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STRENGTH OF GEOPOLYMER CONCRETE REINFORCED WITH BASALT FIBRE

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Abstract - *Concrete is one of the widely used composite materials. The demand for concrete in the construction field is increasing day by day. Cement is used as a binder material in concrete which is highly energy intensive and emits CO_2 to the atmosphere which is responsible for global warming. So, to protect pollution it is necessary to find the alternatives for OPC which is eco-friendly with the environment. Geopolymer is a best solution that utilizes industrial by-products as a binding material and is similar to cement. In this study, fly ash and GGBS is used as a 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, the optimum percentage of fly ash and GGBS was taken as 90% and 10% respectively. With this percentage, specimens like cubes, cylinder and prism were cast with a different percentage of basalt fibers at a dosage increment of 0.1% from 0.1% to 0.50% to find the optimum fiber percentage. Other properties like a split tensile, flexural strength, stress-strain curve test were also conducted and the results were compared with control geopolymer concrete. The test result implies that fiber reinforced geopolymer concrete yields better results in all the aspects when compared to geopolymer concrete without basalt fibers and also strength increases by 60 to 110%.*

***Key words**: Concrete, Geopolymer, Fiber, Fly ash, GGBS, Alkaline Solution, Flexural Strength*

1.INTRODUCTION

Concrete is the second most popular materials in this planet after water. It is versatile material and is widely used in civil engineering practice because of its mouldability, low production cost and high response under compression. Though it have more merit there is some demerit too. Nowadays there is much more problem of global warming which is caused by CO_2 gas. The cement industry plays major role for the emission of CO_2 into the atmosphere. It is said that for producing one ton of Ordinary Portland cement (OPC) about one ton of CO_2 is released into atmosphere. So, to protect the environment, alternative to OPC has been developed as Geopolymer Concrete (GPC) by Joseph Davidovits in 1978[1]. Geopolymer materials are formed by reaction of an aluminosilicate powder with an alkaline silicate solution at ambient conditions. GPC is emerging as a new environmentally friendly construction material for sustainable development, using fly ash and alkali in place of OPC as the binding agent [2]. GPC uses waste material such as fly ash, blast furnace slag to produce concrete. Plain GPC is weak in tension so different types of fibre are added to enhance the strength to the concrete [3]. The different types of fibre are steel fibre, basalt fibre, glass fibres etc. Basalt fibre is a fibre that is obtained from basalt rock and has higher working temperature and has a good resistance to impact load, fire resistance and chemical attack. When amount of basalt fibre is added to GPC, the flexural strength increases upto 68% for the content of 2% [4].

In this study, geopolymer material like fly ash and GGBS is used which is by product of thermal plant and steel plant respectively. Firstly, optimum percentage of fly ash and GGBS is identified and then in that percentage fiber is added at an increase of 0.1% upto 0.5%. Compressive strength for cube, split tensile strength for cylinder and flexural strength for prism is carried out to identify the optimum percentage of fibre. Other properties like stress-strain curve and modulus of elasticity is also studied.

2.MATERIALS

2.1 Fly Ash

Fly ash is by-product of thermal power plant. In this study, class f type fly ash is used that is obtained from Mettur Thermal Power Plant, Tamil nadu. The chemical composition of fly ash is 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)

GGBS is also a by-product that is obtained from steel plant. It is used to increase the strength and resist high acid effect, marine environment. The chemical composition of GGBS is 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

Sodium hydroxide (NaOH) in the form of pellete is used to make a solution of 10 molarity concentration by using tap water. This solution is then mixed with sodium silicate solution to form an alkaline activator solution. The solution is prepared 24 hours before the casting.

2.4 Fine Aggregate

River sand of size below than 2.36mm is used.

Table -3: Properties of Fine Aggregate

Properties	Specific Gravity	Bulk Density	Fineness Modulus
Fine Aggregate	2.6	1736.41 kg/m^3	2.5

2.5 Coarse Aggregate

Crushed stone of 12.5mm down size coarse aggregate is used.

Table -4: Properties of Coarse Aggregate

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

2.6 Basalt Fibre

Basalt fibre is obtained from igneous rock called basalt. It is golden brown in color. It has several advantages in construction field. It has good resistance to acid and chemical attack, UV-light, fungal attack, impact load and fire resistance.

Fig -1: Basalt Fibre

Table -5: Properties of Fine Aggregate

Density	2600 kg/m^3
Tensile Strength	500-600 MPa
Elastic Modulus	90-120 GPa
Elongation at break	3.1%
Length	12mm
Diameter	(7-15) μm
Color	Golden Brown

2.7 Water

Water is added in GPC only for workability.

2.8 Super- Plasticizer

Conplast-sp 430 is used to improve the flow of GPC and to increase the strength.

3.MIX DESIGN

GPC is new material so, there is no any proper mix design. The mix for this experimental work is done as per D.Hardjito and B.V. Rangan.

Table -6: Mix Proportion

Materials	Mix for $1m^3$ 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

Table -7: Mix Composition

Mix Id	Fly Ash (%)	GGBS (%)	Fly Ash (kg/m^3)	GGBS (kg/m^3)	Basalt Fiber %
FGC	100	0	394.3	0	-
FG 1	90	10	354.87	39.43	-
FG 2	80	20	315.44	78.86	-
FG 3	70	30	276.01	118.29	-
FG 4	60	40	236.58	157.72	-
FG 5	50	50	197.15	197.15	-
FFG1	90	10	276.01	118.29	0.1
FFG2	90	10	276.01	118.29	0.2
FFG3	90	10	276.01	118.29	0.3
FFG4	90	10	276.01	118.29	0.4
FFG5	90	10	276.01	118.29	0.5

FG - Fly ash + GGBS

FFG - Fiber+ Fly ash + GGBS

4.CASTING OF SPECIMEN

4.1 Cube for Compressive Strength

The cubes of size 100mmx100mmx100mm were cast to find out the compressive strength of plain geopolymer concrete and fibre reinforced GPC. Six cubes were cast for each ratio of fly ash and GGBS and for fibre also. The fresh concrete mix was filled in mould in three equal layers and each layer is compacted using tamper rod. Ambient curing was done upto 28 days and testing is done in compressive testing machine of 100 ton.

Fig -2: Casting of Cube

4.2 Cylinder for split tensile strength test

The cylinders of 100mmx200mm are cast to find out the tensile strength of GPC and also cylinders of size 150mmx300mm were also cast to see stress-strain relationship. Three number of cylinder for each ratio of fibre is prepared. The fresh concrete mix was filled in mould compacted using tamper rod. Ambient curing was done upto 28 days and testing is done in compressive testing machine of 100 ton.

Fig -3: Casting of Cylinder

4.3 Prism for flexural strength test

The prism of size 100mmx100mmx500mm is cast to find out the flexural strength of GPC. Three number of prism for each ratio of fibre is prepared and cured for 28 days in ambient temperature.

Fig -4: Casting of Prism

5.TESTING PROCEDURE

5.1 Compressive Strength

The Compressive Strength is the primary test to identify the strength of cube specimen. The test is done after 7 and 28 days.

Fig -5: Testing of Cube

5.2 Split Tensile Strength

The split tensile strength is indirect test to measure tensile strength of concrete. The test is done after 28 days of curing.

Fig -6: Testing of Cylinder

5.3 Flexural strength Test

The Flexural strength test is conducted in universal testing machine (UTM) after ambient curing of prism for 28 days. Two point load is applied on the specimen to see pure bending behaviour.

Fig -7: Testing of Prism

6.TEST RESULTS AND DISCUSSION

6.1 Compressive Strength of GPC and FGPC

The compressive strength of geopolymer concrete and geopolymer concrete with fiber at the age of 7 and 28 days are shown in table.

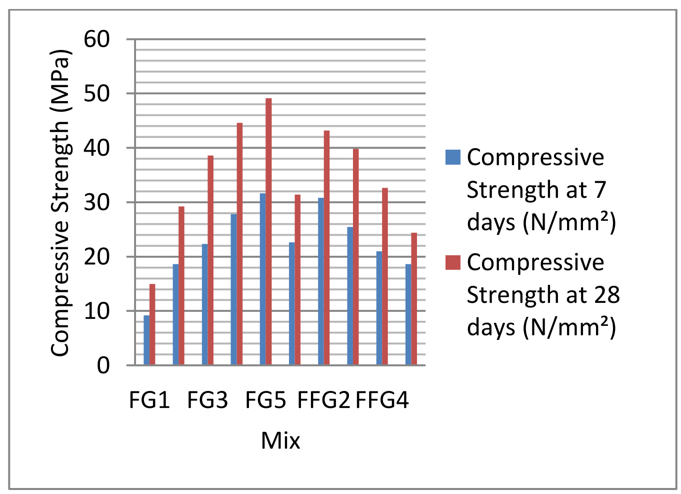


Fig -8: Compressive Strength at 7 & 28 days

The compressive strength increases as the amount of GGBS is increased. So, the optimum percentage is taken as lowest ratio i.e 90% fly ash and 10% GGBS (FG1). In this ratio, fibre is added from 0.1% to 0.5% to get the optimum fibre content to give high strength in concrete. From the test, it is found that 0.2% of fibre gives high strength.

6.2 Split tensile strength

The Split tensile strength test is done in cylinder at 28 days of ambient curing and tested on compressive strength machine.

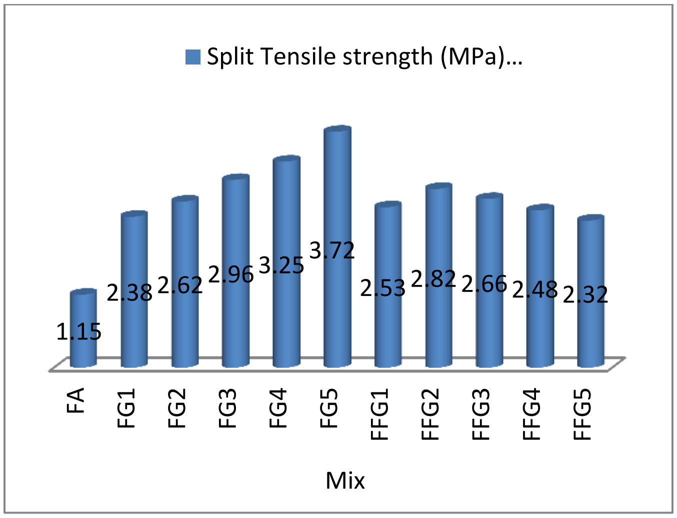
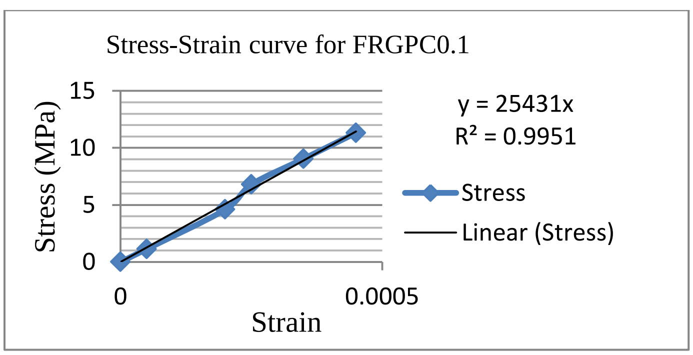


Fig -9: Split Tensile Strength at 28 days

From the test, it is clear that geopolymer concrete shows an increasing pattern of tensile strength but when fibre is added then strength increases upto 0.2% and then decreases by 6%.

6.3 Stress- Strain curve

According to Hook's law, stress is directly proportional to strain within the elastic limit. After elastic limit material behaves like a plastic. The stress-strain curve for different fibre ratio is shown in chart.



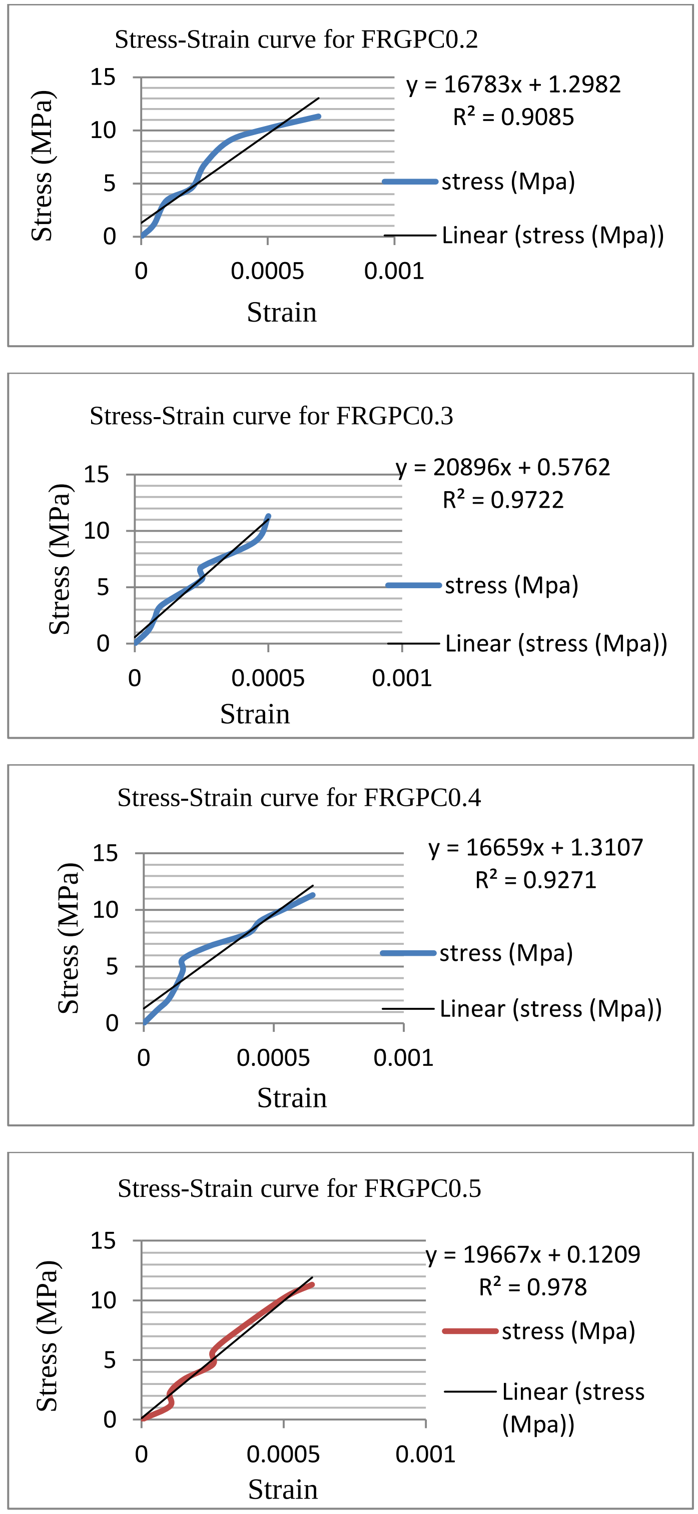


Fig -10: Stress-Strain curve

6.4 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. From the table, we can say that experimental value is greater than theoretical value.

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

As per IS 456,

$$\text{Modulus of Elasticity (E)} = 5000\sqrt{\text{fck}} \quad (2)$$

Where,

$$f_{ck} = \frac{\text{Ultimate load}}{\text{Area of cylinder}} = \text{Characteristic Strength}$$

Table -8: Modulus of Elasticity

Mix	Theoretical (E) (MPa)	Experimental (E) (MPa)
FFG1	21607	22906
FFG2	24663	26874
FFG3	24084	2547
FFG4	22724	25012
FFG5	19723	21146

6.5 Flexural Strength Test

The Flexural Strength test is done for prism in UTM after 28 days of curing in ambient temperature. Two point loads is applied to see pure flexure behaviour. The test implies that as the percentage of GGBS increases the flexure behaviour also increases but when fibre is added in GPC then upto 0.2% strength increases and then decreases simultaneously.

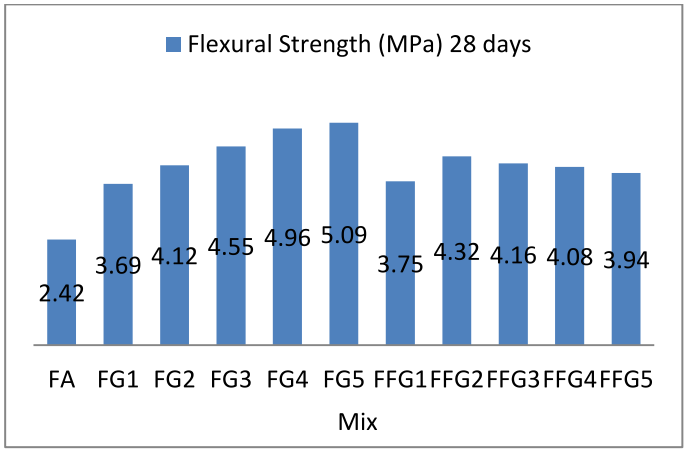


Fig -11: Flexural Strength

7. CONCLUSION

Based on experimental study, it is clear that fly ash alone cannot give strength and when GGBS is added to fly ash the strength increases gradually due to presence of SiO_2 and CaO in pozzolanic material. To obtain high strength and to resist corrosive and chemical attack 12mm basalt fiber is added to arrest crack in concrete, hence increasing strength by 60-110%. It is found that for 90% fly ash and 10% GGBS, 0.2% is responsible for high strength. Beyond 0.2% the strength is reduced because the percentage volume of fibre becomes more and is accumulated at certain places, which decrease the strength. Finally we can say that the use of by-product decrease the waste material of country and makes environment healthy also.

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