

Performance of Fibre Reinforced Geopolymer Concrete: A Sustainable Solution for Enhanced Durability

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Abstract: This research is carried to investigate the fresh, hardened, durability and structural behaviour of Fibre Reinforced Geopolymer (FRGP) concrete members. The casting and testing of FRGP concrete specimens were done according to the specifications followed for ordinary Portland cement. The tests were carried out for the fresh concrete initially. The slump value and percentage of flow for fresh geopolymer concrete with and without polypropylene fibre were tested in accordance. The compressive strength of 150 mm x 150 mm x 150 mm concrete cubes were ascertained by testing as per the procedures stipulated in IS: 516:1959. Split tensile strength test was conducted on 150 mm diameter and 300 mm height cylinders cast and tested in accordance to IS: 5816-1999. FRGP concrete beams of standard size 500 mm x 100 mm x 100 mm confirming to IS: 516-1959 was used for evaluating flexural strength of plain concrete. Durability tests on Geopolymer concrete with and without polypropylene fibre cubes were conducted and the results were compared. Tests on water absorption were also carried out and compared. The Ultrasonic pulse velocity test was conducted as per the procedure given in IS: 13311:1992. Experimental analyses were conducted on M40 grade concrete with varying polypropylene fibre dosages. The results confirm that up to 0.6% fibre inclusion enhances strength and durability significantly, affirming the potential of FRGPC as a sustainable construction material.

Keywords: Geopolymer Concrete, Fly Ash, Compressive Strength, Flexural Strength, UPV, Water Absorption

I. INTRODUCTION:

Geopolymer are produced by the alkali activation of aluminosilicates present in the source material. These gels can be used to bind aggregates, such as sand or natural rocks, to produce mortars and concretes. In simple words, Geopolymer are inorganic binders that function like the better-known Portland cement. French Professor, Davidovits found out that the existence of three-dimensional silicate-aluminium product in the ancient Pyramids had the same structure as Zeolite, and then he designated this man-made rock like product as —Geopolymer. Industrialization leads to the generation and release of undesirable pollutants into the environment. In order to keep pace with the rapid industrialization, there is a necessity to select an engineering process, which would cause minimum pollution into environment. On the other hand, construction industry is increasingly turning towards the use of environmentally friendly materials in order to meet the sustainable aspect required by modern infrastructures. Consequently, in the last two decades, the expansion of this concept and the increasing global warming have raised concerns on the extensive use of Portland cement due to the high amount of carbon dioxide associated with its production.

The brittleness of traditional GPC limits its application, especially under tensile stress. To address this, the addition of Polypropylene Fibre enhances mechanical behavior, crack resistance, and ductility.

This research focuses on Polypropylene Fibre-Reinforced Geopolymer Concrete (FRGPC) for structural applications and assesses its performance against durability challenges.

II. OBJECTIVE OF THE PRESENT STUDY

1. To determine the fresh Geopolymer Concrete (GPC) properties with and without Polypropylene Fibre.
2. To investigate the mechanical strength of hardened GPC with and without addition of Polypropylene Fibre.
3. To test on durability of GPC with and without addition of Polypropylene Fibre.

III. MATERIAL

3.1 Cement: Ordinary Portland cement of grade 53 was used for the experimental analysis.

3.2 Fly Ash: Class F fly ash is used in this research.

3.3 Fine Aggregate: Fine aggregate collected from narmada river & it has been used for experimental study satisfies the requirement as per IS 383:1970.

3.4 Coarse Aggregates: Locally available coarse aggregate of size 20 mm and below was used in this research.

3.5 Polypropylene Fibre: Diameter 10 μ m–1 mm, length 6–48 mm

3.6 Concrete Mix Design: The mix proportion for M40 grade conventional concrete is presented in Table 1 explains about the proportions concrete mix design.

Cement	Water	Fine Aggregate	Coarse Aggregate	Water Cement Ratio
332Kg	155 kg	719 kg	1064 kg	0.36

IV. EXPERIMENTAL PROGRAMME

4.1 Slump Cone Test

The slump cone test was performed as per the procedure given in IS: 7320 - 1974, a mould of 1.6 mm thick galvanized metal in the form of the lateral surface of the frustum of a cone with the base 200 mm in diameter, the top 100 mm in diameter and the height 300 mm is used to study the workability of fresh concrete. The base and the top were open and parallel to each other and at right angles to the axis of the cone. The mould was provided with a foot piece on each side for holding the mould in place, and with handles for lifting the mould from the sample. Tamping rod was a round, straight steel rod 16 mm in diameter and approximately 600 mm in length is used for compaction.

4.2 Compressive Strength Test

GPC of size 150 mm×150 mm×150 mm were cast as per IS:516-1959 with and without Polypropylene Fibre of various percentage of addition and called as GP and FRGP series. During casting, the cubes were mechanically vibrated using a table vibrator. After 24-36 hours, the specimens were demoulded and subjected to curing in normal atmosphere. After curing, the specimens were tested for compressive strength using compression testing machine of 2000 kN capacity. The maximum load at failure was taken.

4.3 Splitting Tensile Strength Test

Concrete cylinders of size 150 mm diameter and 300 mm length were casted as per IS: 516 – 1959, with incorporating Polypropylene fibre as an addition to concrete. During casting, the cylinders were mechanically vibrated using a table vibrator. After 24 hours, the specimens were demoulded and subjected to curing for 28 days in atmosphere. After curing, the cylindrical specimens were tested for split tensile strength using compression testing machine of 2000 kN capacity.

4.4 Flexural Strength Test

Beam specimens of standard size 100 mm x 100 mm x 500 mm were cast as per (IS: 516-1959) to determine the flexural strength of fibre reinforced concrete produced using Polypropylene Fibre. addition of Polypropylene Fibre was ranged from 0% to 1%. All beams are simply supported over an effective span of 400 mm and tested in a frame load test machine of capacity 1000kN. A single, central, concentrated load was placed over the span of the beam. Prior to placing the specimens in the machine, the beam surfaces at the location of supports and loads were smoothly ground to eliminate unevenness.

4.5 Ultrasonic Pulse Velocity Test (UPV)

The UPV test was conducted as per the procedure given in IS: 13311:1992. UPV is a Non-Destructive Technique that measures, involves measuring the speed of sound through materials in order to predict material strength, to detect the presence of internal flaws such as cracking, voids, honeycomb, decay and other damage.

The instrument consists of a transmitter and a receiver (two probes). The time of travel for the wave to pass from the transmitter to the receiver when kept opposite to each other is

recorded in the ultrasonic instrument. The distance between the two probes (path length) was physically measured. Hence,

$$\text{Ultrasonic Pulse Velocity} = \text{Path length} / \text{Transit time}$$

This velocity is related to its compressive strength. The quality and approximate compressive strength of concrete was determined per IS: 13311:1992 which gives the relationship between ultrasonic pulse velocity and quality of concrete.

4.6 Water Absorption Test

The water absorption values for various mixtures of GP and FRGP series concrete were determined on 150 mm x 150 mm x 150 mm cubes as per IS 1124:1974. The specimens were taken out of curing tank at 28 days to record the Water Saturated weight (Ws). The drying was carried out in an oven at a temperature of 105°C. The drying process was continued until the difference between two successive measurements agreed close. Oven-dried specimens were weighed after they cooled to room temperature (W_d). Using these weights, Saturated Water Absorption (SWA) was calculated.

$$\text{SWA} = [(W_s - W_d) / W_d] \times 100$$

V. RESULT AND DISCUSSION

5.1 Tests on Fresh Geopolymer Concrete

The workability of fresh GPC was tested. The FRGP Concrete produced with the addition of Polypropylene fiber was studied, for their slump value and flow percentage. The results were observed, reported and discussed

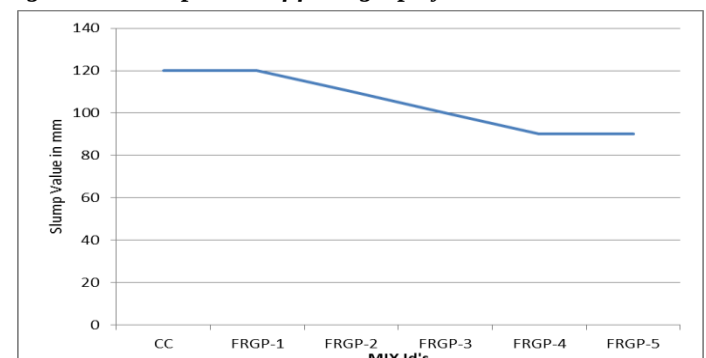
Slump Cone Test

The fresh GPC were prepared for all Mix IDS and were tested using slump cone mould of standard size, for its workability and the results were discussed.

Table 5.1 Slump cone test on fresh geopolymer concrete

S.No	Mix ID	Percentage addition of Polypropylene Fiber	Slump Value in mm
1	CC	0	120
2	FRGP-1	0.2	120
3	FRGP-2	0.4	110
4	FRGP-3	0.6	100
5	FRGP-4	0.8	90
6	FRGP-5	1	90

Figure 5.1 Slump value of fresh geopolymer concrete



Discussions on results

The results indicated that the workability decreases as the percentage addition of Polypropylene Fibre increases. The value lies between 120 mm to 90 mm which there by ensures medium workability on all mix proportions. All the mix which is tested show slump as true slump. There is a loss of 8.3%, 16.66%, 25% and 25% slump value for FRGP-2, FRGP-3, FRGP4 and FRGP-5 respectively in comparison with the control specimen CC.

5.2 Tests on Strength of Hardened Gpc With Polypropylene Fibre

5.2.1 Compressive Strength Test

Geopolymer and FRGP concrete cubes of size 150 mm×150 mm×150 mm are casted for specified Mix IDs and were tested for compressive strength on 7, 14 and 28 days. The test is carried out on all the specimens and was presented and discussed. The strength attained during 3 days, 7 days, 14 days and 28 days on Geopolymer and FRGP concrete cubes are investigated experimentally on each age and their mean results are presented numerically and schematically in Table 5.2 and Figure 5.2

Table 5.2 Behaviour of FRGP concrete under compression

S.No	Mix IDs	Compressive strength in MPa		
		7 Days	14 Days	28 Days
1	GP	32.07	36.98	46.81
2	FRGP-1	32.96	38.86	47.70
3	FRGP-2	33.62	39.68	48.85
4	FRGP-3	34.16	42.85	50.45
5	FRGP-4	32.21	40.60	48.81
6	FRGP-5	30.81	37.85	47.55

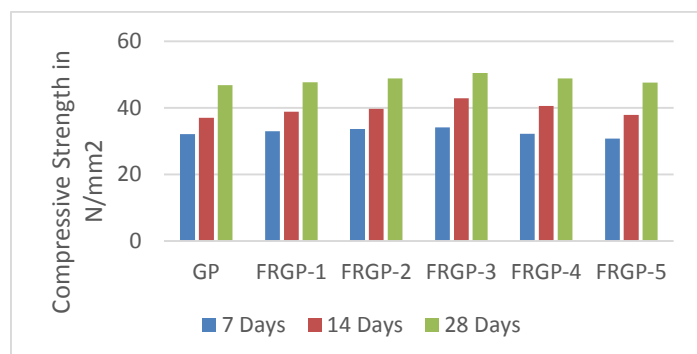


Figure 5.2 Behaviour of FRGP concrete under compression

Discussions on results

The test results indicate that for mixtures prepared using up to 0.6% addition of Polypropylene Fibre shows increase in compressive strength of GPC. However, for mixture with 0.8% and 1% addition shows decrease in compressive strength, particularly 1% addition shows the lowest of Polypropylene added IMPACT FACTOR 6.228

mixtures. Mixture FRGP-3 yielded the highest compressive strength on all days of the test. From the experimental investigation the following observations are made.

5.2.2 Splitting Tensile Strength Test

GPC cylinders of size 150 mm×300 mm are casted on all mix proportions and its splitting tensile strength is observed. From the experimental investigation the splitting tensile strength was determined and presented in Table 5.3 and its corresponding schematic representation in Figure 5.3.

S.No	Mix IDs	7 Days (Mpa)	14 Days (Mpa)	28 Days (Mpa)
1	GP	1.79	2.30	2.47
2	FRGP-1	2.22	2.73	2.86
3	FRGP-2	2.99	3.27	3.45
4	FRGP-3	3.16	3.44	3.76
5	FRGP-4	2.99	3.39	3.49
6	FRGP-5	2.26	2.73	2.89

Table 5.3 Splitting tensile strength of FRGP concrete

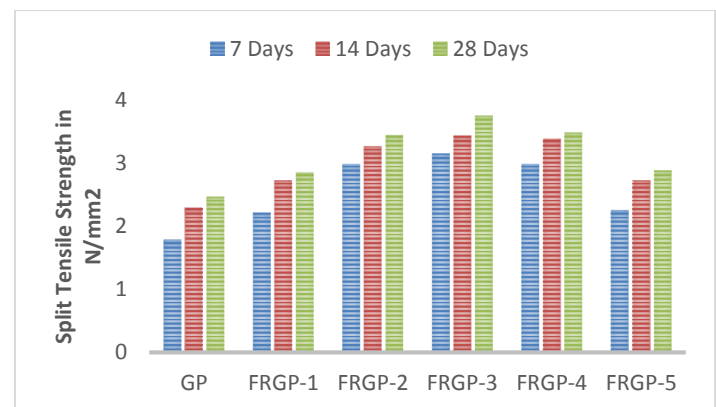


Figure 5.3 Behaviour of FRGP concrete under Tensile Strength

Discussions on results

The result shows that the average splitting tensile strength of Polypropylene Fibre added GPC specimens increased upto 0.6% addition. The splitting tensile strength of FRGP-5 specimens decreased on all ages compared to other FRGP specimens. Still it shows higher strength than that of GP specimen.

5.2.3 Flexural Strength Test

The size of the beam specimen cast for flexure test was 100 mm x 100 mm x 500 mm. The beam specimens were fabricated and tested for its flexural strength. Six numbers of GPC beam specimens were cast for each mix IDs. Three specimens for all mix IDs on 7 days, 14 days and 28 days respectively were tested

and their average results are shown in Table 5.4.

Table 5.4 Flexural strength of FRGP concrete

Mix IDs	Flexural strength on 7 days in MPa	Flexural strength on 14 days in MPa	Flexural Strength on 28 days in MPa
GP	3.89	5.11	5.81
FRGP-1	4.12	5.47	5.94
FRGP-2	4.30	5.75	6.22
FRGP-3	4.75	6.06	6.93
FRGP-4	4.56	5.97	6.69
FRGP-5	4.38	5.89	6.47

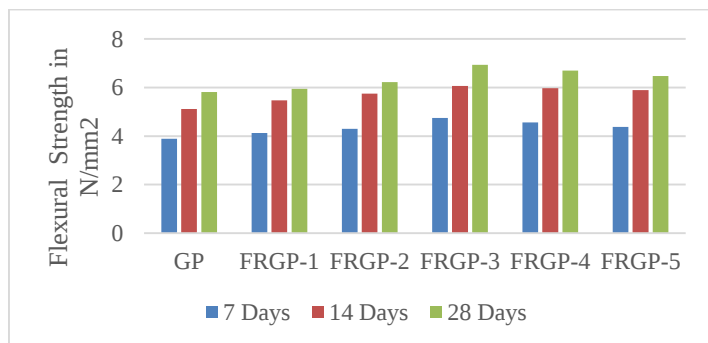


Figure 5.4 Behavior of FRGP concrete under Flexural Strength

Discussions on results

Based on the flexural strength test results at 7, 14, and 28 days for various mix IDs, it is evident that the inclusion of FRGP significantly enhances the flexural performance of Geopolymer Concrete (GPC). The control mix (GP) recorded flexural strengths of 3.89 MPa, 5.11 MPa, and 5.81 MPa at 7, 14, and 28 days respectively. All fibre-reinforced mixes (FRGP-1 to FRGP-5) demonstrated improved flexural strength across all curing ages. Among them, FRGP-3, with 0.6% fibre content, consistently achieved the highest values, reaching 4.75 MPa at 7 days, 6.06 MPa at 14 days, and 6.93 MPa at 28 days.

5.2.4 Ultrasonic Pulse Velocity Test

The UPV test on FRGP Concrete is considerably related to its density and modulus of elasticity. This in turn depends upon the materials matrix used in making FRGP Concrete as well as the method of placing, compaction and curing of GPC. UPV test was conducted for 6 GPC mixes named as CC, FRGP-1, FRGP-2, FRGP-3, FRGP-4 and FRGP-5. The standard of Geopolymer Concrete was assessed using the guide lines given in Table 2 of IS 13311 (Part 1): 1992. Table 5.5 shows the results of UPV test for FRGP Concrete Specimens. These results show all the specimen exhibit excellent quality in terms of pulse wave passed through the GPC. This also relates with the strength of GPC, higher the pulse

velocity shows higher strength.

Table 5.5 Ultrasonic pulse velocity test

S.No	Mix ID	Distance in mm	Transit time(μ Sec)	Pulse Wave Velocity in Km/sec
1	CC	150	32.600	4.68
2	FRGP-1	150	32.300	4.75
3	FRGP-2	150	31.300	4.83
4	FRGP-3	150	30.500	5.03
5	FRGP-4	150	31.400	4.80
6	FRGP-5	150	34.100	4.47

Discussions on results

For control mixes (CC) travel time of ultrasonic waves is 4.68 and when the percentage of polypropylene addition is carried out the pulse velocity increases. Hence the average pulse velocity of FRGP-1, FRGP-2, FRGP-3 and FRGP-4 specimens increased to 1.53%, 3.24%, 7.60%, and 2.58% respectively than that of control specimens. The average pulse velocity of FRGP-5 decreases by 2.52% when compared with control specimen. Therefore it can be concluded that the quality of GPC is excellent for all mix proportions, especially for Polypropylene Fibre addition upto 0.6%, excellent.

5.2.5 Water Absorption Test

The water absorption values for various mixtures of FRGP Geopolymer Concrete were observed on 150 mm x 150 mm x 150 mm cubes and the results were discussed. The results are tabulated in Table 5.6.

Table 5.6 Water absorption of FRGP concrete

S.No	Mix IDs	Weight of saturated specimen in kg	Weight of oven dried specimen in kg	Saturated Water Absorption in percentage
1	CC	8.60	8.48	1.42
2	FRGP- 1	8.59	8.52	0.82
3	FRGP- 2	8.65	8.59	0.70
4	FRGP- 3	8.82	8.75	0.80
5	FRGP- 4	8.58	8.49	1.06
6	FRGP- 5	8.50	8.39	1.31

Discussions on results

Based on investigations, The specimen FRGP-1 and FRGP-2 shows 19.31% and 28.27% of reduction in water absorption when compared with control specimen. In FRGP-3 specimen the average water absorption is only 0.75% which shows 47.58% of water absorption decrement when compared to control specimens. The FRGP-4 specimen shows a decrease of 29.65% of water absorption when compared to control specimen and the average water absorption is 1.02%. The FRGP-5 has highest water absorption rate among all mix proportions. The percentage of water absorption is 1.51% which is 4.13% higher than the control specimen. This increase in water absorption is due to higher voids in FRGP Concrete.

VI.CONCLUSION

Based on the investigations, the following conclusions were drawn

- The results indicated that the workability of fresh FRGP concrete decreases as the percentage addition of Polypropylene Fibre increases. The values of slump cone test on fresh concrete lies between 120 mm to 90 mm which there by ensures medium workability on all mix proportions. The maximum percentage of flow of fresh concrete is observed in control specimen whereas lowest flow percentage is observed in FRGP- 5 specimen.
- The 7 days, 14 days & 28 days result shows that there was 57.14%, 33.33% and 35.38% increase in compressive strength for FRGP-3 specimens respectively over the control specimen GP.
- The 7 days, 14 days & 28 days test results shows that there was 76.39%, 49.76% and 52.08% increase in split tensile strength for FRGP-3, specimens respectively over the control specimen GP.
- The 7 days, 14 days & 28 days flexural strength shows FRGP-3 increases by 22.10%, 18.59% & 19.27% compare to control specimen. After that polypropylene fiber % increases strength decreases
- UPV results show all the specimen exhibit excellent quality in terms of pulse wave passed through the GPC. The UPV results also relate with the strength of GPC, higher the pulse velocity shows higher strength. From the UPV results it can be concluded that the quality of GPC is excellent for all mix proportions, especially for Polypropylene Fibre addition upto 0.6%, excellent.
- The water absorption test shows that FRGP-5 which is the superior specimen in terms of water absorption, the percentage of water absorption is 1.51% which is 4.13% higher than the control specimen. This increase in water absorption is due to higher voids in higher percentage of FRGP Concrete.

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