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Experimental Investigations on Properties of Glass Fiber Reinforced Geopolymer Concrete Composites

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Abstract: *Now a day's Demand for concrete as construction material is increasing and the production of cement also increasing. The production of one ton of cement liberates about one ton of CO_2 to atmosphere. In order to address environmental effect associated with Portland cement, there is need to develop alternative binder to make concrete. Geopolymer concrete (GPC) is one of the best alternatives for conventional concrete. Geopolymer concrete (GPC) that is produced by the polymeric reaction of alkaline liquids with byproduct like fly ash and rice husk ash. Compared with ordinary Portland cement the geopolymer concrete has many advantages. Low calcium fly ash based concrete has excellent compressive strength, suffers very little dry shrinkage and low creep, excellent resistance to sulfate attack and good acid resistance. Total replacement of cement by fly ash has several limitations such as necessity of heat curing and delay setting. In order to overcome these limitations, the present study was developed. Geopolymer concrete composites with fly ash, OPC and alkaline liquids. By the 1960s, steel, glass (GFRC), and synthetic fibers were used in concrete. The Experimental study consists of geopolymer concrete composites by using Glass fibers in volume fractions such as 0.01%, 0.02% and 0.03% of concrete. For M30 grade the compressive strength of Glass Fiber Reinforced Geopolymer Concrete Composites (GFRGPCC) cubes of 150mmx150mmx150mm, split tensile strength cylinders with a diameter of 150mmx300mm length and for flexural strength of GFRGPCC prisms with 500mmx100mmx100mm for evaluation of tests. The present study is designed to evaluate the mechanical properties of Glass Fiber Reinforced Geoploymer Concrete Composites consisting of 85% fly ash, 10% cement, and 5% of GGBS and alkaline liquids.*

Key Words: *Alkaline Solutions, Materials, Mix Proportions, Super Plasticizer, Geopolymer Concrete.*

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I. Introduction

Cement is a versatile construction material and is being used worldwide. But greenhouse gas (CO_2) is produced during its manufacturing process causes environmental impact. 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. Production of one ton of Ordinary Portland Cement (OPC) releases approximately one ton of CO_2 into the atmosphere. Efforts are being made to develop more eco-friendly concrete and one such concrete is Geopolymer Concrete (GPC).

Even though Plain Cement Concrete is the key constituent of the structures all over the world, these structures are prone to a lot of problems like severe moisture ingress, chloride and other chemical attacks, cracking and spalling in extreme temperature conditions. So, in order to overcome these problems, various supplements are being used so that the strengths are not disturbed significantly and the above listed problems are overcome. The admixtures used as a substitute in the project are Fly Ash, Ground Granulated Blast Furnace Slag (GGBS).

Geopolymer cement represents a broad range of materials characterized by networks of inorganic molecule. The fly ash which has high content of Silica (Si) and Alumina (Al) reacts with alkaline solution like Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium Silicate (Na_2SiO_3) or Potassium Silicate (K_2SiO_3) and forms a gel which binds the fine and coarse aggregates. Geopolymer concrete do not require any water for matrix bonding, instead the alkaline solution react with Silicon and Aluminum present in the fly ash. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals.

II. Material Description

2.1 Fly Ash:

Fly ash is a group of materials that can vary significantly in composition. It is residue left from burning coal, which is collected on an electrostatic precipitator or in a bag house. All precast concrete producers can now use a group of materials called "fly ash" to improve the quality and durability of their products. Fly ash improves concrete's workability, pumpability, cohesiveness, finish, ultimate strength, and durability as well as solves many problems experienced with concrete today–and all for less cost.

Good quality fly ash generally improves workability or at least produces the same workability with less water. The reduction in water leads to improved strength. Because some fly ash contains larger or less reactive particles than Portland cement, significant hydration can continue for six months or longer, leading to much higher ultimate strength than concrete without fly ash.

2.2 Ground-Granulated Blast-Furnace Slag (GGBS):

GGBS is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). In general, increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al_2O_3 content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. Several compositional ratios or so-called hydraulic indices have been used to correlate slag composition with hydraulic activity; the latter being mostly expressed as the binder compressive strength.

Table-1 Properties of Binders

Binder	Specific gravity	Fineness (m^2/kg)	Al_2o_3 (%)	Fe_2o_3 (%)	Sio_2 (%)	Mgo (%)	So_3 (%)	Na_2o (%)	Chlorides (%)	L.O.I[a] (%)	Cao (%)
Fly ash	1.91	365	32.4	4.04	58.1	0.71	0.12	0.17	0.02	0.85	1.4
GGBS	2.9	416	16.3	0.68	34.4	8.83	1.44	0.22	0.01	0.19	34.6

2.3 Alkaline Liquid:

An alkaline liquid is used to react with silicon (Si) and aluminum (Al). The main constituents of alkaline liquid are sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate (K_2SiO_3). Generally a combination of NaOH and Na_2SiO_3 are used as an alkaline liquid in the manufacture of GPC. This alkaline liquid when reacts with the source material of geological origin binders are produced. The chemical reaction that takes place in this process is caller polymerization. A solution of 12M sodium hydroxide and sodium silicate were used in this study.

- ✓ Specific gravity of NaOH = 1.47
- ✓ Specific gravity of Na_2Sio_3= 1.6

2.4 Chemical Admixture:

Chemical admixtures reduce the cost of construction, modify the properties of concrete and improve the quality of concrete during mixing, transportation, placing and curing. Super plasticizer - MASTER REOBUILD 1125 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability.

2.5 Glass Fiber:

Glass fiber of density 2600 kg/m^3 is used in this study.

2.6 Cement:

Ordinary Portland cement of 43 grades having specific gravity of 3.10 is used.

2.7 Fine Aggregate:

Specific gravity of fine aggregate is 2.66 and sieve analysis is conducted to the fine aggregate which shows the sand belong to zone II as per IS 383-1970

2.8 Coarse Aggregate:

Crushed granite coarse aggregate of maximum nominal size of 20mm and specific gravity of 2.70 is used.

III. Mix Design

3.1 Design of Geopolymer Concrete Mixtures:

In the mix design of geopolymer concrete the role and the influence of aggregates are considered to be the same as in the case of Portland cement concrete. The mass of combined aggregates may be taken to be between 75% and 80% of the mass of geopolymer concrete. Coarse and fine aggregate together were taken as 77% of entire mixture by mass. Fine aggregate was taken 30% of total aggregate. Fly ash and alkaline liquids was taken 23% of density of concrete. From past literatures, it is clear that the average density of fly ash based geopolymer concrete is similar to that of OPC concrete (2400kg/m3). Knowing the density of concrete the combined mass of alkaline liquid and fly ash can be arrived. By assuming the ratios of alkaline liquid to fly ash as 0.4, mass of alkaline liquid was found out. To obtain mass of sodium silicate solution and sodium hydroxide solution, the ratio of sodium silicate solution and sodium hydroxide solution was fixed as 2.5. Extra water (other than the water used for preparation of alkaline solution) and super plasticizer were added to the mix by 10% and 3% by weight of fly ash respectively to achieve workable concrete.

It was observed that Geopolymer concrete has two limitations such as delay in setting time and necessity of heat curing to gain strength at early ages. In order to overcome these limitations of GPC mix, 10% of fly ash was replaced by OPC to overcome the necessity of heat curing. To accelerate the setting time 5% Ground-Granulated Blast-Furnace Slag (GGBS) is added and the mix proportions are modified. Mix design was altered according which results in geopolymer concrete composites (GPCC mix).

3.2 Mix Design of GPCC: (M30 grade):

GPCC, the blended mix of fly ash, OPC and GGBS was prepared as similar to the GPC. This GPC mix has two limitations such as delay in setting time and necessity of heat curing to gain strength. In order to overcome these limitations of GPC mix, 10% of fly ash was replaced by OPC to overcome the limitation necessity of heat curing and 5% of fly ash was replaced by Ground-Granulated Blast-Furnace Slag (GGBS) to overcome the limitation delay in setting time. In case of Glass fiber reinforced geopolymer concrete composites (GFRGPCC) mixes Glass fibers were added to the geopolymer concrete composites (GPCC mix) in three volume fractions such as 0.01%, 0.02% and 0.03% by density of glass fiber. The mix design was altered according which results in geopolymer concrete composites (GPCC mix). To prepare 12 molarity concentration of sodium hydroxide solution, 480 grams (molarity x molecular weight).The mass of NaOH solids was measured as 361 grams per kg of NaOH solution with a concentration of 12 Molar. 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 solid constituents of the GPCC mix i.e. fly ash, OPC, GGBS and the aggregates were dry mixed in the pan mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done for 4 minutes. In case of glass fiber reinforced GPCC mixes fibers were added to the wet mix in three different proportions such as 0.01%, 0.02% and 0.03% volume of the concrete. Mixes were designated for identification as MIX ID GPCC 1, GPCC 2 and GPCC 3 respectively.

- In the design of GPC mix, coarse aggregate and fine aggregate together was taken as 77% of entire mixture by mass.
- Fine aggregate was taken as 30% of total aggregate, coarse aggregate was taken as 70%. Remaining amount of proportion is taken as fly ash.
- The ratio of alkaline liquids to fly ash is 0.4.
- The ratio of sodium silicate to sodium hydroxide is 2.5.
- The amount of Super plasticizer is 3% of fly ash.
- Extra water was taken 10% of fly ash.
- The proportion of the fibers is taken based on their density.
- Curing of fresh GPC is carried out at room temperature in ambient curing till the date of testing.

Table-2 Details of mix proportions

Mix ID	Fly ash kg/m^3	OPC kg/m^3	GGBS kg/m^3	FA kg/m^3	CA kg/m^3	NaOH solution kg/m^3	Na_2SiO_3 Solution Kg/m^3	SP kg/m^3	Glass fibers kg/m^3
GPCC	335.14	39.43	19.714	554.4	1293.6	45.06	112.65	11.82	-
G0.01	335.14	39.43	19.714	554.4	1293.6	45.06	112.65	11.82	0.26
G0.02	335.14	39.43	19.714	554.4	1293.6	45.06	112.65	11.82	0.52
G0.03	335.14	39.43	19.714	554.4	1293.6	45.06	112.65	11.82	0.78

OPC: Ordinary Portland cement; FA: Fine Aggregate; CA: Coarse Aggregate; NaOH: Sodium Hydroxide; Na_2SiO_3: Sodium Silicate; SP: Super Plasticizer

IV. Methodology

4.1 Preparation of GPC Specimens (Trail Mix):

The prepared solution of sodium hydroxide of 12M concentration was mixed with sodium silicate solution one day before mixing of concrete to get the desired alkalinity in the alkaline activator solution. Initially coarse aggregate, fine aggregate, cement, and fly ash were dry mixed for three minutes in the mixer. After dry mixing, alkaline activator solution was added to the dry mix and wet mix was done for 4 minutes. Finally, extra water along with super plasticizer was added. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture become homogeneous and uniform in color. By the trail mix, it was observed that Geopolymer concrete has two limitations such as delay in setting time and necessity of heat curing to gain strength at early ages. In order to overcome these limitations of GPC mix, 10% of fly ash was replaced by OPC to overcome the necessity of heat curing and 5% of fly ash was replaced by Ground-Granulated Blast-Furnace Slag (GGBS) to overcome the delay in setting time. The mix design was altered according which results in geopolymer concrete composites (GPCC mix).

4.2 Preparation of GPCC Specimens:

The prepared solution of sodium hydroxide of 12M concentration was mixed with sodium silicate solution one day before mixing of concrete to get the desired alkalinity in the alkaline activator solution. Initially coarse aggregate, fine aggregate, cement, fly ash, and GGBS were dry mixed for three minutes in the mixer. After dry mixing, alkaline activator solution was added to the dry mix and wet mix was done for 4 minutes. Finally, extra water along with super plasticizer was added. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture become homogeneous and uniform in color. The fresh geopolymer concrete was used to cast cubes of size 150x150x150mm to determine its compressive strength. The fresh geopolymer concrete was used to cast prisms of size 100x100x500mm to determine its flexural strength. The fresh geopolymer concrete was used to cast cylinders of size 150x300mm to determine its split tensile strength. The casted cubes, cylinders & prisms. Each specimen was cast in three layers by compacting manually as well as by using vibrating table. Each layer received 25 strokes of compaction by standard compaction rod for concrete, followed by further compaction on the vibrating table. The specimens were removed from the mould immediately after 24 hours since they set in a similar fashion as of conventional concrete. All the specimens were left at room temperature in ambient curing till the date of testing.

4.3 Preparation of GPCC Specimens with Inclusion of Glass Fibers:

The prepared solution of sodium hydroxide of 12M concentration was mixed with sodium silicate solution one day before mixing of concrete to get the desired alkalinity in the alkaline activator solution. Initially coarse aggregate, fine aggregate, cement, fly ash, and GGBS were dry mixed for three minutes in the mixer. Now add the calculated amount of glass fibers into the concrete mixer after separating the fibers into pieces. After dry mixing, alkaline activator solution was added to the dry mix and wet mix was done for 4 minutes. Finally, extra water along with super plasticizer was added. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture become homogeneous and uniform in color. Each specimen was cast in three layers by compacting manually as well as by using vibrating table. Each layer received 25 strokes of compaction by standard compaction rod for concrete, followed by further compaction on the vibrating table. The specimens were removed from the mould immediately after 24 hours since they set in a similar fashion as of conventional concrete. All the specimens were left at room temperature in ambient curing till the date of testing.

V. Results And Discussions

Various trail mixes are conducted for geopolymer concrete composites with various percentages of fly ash, GGBS and cement then the mix of good strength and workability is selected as the final mix. In this experimental work a total of 72 numbers of concrete specimens of with and without glass fibers are considered. The specimens considered in this study consisted of 24 number of 150mm size cubes, 24 numbers of 150mm diameter and 300mm long cylinders and 24 numbers of 100 mm X 100mm X 500mm size prisms.

5.1 COMPARISON OF FRESH CONCRETE PROPERTIES:

5.1.1 Workability of GPCC without and With Glass Fibers

The workability was determined by slump cone test the values are given below

Table-3 Workability values of GPCC without and with glass fibers

S.NO	Workability (mm)			
	GPCC	GPCC 1	GPCC 2	GPCC 3
1.	210	198	182	146
2.	210	202	188	154
Average	210	200	185	150

The above results were plotted in graph as shown below

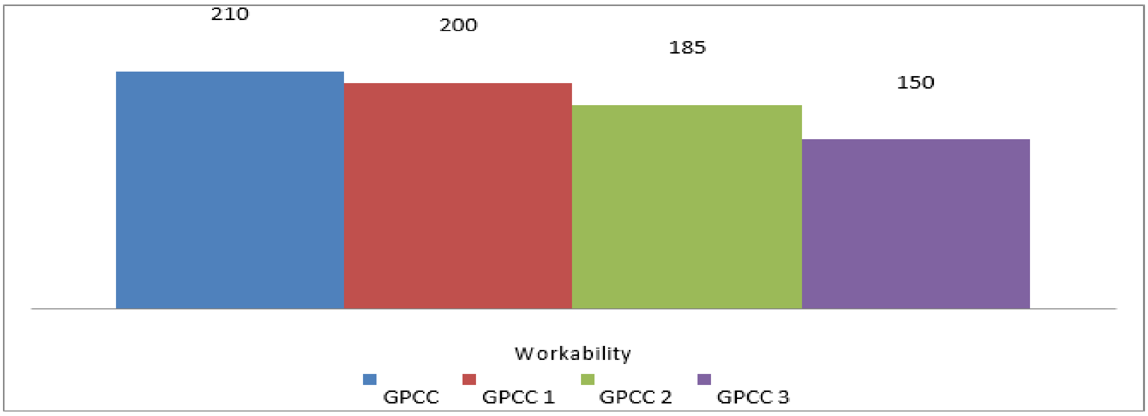

Fig -1 Comparison of Workability of GPCC without & with fibers

From graph it was clear that the workability values are decreased gradually from GPCC to GPCC with glass fibers. Addition of glass fibers causes decrease in workability. Since fibers offer resistance to the flow of the concrete the workability is reduced.

5.2 COMPARISON OF MECHANICAL PROPERTIES

The mechanical properties compressive strength, split tensile strength and flexural strength are presented in.

5.2.1 Compressive Strength:

In this step cubes of GPCC with and without glass fibers are tested and the results are given in the following table

Table-4 Compressive strength values of GPCC without& with glass fibers

S.NO	COMPRESSIVE STRENGTH (Mpa)							
	7 DAYS				28 DAYS			
	GPCC	GPCC1	GPCC2	GPCC3	GPCC	GPCC1	GPCC2	GPCC3
1	18.37	18.98	21.46	17.69	32.28	38.62	37.34	34.86
2	17.98	19.43	20.2	16.12	32.28	36.27	35.28	35.6
3	17.98	19.29	19.53	16.12	36.28	37.14	36.19	34.23
AVERAGE	18.11	19.23	20.39	16.64	33.61	37.34	36.27	34.89

The above obtained results are represented graphically as below

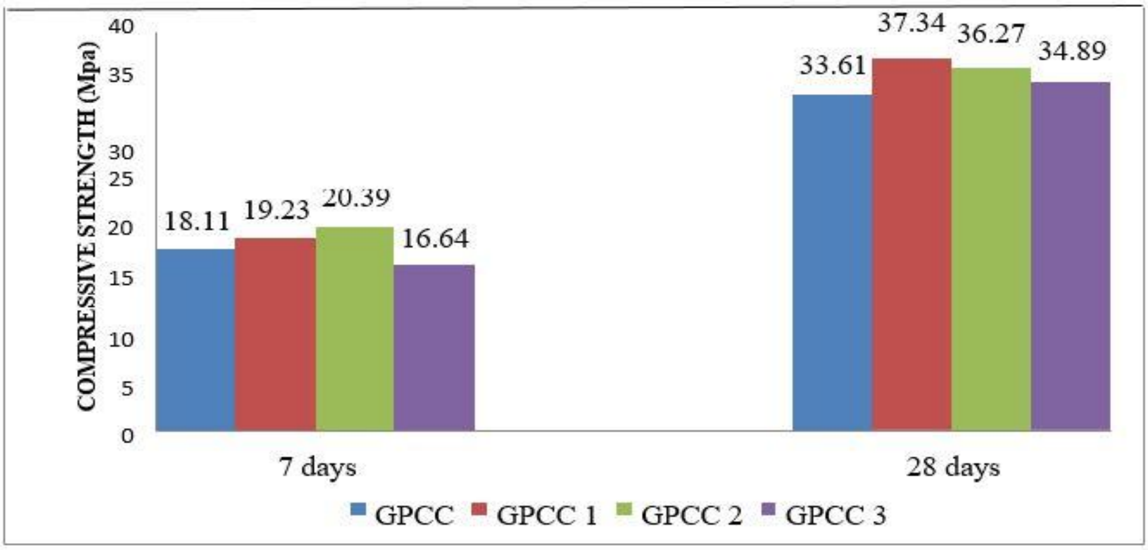

Fig -2 Comparison of Compressive strength of GPCC without& with glass fibers

From the above graph the following results are made:

- As the volume fraction of fibers increased from 0.01% to 0.02% the 7days compressive strength values are increased from 6.18% to 12.18% compared to the GPCC mix without fibers.
- At the age of 28 days with the increase in fiber dosage from 0.01% to 0.03% compressive strength values are failing down by 2.86% and 6.56% compared to the GPCC mix with 0.01% dosage.
- From the above observations it is understood the increase in fibers dosage beyond 0.01% leading to the poor interlocking affect there by resulting in lower strengths. Hence the optimum dosage of fibers is found to be 0.01% at 28 days.
- The rate of increment in Compressive strength values of GPCC, GPCC 1, GPCC 2, GPCC 3 from 7 days to 28 days are 86%, 94%, 78% ,109% respectively. However there is an increment of 11% in the compressive strength is observed at optimum fiber dosage compared to those of GPCC without glass fibers.

5.2.2 Split Tensile strength:

The split tensile strength values were determined by conducting test on cylindrical specimens. The values obtained were given below

Table- 5 Tensile strength values of GPCC without & with glass fibers

S.NO	SPLIT TENSILE STRENGTH(Mpa)							
	7 DAYS				28 DAYS			
	GPCC	GPCC1	GPCC2	GPCC3	GPCC	GPCC1	GPCC2	GPCC3
1	1.073	1.14	1.23	1.33	2.38	2.56	2.88	3.03
2	1.073	1.13	1.13	1.3	2.38	2.73	2.84	2.96
3	1.236	1.13	1.13	1.28	2.42	2.49	2.82	3.01
AVERAGE	1.127	1.133	1.163	1.303	2.393	2.593	2.846	3.00

The above obtained results were represented graphically as shown below

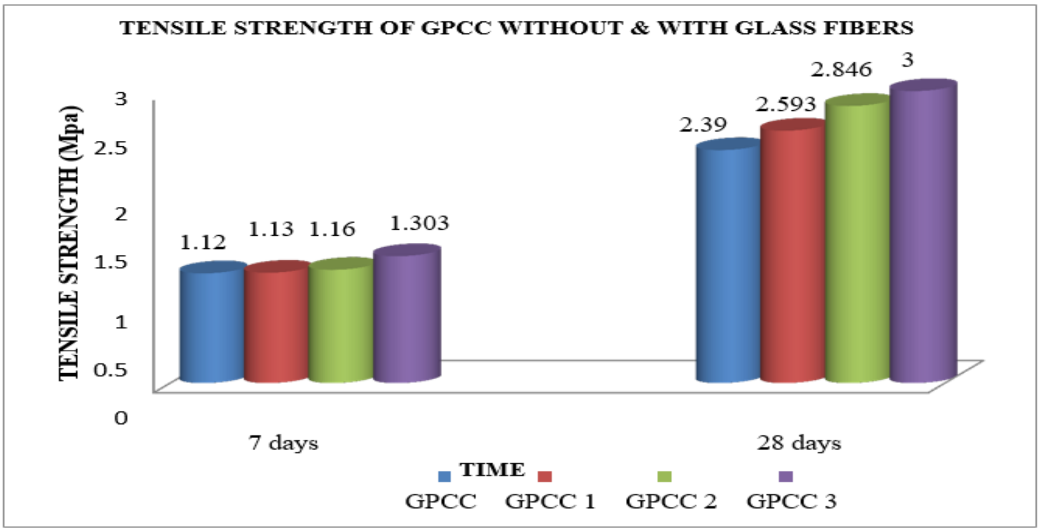

Fig -3 Comparison of Tensile strength of GPCC without & with glass fibers

From the above graph the following results are made:

- As the volume fraction of fibers increased from 0.01% to 0.03% the 7days split tensile strength values are increased from 0.89% to 16.34% compared to the GPCC mix without fibers.
- The increase in tensile strength values of GPCC, GPCC 1, GPCC 2, GPCC 3 from 7 days to 28 days are 113 %, 149 %, 145 %,130 % respectively.
- At the age of 28 days with the increase in volume fraction of fibers from 0.01% to 0.03% the split tensile strength values are increased from 8.5% to 25.5% compared to the GPCC mix without fibers. It is observed that as the fiber content is increased the split tensile strengths are also proportionately increasing. Hence at 28 days, optimum dosage of fibers is found to be 0.03%.
- Maximum increment in the tensile strength is found to be 25.52% at 0.03% volume fraction compared to GPCC without fibers at the age of 28 days.

5.2.3 Flexural strength:

The flexural strength was determined by testing prisms of GPCC without & with glass fibers. The results obtained are as follows.

Table- 6 Flexural strength values of GPCC without & with glass fibers

S.NO	FLEXURAL STRENGTH (Mpa)							
	7 DAYS				28 DAYS			
	GPCC	GPCC1	GPCC2	GPCC3	GPCC	GPCC1	GPCC2	GPCC3
1	3.32	3.52	4.36	4.06	5.6	5.88	6.09	6.44
2	3.28	3.44	4.2	4.68	5.72	6	6.08	6.52
3	3.32	3.92	4.04	4.43	5.48	5.77	5.96	6.36
AVERAGE	3.30	3.626	4.2	4.39	5.6	5.88	6.04	6.44

Above values of flexural strength can be graphically represented as below

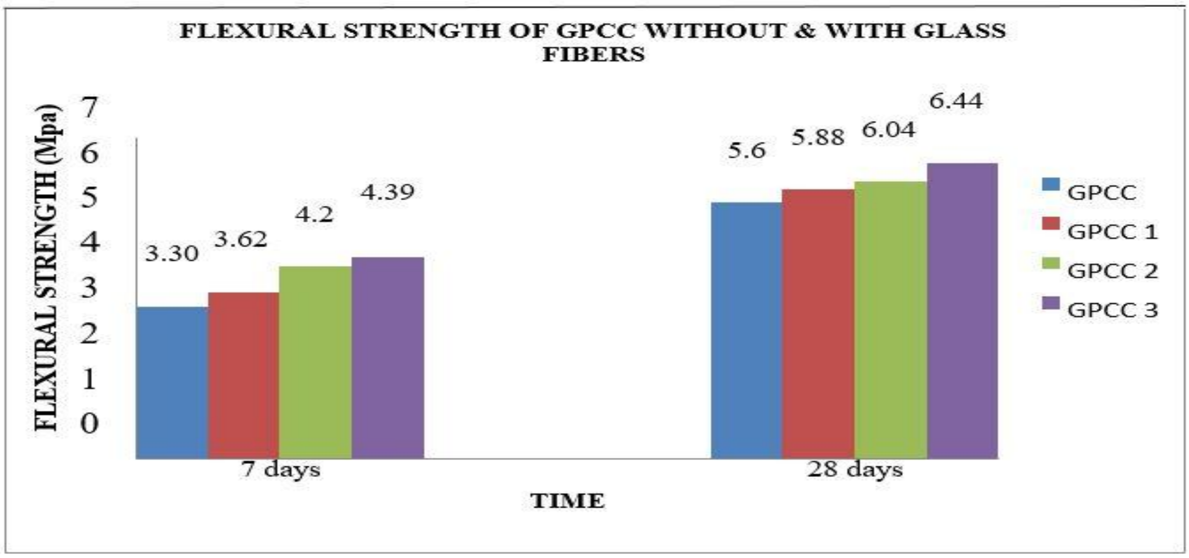

Fig-4 Comparison of Flexural strength of GPCC without and with glass fibers

From the above graph the following results are made

- As the volume fraction of fibers increased from 0.01% to 0.03% the 7days flexural Strength values are increased from 9.7% to 33.3% compared to the GPCC mix without fibers.
- The increase in Flexural strength values of GPCC, GPCC 1, GPCC 2, GPCC 3 from 7 days to 28 days are 70 %, 62 %, 44 %, 46 % respectively.
- 28days Flexural strength values are increased from 5% to 15% as the volume fraction of fibers increased from 0.01% to 0.03% compared to the GPCC mix without fibers. It is observed that as the fiber content is increased the flexural strengths are also proportionately increasing. Hence at 28 days, optimum dosage of fibers is found to be 0.03%
- The flexural strength values of GPCC with glass fibers in 0.03 % volume fractions improved the strength by 15% than those of GPCC without glass fibers.

5.2.4 Water absorption test:

The water absorption was determined by testing cubes of GPCC without & with glass fibers. The results obtained are as follows.

Table-7 water absorption values of GPCC without & with glass fibers

Spec.	Initial weight (gms)	Weight (gms)		Water absorption %	
		at 30 minutes immersion	at 24 hours immersion	at 30 minutes	at 24 hours
GPCC	2296	2336	2366	1.742	3.049
G0.01	2350	2382	2412	1.36	2.64
G0.02	2432	2462	2480	1.23	1.974
G0.03	2408	2430	2470	0.914	2.57

- From the above tabulated values it can be seen that at 30 minutes as the volume fraction of fibers increased from 0.01% to 0.02% the water absorption capacity is decreased.
- At 24 hours the water absorption values for the GPCC specimens for all the volume fraction of fibers were lower than GPCC without fibers.
- Within the fibrous specimens, specimens containing 0.02% of glass fibers perform better by showing lower value of water absorption.

5.2.5 Sorptivity test:
The sorptivity was determined by testing cubes of GPCC without & with glass fibers. The results obtained are as follows.

Table-8 sorptivity values of GPCC without & with glass fibers

Spec.	Sorptivity value in 10^{-5}									
	1min	**4min**	**9min**	**16min**	**25min**	**36min**	**49min**	**64min**	**81min**	**100min**
GPCC	0	3	4.67	4	3.6	3.33	3.428	3.5	3.33	3.2
G0.01	0	1	1.33	1.5	1.6	1.67	1.428	1.5	1.56	1.6
G0.02	0	3	2.67	3	3.2	3.33	2.857	3.25	3.11	3
G0.03	0	2	1.33	1.5	2	1.67	1.714	1.75	2	2

- From the above results it is concluded that inclusion of fibers results in low sorptivity values compared to GPCC without fibers for it reducing the porosity.
- GPCC with volume fraction of 0.01% fibers has the lower sorpitivity value indicates the decrease in porosity.

VI. Conclusions

1. Inclusion of glass fibers reduces the slump values. This is due to the resistance of fibers for the free flow of concrete.
2. At the age of 28 days with the increase in fiber dosage from 0.01% to 0.03% compressive strength values are falling down by 2.86% and 6.56% compared to the GPCC mix with 0.01% dosage. Hence, optimum dosage of fibers is found to be 0.01%.
3. Split tensile strength values are increased from 8.5% to 25.5% with the increase in volume fraction of fibers from 0.01% to 0.03% the compared to the GPCC mix without fibers at the age of 28 days. It is observed that as the fiber content is increased the split tensile strengths are also proportionately increasing. Hence at 28 days, optimum dosage of fibers is found to be 0.03%.
4. As the volume fraction of fibers increased from 0.01% to 0.03% flexural strength values are increased from 5% to 15% compared to the GPCC mix without fibers at the age of 28days. It is observed that as the fiber content is increased the flexural strengths are also proportionately increasing. Hence at 28 days, optimum dosage of fibers is found to be 0.03%.
5. The water absorption values at 30 min for the GPCC specimens for all the volume fractions of fibers were lower than the limit of 3% specified for good concrete.
6. It is concluded that GPCC with volume fractions of 0.01% fibers exhibited the lower sorpitivity values indicates the decrease in porosity.

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