6	122.4	41	103	554	1294	40.8	6.12
F_{60} G_{40}	244.8	163.2	41	103	554	1294	40.8	6.12

4. TEST RESULTS AND INTERPRETATION

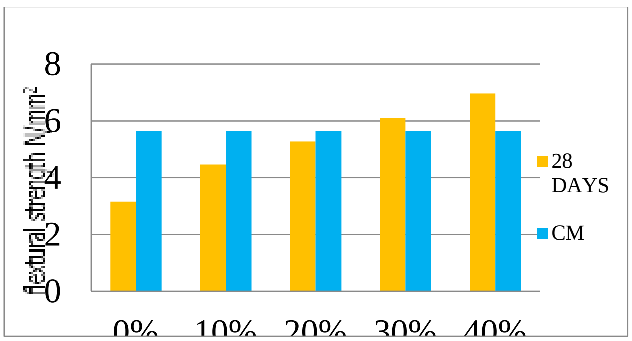
4.1 Interpretation of compressive test results for Experimental mix



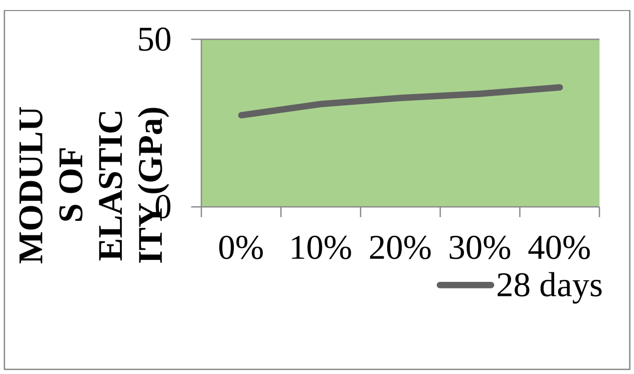
4.2 Interpretation of split tensile test results for experimental mix



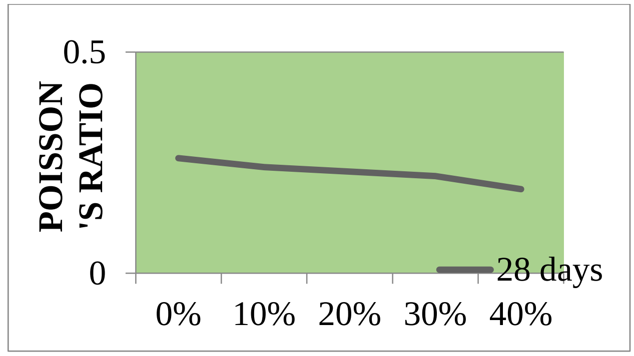
4.3 Interpretation of flexural test results for experimental mix



4.4 Interpretation of Modulus of elasticity for experimental mix



4.5 Interpretation of Poisson's ratio for experimental mix



5. CONCLUSIONS

Based on the experimental investigation the following conclusions are listed below:

- From the test results, it was observed that the maximum strength was obtained for mix with 30% GGBS and 70% flyash.
- As the strength of concrete increases, there is decrease in the average value of Poisson's ratio.
- The Modulus of elasticity values increases with increase in compressive strength of geopolymer concrete.

6. SCOPE FOR FUTURE WORK

- Studies can be made on its durability properties.
- Fiber reinforced Geopolymer composites may be considered a solution to improve flexural strength and fracture toughness.
- Different structural elements like Geopolymer Concrete Beam, Reinforced Geopolymer Concrete Beam, Reinforced Geopolymer Concrete Columns, Reinforced Beam Column joints shall be cast for the above mentioned concentrations of Sodium Hydroxide solution and curing conditions and tested.

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