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Experimental Behaviour of Basalt Fibre Reinforced Geopolymer Concrete Composites

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Abstract: *Concrete is one of the mostly used composite materials composed of fine and coarse aggregate. It is bonded by hydraulic cement and water. The demand of concrete in construction industry is increasing day by day. Cement is used as a binder material in concrete which is highly energy intensive and emits enormous amount of CO_2 to atmosphere and responsible for global warming. So, it becomes necessary to identify the alternatives for OPC which is eco-friendly with environment. Geopolymer are inorganic polymer that utilizes industrial by-products as a binding material and is analogy to cement. In this study, fly ash and GGBS is used as binder material to prepare a geopolymer concrete for replacing cement by 100% to investigate the fresh and hardened properties in addition with different percentages of basalt fibers. Six cubes for each decreasing rate of fly ash (90%, 80%, 70%, 60% & 50%) and in other hand increasing rate of GGBS (10%. 20%, 30%, 40% & 50%) with active alkaline liquids like sodium hydroxide (NaOH) of 10 molarity concentration and Sodium silicate (Na_2Sio_3) was cast and cured on ambient temperature and tested. From different trial mixes, optimum percentage of fly ash and GGBS was identified as 70% and 30% respectively. With this control percentage, specimens were casted with different percentage of basalt fibers at a dosage increment of 0.1% from 0.1% to 0.50% and optimum fiber percentage was selected. Other properties like slump, split tensile, flexural strength test was also conducted and the results were compared with control geopolymer concrete. The test result indicates that fiber reinforced geopolymer concrete yields better results in all the aspects when compared to geopolymer concrete without basalt fibers.*

Keywords*:* *Geopolymer, Fiber, Fly ash, GGBS, Alkaline Solution*

I. Introduction

Concrete is very common in this world because of its uses in almost all types of construction. Ordinary Portland Cement (OPC) is widely used as the primary binder in concrete which emits CO2 gas that is responsible for greenhouse effect. In order to rectify environmental pollution, a waste product such as fly ash (class f type) and GGBS are used. The term Geopolymer concrete (GPC) was coined by Daidovits in 1978.GPC is an innovative and eco-friendly construction material. It is also best alternative to cement. Addition of fibre in concrete increases structural integrity and improves the mechanical and elastic properties. The fiber in

concrete also acts as reinforcing material. Though the use of Portland cement is inevitable, many efforts are being made in order to reduce the use of Portland cement in concrete.

B.Vijaya Rangan et. al (2014) concluded that the compressive strength increases with increase in curing time, curing temperature and decrease with increase in the ratio of water to geopolymer solids by mass. GPC shows excellent resistance to sulphate attack, undergo low creep, and suffers very less drying shrinkage and from the economic point of view; GPC is 10 to 30 percent cheaper than that of Portland cement concrete [1].

N.Veerendra Babu et. al (2017) mentioned that when molarity increases compressive strength, split tensile strength, and flexural strength also increases [2]. **Ganapati Naidu. P et. al (2012)** describes the strength properties of geopolymer concrete with addition of GGBS and found that higher percentage of GGBS results in higher compressive strength. It is not necessary to expose GPC to higher temperature to attain maximum strength if minimum 9% of fly ash is replaced by GGBS and also observed that 25% loss in compressive strength when exposed to 500°C for two hours [3]. **D.Naveen Kumar et. al (2017)** concluded that the addition of fiber in concrete shows better results in Abrasion, resistance against sulphate, acid resistance, water absorption tests [4].

In the present study, geopolymer concrete with fly ash (low calcium) and GGBS with alkaline solution of 10M is used. The optimum percentage of fly ash and GGBS are identified by trial and error method (ie. decreasing % of fly ash from 90% to 50% and increasing percentage of GGBS from 10% to 50% respectively).

After finding the optimum percentage of fly ash & GGBS, Basalt fiber of 12mm is used. 12.5mm aggregate and river sand with less amount of water is used to get good workability. 3% super-plasticizer is used to provide strength to GPC and also to retard the setting time of concrete. The study of mechanical properties such as compressive strength test on cubes and comparison with NDT (Non-Destructive Test), split tensile strength test on cylinder, flexure strength test on prism and modulus of elasticity are studied throughout.

II. Materials

2.1. Fly Ash

Fly ash is a pozzolanic material. It is a residue obtained from thermal power plant. The percentage of silica and alumina is high so, it can play vital role in geopolymerization process. Fly ash improves the workability of fresh concrete, improve concrete durability, reduces water demand, segregation, bleeding, reduce the use of energy, diminished greenhouse gas production and lowers heat of hydration. It increases strength by reducing permeability due to finer particles. The specific gravity, bulk density and percentage of fineness were obtained as 2.3, 1438kg/m^3 & 8.15% respectively. In this experimental work, the fly ash used is class f (low calcium) type because presence of high calcium amount may interfere with polymerization process and alter the microstructure. It is provided from Mettur Thermal Power Plant, Tamil nadu. The chemical composition of fly ash is tested by SONASTARCH as shown in Table 1.

Table 1. Chemical Composition of Fly Ash

Compound	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	LOI
Fly Ash (%)	68.09	1.24	1.70	2.07	19.23	1.78

2.2. GGBS (Ground Granulated Blast Furnace Slag)

It is the waste product obtained from steel plants by quenching molten iron slag from a blast furnace in water or steam and then dried and ground into a fine powder. The specific gravity of GGBS is 2.8 with bulk density of 1308 kg/m^3. The color of GGBS is less white and their chemical composition is tested by SONASTARCH as shown in Table 2.

Table 2. Chemical Composition of GGBS

Compound	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	LOI
GGBS (%)	48.24	23.65	3.05	1.17	11.95	1.56

2.3. Alkaline Activator Solution (AAS)

In this study, to make Alkaline Activator Solution, three materials are taken that is sodium hydroxide (NaOH) pellets, portable water and sodium silicate (Na_2SiO_3) solution. To make sodium hydroxide solution, NaOH pellets were dissolved in water (i.e. 100gm of NaOH pellet is dissolve in 250ml of water) to get concentration of 10M. Now this solution is mixed with sodium silicate solution and left for 24 hour to reduce heat and to complete the chemical reaction. AAS is used to dissolve the reactive portion of source material i.e. silica and alumina present in fly ash & GGBS and also provides good binding solution for Geopolymeric mix.

2.4. Sodium Hydroxide (NaOH)

Sodium Hydroxide is also known as caustic soda with molecular formula NaOH. It is white solid ionic compound consisting of sodium cations and hydroxide ions. The NaOH in the form of pellets are used in this study.

2.5. Sodium Silicate (Na_2SiO_3) Solution

Sodium Silicate is also known as water glass or liquid, available in liquid or gel form. It is a compound containing sodium oxide and silica that forms a glassy solid with a very useful property of being soluble in water.

2.6. Fine Aggregate

Fine Aggregate is that material that passes through 4.75 mm sieve. In this experiment river sand with following properties is used as given in Table 3.

Table 3. Properties of Fine Aggregate

Properties	Specific Gravity	Bulk Density	Fineness Modulus
Fine Aggregate	2.55	1726.41 kg/m^3	2.807

2.7. Coarse Aggregate

Those particles that retained on 4.75mm sieve is coarse aggregate. Crushed stone of 12.5mm down size is used in this study. The properties of coarse aggregate are given in Table 4.

Table 4. Properties of Coarse Aggregate

Properties	Specific Gravity	Bulk Density	Fineness Modulus
Coarse Aggregate	3.24	1632.07 kg/m^3	6.92

2.8. Fibers

Fiber is a natural or synthetic substance that is significantly longer than its width. To add more strength in concrete, fibre is used. There are many type of fibre such as carbon fibre, steel fibre, glass fibre etc. In this experiment, Basalt fibre is used because it is more stable in strong alkali, possess high resistance to UV light & fungal and biological attack, high fire proof and explosion proof and also it is good in moisture resistance. As it has high advantage we can use this material in bridges, highways, heat & sound insulation for residential and industrial buildings [5]. The properties of basalt fiber are given in Table 5.

Table 5. Properties of Basalt Fiber

Density	2670 kg/m^3
Tensile Strength	515-580 MPa
Elastic Modulus	90 GPa
Elongation at break	3.1
Length	12mm
Diameter	(7-15) µm
Color	Golden Brown

2.9. Water

The amount of water used in this work is 20% of cementitious material. It is added to concrete only for workability and easiness in placing the concrete [6].

2.10. Super-plasticizer

Super-plasticizer is high range water reducers and is used to improve the flow of Geopolymeric concrete. Conplast SP 430 which is brown in color of about 3% of cementitious material is used in this project.

Mix Proportion of Geopolymer Mix

As there is no proper codal provision for the design of GPC (Geopolymer Concrete), the mix design was done by trail & error method to find the optimum percentage of fly ash & GGBS. The total mix design is done as per D.Hardjito and B. V. Rangan [7]. Final mix for GPC per m^3 is given in Table 6. From the trail, FAGB3 gives the high strength and then fiber was added gradually by increasing their percentage from 0.1, 0.2, 0.3, 0.4 & 0.5 %. After conducting direct and indirect test it is found that 0.2% of fiber is the optimum percentage.

Table 6. Mix Proportion for 1m^3 GPC

Materials	**Mix for 1$m^3{}_{GPC}$**
Fly Ash+GGBS (kg/m^3)	394.3
Fine Aggregate (kg/m^3)	554.4
Coarse Aggregate(kg/m^3)	1293.6
NaOH (kg/m^3)	45.06
Na2SiO3 (kg/m^3)	112.65
Water (kg/m^3)	59.142
Super plasticizer (kg/m^3)	11.828

III. Test Results & Discussion

To determine the hardened properties, standard specimen like cubes, cylinders and prisms were prepared and cured on ambient temperature. After curing, specimens were tested as discussed below.

3.1 Slump Test

This test helps to know the workability of fresh concrete. The height of slump cone vessel is 305mm and after test the height of slump is 270mm. The slump value of GPC is very less because of the alkaline solution used for mixing the concrete.

3.2 Compressive Strength Test

The compressive strength test is carried on the cube specimen of 100*100*100mm as per IS 516-1959 as in Fig. 1. The test was carried for 7 & 28 days with and without fibre. Firstly, the cube with varying percentage of fly ash and GGBS were casted and tested for 7 and 28 days to find the optimum percentage of fly ash and GGBS. The Compressive strength test for geopolymer concrete is given in Fig. 2.

Fig. 1. Compressive Strength Test

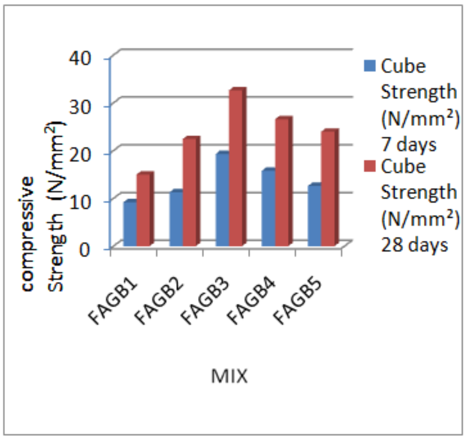

Fig. 2. Compressive Strength Test

Where,
FAGB1= 90%Fly ash + 10%GGBS
FAGB2= 80%Fly ash + 20%GGBS
FAGB3= 70%Fly ash + 30%GGBS
FAGB4= 60%Fly ash + 40%GGBS
FAGB5= 50%Fly ash + 50%GGBS

The mix FAGB3 shows the high strength. So, basalt fibre is added in this ratio to reinforce the material. The Graph in Fig. 3 shows the compressive strength of Geopolymer concrete cubes for different percentage of fiber and found that 0.2% of volume of concrete is optimum percentage ie.FRGPC0.2.

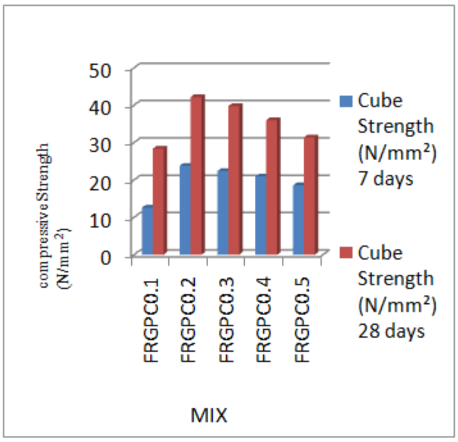

Fig. 3. Compressive Strength of FRGPC

Where,
FRGPC0.1= 90%Flyash + 10%GGBS &0.1% fiber
FRGPC0.2= 80%Flyash + 20%GGBS &0.1% fiber
FRGPC0.3= 70%Flyash + 30%GGBS &0.1% fiber
FRGPC0.4= 60%Flyash + 40%GGBS &0.1% fiber
FRGPC0.5= 50%Flyash + 50%GGBS &0.1% fiber

3.3 Non-Destructive Test

It is one of the ways to determine the strength of concrete without destruction of material. Rebound hammer test provides the direct compressive strength while Ultrasonic pulse velocity (UPV) method identifies the crack or voids present in the concrete cube. Both tests was carried to check the strength of cube and to check the quality of cube specimen. The rebound hammer test was done on the top surface of cube at 28 days with the results shown in Fig. 4. Similarly, UPV test was also conducted to identify the quality of cubes which is shown in Table 7. From the test it is clear that there are no voids and cracks in the specimen.

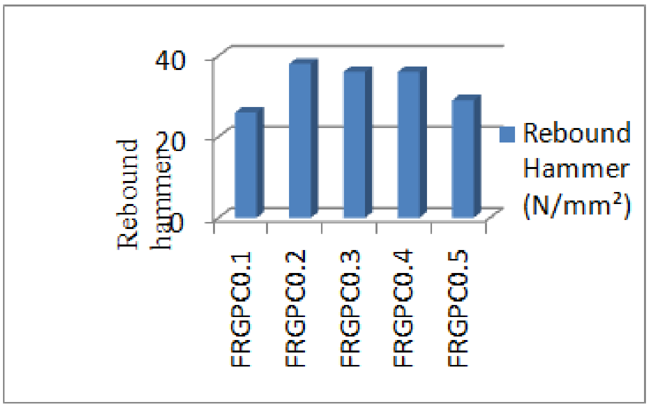

Fig. 4. Rebound Hammer of FRGPC

Table 7. Ultrasonic pulse velocity for cube

Mix	Ultrasonic Pulse velocity (km/sec)	Quality
FRGPC0.1	10.63	Excellent
FRGPC0.2	9.26	Excellent
FRGPC0.3	11.76	Excellent
FRGPC0.4	10.63	Excellent
FRGPC0.5	9.43	Excellent

3.4 Split Tensile Strength Test

Split Tensile Strength Test is indirect method of testing the tensile strength of concrete which is carried on cylinder of size 100*200mm at 28 days. For testing, the cylinder is placed laterally below compression testing machine. Below and above the specimen, a wooden or steel plate is kept and then load is applied uniformly till specimen fails as shown in Fig. 5. The split tensile strength is shown in Fig. 6, where, FRGPC0.2 mix shows high strength.

Fig. 5. Split Tensile Test

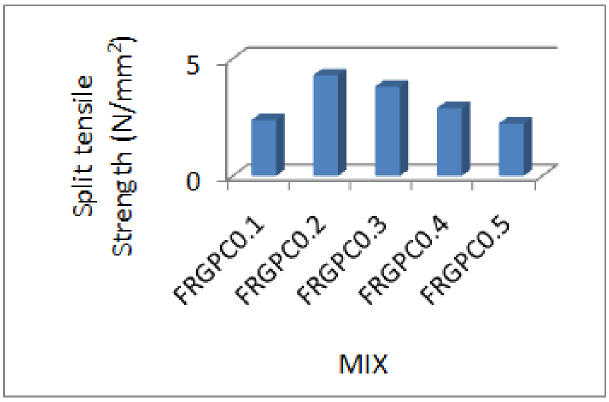

Fig. 6. Split Tensile strength

3.5 Flexural Strength Test

Flexural strength test was carried on prism of size 100*100*500mm at 28 days. The load applied on prism was two – point loading system to find the mechanism of pure bending. For testing, the prism was kept in UTM (Universal Testing Machine) and two loads were applied at a distance of l/3 from the edge of support as in Fig. 7. The cracking load was noted and calculation was done and strength is shown in Fig. 8.

Fig. 7. Flexural Strength Test

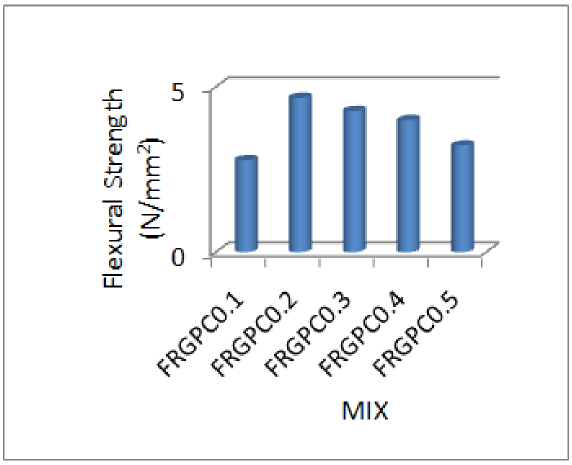

Fig. 8 Flexural strength test

3.6 Modulus of Elasticity

The ratio of stress to strain is Modulus of Elasticity (E). It indicates the stiffness of material that means how easily it is bended or stretched. To find the modulus of elasticity, a specimen of 150*300mm were casted and then testing was done. Eq.1 and Eq.2 gives the modulus of elasticity based on experimental value and IS Code value respectively. For the maximum value of f_{ck} (42.2MPa), from Eq.1, the modulus of elasticity is 32480MPa. The experimental and codal value of modulus of elasticity is found somewhat similar as shown in Table 8.

$$\text{Modulus of Elasticity (E)} = \frac{\text{Stress}}{\text{Strain}} \qquad \dots (1)$$

As per IS 456,
Modulus of Elasticity (E) = $5000\sqrt{fck}$ … (2)
Where,
f_{ck} = Characteristic Strength

Table 8. Modulus of Elasticity

Mix	Experimental E (MPa)	Based on Comp. Strength (MPa)
FRGPC0.1	22906	26445
FRGPC0.2	26874	32480
FRGPC0.3	25475	31543
FRGPC0.4	25012	30000
FRGPC0.5	21146	28017

IV. Conclusion

In this paper, different experimental investigations and test are carried out in the geopolymer concrete to find the optimum percentage of fly ash, GGBS and basalt fibers. The following conclusions are formed:

1. Low calcium (1.24%) fly ash is used in combination with GGBS (23.65%) to obtain the high strength of GPC. High calcium amount in fly ash may interfere the polymerization process and alter the microstructure. GGBS is used for binding and to produce more dense concrete.
2. 70% fly ash & 30% GGBS is optimum percentage to gain high strength in GPC.
3. River sand is used instead of M-sand to avoid the chemical and mineral reaction present in M-sand and other materials of geopolymer.
4. Very less amount of water is added to attain good workability and 3% of super-plasticizer is used to enhance the charge of geopolymer and to retard the setting time.
5. Use of fiber increases the compressive strength almost twice.
6. The UPV test also clarifies that, there is no crack and voids present in cube specimen.
7. 0.2%, basalt fiber by volume of specimen is optimum amount to get high strength because above that the fiber may accumulate at certain place so that the concrete cannot mix properly as a result failure occurs.
8. The prism is tested under two point loading system to identify either the failure is due to shear or flexure and is found that failure of prism is totally by flexure only. Also two point load gives pure bending i.e. shear is zero.
9. The modulus of elasticity for fiber reinforced geopolymer concrete is found almost 15-25% less than that of compressive strength value.

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