Strength Properties of Fly Ash, GGBS, M-Sand Based Polypropylene Fiber Reinforced Geopolymer Concrete

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Abstract – *Since ages the construction industry mostly depends on Ordinary pozzolana cement i.e. OPC as binding material. The production of cement is responsible for equal amounts of major greenhouse gas Carbon dioxide emissions. To address this problem it is essential to find an alternative binding material. Geopolymer concrete is one such alternative to OPC. Alkali activation of alumino-silicate materials under heat forms the Geopolymer. In GPC, Cement is completely replaced by fly ash or slag or other supplementary cementitious materials. Fibers are added to concrete to arrest cracks there by improve the ductility of concrete. This research paper deals with the study of strength properties of Polypropylene fiber reinforced Geopolymer concrete prepared by using Fly ash, GGBS, M-Sand and Coarse aggregates. Volume fraction of polypropylene fibers: 0% , 0.1% , 0.2% and 0.3%. NaOH and Na_2SiO_3 solutions used as alkaline liquid and 16M Concentration of NaOH was maintained. Cube, Cylinder, Prism specimens were casted to find out Compressive strength, Split tensile strength, Flexural strengths respectively and cured at 90°c in dry air oven for 24 hours then all the specimens were left at room temperature in ambient curing till the date of testing. The test result shows that the inclusion of fibers reduces workability and density marginally. There is increase in compressive strength due to addition of polypropylene fibers is about 2.86%, 8.13% and 15% for 0.1%, 0.2% and 0.3% volume fractions respectively. The improvement in the split tensile strength at 28 days was found to be 3%, 5.4% and 7.75% for volume fractions of 0.1%, 0.2% and 0.3% respectively. The flexural strength improved by 12%, 11% and 17% for volume fractions of 0.1%, 0.2% and 0.3% of polypropylene fibers respectively at the age of 28 days.*

Key Words: Greenhouse gas, Polypropylene fiber, Molarity, Flexural strength, Volume fraction…

1.INTRODUCTION

Joseph Davidovits, French materials scientist in 1978 coined the term Geopolymer. Geopolymers are new binder materials manufactured by activating an aluminosilicate source materials such as fly ash, silica fume, blast furnace slag etc, with a highly alkaline solution and moderate thermal curing. At present progress in study of geopolymer concrete is increasing due to their proved advantages over ordinary Portland cements. Geopolymer materials are reported to exhibit high early strength, better durability and have almost no alkali-aggregate reaction[1]. Davidovit selected the name "Geopolymer" because of its similarities with organic condensation of polymers as far as their hydro thermal synthesis conditions are concerned. Silicon and aluminum are main source materials of Geopolymers provided by thermally activated natural materials like kaolinite or industrial byproducts like fly ash or slag and an alkaline activating solution which polymerizes these materials into molecular chains and networks to create hardened binder. It is also called as alkali-activated cement or inorganic polymer cement. Among the source materials, Fly ash is the best choices for researchers because of its availability and other dumping issues related to it. An early studies shows that inclusion of GGBS in GPC will improve the compressive strength [2]. The present investigation aimed to study the mechanical properties of Fly ash and GGBS based polypropylene fiber reinforced geopolymer concrete composites (PFRGPCC) for different fiber volume fractions.

2. MATERIALS

2.1. Fly ash: The fly ash used in the Present investigation was from BTPS KPCL, Kudathini, Bellary (Dist), Karnataka. It is pozzolonic fly ash belonging to ASTM classification "F". The fly ash is collected directly from open dry dumps. The colour of fly ash is light grey, Surface area is 310 m^2/kg and Specific gravity is 2.1.

2.2. GGBS: The GGBS used in the Present investigation was from RMC Ready mix (India), Kumbalagod Industrial Area, Bangalore. The white coloured GGBS has specific gravity of 2.8 and Surface area of 450 m^2/kg.

2.3. Fine aggregate - M - sand: The M- SAND used in the Present investigation is from Tavara Mines & Minerals, Jigani Industrial area, Anekal Taluk, Bangalore, Karnataka. It satisfies the requirements of grading "Zone 2" as per IS: 383-1970 (Reaffirmed in 2007).

2.4. Coarse aggregates: The coarse aggregate used in the Present investigation was brought from a local supplier, Magadi road, Bangalore, Karnataka. . For present work Coarse aggregates of size 16mm passing and 12.5mm retained were used.

2.5. Sodium hydroxide and sodium silicate: The alkaline liquid used in the present study was a combination of sodium hydroxide and sodium silicate solutions in a definite proportion. Sodium-based solutions were chosen because they were cheaper than potassium-based solutions. Sodium silicate facilitates faster dissolution of the binder components. Both the alkalis were of commercial grades and procured from local suppliers. Sodium hydroxide pellets were of 99% purity, with Specific Gravity of 2.13. The aqueous solution of sodium silicate with SiO_2 / Na_2O ratio of 2.06 and pH 12 was used.

2.6. Super plasticizer: To achieve workability of fresh geopolymer concrete, Sulphonated naphthalene polymer based super plasticizer Conplast SP 430 in the form of a brown liquid instantly dispersible in water, manufactured by Fosroc Chemicals (India) private limited, Bangalore, was used in all the mixtures.

2.7. Water: Distilled water was used for the preparation of sodium hydroxide solution and for extra water added to achieve workability.

2.8. Polypropylene fiber: Polypropylene fibers having a length of 12 mm and a diameter of 0.02 mm were used. As per manufacturer's data these fibers have a density of 910 kg/m^3, modulus of elasticity of 3500 MPa and yield strength of 550 MPa.

3. Preparation Of Alkaline Activator Solution

A combination of Sodium hydroxide solution of 16 molarities and sodium silicate solution was used as alkaline activator solution for geo polymerization. To prepare sodium hydroxide solution of 16 molarity (16 M), 640 g (16 x 40 i.e. molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup to one litre.

4. Mix Proportion of PFRGPCC

In case of PFRGPCC mixes polypropylene fibers were added to the GPCC mix in three volume fractions such as 0.1%, 0.2% and 0.3% by volume of the concrete. The mix proportions are given in Table 1.

Fly Ash kg/m^3	394.3
Fine Aggregate kg/m^3	554
Course Aggregate kg/m^3	1294
NaOH Solution kg/m^3	46.06
Na2SiO3 Solution kg/m^3	112.64
Extra Water kg/m^3	3.943

Table-1: The mix proportions of GPCC and PFRGPCC

The prepared solution of sodium hydroxide of 16 M concentration was mixed with sodium silicate solution one day before mixing the concrete to get the desired alkalinity in the alkaline activator solution. Initially Fine aggregates, fly ash, coarse aggregates and polypropylene fibers were dry mixed for 3 minutes in a horizontal pan mixer. After dry mixing, alkaline activator solution was added to the dry mix and wet mixing was done for 4 minutes. Finally extra water along with super plasticizer was added.

5. EXPERIMENTAL INVESTIGATION

The main aim of present investigation was to study the effect of addition of polypropylene fibers on the strength characteristics of geopolymer concrete composites. To investigate the fresh and hardened properties such as workability, density, compressive strength, split tensile strength, flexural strength of controlled GPCC specimens without fibers and Polypropylene Fiber Reinforced Geopolymer Concrete Composites (PFRGPCC). A comparison on the strength aspects between GPCC and PFRGPCC is also studied.

5.1. Workability

All the freshly prepared GPCC and PFRGPCC mixes were tested for workability by using the conventional slump cone apparatus. All the mixes were generally cohesive and shiny in appearance due to the presence of sodium silicate solution. Inclusion of polypropylene fibers reduces the slump values. Increase in fiber content dosage additionally reduces the workability of PFRGPCC specimens as shown in Chart-1.

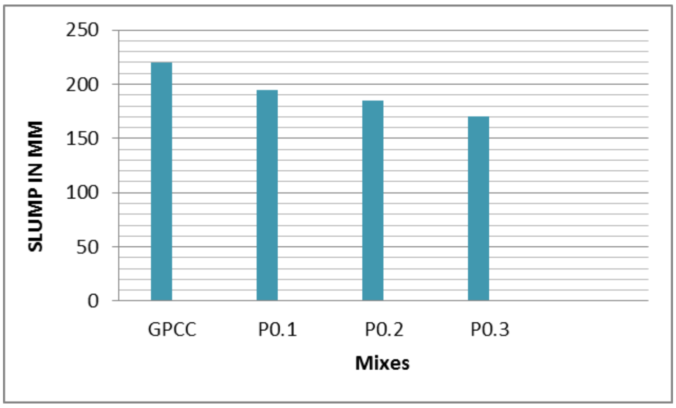

Chart-1: Effect of polypropylene fibers on workability

5.2. Density

The density of GPCC without polypropylene fibers ranges from 2385.12 kg/m^3 to 241.72 kg/m^3, density of GPCC containing 0.1% of polypropylene fibers ranges from 2387.65 kg/m^3 to 2401.48 kg/m^3, density of GPCC containing 0.2% of polypropylene fibres ranges from 2371.85 kg/m^3 to 2459.65 kg/m^3 and density of GPCC containing 0.3% of polypropylene fibres ranges from 2320.99 kg/m^3 to 2419.88 kg/m^3 as shown in Table-2.

Specimens	**Avg. Density in kg/m3**		
	3 days	**7 days**	**28 days**
GPCC	2410.72	2388.97	2385.12
PFRGPCC (0.1%)	2401.48	2393.58	2387.65
PFRGPCC (0.2%)	2359.65	2374.24	2371.85
PFRGPCC (0.3%)	2419.88	2392.10	2320.99

Table-2: Density of GPCC and PFRGPCC specimens

The density of GPCC and PFRGPCC is found close to that of ordinary Portland cement concrete. It was found from the test results that for most of the cases, inclusion of polypropylene fibres in concrete resulted in a marginal decrease in unit weight as shown in Chart-2.

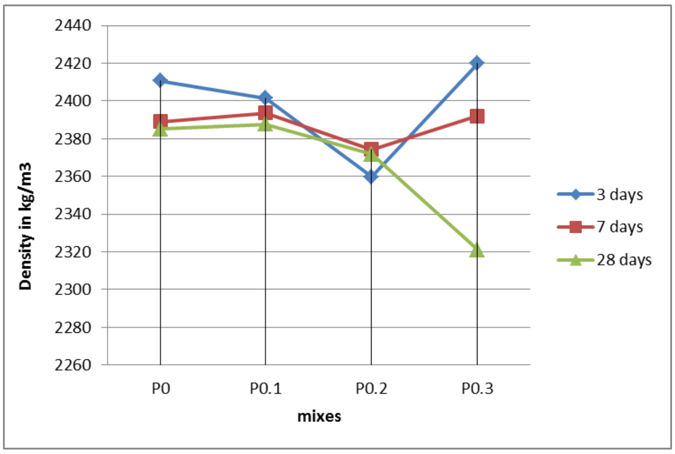

Chart-2: Density ranges of GPCC and PFRGPCC specimens

5.3. Compressive Strength

5.3.1. Preparation of Test Specimens and Curing

The cubes of size 150 mm x 150 mm x 150 mm were casted to study the compressive strength of GPCC and PFRGPCC. Standard cast iron moulds were used for casting the test specimens. Before casting, machine oil was smeared on the inner surfaces of moulds. Geopolymer concrete with polypropylene fibers was mixed using a horizontal pan mixer and was poured into the moulds in layers. Each layer of concrete was compacted using a taming rod. The specimens cured at 90^{o}c in dry air oven for 24 hours then all the specimens were left at room temperature in ambient curing till the date of testing.

5.3.2. Instrumentation and Testing Procedure

To evaluate compressive strength, all the GPCC and PFRGPCC cube specimens were subjected to a compressive load in a Compression Testing Machine with a loading capacity of 2000 KN. Specimens were tested as per the procedure given in I.S.516. The maximum load applied to the specimen was recorded. The compressive strength of the specimen was calculated by dividing the maximum load applied to the specimen by the cross-sectional area.

Fig-1: Compressive stregth testing

5.3.3. Results and Discussions

The effect of addition of polypropylene fibers in different volume fractions and age of concrete at the time of testing on the compressive strength of geopolymer concrete composite has been investigated and presented in Table-3.

At the age of 3 days PFRGPCC specimens gained about 33% of its 28 days strength and at the age of 7 days PFRGPCC specimens gained 54% of its 28 days strength as an average as shown in Chart-3.

specimens	Avg. Compressive Strength MPa		
	3 days	7 days	28 days
GPCC (0)	13.28	22.44	42.40
PFRGPCC (0.1%)	13.68	22.97	43.02
PFRGPCC (0.2%)	14.26	23.64	43.60
PFRGPCC (0.3%)	14.97	23.86	44.13

Table-3: Compressive strength of GPCC and PFRGPCC specimens

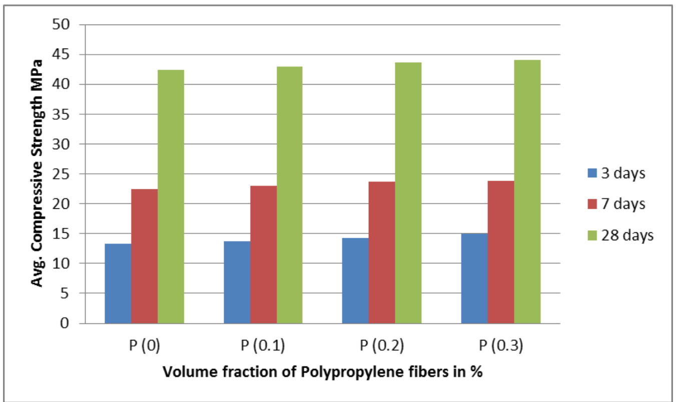

Chart-3: compressive strength with age

As the age of concrete increases from 3 day to 28 days, compressive strength also increases for all the mixes. Test results shows that, the 28 days compressive strength of geopolymer concrete composites containing polypropylene fibers was slightly higher than those of GPCC without polypropylene fibers. The increase in compressive strength due to addition of polypropylene fibers is not much significant and it was only about 2.86%, 8.13% and 15% for 0.1%, 0.2% and 0.3% volume fractions respectively.

5.4. Split Tensile Strength

5.4.1. Preparation of Test Specimens and curing

The cylinder specimens with a diameter of 150 mm and 300 mm height were casted to evaluate the split tensile strength of GPCC and PFRGPCC. Standard cast iron moulds were used for casting the test specimens. Before casting, machine oil was smeared on the inner surfaces of moulds. Geopolymer concrete with polypropylene fibres was mixed using a horizontal pan mixer and was poured into the moulds in layers. Each layer of concrete was compacted using a tamping rod. The specimens were cured at 90°c in dry air oven for 24 hours then all the specimens were left at room temperature in ambient curing till the date of testing.

5.4.2. Instrumentation and Testing Procedure

To evaluate the splitting tensile strength of GPC concrete and polypropylene fibre reinforced geopolymer concrete composites, all the cylinder specimens were subjected to split tensile test in a 2000 kN digital Compression Testing Machine. Specimens were tested as per the procedure given in IS.5816. Split tensile strength of the specimen was calculated by recording maximum load applied to the specimen.

5.4.3. Results and Discussions

The effect of addition of polypropylene fibers in different volume fractions and age of concrete at the time of testing on the split tensile strength of geopolymer concrete composites has been investigated and presented in Table-4.

Specimens	Avg. Split tensile Strength MPa		
	3 days	7 days	28 days
GPCC	0.42	3.01	3.39
PFRGPCC (0.1)	0.48	3.12	3.49
PFRGPCC (0.2)	0.52	3.24	3.69
PFRGPCC (0.3)	0.59	3.36	4.00

Table-4: Split tensile strength of GPCC PFRGPCC specimens

Within 3 days PFRGPCC specimens gained 12%, 14% and 15% of its 28 days split tensile strength and Within 7 days, PFRGPCC specimens gained 89%, 87% and 84% of its 28 days split tensile strength for volume fractions of 0.1%, 0.2% and 0.3% respectively as shown in Chart-4. As the volume fractions of polypropylene fibers increases from 0% to 0.3%, the split tensile strength also increases.

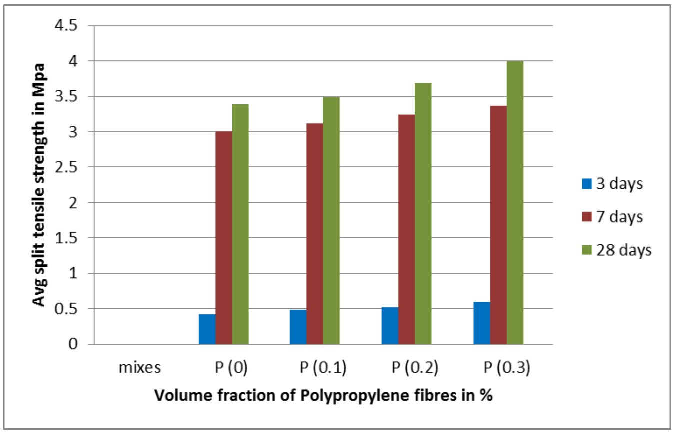

Chart-4: Split tensile strength with age

The improvement in the split tensile strength at 28 days was found to be 3%, 5.4% and 7.75% for volume fractions of 0.1%, 0.2% and 0.3% respectively. Once the splitting occurred and continued, the polypropylene fibres that bridges across the split portions of the geopolymer matrix acted through the stress transfer from the matrix to the fibers and, thus, gradually supported the total load. The stress transfer improved the tensile strain capacity of the PFRGPCC specimens thereby increasing the split tensile strength over the unreinforced controlled GPCC specimens. The increase in split tensile strength may be also due to the role of polypropylene fibers to resist cracking and spalling across the failure planes.

5.5. Flexural Strength

5.5.1 Preparation of Test Specimens and Curing

The prisms of size 500 mm x 100 mm x 100 mm were casted to study the flexural strength of PFRGPCC. Standard cast iron moulds were used for casting the test specimens. Before casting, machine oil was smeared on the inner surfaces of moulds. Geopolymer concrete with polypropylene fibers was mixed using a horizontal pan mixer and was poured into the moulds in layers. Each layer of concrete was compacted using a tamping rod. The specimens cured at 90°c in dry air oven for 24 hours then all the specimens were left at room temperature in ambient curing till the date of testing.

5.5.2. Instrumentation and Testing Procedure

Flexural strength of GPCC and polypropylene fiber reinforced geopolymer concrete composites was determined using prism specimens by subjecting them to two point loading in Universal Testing Machine having a capacity of 1000 kN. Specimens were tested as per the procedure given in IS.516. The maximum load applied to the specimen was recorded and the flexural strength of the specimen was calculated.

Fig-2: Flexural strength testing

5.5.3. Results and Discussions

The effect of addition of polypropylene fibers with different volume fractions and age of concrete at the time of testing on the flexural strength of geopolymer concrete composite has been investigated and presented Table-5.

specimens	Avg. Flexural Strength MPa	
	7 days	28 days
GPCC	3.00	5.50
PFRGPCC (0.1)	4.25	6.25
PFRGPCC(0.2)	5.25	7.00
PFRGPCC(0.3)	6.00	8.50

Table-5: Flexural strength of GPCC and PFRGPCC specimens

Geopolymer concrete composite specimens harden immediately and start gaining flexural strength. Within 7 days, PFRGPCC specimens gained 55% to 70% of its 28 days flexural strength as shown in Figure 5. As in the case of split tensile strength, PFRGPCC specimens resulted in significant increase of flexural strength when compared to controlled GPCC specimens as shown in Chart-5.

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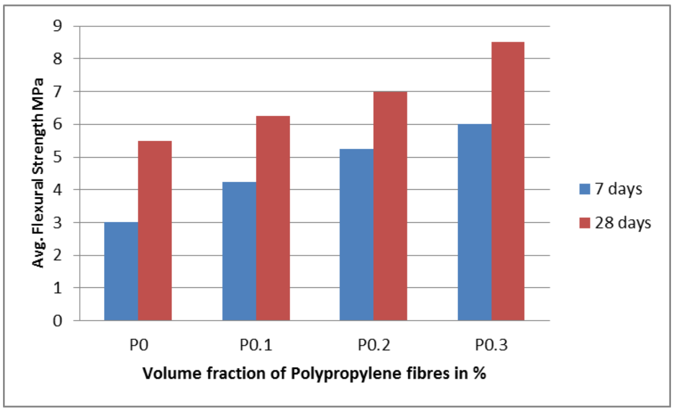

Chart-5: Flexural strength with age

The flexural strength improved by about 12%, 11% and 17% for volume fractions of 0.1%, 0.2% and 0.3% of polypropylene fibers respectively at the age of 28 days. This increase in flexural strength might have resulted primarily from the polypropylene fibers intersecting the cracks in the tension zone of the flexure beam. These fibers arrest the crack face separation by stretching themselves, thus providing an additional energy absorbing mechanism.

6. CONCLUSIONS

Based on the results obtained in this investigation, the following conclusions were drawn:

[1] Addition of polypropylene fibers reduces the slump values. Increase in fiber content dosage additionally reduces the workability of PFRGPCC specimens.

[2] The density of GPCC without polypropylene fibers was almost same as conventional concrete.

[3] The test result shows that in most of the cases, addition of polypropylene fibers in concrete resulted in marginal decrease in density.

[4] There is increase in compressive strength PFRGPCC. It is due to addition of polypropylene fibers with reference to GPCC mix without polypropylene fibers.

[5] The split tensile strength increases as the volume fraction of polypropylene fibers increases from 0% to 0.3% compared to controlled GPCC due to the role of polypropylene fibers to resist cracking and spalling across the failure planes.

[6] Addition of polypropylene fibers to GPCC resulted in improvement of flexural strength.

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