

Properties and Strength of Glass Fibre Reinforced Geopolymer Concrete

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ABSTRACT: Concrete is one of the most widely used construction material, it is usually associated with Portland cement as the primary binder. The production of one tonne of cement emits approximately one tonne of carbon-di-oxide in to the atmosphere which contributes to the global warming. On the other hand huge volume of fly ash is disposed in to the landfill which affects the surface bodies of fresh water and aquifers. An effort in this regard is the development of Geopolymer concrete. In this work low calcium fly ash based geopolymer is used as the binder instead of Portland cement paste to produce concrete. This paper presents the results of an experimental program on the mechanical properties of Geopolymer Concrete Composites (GPCC) containing Fly ash (FA), alkaline liquids and glass fibres. Alkaline liquid to fly ash ratio was fixed as 0.4 with 100% replacement of OPC. Glass fibres were added to the mix in 0.01%, 0.02% and 0.03% by volume of concrete. Based on the test results, the Geopolymer concrete composites have relatively higher strength in short curing time (one day) than the Geopolymer concrete and ordinary Portland cement concrete.

KEYWORDS: Fly ash, Geopolymer Concrete Composites, Alkaline Liquids, Glass Fibres, Density, Compression Test, Split Tensile Test, Ultrasonic Pulse Velocity Test, Rebound Hammer Test.

I. INTRODUCTION

GEOPOLYMER

Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders. The properties of Geopolymer include high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance and corrosion resistance. These high-alkali binders do not generate any alkali-aggregate reaction. The Geopolymer binder is a low-CO₂ cementitious material.

Production of Portland cement is currently exceeding 2.6 billion tons per year worldwide and growing at 5 percent annually. 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. Although the use of Portland cement is still unavoidable until the foreseeable future, many efforts are being made in order to reduce the use of Portland cement in concrete. These efforts include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and finding alternative binders to Portland cement.

In this respect, the Geopolymer technology proposed by Davidovits shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of reducing the global warming, the Geopolymer technology could reduce the carbon-di-oxide emission to the atmosphere caused by cement and aggregates industries by

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about 80%. Also the concept of using fibres as reinforcement is not new. By the 1960s, steel, glass (GFRC), and synthetic fibres such as polypropylene fibres (PFRC) were used in concrete, and research into new FRCs continues today. The addition of glass and polypropylene fibres to concrete increased the splitting tensile strength of concrete by approximately 20–50%.

Literatures indicated that several researchers have investigated the effect of inclusion of fibres in concrete consisting of either 100% cement or partial replacement of cement by fly ash. The present investigation is designed to evaluate the mechanical properties of glass fibre reinforced Geopolymer Concrete Composites consisting of 100% Fly ash and alkaline liquids.

II. EXPERIMENTAL INVESTIGATION

MATERIALS

Fly Ash

Low calcium, Class F (American Society for Testing and Materials) dry fly ash obtained from Ennore Thermal Power Station-Chennai was used as the source material to make Geopolymer concrete in the laboratory [1].

Fine and Coarse Aggregates

Fine Aggregate (sand) used is clean dry river sand. Fine aggregate having a specific gravity of 2.75, bulk density of 1672 kg/m^3 and fineness modulus of 2.41 was used. Coarse aggregates of 20 mm maximum size having a fineness modulus of 6.60, bulk density of 1515 kg/m^3 and specific gravity of 2.68 were used [2].

Alkaline Liquid

A combination of Sodium hydroxide solution and sodium silicate solution was used as alkaline activators for Geopolymerisation [3]. Sodium hydroxide is available commercially in flakes or pellets form. For the present study, sodium hydroxide pellets with 98% purity were used for the preparation of alkaline solution. Sodium silicate is available commercially in solution form and hence it can be used as such. The chemical composition of sodium silicate is $\text{Na}_2\text{O}:7.5\text{-}8.5\%$, $\text{SiO}_2:25\text{-}28\%$ and water:1.35 g/ml. To prepare 16 molarity concentration of sodium hydroxide solution, 640 grams (molarity x molecular weight) of sodium hydroxide pellets was dissolved in distilled water and makeup to one litre [4]. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete to get the desired alkaline solution. The solids constituents of the GPCC mix i.e. fly ash and the aggregates were dry mixed in the pan mixer for about 3 minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done for 4 minutes. Finally extra water along with super plasticizer was added to achieve workable GPC mix. In case of glass fibre reinforced GPCC mix, fibres were added to the wet mix in three different proportions such as 0.01%, 0.02% and 0.03% volume of the concrete. In this experimental work a total of 48 numbers of concrete specimens were cast with and without glass fibres. The specimens considered in this study consisted of 24 numbers of 150mm side cubes and 24 numbers of 100mm diameter with 200mm long cylinders [5-6].

Before casting, Automotive Grease was smeared on the inner surfaces of the cast iron mould. Concrete was poured into the moulds and compacted thoroughly using a table vibrator. The top surface was finished using a trowel. The GPC specimens were removed from the mould after 4 days after the concrete set. Dry heat curing was used in this study. For dry curing, the test specimens were cured in the oven. Geopolymer concrete specimens should be wrapped during curing at elevated temperatures in a dry environment (in the oven) to prevent excessive evaporation. The test specimens were cured at 90°C for 24 hours. All the specimens were left at room temperature till the day of testing. Tests for compressive and split tensile strengths were conducted using Compression testing machine [7].

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III. TEST RESULTS

Density

Density of Geopolymer concrete composites is presented in Figure 1. Average Density values of Geopolymer concrete composites ranges from 2369 to 2426 kg/m³. The density of Geopolymer concrete composites was found approximately equivalent to that of conventional concrete [8].

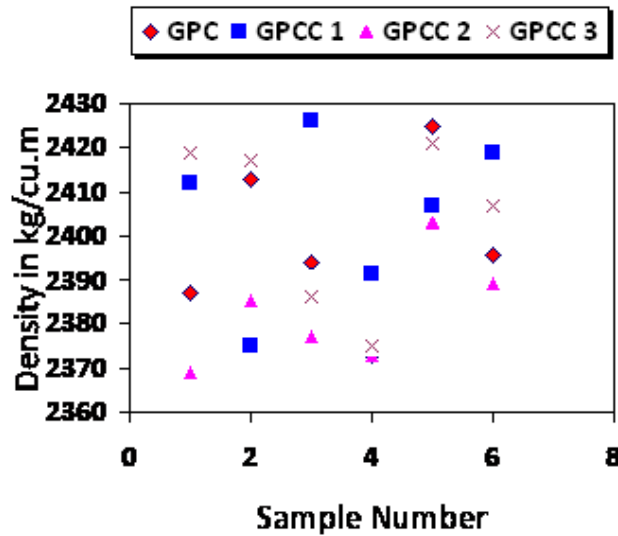


Figure 4.1 Density of the samples

Compressive Strength

The average compressive strength of GPC and GPCC at the age of 1 day and 28 days for 24hours heat curing is given below. As the age of concrete increases from 1 day to 28 days, compressive strength also increases for all the mixes [9]. However, the increase in strength beyond 1 day is not significant. From the test results it can be seen that, average compressive strength of GPCC1 and GPCC2 were increased with respect to that of the GPC mix, while the compressive strength of GPCC3 was decreased gradually with respect to that of the GPCC2 mix. The increase in 1 day compressive strength was about 10% and 20% for GPCC1 and GPCC2 with respect to GPC mix and decrease in 1 day compressive strength was about 5% for GPCC3 with respect to GPCC2 mix is clearly given in the table [10].

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Table 4.1 Compressive strength of samples after 1 day

Sample ID	Age of concrete	Average load KN	Compressive strength N/mm ²	% increase in strength
GPC	1 day	513.34	22.81	-
GPCC1	1 day	564	25.06	9.86%
GPCC2	1 day	617.33	27.43	20.25%
GPCC3	1 day	586.66	26.07	14.29%

Table 4.2 Compressive strength of samples after 28 days

Sample ID	Age of concrete	Average load KN	Compressive strength N/mm ²	% increase in strength
GPC	28 days	546	24.26	-
GPCC1	28 days	606.33	26.94	11.04%
GPCC2	28 days	646.66	28.74	18.46%
GPCC3	28 days	620.66	27.58	13.68%

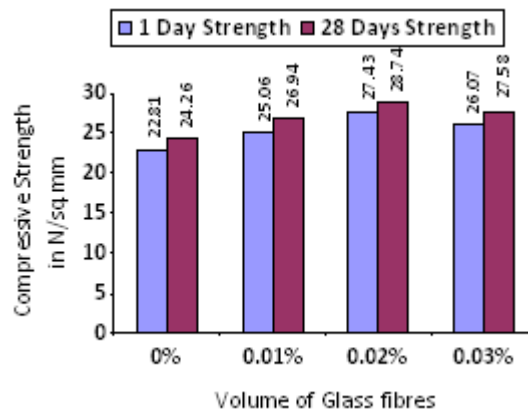


Figure 4.2 Compressive strength

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Split Tensile Strength

The average tensile strength of GPC and GPCC at the age of 1 day and 28 days for 24 hours heat curing is given below [11]. As the age of concrete increases from 1 day to 28 days, tensile strength also increases for all the mixes. However, the increase in strength beyond 1 day is not significant. From the test results it can be seen that, average tensile strength of GPCC1 and GPCC2 were increased with respect to that of the GPC mix, while the compressive strength of GPCC3 was decreased gradually with respect to that of the GPCC2 mix. The increase in 1 day tensile strength was about 18% and 29% for GPCC1 and GPCC2

with respect to GPC mix and decrease in 1 day tensile strength was about 10% for GPCC3 with respect to GPCC2 mix is clearly given in the table [15]. Based on the test results of this investigation, the equation for predicting the split tensile strength of glass fibre reinforced Geopolymer concrete composites in terms of its compressive strength is given in as

$$f_{st} = 0.084f_{cs}$$

where,

f_{st} = Split tensile strength of glass fibre reinforced Geopolymer concrete composites.

f_{cs} = Compressive strength of glass fibre reinforced Geopolymer concrete composites.

Table 4.3 Tensile strength of samples after 1day

Sample ID	Age of concrete	Average load KN	Tensile strength N/mm ²	% increase in strength
GPC	1 day	57.66	1.84	-
GPCC1	1 day	68.33	2.18	18.48%
GPCC2	1 day	74.33	2.37	28.80%
GPCC3	1 day	69	2.2	19.56%

Table 4.4 Tensile strength of samples after 28 days

Sample ID	Age of concrete	Average load KN	Tensile strength N/mm ²	% increase in strength
GPC	28 days	60.66	1.93	-
GPCC1	28 days	72.33	2.3	19.17%
GPCC2	28 days	78.66	2.5	29.53%
GPCC3	28 days	73.33	2.33	20.72%

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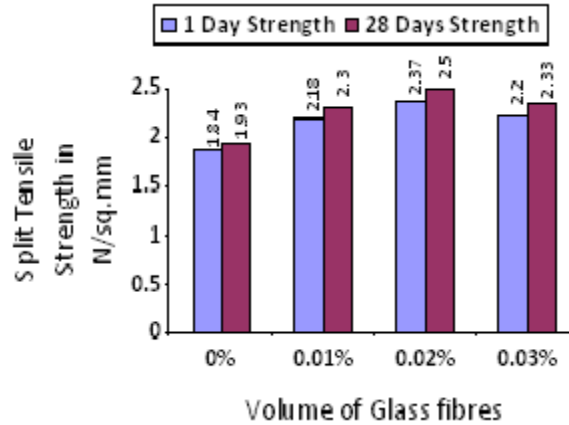


Figure 4.3 Split tensile strength

Ultrasonic Pulse velocity test

The Ultrasonic pulse velocity meter is used to determine the homogeneity of concrete. It depends on the materials and the mix proportion used in making concrete and it is related to its density and modulus of elasticity. From the test results given below, it can be seen that the quality of the Glass fibre reinforced Geopolymer concrete is good [12].

Rebound hammer test

Structural health monitoring of any structure is being carried out by Rebound hammer [13-14]. The result depends on the hardness of the concrete. From the test results given below, it can be seen that the Glass fibre reinforced Geopolymer concrete has good surface layer.

Table 4.5 Ultrasonic pulse velocity of cubes

Sample D	Age of concrete	Average transmit time μ sec	Path length mm	Average pulse velocity km/sec	Concrete quality
GPC	1 day	39.6	150	3.78	Good
GPCC1	1 day	41.3	150	3.63	Good
GPCC2	1 day	38.2	150	3.92	Good
GPCC3	1 day	41.1	150	3.65	Good
GPC	28 days	37.7	150	3.97	Good
GPCC1	28 days	39.2	150	3.82	Good
GPCC2	28 days	37.7	150	3.97	Good
GPCC3	28 days	36.1	150	4.15	Good

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Table 4.6 Rebound hammer test

Sample ID	Age of concrete	Average rebound number	Concrete quality
GPC	1 day	32.2	Good layer
GPCC 1	1 day	34.5	Good layer
GPCC 2	1 day	35.6	Good layer
GPCC 3	1 day	33.2	Good layer
GPC	28 days	33.4	Good layer
GPCC 1	28 days	35.5	Good layer
GPCC 2	28 days	36.4	Good layer
GPCC 3	28 days	34.6	Good layer

III.CONCLUSION

Based on the experimental work, the following conclusions are drawn:

1. Fibre reinforced fly ash geopolymer concrete will completely eliminate the use of cement in concrete.
2. Fibre reinforced fly ash geopolymer concrete helps in faster construction as it attains its strength in 1day curing.
3. The results from the ultrasonic pulse velocity test and Rebound hammer test prove that the Glass fibre reinforced concrete have Good quality.
4. Geopolymer concrete can be widely used in manufacture of precast structure in industries.
5. The density of geopolymer concrete composites was found approximately equivalent to that of conventional concrete.
6. The increase in compressive strength was about 10% and 20% for GPCC 1 and GPCC 2 with respect to GPC mix and decrease in compressive strength was about 5% for GPCC 3 with respect to GPCC 2 mix.
7. The increase in tensile strength was about 18% and 29% for GPCC 1 and GPCC 2 with respect to GPC mix and decrease in tensile strength was about 10% for GPCC 3 with respect to GPCC 2 mix.
8. Geopolymer concrete manufacture found to be costly. We can reduce the rate up to 20% to 30% if the raw materials are purchased in bulk from the manufactures. Then comparing with plain cement concrete the manufacture of fly ash based geopolymer concrete will be only 20% to 30% higher.

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