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Investigation on mechanical properties of Fibre reinforced geopolymer concrete beams with ambient curing

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Abstract

Most previous works on fly ash based geopolymer concrete focused on concretes subjected to heat curing. This study has focused on a fly ash-GGBS based geopolymer concrete suitable for ambient curing condition. Class F fly ash was used as a binder material, 40% of GGBS (Ground Granulated Blast-Furnace Slag) was also added. 5% of ordinary Portland cement (OPC) was added with low calcium fly ash to accelerate the curing of geopolymer concrete instead of using elevated heat. GGBS and OPC were improved the setting time of the geopolymer concrete. Geopolymer concrete usually undergone catastrophic failure. To overcome this failure the glass fibre was added to the geopolymer concrete. Various percentage of glass fibre was added to the geopolymer concrete to improve the flexural strength. Based on the literature survey the glass fibre percentage was varied by 0.01 to 0.04 to the volume of geopolymer concrete. The curing of geopolymer concrete was done in ambient temperature. Based on the result it was observed that addition of glass fibre resulted in considerable increase in mechanical properties. 0.03% of glass fibre provided the maximum strength geopolymer concrete compared to the geopolymer concrete without using glass fibre.

Keywords: Geopolymer, glass fibre, GGBS, Fly ash, ambient curing

1. Introduction

Concrete is the most versatile, durable and reliable construction material. Concrete is conventionally produced by using the OPC as the primary binder. The environmental issues associated with the production of OPC are well known. The amount of the carbon di-oxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced [1]. In addition, the amount of energy required to produce OPC is only next to steel and aluminium. On the other side, the abundance and availability of fly ash worldwide create opportunity to utilize this by-product of burning coal, as partial replacement or as performance enhancer for OPC [1].

Fly ash in itself does not possess the binding properties, except for the high calcium or ASTM class c fly ash. However, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel [2].

Geopolymer is a term used to describe inorganic polymers based on aluminosilicates and can be produced by synthesizing pozzolanic compounds or aluminosilicate source materials with highly alkaline solutions [1, 2]. The chemical composition of the geopolymer material is similar to natural zeolitic materials [2], but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds [1].

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in in silicon and aluminum [5]. These could be natural minerals such as kaolinite, clays, etc. alternatively, by-product materials such as fly ash, silica fume, ground granulated blast furnace slag, rice-husk ash, red mud etc. [4] could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium-based.

The most common alkaline liquid used in geo- geo-polymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. The alkalinity of the activator can be low to mild or high. In the first case, with the low to medium alkalinity of the activator, the main contents to be activated are silicon and calcium in the by-product materials such as blast furnace slag. The main binder produced is a C-S-H gel, as the result of a hydration process [1, 2]. In the latter case, the main constituents to be activated with high alkaline solutions are mostly the silicon and aluminum present in the by-product material such as low calcium fly ash. The binder produced in this case is due to the geopolymerization.

Water was not involved in the chemical reaction of geopolymer concrete and instead water is expelled during curing and subsequent drying. This is in contrast to the hydration reactions that occur when OPC is mixed with water, which produce the primary hydration products calcium silicate hydrate and calcium hydrate and calcium hydroxide [8]. This difference has a significant impact on the mechanical and chemical properties of the resulting geopolymer concrete, and also renders it more resistant to heat, water ingress, alkali-aggregate reactivity, and other types of chemicals attack.

In this work, supplementary cementitious material (fly ash-GGBS) based geopolymer was used as the binder, to produce geopolymer concrete and also the glass fibre was added for improving the flexural strength. Mechanical properties such as compressive strength, splitting tensile strength, flexural strength and load-deflection behaviour of slag based geopolymer concrete was studied in detail. The fly ash based geopolymer paste binds the loose coarse aggregates, fine aggregates and other unreacted materials together to form the geopolymer concrete, with or without the presence of admixtures. The manufacture of geopolymer concrete was carried out using the usual concrete technology methods.

2. Materials

The materials used for making glass fibres reinforced geopolymer concrete were low calcium fly ash, GGBS, Ordinary Portland Cement, alkaline liquids, coarse and fine aggregates, glass fibres, Superplasticizer and water.

A. Fly ash

Fly ash was a residue from the combustion of pulverized coal collected by mechanical or electrostatic separators from the flue gases of thermal power plants. The spherical form of fly ash particles improved the flow ability and reduced the water demand. In this experimental work low calcium dry fly ash procured from thermal power station was used as source material.

Fly ash particles were typically spherical, finer than Portland cement and lime, ranging from less than 1µm to not more than 150 µm. Fly ash plays the role of an artificial pozzolona, where its silicon di-oxide content reacts with the calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (C-S-H) gel [1, 2]. The spherical shape of fly ash improved the workability of the fresh concrete, while its small particle size also played as filler of voids in the concrete; hence it produced dense and durable concrete.

B. GGBS (Ground Granulated Blast-furnace Slag)

Ground Granulated Blast Furnace Slag (GGBS) was a byproduct of the steel industry. Blast furnace slag was defined as the non-metallic product consisting essentially of calcium silicates and other bases that was developed in a molten condition simultaneously with iron in a blast furnace. In the production of iron, blast furnaces were loaded with iron ore, fluxing agents, and coke [14]. When the iron ore, which was made up of iron oxides, silica, and alumina, comes together with the fluxing agents, molten slag and iron were produced. The molten slag then gone through a particular process depending on what type of slag it will become. Air-cooled slag has a rough finish and larger surface area when compared to aggregates of that volume which allows it to bind well with Portland cements as well as asphalt mixtures. GGBS was produced when molten slag was quenched rapidly using water jets, which produces a granular glassy aggregate.

C. OPC

In this experimental study ordinary Portland cement grade 53 was used for improving the cuing in ambient temperature. GGBS and OPC were improved the setting time and curing of the geopolymer concrete.

D. Alkaline liquid

A combination of sodium hydroxide solution and Sodium silicate solution was used as alkaline activators for geopolymerization. Sodium hydroxide was available commercially in flakes and pellets form. For this experimental program sodium hydroxide flakes with 98% purity were dissolved in distilled water to make NaOH solution. The chemical composition of Sodium silicate was.

Na_2O=16.37%, SiO_2=34.35%, water=49.28%

E. Aggregates

Coarse aggregates comprising of maximum size 20 mm having bulk density 1517.07 kg/m^3, specific gravity of 2.7 were used. Fine aggregate (sand) was clean dry river sand and it was sieved through 4.75 mm sieve to removed pebbles, confirming to grading zone-I as per IS 383-1970 having specific gravity 2.63, bulk density of 1551.97 kg/m^3, & fineness modulus of 3.35 was used. Both aggregates were in saturated surface dry condition.

F. Glass Fibre

Glass fibres were made of silicon oxide with addition of small amount of other oxides. Glass fibres were characteristic for their high strength, good temperature resistance, and corrosion resistance available at low price. In this investigation alkali resistance glass fibres of 12 mm length and 14 microns nominal diameter having density of 2580 kg/m^3 were used.

G. Superplasticizer

Cera concrete tonic 350 was used as a super plasticer in this experiment to achieve the good workability of the geopolymer concrete.

H. Water

Ordinary tap water was used in experimental study and water was used only for the preparation of sodium hydroxide solution.

3. Mix Design: In Geopolymer concrete there was no standard mix design procedure, it was done with the reference of literature reviews. For the mix design alkaline solution to aluminosilicate base material ratio was fixed by 0.46 and alkaline solution ratio was fixed by 2.5. The sodium hydroxide with 97-98% purity, in flake or pellet form, was commercially available. The solids were dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide was 8 Molarity. The mass of NaOH solids in a solution varied depending on the concentration of the solution. For instance, NaOH solution with a concentration of 8 Molar consists of 8x40 = 320 grams of NaOH solids per liter of the solution, where 40 was the molecular weight of NaOH. The mass of NaOH solids was measured as 320 grams per kg of NaOH solution with a concentration of 8 Molar. Note that the mass of water was the major component in both the alkaline solutions. In order to improve the workability, a high range water reducer super plasticizer and extra water added to the mixture. Ordinary Portland cement added as additive material to improve the curing at ambient temperature.

Table 1: General Mix Design

S. No	Material	Unit Weight (kg/m^3)
1	Fly ash	227
2	GGBS	151
3	F A	554
4	C A	1294
5	Sodium hydroxide	50
6	Sodium silicate	124
7	Superplasticizer	7.5

*GGBS-Ground Granulated Blast Furnace Slag; SP- Superplasticizer; OPC-Ordinary Portland cement; FA- Fine Aggregate; CA- Coarse Aggregate.

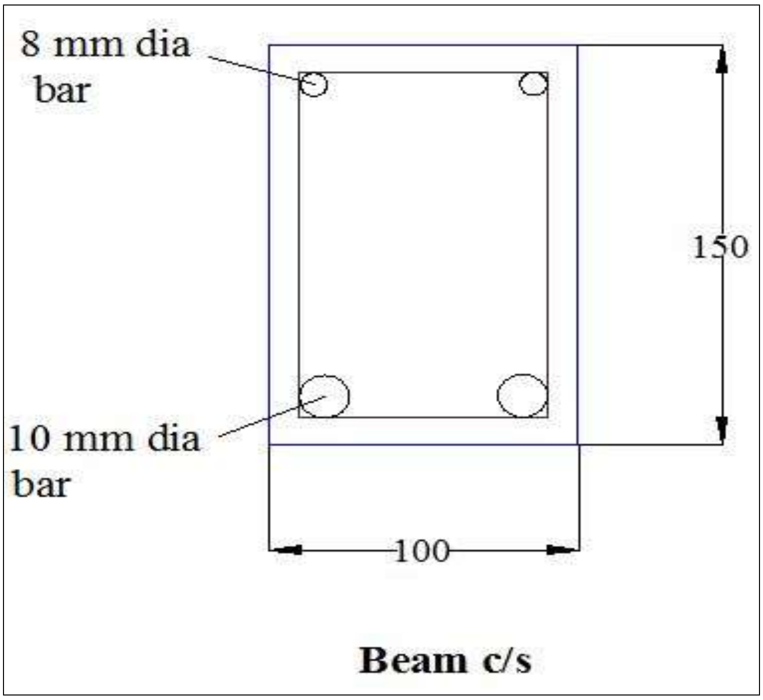
4. Experimental Work

A. Specimen detailing for strength test

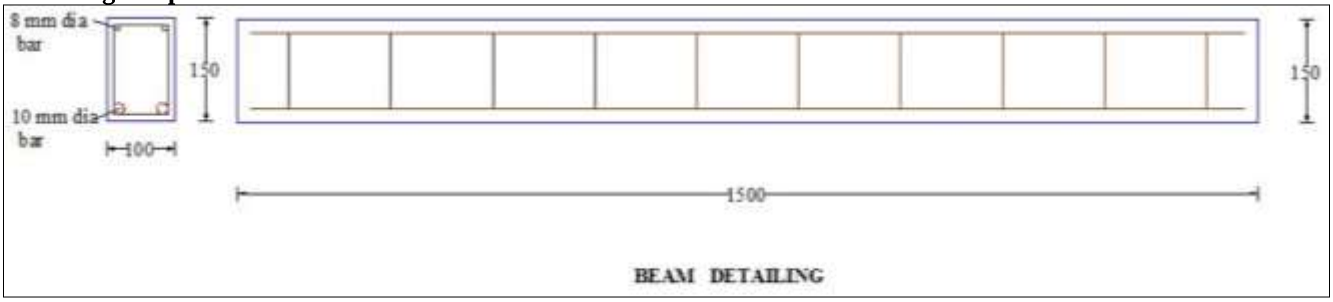
Specimen of size 150 mm x 150 mm x 150 mm was used for evaluating compressive strength in 2000 kN testing machine. Specimen of size of 300 mm length and 150 mm diameter was used for evaluating the split tensile strength in

B. Cross Section Beam

Testing machine and 100 mm x 100 mm x 500 mm size of specimen was used for evaluating flexural load in UTM. Beam size of 1500 mm x 100 mm x 150 mm was used for evaluating flexural strength and load deflection in 100 ton capacity of load frame setup.



C. Loading setup of beam



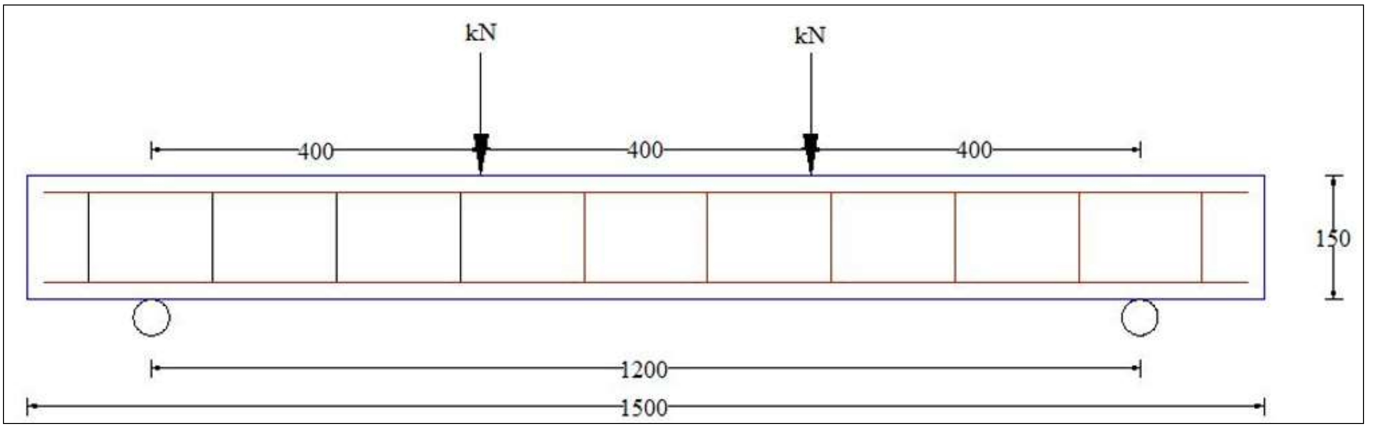


Fig 1: Loading setup of beam

For the experimental work following specimens will be casted

Table 1: Specimen Casting Detail

Mix ID	Fibre (%)	Cube	Cylinder	Prism	Beam
GC	Control	3	3	3	1
FGC 1	0.01	3	3	3	1
FGC 2	0.02	3	3	3	1
FGC 3	0.03	3	3	3	1
FGC 4	0.04	3	3	3	1

5. Results and Discussions

A. Compressive strength

The average compressive strength of the geopolymer concrete at the age of 28 days is shown in Table 2 and figure 2.

Table 2: Compressive strength of geopolymer concrete

Mix ID	Glass Fibre (%)	Compressive strength (N/mm²)
GC	0	35.77
FGC 1	0.01	37.12
FGC 2	0.02	38.24
FGC 3	0.03	41.78
FGC 4	0.04	40.92

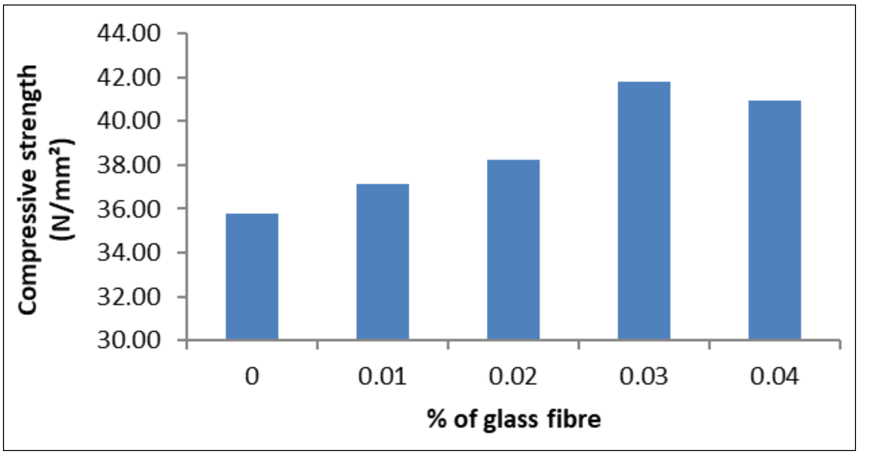


Fig 2: Compressive strength

Compressive strength of geopolymer concrete is increased with respect to the addition of glass fibre. Addition of 0.03% of glass fibre to the volume of geopolymer concrete provided the maximum compressive strength. The percentage of maximum increase in compressive strength was 14.38% compared to the GC mix.

B. Split tensile strength

The average split tensile strength of the geopolymer concrete at ambient temperature at the age of 28 days was shown in Table 3 and figure 3.

Table 3: Split tensile strength of geopolymer concrete

Mix ID	Glass Fibre (%)	Split tensile strength (N/mm²)
GC	0	4.20
FGC 1	0.01	4.43
FGC 2	0.02	4.59
FGC 3	0.03	4.91
FGC 4	0.04	4.73

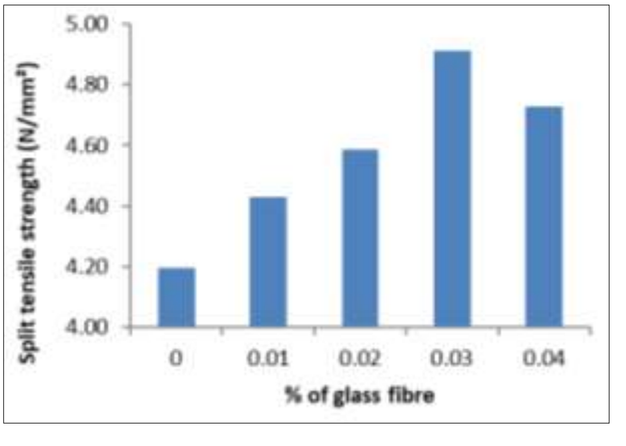


Fig 3: Split tensile strength

Split tensile strength of geopolymer concrete also increased with respect to the addition of glass fibre at ambient temperature. Addition of 0.03% of glass fibre to the volume of geopolymer concrete provided the maximum splitting tensile strength. Maximum increase in split tensile strength was 14.46% compared to the GC mix.

C. Flexural load

Flexural load of the geopolymer concrete at ambient temperature at 28 days was shown in table 4 and figure 4

Table 4: Flexural load of geopolymer concrete

Mix ID	Glass Fibre (%)	Flexural load (kN)
GC	0	4.67
FGC 1	0.01	5.67
FGC 2	0.02	6.00
FGC 3	0.03	7.00
FGC 4	0.04	6.67

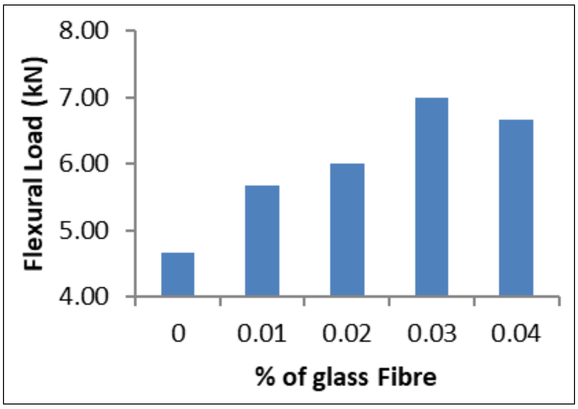


Fig 4: Flexural Load

Flexural load of the geopolymer concrete at ambient temperature was increased with the addition glass fibre. It was gradually varied with the different percentage of glass fibre to the volume concrete. 0.03% of glass fibre gives the maximum flexural load. Maximum increase in flexural load was 33.28% compared to GC mix.

D. Flexural strength

Flexural strength of the geopolymer concrete beam 28 days curing at ambient temperature was shown in figure 4

Flexural strength of the beam is increased with addition of glass fibre. The geopolymer concrete beam undergoes the curing at ambient temperature for 28 days. From the figure 5 addition of 0.03% glass fibre into the geopolymer concrete withstand the maximum flexural strength compared to the control specimen with the minimum deflection of 22 mm.

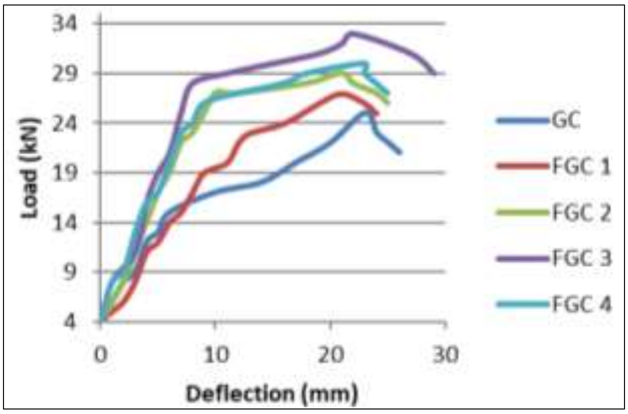


Fig 5: Load to deflection curves for geopolymer concrete beam

6. Conclusion

1. 5% of OPC to the total volume of slag was added in slag based geopolymer concrete. Mechanical properties were increased due to the addition of OPC in geopolymer concrete at room temperature.
2. Inclusion of glass fibre into geopolymer concrete showed the considerable increase in mechanical properties of concrete like compressive strength, split tensile strength and flexural strength of FGC compared to GC.
3. Addition of 0.03% glass fibres showed maximum increase in Compressive strength, split tensile strength & Flexural strength by 14.38%, 14.46% & 33.28% respectively with respect to GC mix without fibres.
4. Addition of 0.03% glass fibre into the geopolymer concrete beam withstand the maximum flexural strength of 33 kN compared to the control specimen with the minimum deflection of 22 mm.

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