EXPERIMENTAL INVESTIGATION ON MECHANICAL AND DURABILITY CHARACTERISTICS OF BASALT FIBRE REINFORCED GEOPOLYMER CONCRETE

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Abstract

This work presents the experimental results of investigation carried out on basalt fibre reinforced geopolymer concrete. The class F fly ash based geopolymer concrete was considered for this study and m-sand has been used as fine aggregate. Sodium based alkali activator solution of 10 molality was used in geopolymer. Totally six design mixes were arrived by varying the volume fraction of basalt fibre from (0 to 1%), in addition with conventional concrete. Mechanical and durability test were conducted for all the six trials. The Geopolymer concrete with 0.5% of basalt fibre shows 19.6% increment in compression and the mix with 0.75% express 73.2% and 70.4% increases in tensile and flexure respectively, when compare with conventional concrete. The mix 0.5% shows appreciable performance in durability properties.

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1. Introduction

Currently, construction industry is highly influential sector in the world, where infrastructures developments are becoming standardized and improvised at the same time the cement manufacturing process release 5-7 % emission of carbon-di-oxide gas leads to global warming. Hence a deeper attention is needed on arriving feasible and sustainable alternative for cement. Fly ash is utilized in the construction of landfills, embankments, pavement foundations, and sub base course, as well as in the production of blended cement, to an extent of around 30%. Geopolymer concrete is a relatively new type of concrete that differs from traditional Portland cement concrete in its composition and manufacturing process. It is known for its durability, strength and environmental benefits. The concept of geopolymerization, the process of forming inorganic polymers from aluminosilicate materials, was developed by Joseph Davidovits, a French materials scientist, in the year 1970's.

Geopolymer is a material which is a formed by polymerizing aluminosilicate such as metakaoline, rice husk ash, fly ash , slag and alkaline activator solutions which consist of a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) or potassium hydroxide (KOH) and potassium silicate (K_2SiO_3).

Industrial waste can be utilized as main components in geopolymer. Alccofine is a slag which contains excessive glass. It results in good workability and reduces the water content. The size of alccofine plays a major role in concrete pores to attain the high strength. Bhavanah sagar et al[1] and Bhotla Harish et al[2] concluded that 10% replacement of alccofine with cement leads to good mechanical properties on concrete because of high formation of C-S-H. Guatham kishore reddy et al[3] revealed that the usage of alccofine in ultra high performance concrete enhances the workability and strength properties compared to silica fume incorporated ultra-high performance concrete. Shivang Jayswal et al[4] concluded that at different category of elevated temperature Alccofine based high strength concrete enhances formation of calcium hydroxide which leads to perform a stable microstructure. Srinivas K et al[5] concluded that in high strength concrete, alccofine were used to boosting the strength at all period and also reduction in heat of hydration.

Boobalan S.C et al[6] revealed that the usage of alccofine based concrete give many advantages compare to regular mix. Faster removal of shuttering, low permeability, high workability and better pumpability of concrete and also reduces the heat of hydration. Bharat Bhushan Jindal et al[7] investigated the low calcium fly ash geopolymer with various percentage of alccofine (0, 5 and 10%) cured at both ambient and heat curing. Sodium hydroxide and sodium silicate were used as alkaline activator solution. The study concludes that the fly ash based geopolymer with alccofine produce acceptable results in ambient curing too.

Parveen et al[8] investigated that the geopolymer concrete in both fresh and hardened properties. Fly ash and alccofine were used as aluminosilicate materials, sodium silicate and sodium hydroxide were used as alkaline activators solution. The slump value increase by 15% with molarities change from 16M to 8M.The presence of calcium content in both alccofine and fly ash helps in the formation of Calcium silicate hydrate (CSH) gel apart from Calcium aluminate silicate hydrate (CASH) gel and Sodium aluminate silicate hydrate (NASH) gel which lead to increased solidification and hardening. Kumutha R et al[9] conducted the experiments to find compressive, split tensile and flexural strength for basalt fibre reinforced geopolymer concrete. The fibre was added in a volume fraction for the range of 0%, 0.5%, 1%, 1.5% and 2%. Cracks were arrested for the geopolymer concrete with basalt fibre compare to geopolymer concrete without basalt fibre.

Yamin Wang et al[10] evaluate the different percentage of basalt fibre as 0.025%, 0.05%, 0.1% and 0.15% for fracture characteristics of basalt fibre reinforced fly ash geopolymer concrete. The report shows that the addition of basalt fibre should improve the fracture toughness, fracture energy and peak load, due to the bridging action between fibre and geopolymer concrete. Karthiga Bakthavatchalam et al[11] show better results while incorporating the hybrid fibre (Steel and Basalt fibre) in the geopolymer concrete by arresting the propagation of cracks by increase its strength. In geopolymer concrete, Alkali activator solution are Potassium hydroxide and potassium silicate along with aluminosilicate material are fly ash and Ground Granulated Blast Furnace Slag.0.5% Steel fibre and 1.5% Basalt fibre, enhance good strength among other combination in compressive , split tensile and flexural strength. Addition of fibre content lead to poor workability, formation of pours in concrete and decrease in strength.

Khoa V.A Pham et al[12] studied geopolymer composite reinforced with polypropylene and hooked end steel fibre as volume fraction of 0% to 1.5%.In addition of 0.5% polypropylene fibre with geopolymer, there was an improvement in compressive strength and splitting tensile strength as the range of 26% and 12% respectively. For addition of 1% hooked end steel fibre with geopolymer, similarly 46% and 28% respectively was observed in compressive strength and splitting tensile strength. Flexural strength 1.5% of polypropylene and hooked end steel fibre perform more compare with non-fibre geopolymer. S Sunderkumar et al[13] have reported 0.75% steel fibre reinforced geopolymer with binder material as 75% class-f fly ash and 25% ground granulated blast furnace slag which enhance fracture properties,flexural strength and ductility.

1.1 Research Significance

During the manufacturing process of cement the emission of carbon-di-oxide was abundantly high. As mentioned earlier, geopolymer concrete majorly plays a vital role in reduction of carbon-di-oxide emission. Many researchers used fly ash, silica fume metakaoline etc as alumino silicate material only few researchers used alccofine as aluminosilicate material. In this study alccofine based geopolymer concrete with M-sand as fine aggregate and also basalt fibre in volume fraction of 0%,0.25%,0.50%,0.75% and 1% is considered for investigation. The results were compared with conventional concrete to evaluate the strength and durability property. Here, Sodium hydroxide and sodium silicate are carried out as alkaline activator solution.

2 Materials and Methods

2.1 Fly ash

By conforming to IS:3812 (part 2) – 2013[14], a low Calcium class F-Fly ash were used which is procured from Thermal Power Plant, Mettur - Tamil Nadu .The Specific gravity is 2.08.The minimum requirement and chemical components presents in the fly ash are shown in table 1. Figure 1 and 2 shows SEM image and EDS graph which indicate the shape of the particle and composition of chemicals present in fly ash.

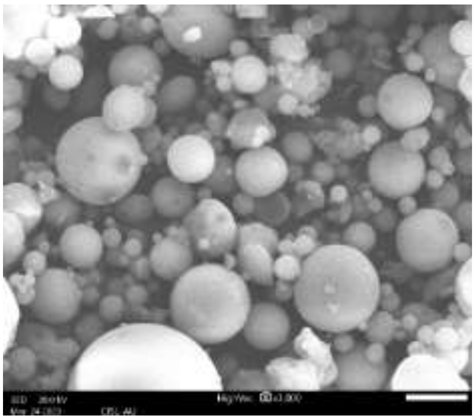


Figure 1.SEM image of Fly ash.

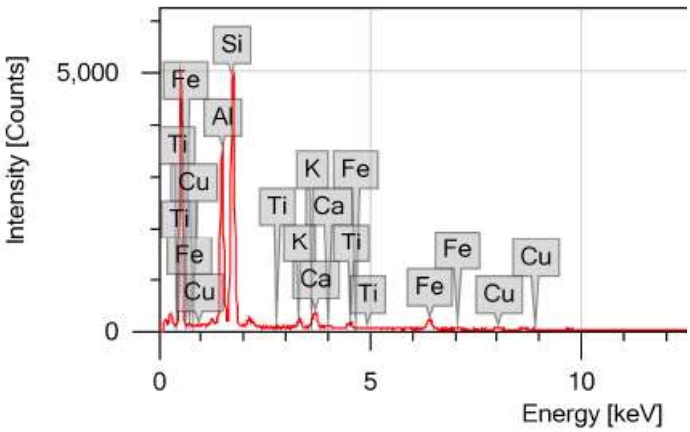


Figure 2.EDS image of Fly ash.

Table 1: Chemical composition of Fly ash

Characteristic	IS 3812-2013 Requirement	Class-F Fly Ash (Mattur)
Silica + Alumina + Iron Oxide (SiO_2 + Al_2O_3 + Fe_2O_3): wt%	70.0(Min)	93.82
Magnesia (MgO) : wt%	5.0(Max)	0.38
Sodium Oxide (Na_2O) : wt%	1.5(Max)	0.51
Calcium Oxide (CaO) : wt%	Not Mentioned	1.02
Sulfur Trioxide (SO_3) : wt%	3.0(Max)	1.28
Silica (SiO_2) : wt%	35.0(Min)	61.04
Total Chlorides : wt%	0.05(Max)	0.1
Specific Gravity	____	2.08
Fineness-specific surface,m^2/kg	320(Min)	321.68
Loss on Ignition : wt%	5.0(Max)	0.52

2.2 Alccofine 1203

Alccofine 1203 is a low calcium silicate which possesses high reactivity. It is a finely powdered material produced by grinding ground granulated blast furnace slag to a fineness of 12,000 cm^2/g. It creates a strong pozzolanic action which helps in strengthening and densification the both Geopolymer concrete and Normal Concrete. SEM image and EDS graph shows the shape of the partial and composition of chemicals present in alccofine as shown in figure 3 and 4 respectively.

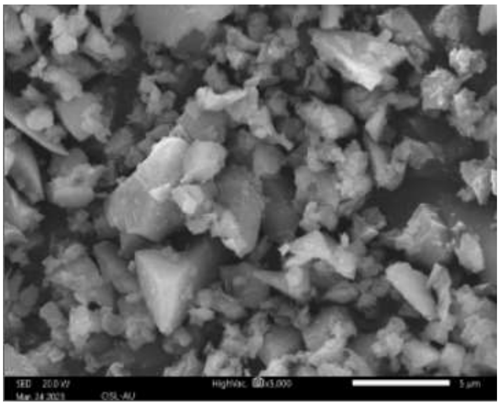


Figure 3.SEM image of Alccofine 1203.

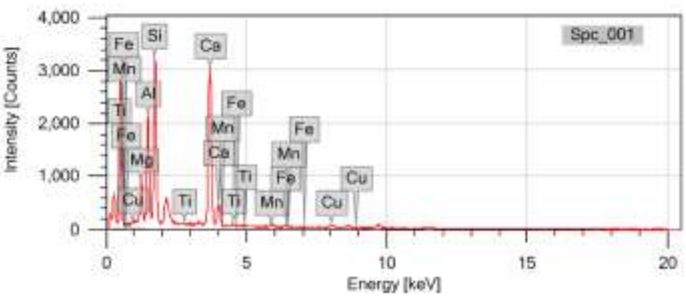


Figure 4.EDS image of Alccofine 1203.

2.3 Alkaline Solution

Sodium hydroxide (NaOH) in pellets form and Sodium silicate (Na_2SiO_3) as liquid form were used for polymerization of Geopolymer concrete. 98% pure with 10 Molar, (10 X 40 = 400 grams) of NaOH solids per litter of the solution were prepared, here 40 is the molecular weight of NaOH. Properties of Sodium hydroxide are given in table 2. A gel form of sodium silicate were used and its properties are given in table 3.

Table 2: Properties of Sodium hydroxide

S.NO.	Details	Contents
1	Molecular formula	NaOH
2	Colour	White orthogonal crystals
3	Density g/cm_3	2.13 @25°C
4	Molar mass	39.997 g/mol

5	pH	13
6	Viscosity	4cm@ 350°C
7	Heat of vaporization	175kJ/mol @1388°C
8	Refractive Index	1.433
9	Melting point	318°C to 605°C
10	Boiling point	1388°C to 2534°C
11	Solubility in water	111 g/100ml
12	Odor	Odorless

Table 3: Properties of sodium silicate

S.NO.	Details	Contents
1	Molecular formula	Na_2SiO_3
2	Appearance	colorless solution
3	Silica	26%
4	Sodium Oxide	8.5%
5	Boiling point [°C]	100°C
6	Density [g/cm^3]	1.39
7	Vapour density	0.7
8	pH value	11.2
9	Total Solids	47.09

2.4 Cement

Ordinary Portland cement of 53 grade conforming to IS: 12269-2013[15] was used for the conventional concrete and its Mix ID is NCBF0 (NC=Normal Concrete, BF=Basalt Fibre).Its properties was summarized in Table 4.

Table 4: Properties of Cement

S.No	Physical Properties	Results
1	Specific gravity	3.11
2	Setting Time - Initial	40 min
3	Setting Time - Final	560 min

2.5 Aggregates

Locally available m-sand with bulk density of 1600 kg/m^3 was used in this study. The specific gravity and fineness modulus is 2.66 and 2.80 respectively. It fits to the limitations of Grade Zone II according to particle size distribution, and the grading limit curve for a typical m-sand sample is shown in figure 5. The coarse aggregate were tested according to IS 2386: 1963(R2016) [16]. Its size and specific gravity is 20mm and 2.74 respectively.

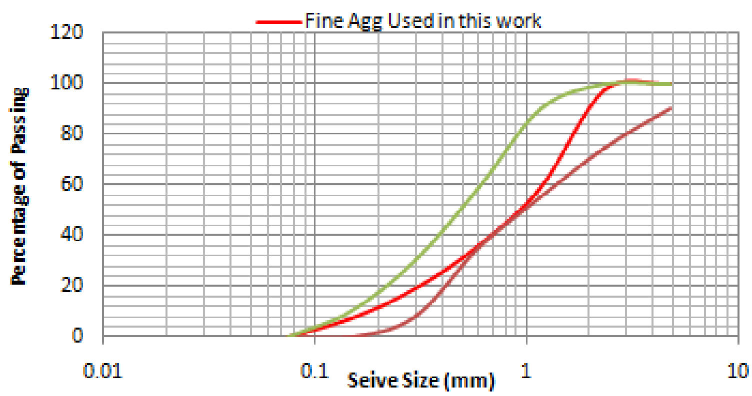


Figure 5. Gradation curve for Fine aggregate

2.6 Water

For mixing the ingredients and curing purposes, good quality potable water which should be free from organic matter were used.

2.7 Super plasticizer

The alkaline solution used in Geopolymer concrete is more viscous, results in poor workability. In order to improve the workability, Naphthalene based super plasticizer (Conplast SP430) was used in this work.

2.8 Basalt fibre.

In this study discrete basalt fibre of length12mm and diameter 0.013mm was used as shown in figure 6.This fibre was derived from basalt rock which is volcanic in origin and having a melting point of around 1350˚C .The physical properties of the fibre provided by the manufacturer is presented in table 5.

Figure 6. Basalt Fibre

Table 5: Basalt Fibre Properties

Sl. No.	**Properties of Basalt Fibre**	**Results**
1	Diameter (mm)	0.013
2	Cut Length (mm)	12
3	Aspect Ratio	923
4	Density (g/cm^3)	2.70
5	Elongation (%)	3.1
6	Tensile Strength (MPa)	4150
7	Elastic Modulus (GPa)	93.3
8	Moisture content (%)	1
9	Melting point (˚C)	1350

3. Methodology

3.1 Mix Design

For Geopolymer concrete the water/geopolymer solid ratio was 0.4 used and for the purposes of improving the workability, in addition Naphthalene based super plasticizer of 2% was used to maintain the slump as medium range (75 to 100 mm).Table 6 displays the five geopolymer mix content (GPBF0,GPBF0.25,GPBF0.50,GPBF0.75,GPBF1). 7.5% extra water was added for all the categories of geopolymer mix. For the conventional mix NCBF0 the water cement ratio and mix ratio are 0.4 and 1:1.69:3.1 respectively were adopted. The slump was maintained as medium (the range of the slump value is 75 to 100).Table 7 display the proportions of conventional mix details.

Table 6: Proportions of Geopolymer mix

Mix ID	NaOH kg/m^3	Na_2SiO_3 kg/m^3	Alccofine kg/m^3	Fly ash kg/m^3	FA kg/m^3	CA kg/m^3	Water kg/m^3	Basalt Fibre kg/m^3	Basalt Fibre (%)
GPBF0	18.94	118.425	40.712	366.412	688.50	1262.49	28.42	0	0
GPBF0.25	18.94	118.425	40.712	366.412	688.50	1262.49	28.42	6.75	0.25
GPBF0.50	18.94	118.425	40.712	366.412	688.50	1262.49	28.42	13.5	0.50
GPBF0.75	18.94	118.425	40.712	366.412	688.50	1262.49	28.42	20.25	0.75
GPBF1	18.94	118.425	40.712	366.412	688.50	1262.49	28.42	27	1

Table 7: Proportions of conventional mix

Mix ID	Cement kg/m^3	FA kg/m^3	CA kg/m^3	Water kg/m^3	W/B ratio	SP kg/m^3	Basalt Fibre kg/m^3	Basalt Fibre (%)
NCBF0	407.125	688.50	1262.49	162.85	0.4	1.7	0	0

3.2 Mixing and Casting Procedure

Compare to that of potassium base solution, sodium base solution was less in cost. Alkaline solution has been prepared 24 hours prior to casting. Sodium hydroxide pellets were mixed in water with required molarity. In order to maintain a smooth exothermic reaction, the solutions remain undisturbed for a period of two hours. Later the required quantities of sodium silicate solution were added to the sodium hydroxide solution. The prepared solution was added to the dry mix for the preparation geopolymer concrete. The required quantity of basalt fibre has been added and mix properly to ensure homogeneity.

Figure 7. sodium silicate and sodium hydroxide

Figure 8. sodium hydroxide pellets

Figure 9. Alkaline activation solution

Figure 10. Geopolymer concrete mixing

3.3 Specimens details

According to the codal specification, specimens like cube, cylinders, discs and prisms were cast in required numbers in order to determine the strength and durability properties. The details of the specimens are presented in the table 8.

Table 8: Details of Control Specimens

S. No.	Test	Specimen	Size (mm)	No. of Specimens
1	Compressive Strength Test	Cubes	150 X150 X 150	36
3	Split Tensile Strength Test	Cylinders	150 X 300	36
5	Flexural Strength Test	Prisms	100 X 100 X 500	36
6	Water Absorption Test	Cubes	100 X100 X100	6
7	Sorptivity Test	Discs	100 X 50	6
8	Porosity Test	Cubes	100 X100 X100	6
9	Pull-Out Test	Cubes	150 X150X 150	36

4. Testing of specimen

4.1 Compression Test

By adopting the test procedure given in IS 516 (part1/sec1):2021[17], the compressive strength test has been carried out in cubes specimens. The cubes of size 150mm were caste in required number and allowed to cure for the period of 7 and 28 days. After completion of necessary curing period, the specimen were taken out from water and cleaned thoroughly to ensure the surface dry condition and tested in a compression testing machine of 2000kN capacity. The crushing load for each specimens were noted and presented in table 9.The test setup and typical failure pattern are shown in figure 11and 12 respectively.

Figure 11. Testing of cube specimen

Figure 12. Failure of cube

4.2. Split tensile test

In accordance with IS 516 (part1/sec1):2021[17], the tensile test on concrete has been carried out on cylinder specimen of size 150 X 300 mm. The specimens were kept in immersion curing for a period of 7 and 28 days. The tensile load for each specimen were noted and presented in table 10. The test setup and typical failure pattern are shown in figure 13 and 14 respectively.

Figure 13. Testing of cylinder specimen

Figure 14. Failure of cylinder

4.3 Flexure Test

By conforming the procedure given in IS 516 (Part1/Sec1):2021[17], modulus of rupture for the concrete specimen size of 100 X 100 X 500mm were cast. The curing period for the specimen is 7 and 28 days. After the curing period, specimens were taken out from the water and surface was cleaned thoroughly. The two point load was applied and the test was carried out till the specimens were failed. The peak load for each specimen were noted and presented in table 11. The test setup and typical failure pattern are shown in figure 15 and 16 respectively.

Figure 15. Testing of prism specimen

Figure 16. Failure of prism

4.4 Sorptivity and Water absorption test

Sorptivity and water absorption test was carried out as per the guidance of ASTM C1585-13[18] and ASTM C642-21[19] respectively. After the curing period, the specimens were kept in oven. For sorptivity, maintain the temperature of 50˚C for three days. The specimens were allow to cool for 15days in room temperature .To determine the absorption rate, except the bottom side all other sides of the specimens were sealed properly by using the waterproof tape and kept in water as illustrated in figure 17. For water absorption test, maintain the temperature of 110˚C for 24 hours, dry weight was noted. After that specimens were kept into water for the period of 48hours at 21˚C. Saturated dry weight were calculated, repeat the procedure for the period of 28hours at 21˚C, until the two successive value were an increase in weight of less than 0.5 percentage of the highest value. The values were tabulated in table 13.

Figure 17. Sorptivity test

Figure 18. Water absorption test

4.5 Pullout test

Pullout test was used to calculated the bond strength .As per IS 11309-1985[20], the steel rod was embedded in cube and axial load was applied on the specimen placed in universal testing machine of capacity 2000kN. Load was applied at a rate of 0.5kN/min and note down the load at which the specimen fails. The test setup and failure pattern was shown in figure 19 and 20 respectively.

Figure 19. Pull out test setup

Figure 20. Failure of pull out specimen

5. Results and Discussion

5.1 Compression test

The obtained results from the compression test for the six mixes in two categories (7days and 28days) were tabulated in table 9 and the individual failure pattern was shown in figure 22. From the results, geopolymer concrete with 0.50% basalt fibre mix shows 10% and 19.6% increment to that of non-fibre geopolymer concrete (GPBF0) and conventional concrete mixes (NCBF0) respectively. This may be due to the even distribution of fibre and also due to combined polymerization reaction of lime presents in both fly ash and alccofine result into higher strength. Furthermore addition of fibre tends to decrease in compressive strength as shown in figure 21 due to uneven distribution of fibre in geopolymer concrete.

Table 9: Compression test results

Mix ID	7 Days		Average	28 Days		Average
	kN	Mpa	Mpa	kN	Mpa	Mpa
NC BF 0	535.1	23.75	23.61	880.4	39.08	39.09
	515.0	22.86		899.1	39.92	
	545.4	24.21		862.2	38.28	
GP BF 0	834.5	37.05	37.22	978.4	43.44	43.40
	851.4	37.80		994.6	44.16	
	829.4	36.82		960.1	42.62	
GP BF 0.25	854.6	37.94	38.30	1002.4	44.50	44.67
	869.4	38.60		1011.5	44.91	
	864.5	38.38		1004.6	44.60	
GP BF 0.50	934.5	41.49	41.26	1075.4	47.74	47.74
	929.4	41.26		1079.4	47.92	
	924.6	41.05		1071.5	47.57	
GP BF 0.75	889.4	39.48	39.55	1024.6	45.49	45.65
	894.6	39.72		1034.1	45.91	
	888.6	39.45		1026.4	45.57	
GP BF 1	859.4	38.15	37.97	1001.5	44.46	44.71
	854.6	37.94		1008.4	44.77	
	851.8	37.81		1011.4	44.90	

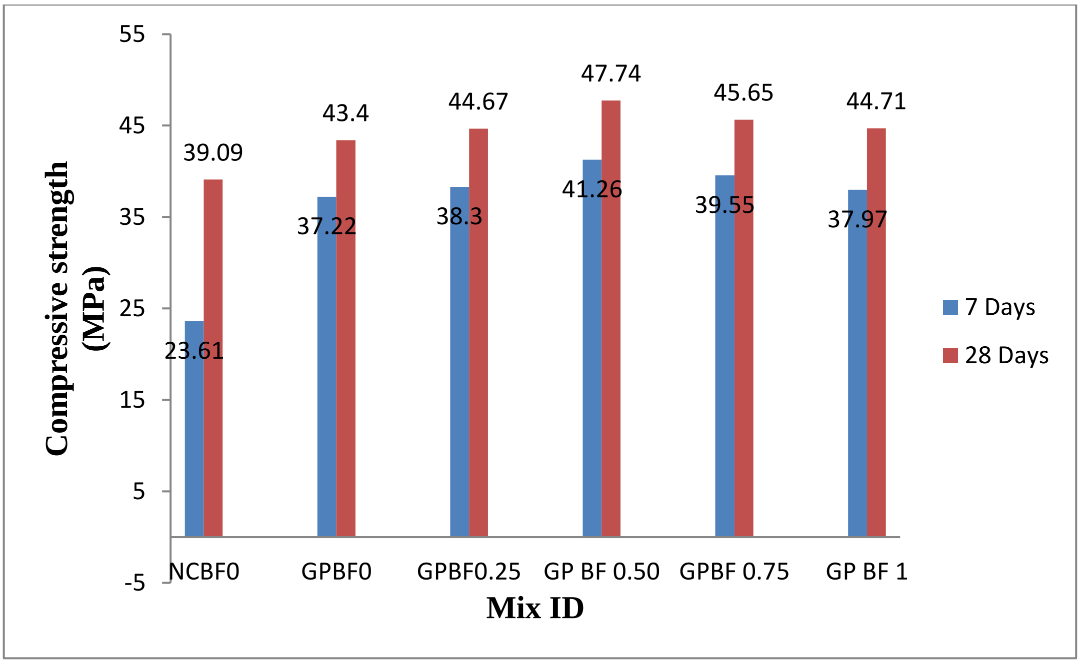


Figure 21.Compression test results

NC BF 0 GP BF 0 GP BF 0.25 GP BF 0.50 GP BF 0.75 GP BF 1

Figure 22.Failure of cube

5.2 Split tensile test

On adding the basalt fibre percentage of 0.25%, 0.50% and 0.75% in geopolymer concrete results in increasing of tensile strength, when compare to both conventional concrete (NCBF0) and non-fibre geopolymer concrete (GPBF0).Beyond0.75% addition of fibre, geopolymer concrete shows decreased tensile strength due to poor workability and clumping of fibres.

Table 10: Split tensile test results

Mix ID	7 Days		Average	28 Days		Average
	kN	Mpa	Mpa	kN	Mpa	Mpa
NC BF 0	240.8	3.39	3.37	258.8	3.64	3.66
	239.5	3.37		261.4	3.68	
	238.4	3.36		259.4	3.65	
GP BF 0	355.4	5.01	5.00	381.4	5.37	5.39
	356.4	5.02		385.4	5.43	
	352.8	4.97		380.4	5.36	
GP BF 0.25	371.4	5.23	5.27	394.5	5.56	5.58
	374.6	5.28		395.6	5.57	
	375.42	5.29		398.4	5.61	
GP BF 0.50	393.5	5.54	5.55	415.4	5.85	5.88
	391.5	5.52		417.5	5.88	
	396.4	5.58		419.4	5.91	
GP BF 0.75	417.5	5.88	5.96	448.4	6.32	6.34
	425.8	6.00		451.8	6.37	
	424.8	5.98		449.5	6.33	
GP BF 1	380.5	5.36	5.41	411.5	5.80	5.80
	384.8	5.42		410.3	5.78	
	385.9	5.44		413.2	5.82	

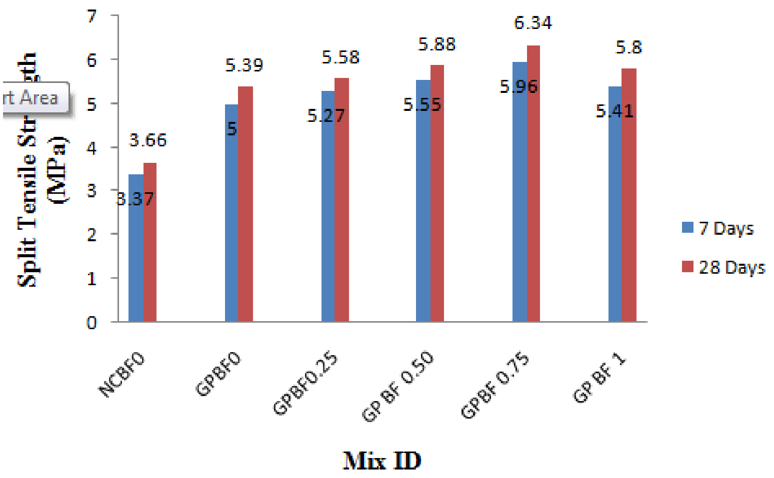


Figure 23.Split tensile strength

Figure 24.Failure of cylinder

5.3Flexure test

The test results are tabulated in table11. From that it is very clear, on adding the basalt fibre upto 0.75%, the increase in flexural strength to the maximum of 43.6% and 70.4% compare to that of mix GP BF 0 and NC BF 0 respectively was noticed. This is due to high tensile strength and modulus of elasticity of basalt fibre. Beyond 0.75% addition of fibre, a decrease in flexural strength was observed. The failure pattern was shown in figure 26.

Table 11: Flexure test results

Mix ID	7 Days		Average	28 Days		Average
	Div	Mpa	Mpa	Div	Mpa	Mpa
NC BF 0	22	4.31	4.64	38	7.45	7.71
	23	4.51		41	8.04	
	26	5.09		39	7.64	
GP BF 0	34	6.66	6.93	46	9.02	9.15
	37	7.25		49	9.61	
	35	6.86		45	8.82	
GP BF 0.25	40	7.84	8.10	54	10.59	10.26
	41	8.04		52	10.19	
	43	8.43		51	10.00	
GP BF 0.50	49	9.61	9.61	59	11.57	11.89
	50	9.80		63	12.35	
	48	9.41		60	11.76	
GP BF 0.75	53	10.39	10.72	65	12.74	13.14
	54	10.59		69	13.53	
	57	11.17		67	13.14	
GP BF 1	45	8.82	8.82	57	11.17	11.17
	44	8.62		56	10.98	
	46	9.00		58	11.37	

*Note: 1 Div = 0.05T

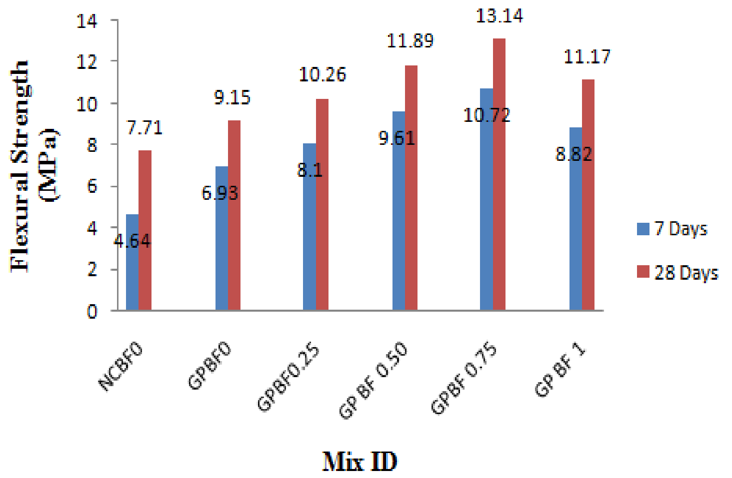


Figure 25.Flexure strength test

Figure 26.Failure of prism

5.4 Sorptivity and Water absorption test

The observed results are tabulated in table 12and 13 for sorptivity and water absorption test respectively. For both the test, mix GPBF 0.50 shows low absorption rate and good resistance against the capillary suction. Due to the smaller particles size, alccofine results in dense packing attributed to low absorption rate. Increase in percentage of fibre leads to balling effect followed by low workability and high permeability.

Table 12: Sorptivity test results

Duration	T^(1/2)	I(mm)					
		GP BF 0	GP BF 0.25	GP BF 0.50	GP BF 0.75	GP BF 1	NC BF 0
1 min	7.75	0.89	0.76	0.89	1.01	0.89	0.76
5 min	17.32	1.40	1.27	1.01	1.27	1.27	1.02
10 min	24.49	1.65	1.52	1.40	1.52	1.52	1.78
20 min	34.64	1.78	1.78	1.41	1.65	1.65	2.17
30 min	42.43	2.16	1.91	1.52	1.78	1.91	2.93
60 min	60.00	2.92	2.92	1.91	2.03	2.54	3.06
2 hr	84.85	3.69	3.43	2.03	2.42	3.18	3.82
3 hr	103.92	3.94	3.94	2.29	2.67	3.34	4.08
4 hr	120.00	4.33	4.20	2.54	2.8	3.54	4.08
5 hr	134.16	4.45	4.33	2.67	2.92	3.69	4.33
6 hr	146.97	4.58	4.45	2.80	3.00	3.94	4.33
1st Day	328.63	4.84	4.58	2.94	3.56	4.07	4.71
2nd Day	440.91	4.96	4.71	3.14	3.57	4.33	4.84
3rd Day	529.91	5.09	4.84	3.29	3.69	4.58	4.84
4th Day	605.97	5.09	4.84	3.31	3.7	4.71	4.85
5th Day	673.50	5.22	4.96	3.31	3.82	4.71	4.97
6th Day	734.85	5.22	4.96	3.31	3.82	4.71	4.97
7th Day	791.45	5.22	4.96	3.31	3.82	4.71	4.97

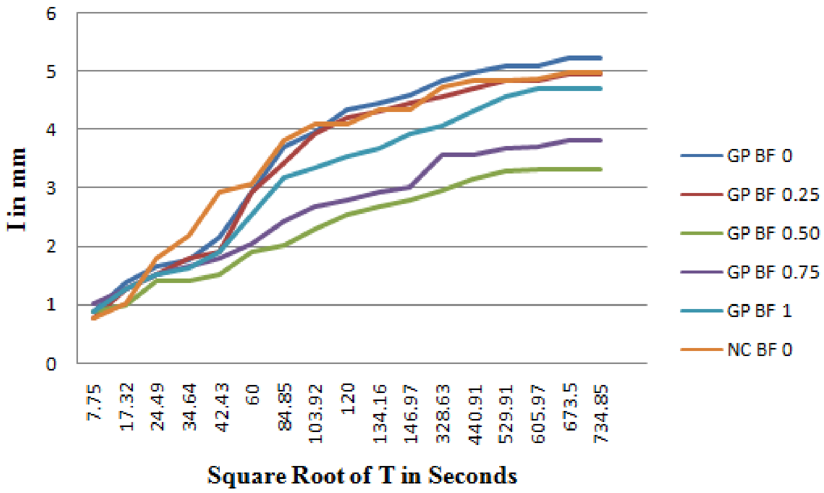


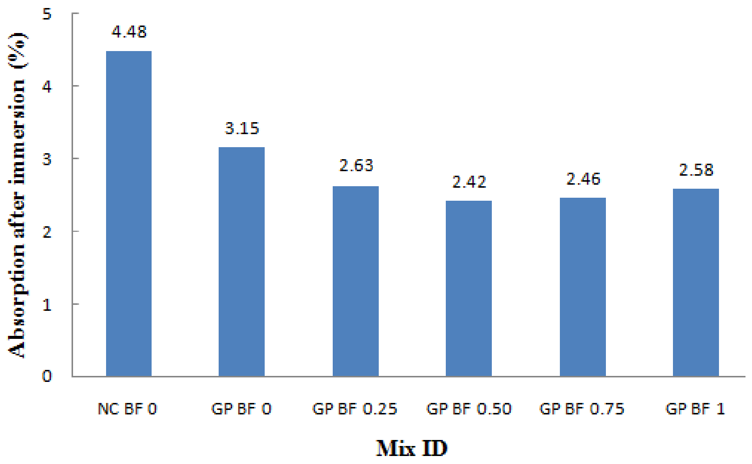
Figure 27.Sorptivity of various mix

Table 13: Water absorption test results

Mixture ID	A	B	C	D	Absorption after immersion (%)	Absorption after immersion and boiling (%)
NC BF 0	2321	2425	2442	1450	4.48	5.21
GP BF 0	2444	2521	2530	1465	3.15	3.52

GP BF 0.25	2470	2535	2538	1545	2.63	2.75
GP BF 0.50	2563	2625	2627	1535	2.42	2.50
GP BF 0.75	2603	2667	2668	1599	2.46	2.50
GP BF 1	2523	2588	2590	1535	2.58	2.66

Mixture ID	Bulk density(Dry) mg/m^3	Bulk density after immersion mg/m^3	Bulk density after immersion and boiling mg/m^3	Apparent Density mg/m^3	Volume of permeable pore space (Voids) (%)
NC BF 0	2.34	2.44	2.46	2.66	12.20
GP BF 0	2.29	2.37	2.38	2.50	8.08
GP BF 0.25	2.49	2.55	2.56	2.67	6.85
GP BF 0.50	2.35	2.40	2.41	2.49	5.86
GP BF 0.75	2.43	2.49	2.50	2.59	6.08
GP BF 1	2.39	2.45	2.45	2.55	6.35



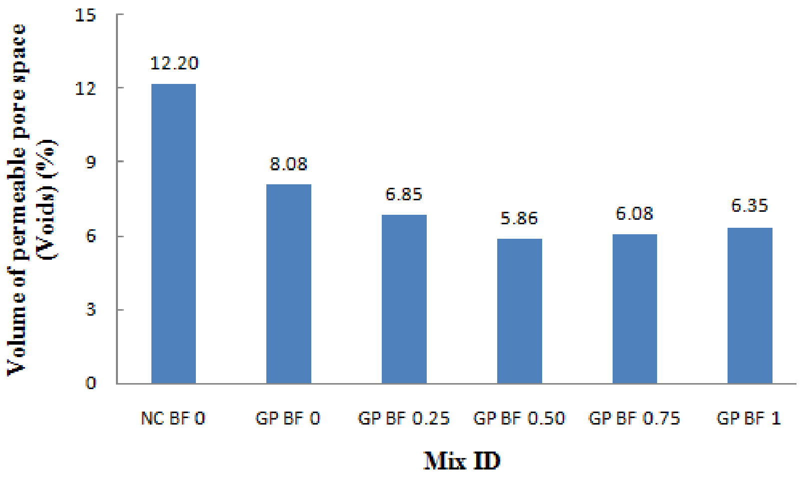


Figure 28.Water absorption rate and voids in percentage

5.5 Pullout test

From the test results in table 14, geopolymer concrete with 0.5% basalt fibre enhances the strength compare to control concrete and non fibre geopolymer concrete. It may be due to the combined effect of appreciable calcium silicate hydrate bonding, sodium aluminate silicate hydrate bonding & calcium aluminate silicate hydrate bonding.

Table 14: Pullout test results

Mix ID	Diameter (mm)	Peak load (kN)	Bond strength (MPa)
NC BF 0	12	45.83	9.73
GP BF 0	12	54.8	11.63
GP BF 0.25	12	55.79	11.84
GP BF 0.50	12	60.78	12.90
GP BF 0.75	12	58.79	12.48
GP BF 1	12	57.79	12.26

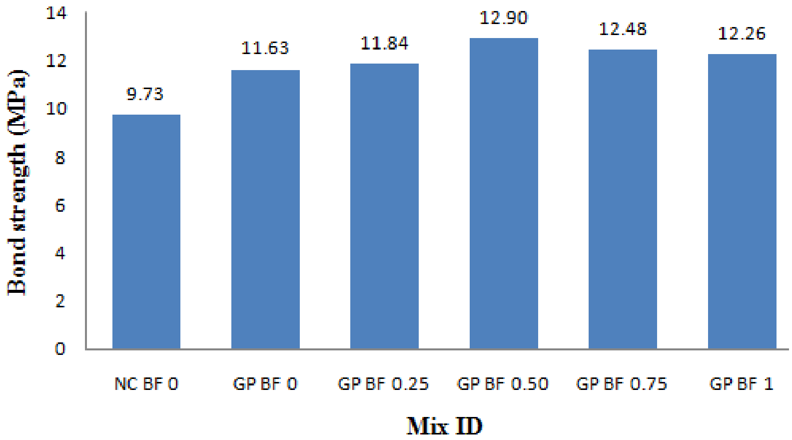


Figure 29.pullout test results

6. Conclusion

From the detailed experimental work on the mechanical and durability aspect of geopolymer concrete, the following conclusions were drawn.

- Geopolymer concrete on inclusion of 0.5% basalt fibre shows an increased compressive strength of 19.6% with conventional concrete, and an increment of 10% was noticed on comparison withnon-fibre geopolymer concrete.
- Geopolymer concrete on inclusion of 0.75% basalt fibre shows an increased tensile strength of 73.2% with conventional concrete, and an increment of 17.6% was noticed on comparison of non-fibre geopolymer concrete.
- Geopolymer concrete on inclusion of 0.75% basalt fibre shows an increased flexural strength of 70.4% with conventional concrete, and an increment of 43.6% was noticed on comparison of non-fibre geopolymer concrete.
- The mix with addition of 0.5 % basalt fibre shows better performance in compression and durability tests of basalt fibregeopolymer concrete.

- Geopolymer concrete shows better mechanical properties in comparison with conventional concrete.
- The durability aspect of geopolymer concrete with basalt fibre is appreciably good

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