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An Experimental Study on the Properties of Glass Fibre Reinforced Geopolymer Concrete

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ABSTRACT

This paper is a part of an experimental research to determine the mechanical properties of Geopolymer Concrete Composites (GPCC), which contains 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, it was observed that 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; Alkaline Liquids; Glass Fibres.

1. Introduction

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. Five to eight percent of all human-generated atmospheric carbon-di-oxide worldwide comes from the concrete industry. 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. On the other hand, a huge volume of fly ash is generated around the world. Most of the fly ash is not effectively used, and a large part of it is disposed in landfills which affects aquifers and surface bodies of fresh water. Fibre reinforced cement or concrete is a relatively new composite material in which fibres are introduced in the matrix as micro reinforcement, so as to improve the tensile, cracking and other properties of concrete. Glass Fiber Reinforced Concrete (GFRC) is a type of fiber reinforced concrete which are mainly used in exterior building facade panels and as architectural precast concrete.

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. Wallah et. al, (2006) Explained that, heat-cured fly ash-based geopolymer concrete undergoes low creep and very little drying shrinkage in the order of about 100 micro strains after one year. And it has an excellent resistance to sulfate attack. Aleem et. al, (2012) mentioned that, Geopolymer Concrete can be used in the precast industries, so that huge production is possible in short duration and the breakage during transportation shall also be minimized. It shall be effectively used for the beam column junction of reinforced concrete structures and infrastructure works. In addition to that the Flyash shall be effectively used and hence no landfills are required to dump the flyash. Anuar et. al, (2011) explained that the higher concentration of sodium hydroxide solution inside the geopolymer concrete will produce higher compressive strength of geopolymer concrete; because NaOH will make the good bonding between aggregate and paste of the concrete.

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.

2. Materials

The materials used for making fibre reinforced fly ash geopolymer concrete specimens are low-calcium dry fly ash as the source material, aggregates, glass fibre, alkaline liquids, water, and super plasticizer.

2.1 Fly Ash

Fly ash is the residue from the combustion of pulverized coal collected by mechanical or electrostatic separators from the flue gases of thermal power plants. One of the important characteristics of fly ash is the spherical form of the particles. This shape of particle improves the flowability and reduces the water demand. In this experimental work, low calcium, Class F (American Society for Testing and Materials) dry fly ash obtained from the silos of Ennore Thermal Power Station, Chennai, was used as the base material.

2.2 Alkaline Liquid

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions. Sodium hydroxide solution with a concentration of 8M consisted of 8x40 = 320 grams of sodium hydroxide solids (in pellet form) per litre of the solution. The chemical composition of the sodium silicate solution was Na_2O=8%, SiO_2=28%, and water 64% by mass.

2.3 Aggregates

Coarse aggregates comprising maximum size of 20mm having fineness modulus of 6.60, bulk density of 1515 kg/m^3 and specific gravity of 2.68 were used. Fine aggregates having a specific gravity of 2.75, bulk density of 1672 kg/m^3 and fineness modulus of 2.41, in saturated surface dry condition, were used.

2.4 Glass Fibre

Glass fibres are made of silicon oxide with addition of small amounts of other oxides. Glass fibres are characteristic for their high strength, good temperature and corrosion resistance, and low price. Alkali resistant E-glass fibres of 12mm length, 0.014mm nominal diameter, specific gravity of 1.9 and density of 2650 kg/m^3 were used.

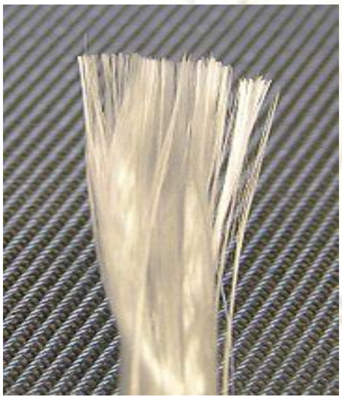

Figure 1: Glass Fiber in Strand Form **Figure 2:** Glass Fiber in Mat Form

2.5 Superplasticizer

Use of superplasticizer permits the reduction of water to the extent up to 30 percent without reducing the workability, in contrast to the possible reduction up to 15 percent in case of plasticizers. The use of superplasticizer is practiced for production of flowing, self leveling, self compacting, and for production of high strength and high performance concrete. The sulphonated napthlene-formaldehyde (superplasticizer) is used in this experiment.

3. Material Testing

3.1 Aggregate Crushing and Impact Value

Aggregate Crushing value obtained as **26.13 %** and Aggregate Impact Value **13.99 %**. Since the values are less than 30%, the aggregate can be used for all purpose.

3.2. Test for Determination of Fineness Modulus

Table 1: Sieve Analysis for Fine Aggregate

IS Sieve Size	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative % Weight Retained	Cumulative % Passsing
10mm	0	0	0	100
4.75mm	8	8	1.6	98.4
2.36mm	43	51	10.2	89.8
1.18mm	58	109	21.8	78.2
600micron	87	196	39.2	60.8
300micron	180	376	75.2	24.8
150micron	92	468	93.6	6.4
PAN	31	499	-	0.2
Total	499		241.6	

The Fineness modulus is 2.41. Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

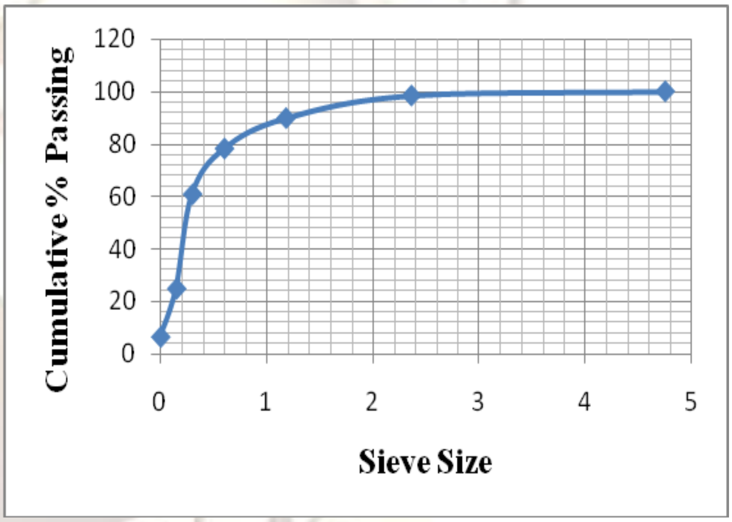

Figure 3: Particle size distribution of fine aggregates

3.3 Standard Consistency of Cement

Table 2: Standard Consistency Test

Percentage of Water Added	Height not Penetrated (mm)
25	26
30	19
35	10
38	7

Thus the consistency of cement is found to be 38%.

3.4 Setting Time of Cement

Table 3: Initial Setting Time of Cement

Time in Minutes	Depth not Penetrated (mm)
10	2
20	4
30	5

The initial setting time of cement is found to be 30 minutes.

3.5 Soundness Test

Table 4: Soundness Test

Initial Reading D_1 (mm)	Final Reading D_2 (mm)	Expansion D_2 - D_1 (mm)
5	7	2
11	12	1

The soundness of cement paste is found to be 1.5mm. Since it is less than 10mm, the cement is sound.

3.6 Mix Proportions

The fly ash and the aggregates were first mixed together for about 3 minutes. The liquid component of the mixture was then added to the dry materials and the mixing continued for further about 4 minutes to manufacture the fresh concrete. 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.

Table 5: Concrete Mixture Proportion

Materials	Coarse Aggregate	Fine Aggregate	Fly Ash	NaSi Solution	NaOH Solution	Super Plasticizer	Water
Mass/m³ (kg)	1293.6	554.4	394.28	112.64	45.08 (16 M)	11.83	78.86

Four mixes are prepared. GPC- Mix without glass fibres and GPCC1, GPCC2 and GPCC3 with Glass fibres in 0.01%, 0.02% and 0.03% by volume of concrete

Mix ID	GPC	GPCC 1	GPCC 2	GPCC 3
Glass Fibre (Kg/ m³)	-	0.265	0.530	0.795

4. Test Results

4.1 Slump Test

Table 6: Slump Test

Geopolymer Mixture	Slump (mm)	Degree of Workability
GPCC	100	High
GPCC1	80	Medium
GPCC2	85	Medium
GPCC3	80	Medium

4.2 Compressive Strength Test

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.

Table 7: Compressive Strength of Samples

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%
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%

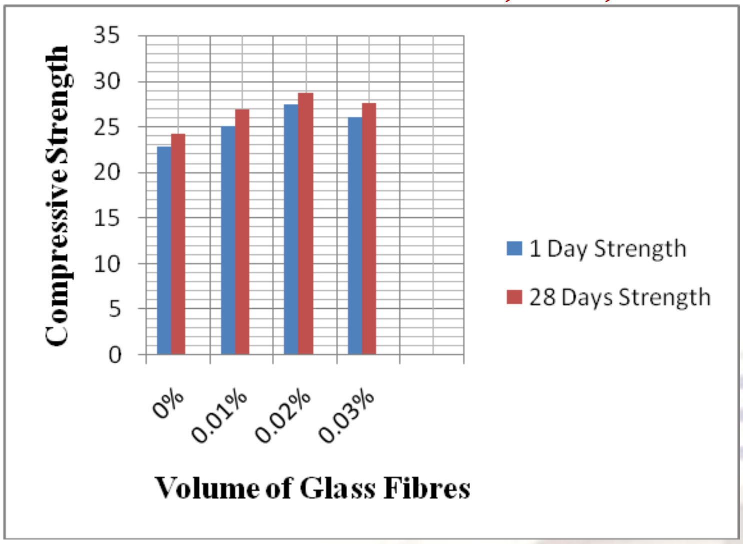

Figure 4: Compressive Strength of Glass Fibre Reinforced GPCC

4.3 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. As the age of concrete increases from 1 day to 28 days, tensile strength also increases for all the mixes.

Table 8: Split 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%
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%

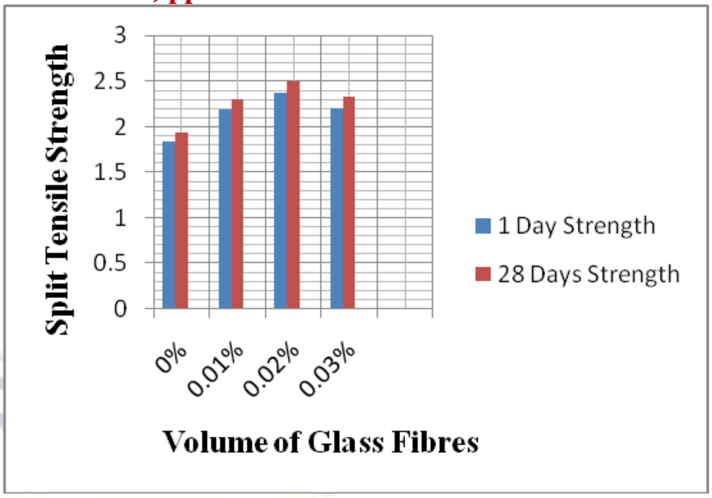

Figure 5: Split Tensile Strength of Glass Fibre Reinforced GPCC

4.4 Density of Concrete

Density of Geopolymer concrete composites is presented in Figure 6. Average Density values of Geopolymer concrete composites ranges from 2369 to 2426 kg/m^3. The density of Geopolymer concrete composites was found approximately equivalent to that of conventional concrete.

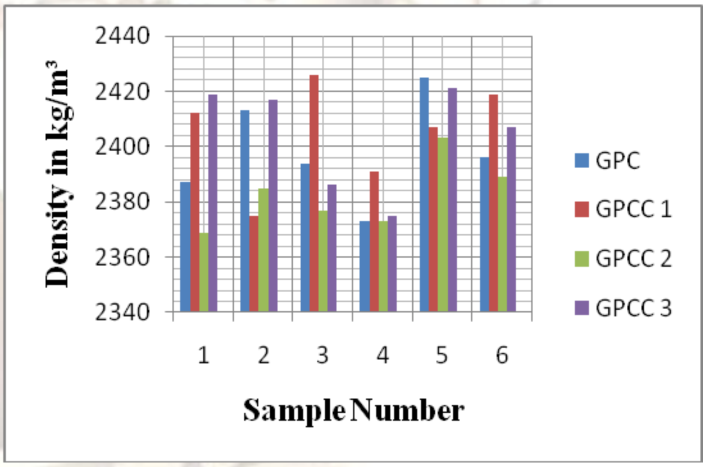

Figure 6: Density of the Samples

4.5 Ultrasonic Pulse Velocity Test

Table 9: Ultrasonic Pulse Velocity of Cubes

Sample ID	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

4.6 Rebound Hammer Test

From the test results given below, it can be seen that the Glass fibre reinforced Geopolymer concrete has good surface layer.

Table 10: Rebound Hammer Test

Sample ID	Age of concrete	Average rebound number	Concrete quality
GPC	1 day	32.2	Hard layer
GPCC1	1 day	34.5	Hard layer
GPCC2	1 day	35.6	Hard layer
GPCC3	1 day	33.2	Hard layer
GPC	28 days	33.4	Hard layer
GPCC1	28 days	35.5	Hard layer
GPCC2	28 days	36.4	Hard layer
GPCC3	28 days	34.6	Hard layer

5. Results and Discussions

- The results from the ultrasonic pulse velocity test and Rebound hammer test prove that the Glass fibre reinforced concrete have Good quality.
- The density of geopolymer concrete composites was found approximately equivalent to that of conventional concrete.
- The increase in compressive strength was about 10% and 20% for GPCC1 and GPCC2 with respect to GPC mix and decrease in compressive strength was about 5% for GPCC3 with respect to GPCC2 mix.
- The increase in tensile strength was about 18% and 29% for GPCC1 and GPCC2 with respect to GPC mix and decrease in tensile strength was about 10% for GPCC3 with respect to GPCC2 mix.

6. Conclusion

- Geopolymer concrete can be widely used in the manufacture of precast structures.
- It can be used in areas where faster strength achievement is needed.
- Fibre reinforced geopolymer concrete completely eliminates the use of cement in concrete and helps to prevent global warming and to utilize the fly ash effectively.

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