

Durability Characteristics of Fiber Reinforced Geopolymer Concrete Incorporated with Fly-ash and GGBS

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Abstract: The growth of geopolymer concrete has increased its demand from past years. The importance of geopolymer concrete has been boosted up in present trends due to its exhibition of excellent Strength and Durability Properties while compared to ordinary Portland cement based concrete the geopolymer concrete can be easily taken into consideration by replacement of cement concrete. As, CO₂ the major harmful exponent ejected during cement production which result in deterioration of environment and effects the global warming in order to reduce this, CO₂ content in geopolymer concrete alternate binders like low calcium based fly ash and GGBS are used which are less hazardous compared to ordinary Portland cement. This experimental work deals with the tests like sulphate resistances, chloride resistance, water Absorption, Abrasion resistance tests for specimens have been carried out to determine the durability characteristics as extension of strength properties developed for fiber reinforced geopolymer concrete at a Standard grade of (G40) by incorporating polypropylene and basalt fibers the dosage of fibers were varied in volume fractions at 0%, 0.1%, 0.2%, 0.3%, 0.4%.. Basalt fibers were kept constant as 0.05% for all mixes conducted. Active alkaline liquids like sodium hydroxide (NaOH) of 12 molarity concentration, sodium silicate (Na₂SiO₃) gel, and naphthalene based super plasticizer SP 430 were used.

Key words: geopolymer concrete, fly-ash, GGBS, polypropylene fiber, basalt fiber, sodium silicate, sodium hydroxide, SP430, Compressive strength, Chloride resistance, Sulphate resistance, Water absorption, Abrasion resistance.

I. INTRODUCTION

Concrete usage around the globe is secondary to water. The durability characteristics of concrete are normally one of the prime issues within in the concrete industry. This phenomenon is even more important for geopolymer concrete. Even then it is still considered as one of the tough problems in concrete community due to their large scale production and commercialization. The development of low calcium fly-ash based geopolymer concretes offers promising criterion for bring a drastic change in producing concrete. However, considering Geopolymer binders as an alternative to ordinary Portland cement, varies strength related matters of new material should be evaluated for comparative analysis.[5][7][9] The binary blended geopolymer concrete, concrete made up of GGBS fly ash, fine river sand, Standard sized coarse aggregate, and alkaline activators like sodium silicate & sodium hydroxide, runs a significant role in its environmental control of green house effect. The minimising of carbon dioxide from cement producing industries can contribute the deterioration of ecosystem and prevailing environment. Concrete exposed to environment they are considered as they were subjected to several types of aggressive materials mechanical agents, such as admixtures water reducers etc, and deterioration due effect of chemical solutions they attacks due to presence of chlorides and sulphates, with respect to changes in temperature. The damage of concrete structures happens due to the aggressive agents, such as alkaline activators, In case of fibre reinforced concrete.[9] Additionally, the durability properties of fiber reinforced geopolymer concrete are independent of its intrinsic qualities it varies according to the type of exposure in the different environmental conditions and the strategy of immersion. when fiber reinforced geopolymer Concrete reacts with various chemical solutions consisting sulphates, chlorides, nitrates etc and zinc magnesium ions impacts the mechanisms like crystallization of salts and precipitation of insoluble particles due to attack of chemical solutions.[1] Permeability factor is the important phenomenon for the determination of long-term durability characteristics of fibre reinforced concrete in prevailing environment. The denser the geopolymer concrete will be it becomes difficult for the deterioration. In the current trends the manufacturing of geopolymer concrete, is done by mixing waste product exhibited by thermal power plants like fly ash and Ground granulated blast furnace slag which can be completely used as replacement of ordinary Portland cement. In the Current experimental investigations for durability has been carried out on

double fiber incorporated geopolymer concrete are mainly given attention on geopolymer technology to make use of bi product based geopolymer concrete by determining its physical and chemical properties. [3][5] Typically there are no specific standard Codal provisions or rules available for judging the durability properties of geopolymer concrete. This paper gives a brief explanation by investigating the durability properties of binary blended fiber reinforced geopolymer concrete, The compressive strength, chloride sulphate resistance, abrasion resistance, water absorption tests were performed and investigated when exposed to natural and standard environmental conditions.

II. LITERATURE REVIEW

S. S. Patil and A. A. Patil had investigated and reported the Durability characteristics of fly ash based geopolymer concrete incorporating of silica fume at standard grade of (G40). Geopolymer is a green cementations material which possesses excellent mechanical characteristics; low amount of heat is liberated and emits less carbon dioxide which is a toxic environmental pollutant. In this current paper, the study on durability properties of fly ash based geopolymer concrete on addition of silica fume have been investigated by placing the cubes in two percent of sulphuric acid and five percent of sodium chloride liquids. The resistance of fly-ash and silica fume based geopolymer specimens to chemical attack was thoroughly evaluated the modifications in the weights and percentage loss in compressive strength at different durations of time. A control mix was also casted for M40 grade with normal OPC concrete for comparison. Percent losses in compressive strengths in the case of control (M40) and GPC in 2% sulphuric acid at 90 days Were found 35 and 9%. Percent loss in compressive strength for the control mix and GPC in 5% sodium chloride at 90 days were 16% and about 0%. Hence the resistance of fly-ash based geopolymer concrete incorporating silica fume in sulphuric acid and chloride solution was significantly higher than that of the OPC concrete mix. [1][3] Ganesan lavanya and Josephraj Began had performed studies on Durability phenomenon of High Calcium Fly Ash Based Geopolymer Concrete how the geopolymer concrete behaves when it gets reacted with high calcium contend fly ash along with alkaline liquids when subjected to two percentage of H_2SO_4 acidic solution and five percent of $MgSO_4$ at a duration of 90 days. The water absorption and Sorptivity was also measured. The investigations were carried out for control mix of standard grade such as M20 M40 and M60. the ratio of alkaline liquid was assumed to be 2.50. The molar concentration of sodium hydroxide was chosen as 12. the cubes of standard dimensions 150^3 was casted and circular discs of 100mm x 200mm was casted and cured at ambient condition. The surface wearing, strength, density was observed at durations of 7 days 14 days and 60 days. [7] The results were detected as the decrease in strength for GPC was nearly 14% and OPC was 26% for $MgSO_4$ solution. The decrease in compressive strength was about 19% for GPC and 28% for OPC specimens. The GPC and OPC mixes indicated small changes in weight and strengths when the specimens were immersed into sulphuric acid and magnesium sulphate solutions. The water absorption and sorptivity of GPC were negligible. Bapugouda Patil Veranda Kumar M, Dr. H Narendra had done experimental investigation on Durability Studies On Sustainable Geopolymer Concrete The main focussed in this paper was to retrieve the durability properties of high strength geopolymer concrete and to comparative differences between normal strength concrete and high strength geopolymer concrete was focused. The resistance to chloride attack sulphate attack and fire resistance was analysed. Their main aim of the study was to develop sustainable GPC by using of low calcium based fly ash, GGBS, pond ash obtained from thermal power plants which are treated to be waste product and M-sand. Compressive strength and durability properties of high strength GPC was compared with that of Normal strength concrete. The results of compressive strength test of GPC cubes left for ambient curing, reported that the development of M30 grade through which the compressive strength can be achieved without heat curing. In the Current experimental program it was noticed that GGBS plays a majestic role in increasing the compressive strength of the fly ash a based geopolymer concrete with incorporation of GGBS in GPC showed better results in both ambient curing and heat curing conditions. The compressive strength was slightly higher in heat cured specimens than ambient cured specimens. [8] The 16M molarity concentration use of sodium hydroxide pellets has resulted in giving optimal condition while compared all molarities which can be suggested for future geopolymeric applications. Durability of geopolymer concrete is equally to that of strength parameters of the geopolymer concrete for the structure to have great life. Durability test like acid resistance test (HCl), chloride resistance test (NaCl), sulphate resistance test ($MgSO_4$), fire resistance test and water absorption test were conducted on both GPC and normal strength specimens. Gain of mass in GPC specimens immersed in sodium chloride and Magnesium sulphate solution was noticed while compared to that normal strength concrete specimens.

III. MATERIALS

3.1 Fly-ash:

The fly ash was obtained from navyug thermal plants which are classified as Low calcium, Class F (American Society for Testing and Materials 2001) dry fly ash which is grey in colour this fly ash contained a very low percentage of carbon as indicated by the low Loss on Ignition (LOI) values.

3.2 Ground Granulated Blast Furnace Slag:

Ground-granulated blast-furnace slag (GGBS or GGBFS) 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. Ground granulated blast furnace slag is obtained from kakatiya power plant located in Warangal.

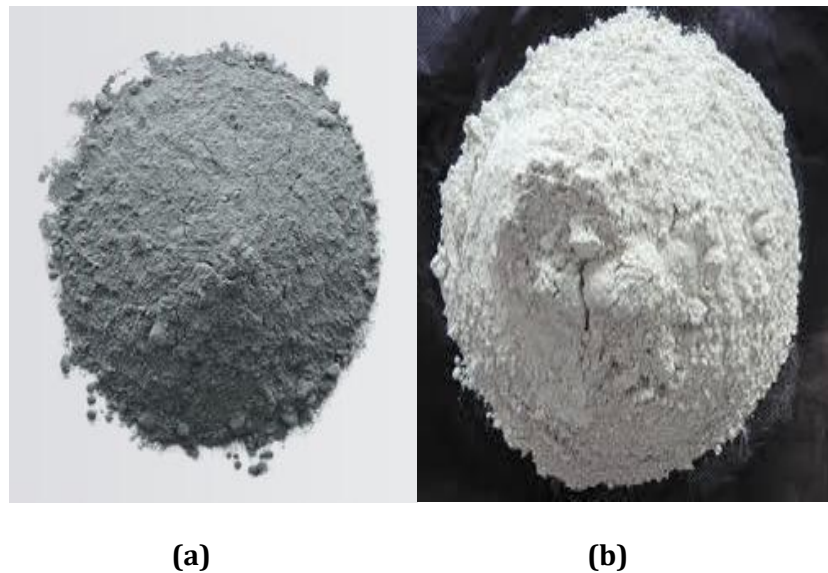


Figure.1 (a) fly-ash & (b) GGBS

Table.2 Chemical Properties of fly-ash & GGBS.

Particulars	Class F fly ash	GGBS
% Silica(SiO ₂)	65.6	30.61
% Alumina(Al ₂ O ₃)	28.0	16.24
% Iron Oxide(Fe ₂ O ₃)	3.0	0.584
% Lime (CaO)	1.0	34.48
% Magnesia (MgO)	1.0	6.79
% Titanium Oxide (TiO ₂)	0.5	-
% Sulphur Trioxide (SO ₃)	0.2	1.85
Loss on Ignition	0.29	2.1

Table.3 Physical Properties of Fly-ash & GGBS.

Property	Fly-ash	GGBS
Specific gravity	2.21	2.82
bulk density Kg/m ³	540-860	100-1200
appearance	grey	Grayish white
Particle size	30 microns	25 microns
Fineness(m ² /kg)	360	400

3.3 Alkaline Liquids:

A mixture of sodium silicate (Na₂SiO₃) solution and sodium hydroxide (NaOH) solution are chosen as the alkaline liquid. The sodium hydroxide material used at a standard grade in the form of pellets form (5mm), with a specific gravity of 2.430, 96.5% of purity. The sodium hydroxide (NaOH) solution was prepared by dissolving these pellets in water for 24 hours before usage. Sodium Silicate was obtained from caelmil Industries, Shirag kinch pvt ltd Madhya Pradesh. The chemical composition of the sodium silicate solution was Na₂O=14.33%, SiO₂=30.10%, and water 55.57% by mass.



Figure.2 (b) sodium silicate & (c) Sodium Hydroxide pellets

Table.4 Properties of Sodium Silicate

Specific gravity	1.65
Molar mass	112.06 gram/mol
Na ₂ O	12.80%
SiO ₂	28.46%
Water (by mass)	58.70%
Weight ratio (SiO ₂ to Na ₂ O)	2.5
Molarity ratio	0.94

Table.5 Properties of Sodium Silicate

Molar mass	40 gr/mol
Appearance	White
Density	2.25 gr/cc
Melting point	315 ⁰ C
Boiling point	1380 ⁰ C
Amount of heat liberated when dissolved in water	268 cal/gr

3.4 Fine aggregate:

Locally available sand is used. The specific gravity of 2.655 and fineness modulus of 3.682 are used as fine aggregate. The water absorption is about 1%.

3.5 Coarse Aggregate:

The fine Crushed aggregate available from local sources has been used. The coarse aggregates with maximum size of 20mm having the specific gravity value of nearly 2.82. The water absorption of coarse aggregate was about 0.55 %.

Table.6 Properties of Coarse Aggregates & Fine Aggregates

Property	Coarse Aggregate	Fine Aggregate
Specific gravity	2.86	2.59
Water absorption	0.35%	0.9%
Fineness modulus	6.95	2.42
Bulk density Kg/m³	1660	1585
Source	Crushed granite stone	Sea Shore



(e)



(f)

Figure.3 (e) fine aggregate & (f) coarse aggregate 20mm

3.6 Fibers:

(a) Polypropylene fibers:

Polypropylene is derived from monomer C_3H_6 which is purely hydrocarbon. These fibers possess high crystalline nature. Chemical inertness makes the fibers resistant to most chemicals. [6]The main use of polypropylene fibers is to arrest crack width which can improve flexural behaviour of geopolymer concrete. In the present experimental investigation polypropylene fibers of 12mm in length are used for all mixes performed in the experiment. The polypropylene fiber is widely preferred because it gives an advantage of easy dispersion while concrete mix. In present experiment 12mm monofilament polypropylene fibers are used.

(b) Basalt fibers:

The basalt fibers are originated from basalt mineral rock these are very fine in nature incorporated with minerals like plagioclase, pyroxene, and olivine. Basalt fiber used in fiber reinforced composites and structural elements has high potential to impart tensile strength of geopolymer concrete.[4][2] It can provide good mechanical properties and chemical resistance in acid & alkali environment. Basalt fibers impart non-corrosive reinforcement High modulus of elasticity and excellent heat resistance. Basalt fibers in geopolymer concrete helps in increasing tensile strength from 25-30%. In present experimental work basalt fibers of 12mm are incorporated and were kept constant at 0.05%.

Table.7 Properties of Fibers

Property	Polypropylene fibers	Basalt fibers
Type	Macro filament	crimped
Cut length	12mm	12mm
Diameter	0.0045	Fine(7-15 μ m)
Tensile Strength	550-700 MPa	515-580 MPa
Density	0.91 gm/cm ³	2.6 gm/cm ³
color	white	brown
Elongation at failure	20%	3.1%
Modulus of elasticity(GN/m ²)	3.5-6.8	100-110
Electric conductivity	low	medium



(g)

(h)

Figure.4 (g) polypropylene fibers & (h) Basalt Fibers

4. Mix design for Polypropylene and Basalt fiber reinforced geopolymer concrete:

The common difference between Geopolymer concrete and ordinary Portland concrete is the binder. The Al and Si oxides in low calcium fly ash with react the alkaline solution to form geopolymer paste that binds the coarse aggregate, fine aggregate and other un-reacted material together to form geopolymer concrete paste in OPC the aggregate occupied 70-80% of the total mass of concrete. So the assumed aggregate percentage was 77% .The ratio of binder i.e. fly-ash, GGBS to alkaline solution ratios is assumed to 0.40. The ratio of sodium silicate to sodium hydroxide solution was taken as 2.5 for all the mixtures because the sodium silicate is cheaper than the sodium hydroxide pellets based solution. The molarity concentration of NaOH solution was taken as 12M for all consecutive mixes. The water reducer used was naphthalene based super plasticizer Forsec SP 430(8). Extra water content was added according to demand for settling of geopolymer concrete paste.

5. Experimental Procedure

To prepare 12M molarity concentration of NaOH solution of NaOH pellets was mixed in the water & makes it up to one litre solution. The NaOH solution should be prepared 24 hours prior to use, because after dissolving pellets of NaOH in water, solution increases up to 700c to 800c in temperature. Hence for usage it has to be cooled at room temperature. The NaOH solution prepared was dissolved together with Na₂SiO₃ solution to get required alkaline solution. The solid constituents of geopolymer concrete like fly ash, GGBS , fine & course aggregates, were mixed for about four minutes in the pan mixer.[1][6][7]. Then alkaline solution added to the entire mix thoroughly for three minutes to get homogeneous geopolymeric concrete paste. For Polypropylene fibers reinforced geopolymer concrete mixes, fibers were added to dry mix in three different proportions from 0-0.4% by volume and putting basalt fibers constant at 0.05% for all mixes fibers chosen are of 12mm in length, the mix goes as six different mixes such as the (0.1PPF+0.05BF),(0.2PPF+0.05BF),(0.3PPF+0.05BF),(0.4PPF+0.05BF), in volume fractions (density) i.e (910 kg/m³ for Polypropylene & 2650 kg/m³ Basalt fibers). In this experimental work, 150 X 150 X 150mm size cubes. After 24 hours of casting all specimens were demoulded & then placed in an oven for Heat (oven) curing at standard temperature of 60 C for 12 hours duration. Then specimens were removed from oven & kept at room temperature. After 28 days, weight of specimens was taken to determine for compressive strength. Cubes were immersed in 5% HCL solution, 5% MgSO₄ solution and 5% H₂SO₄ solution.

Table.8 Mix Design Data

Contents	Kg/m ³
Fly Ash	197.64
GGBS	197.64
Coarse Aggregate	1201.8
Fine Aggregate	646.8
NaOH	45.06
Na ₂ SiO ₃	112.65
SP (430)	7.889

Table.9 fiber Dosage

Sno	Mix id	Polypropylene Fibers (Kg/m ³)	Basalt Fibers (Kg/m ³)
1	M1 (0%)	0	0
2	M2 (0.1%)	0.91	1.325
3	M3 (0.2%)	1.82	1.325
4	M4 (0.3%)	2.73	1.325
5	M5 (0.4%)	3.64	1.325

6. Results & Discussions

1. Compressive Strength:

Compressive strength is the major property of concrete. The specimens were tested on 2000kN As per IS: 10086-1982. The geopolymer concrete mixes were formulated in such a way that the fibers were varied replaced partially with 0.1%, 0.2%, 0.3%, and 0.4%. By putting basalt fibers constant at 0.05 %.

Table.10 Compressive Strength Results:

Mix id	7 days	28 days
FRGPC (0%)	26.75	45.44
FRGPC (0.1%)	35.25	47.4
FRGPC (0.2%)	37.11	55.84
FRGPC (0.3%)	32.06	49.19
FRGPC (0.4%)	21.33	37.5

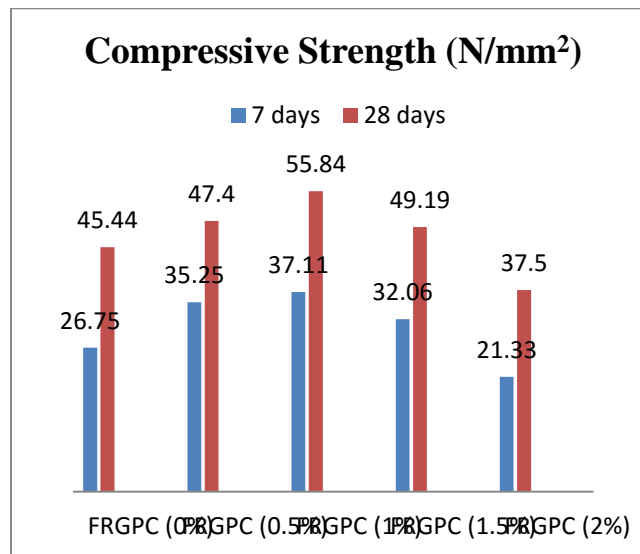


Figure.5 Compressive Strength Variation

1.2. Abrasion Resistance (water method):-

Abrasion resistance refers to the ability of materials and structures to withstand the wearing activity. It is a strategy of erosion or rubbing away the contact surface of concrete by means of friction. Abrasion resistance resists the wear caused due to mechanical action. the resistant materials are useful for both at when materials are at motion and static condition. The Moto of abrasion resistance of concrete is to determine the toughness of aggregate and strength of aggregate bonded together in the concrete matrix. Abrasion resistance can be controlled by usage of surface hardeners, lubricants covering the material with coating agents, sliding and impinged or resurfacing the concrete elements. Confined to ASTM code no. 1138. In the present experimental work abrasion resistance is performed for optimal strength 55.84 N/mm².

The Abrasion loss can be calculated as follows:

Volume of the specimen at any time can be computed using

$$V V_t = (W_{air} - W_{water}) / G_w$$

Where W_{air} is the mass of the specimen in air at the desired time in kg, W_{water} is apparent mass of the specimen in water at the desired time in kg, G_w is the unit weight of water, kg/m^3 The volume of concrete lost at the end of any time increment of testing as follows:

$$V_{L_t} = V_i - V_t$$

Where V_{L_t} = Volume of material lost by abrasion at the end of the test increment in question, m^3 .

V = volume of specimen before testing, m^3 and

V_t = volume of the specimen at the end of the test increment in question, m^3



Figure.6 (i) GPC after wearing

(j) FRGPC after wearing action

Table.11 Mix design for Abrasion Resistance:

Grade of concrete	GPC	FRGPC
Fly-Ash (Kg/m^3)	197.64	197.64
GGBS	197.64	197.64
Fine Aggregate (Kg/m^3)	646.8	646.8
Coarse Aggregate (Kg/m^3)	1201.2	1201.2
Water (Kg/m^3)	20	15
S.P (Kg/m^3)	3.5	3.5
W/C Ratio	0.4	0.4
Polypropylene Fibers	0	0.20%
Basalt Fibers	0	0.05%

Table.12 Abrasion Results for plain GPC:

duration	mass Air	mass water	Vt	VLt	Avg. depth of abrasion(mm)
0	15.98	11.862	4.118	-	-
12	14.81	11.486	3.324	0.794	2.53
24	14.486	11.296	3.19	0.134	3.056
36	14.142	11.118	3.024	0.166	2.858
48	13.789	10.909	2.88	0.144	2.736
60	13.486	10.742	2.744	0.136	2.608
72	13	10.568	2.432	0.312	2.12
					15.908

Total abrasion loss is 15.908 mm

Table.12 Abrasion Results for fiber reinforced optimal mix:

duration	mass Air	mass water	Vt	VLt	Avg. depth of abrasion(mm)
0	13.825	11.852	1.973	-	-
12	13.428	11.645	1.783	0.19	1.593
24	13.176	11.566	1.61	0.173	1.437
36	12.942	11.498	1.444	0.166	1.278
48	12.623	11.335	1.288	0.156	1.132
60	12.482	11.332	1.15	0.138	1.012
72	12.202	11.168	1.034	0.116	0.918
					7.37

Total abrasion loss for fibers incorporated mould is 7.37 mm

1.3. Sulphate Resistance Test (MgSO₄)-

The sulphate resistance test was performed to study the performance of geopolymer concrete subjected to 5% of MgSO₄ solution Sulphates may be present in constituents which develop the contact of geopolymer matrix and affect it.



Figure.7 Specimens in MgSO₄ & NaCl

Table.13 shows the average weight gain in (%) for the cubes immersed in MgSO₄

mix id	60DAYS	90 DAYS
M1 (0%)	1.11	1.25
M2 (0.2%)	1.32	1.38
M3 (0.3%)	1.37	1.42

1.4 Acid Resistance test (H₂SO₄):

Acid resistance property of geo polymer concrete mixes has been studied by exposing the concrete specimens in 5% of sulphuric acid for 60 and 90 days. Various parameter evaluated are visual appearance, change in mass and change in compressive strength after the exposure period of both type of concrete. pH value of the solution was checked at 20 days interval and maintained throughout the test period.

Table.14 shows weight loss of specimens when exposed to 5% of H₂SO₄

MIX ID	Initial weight	Final weight	% loss 60 days	% loss 90 days
M1 (0%)	8.78	8.64	1.59	6.30
M2(0.2%)	8.46	8.37	1.06	4.20
M3(0.3%)	8.42	8.35	0.83	7.44

1.5 Chloride Resistance Test-

Test specimens for **Sodium chloride** resistance and change in mass test were 150X150X150mm cubes of geopolymer concrete each. 3 specimens for each test were prepared for chloride resistance test to take average result of the specimen.

Table.15 shows the average weight gain for the cubes immersed in NaCl for 60& 90 days

MIX ID	Initial weight kgs	Final weight kgs	% gain in 60 days	% gain in 90 days
M1 (0%)	8.59	8.82	2.68	0.46
M2(0.2%)	8.46	8.64	2.13	0.70
M3(0.3%)	8.42	8.54	1.43	0.24

1.6 Water Absorption test:-

Water absorption tests for the GPC & FRGPC cubes were carried out for water Absorption test. The cubes once sufficiently dried were weighed to find their initial weights and then immersed completely in water for 24 hours. After the 24 hour duration, the specimens are removed and its saturated surface dry weight was recorded as the final weight. Water absorption of specimens is reported as the percentage increase in weight.

Water Absorption in % can be determined using the formula give below

$$\text{Water absorption} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100$$

Table.16 shows the percentage % saturated water absorption after 60 & 90 days

MIX ID	60 days	90 days
M1 (0%)	5.62	6.15
M3(0.2%)	2.81	3.23
M5(0.3%)	3.45	4.15

Conclusions

After performing various tests on fiber reinforce geopolymer concrete the compressive strength resulted optimal strength at 1% of fiber inclusions so, the durability tests are carried out for two consecutive optimal strength obtained mixes i.e. is volume fractions of 0.2 % and 0.3% of incorporation of Polypropylene fibers and 0.05% of basalt fibers. The fiber reinforced composites has performed better results in Abrasion, resistance against sulphate, acid resistance, water absorption tests As compared to control mix i.e. without fibers. Addition of fly-ash & GGBS has improved the performance of fiber reinforced geopolymer concrete. The fiber reinforced geopolymer concrete has low demand for water as compared to control.

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