JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Strength properties of Fly ash and GGBS based Geo-polymer Concrete.

[1]Darshan J.Parmar,[2]Prashant K.Bhuva,[3]Kalpesh L. Kapadiya

[1] P.G.Student,[2]Assistant Professor,[3]Assistant Professor

[1]Department of Civil Engineering,

Dr.Subhash University, Junagadh, India.

Abstract: The Second most Consumed Product in the world is Cement. It contributes nearly 7% of the global Carbon Dioxide Emission. Geo-polymer Concrete is (GPC)is a special type of concrete and it is manufactured using like a industrial waste like as a fly ash, GGBS and it is more alternatively and eco-friendly material compared to ordinary Portland Concrete(OPC).This Project is mainly Focused in the different proportions of GGBS(Ground Granulated blast Furnace slag)and Fly ash(FA) effects and it's mechanical Properties of Geo-Polymer Concrete when they replaced at cement for different partial replacement levels with the help of using Alkaline Activators like as a Sodium Silicate(Na_2SiO_3) and Sodium Hydroxide(NaOH). The different moulds were casted and cured for different curing time like as a 7, 28,56 days at a room Temperature. To determine the mechanical Properties like as a Compressive strength, Split Tensile strength and Flexural Strength of Geo-polymer Concrete.

Index Terms: Geo-polymer Concrete, GGBS, Fly-Ash, Sodium Silicate, Sodium Hydroxide, Compressive Strength, Split Tensile Strength,Flexural Strength.

I.Introduction

The contribution of ordinary Portland cement (OPC) production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually or approximately 7% of the total greenhouse gas emissions to the earth's atmosphere. also it has been reported the concrete structures and it's start to deteriorate after 20 to 30 years. To Produce Environmentally friendly concrete the use of fewer natural resources, less energy and to minimize carbon dioxide emissions.

In line with the above view, one of the efforts to produce more environmentally friendly concrete is to partially replace the amount of OPC in concrete with by-product materials such as fly ash. An important achievement in this regard is the development of high-volume fly ash (HVFA) concrete that uses only approximately 40% of OPC, and yet possesses excellent mechanical properties with enhanced durability performance. The test results show that HVFA concrete is more durable than OPC concrete. Fly ash, one of the source materials for geopolymer binders, is available abundantly worldwide, and yet its use to date is limited.

This Paper presents the technology of making Geo-polymer concrete using fly ash and GGBS and it's source material and perform the laboratory test.

II.Literature Review

Mohammed Rabbani Nagral, Tejas Ostwal,,Manojkumar V Chitawadagi The effect of curing temperature, curing hours on Geo-polymer Concrete(GPC) specimens and also the effect of extra water on workability and compressive strength of GPC cubes were studied. Fly ash and GGBS were used as binder, combined with an alkaline solution to form geopolymer paste instead of cement paste to bind the aggregates. The experiments were conducted on GPC cubes for curing temperature of 80° C, 90° C and 100° C with curing period of 12 and 24 hours by adopting hot oven curing method. The constants used in the experiments were alkaline solution to binder ratio taken as 0.45, molarity of NaOH solution as 12M and ratio of sodium silicate to sodium hydroxide as 2.5. All the specimens were kept at one day rest period. Results showed that increase in water to geopolymer solids ratio and extra water increased the workability of GPC and decreased the compressive strength of GPC.[1]

D Hardjito To reduce greenhouse gas emissions, efforts are needed to develop environmentally friendly construction materials. This paper presents the development of fly ash-based geopolymer concrete. In geopolymer concrete, a by-product material rich in silicon and aluminum, such a slow-calcium (ASTM C 618 Class F) fly ash, is chemically activated by a high-alkaline solution to form a paste that binds the loose coarse and fine aggregates, and other unreacted materials in the mixture.[2]

Subhash V. Patankar An experimental investigation has been carried out for the gradation of geopolymer concrete and a mix design procedure is proposed on the basis of quantity and fineness of fly ash, quantity of water, grading of fine aggregate, fine to total aggregate ratio. Sodium silicate solution with Na2O = 16.37 %, SiO2 = 34.35 % and H2O = 49.28 %and sodium hydroxide solution having 13M concentration were maintained constant throughout the experiment. Water-to-geo polymer binder ratio of 0.35, alkaline solution-to-fly ash ratio of 0.35 and sodium silicate-to-sodium hydroxide ratio of 1.0 by mass were fixed on the basis of workability and cube compressive strength. Workability of geopolymer concrete was measured by flow table apparatus and cubes of 150mm side were cast and tested for compressive strength after specified period of oven heating. The temperature of oven heating was maintained at 60 °C for 24 h duration and tested 7 days after heating. It is observed that the results of workability and compressive strength are well match with the required degree of workability and compressive strength.[3]

Subhash V. Patankar Experimental investigation has been carried out to study the effect of concentration of sodium hydroxide, temperature and its duration on flow and compressive strength. Activated liquid to fly ash ratio of 0.40 by mass was maintained in the experimental work on the basis of past research. Sodium silicate solution with Na0 = 16.37%, Si02 = 34.35% and H20 = 49.28% was considered. The concentration of sodium hydroxide solution is varied as 2.91, 5.6, 8.1, 11.01, 13.11 and 15.08 Moles.. The temperature of curing was varied as 60. 90. and 1200C and the duration of curing for each temperature as 6, 12, 18 and 24 hours after remolding. Test results show that the flow of geopolymer mortar increases with increase in the concentration of sodium hydroxide, rill' compressive strength of geopolymer mortar increases with increase in duration of heating at run-runt temperature. Ternperature also plays vital role in accelerating the strength.[4]

G. Mallikarjuna Rao, Y. Anil Kumar This research work focuses on the performance of Fly Ash and GGBS based geo- polymer concrete cured in outdoor conditions using a single alkaline activator solution (Geo activator). The variations of Fly Ash and GGBS were (FA100-GGBS0; FA90-GGBS10; FA70-GGBS30; FA50-GGBS50). In this study, only the Geo activator is used to activate Fly Ash and GGBS in the mixtures. Geo polymer concrete of size 100 mm x 100 mm x 100 mm was used in this research work to measure compressive strength at different ages of 7 days and 28 days. The results reveal that the increase in the proportion of GGBS content in the mix increases compression strength of concrete. The cost analysis was also carried for geopolymer concrete, compared with conventional concrete and the results reveals that for the lower grades, the cost will be the same as for conventional concrete and for the higher grades, the use of geo polymer concrete can reduce the cost of construction up to some extent.[5]

III.What is Geo-polymer Concrete?

Geopolymer used as a binder, instead of cement paste, to produce concrete. The geopolymer paste binds the loose aggregates, fine aggregates and other unreacted materials together to form the geopolymer concrete.

Portland cement concrete, the aggregates occupy the largest volume that is approximately 75% by mass in geopolymer concrete. The silicon and the aluminum in the fly ash are activated by a combination of Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH) to form the geopolymer paste that binds the aggregate and other unreacted materials.

IV. Experimental Work

In the proposed mix design method, low calcium processed fly ash of thermal power plant was used as source material. The Laboratory grade sodium Hydroxide in the flake form (97% purity) and sodium silicate (50.72% solids) Solutions are used as alkaline activators. Locally available river sand is used as fine aggregate and locally available 20 and 10 mm sized coarse aggregates are taken.

Parameters considered for Mix Proportioning of Geopolymer concrete.

1. Fly Ash and GGBS
2. Alkaline Activators
3. Water
4. Aggregates
5. Water to geopolymer Binder Ratio.

Preparation of Geopolymer Concrete Mixes

Preparation of geopolymer concrete is similar to that of cement concrete. Two types of coarse aggregates, sand, fly ash and GGBS were mixed in dry state. Then add prepared mixture solution of sodium hydroxide and sodium silicate along with extra water based on water-to-geopolymer binder ratio and mix thoroughly for 3–4 min so as to give homogeneous mix.

Material Properties:
Binders:
Fly ash and GGBS used as a binder in geopolymer concrete and their physical and chemical Properties of the ground granulated blast furnace slag were described below

Chemical and Physical Properties of Class F fly ash and GGBS

Particulars	Class F fly ash	GGBS
Chemical composition		
% Silica(SiO_2)	65.6	30.61
%Alumina(Al_2O_3)	28.0	16.24
%Iron Oxide(Fe_2O_3)	3.0	0.584
%lime(Cao)	1.0	34.48
%Magnesia(MgO)	1.0	6.78
%Titanium Oxide(TiO_2)	0.5	---
%Sulphur Trioxide(SO_3)	0.2	1.85
Loss of Ignition	0.28	2.0
Physical Properties		
Specific Gravity	2.20	
Fineness(m^2/kg)	360	400

The binder material employed in this research work was fly ash (class F) procured from thermal plant and GGBS. A binder proportion ratio of 50:50 has been used in this research work. The specific gravity of GGBFS and fly ash being 2.9 and 2.15, respectively.

Cement
OPC 43 grade Ultratech cement, tested as per IS: 8112(1989), it was found that specific gravity = 3.15, initial setting time = 60 minutes and final setting time = 470 minutes.

M-Sand
Locally available M-Sand has been used in this research work, and the specific gravity of M-Sand was 2.64 tested as per IS 2386 part 3 (1963).

Sodium Silicate (Na2SiO3)
a ratio of 1:2.2 between Na2O and SiO2 is used. The specific gravity was 2.2.

Sodium Hydroxide (NaOH)
Sodium hydroxide flakes been used in this research work, having a purity of 98 %. The specific gravity of sodium hydroxide flakes was 1.52

Alkaline Activator Solution Sodium hydroxide with sodium silicate is mixed at room temperature and kept for 24 hours before use, as an engaging, warm solution decreases the workability and strength of concrete [16], the molarity of 8M has been used in the research work, where 1M is equal to 40gms of NaOH mixed in 1 liter of water. Hence, 8M=320gms of NaOH has been used in 1 liter of water.

Casting of Specimens
The design mix of GPC has been carried out in accordance with IS 10262 – 2019 specifications.Initialy,Moulds were cleaned with dry cloth and oiled for a smooth release of the specimens.The specimens were cast using 150 mm * 150 mm cubes for compression with a cylinder diameter,150 mm height and 300 mm for tensile strength. The casted GPC specimens were demoulded after 24 hours and kept for curing at an ambient temperature of 27^0 C – 36^0 C

Ingredient materials and their cost

Sr No.	Materials	Rate in Rs./Per
1	Cement	400/50kg
2	Fly Ash	800/MT
3	GGBS	2/kg
4	Fine Aggregate	1100/MT
5	Coarse Aggregate	750/MT
6	Sodium Silicate(Na_2SiO_3)	17/kg
7	Sodium Hydroxide(NaOH)	60/kg
8	Super Plasticizers(Conplast s p 430)	250/kg

Procedure of Design Mix

Mix Proportioning
a) Characteristic compressive strength at 28 days as per IS 10262-2019
b) The specific gravity of the constituent of concrete
c) Type and size of aggregates
d) Selection of liquid binder ratio and alkaline activators
e) Calculation of water in activator content
f) Aggregate calculation

Air Content The approximate amount of entrapped air to be expected in normal non-entrained air) concrete as per (IS 10262-2019)

Maximum Nominal Size of aggregate in mm	Entrapped Air, as a percentage of the volume of concrete
20	1.0

Concrete Mix Design for M40 Grade GPC

As per the design mix proportioning data, M40 grade mix proportion is carried out

a) Compressive strength (characteristic) fck at 28 days = 40Mpa

b) Specific gravity (M-Sand) = 2.64

c) Specific gravity (Coarse Aggregate) = 2.74

d) Specific gravity (Fly ash) = 2.15

e) Specific gravity (GGBS) = 2.9

f) Specific gravity (NaOH) = 1.52

g) Specific gravity of Na2SiO3 = 2.2

h) Workability : 75-100mm slump

i) Molarity: 8M

j) Nominal size of aggregate : 20mm (maximum)

k) Binder content : 300 kg/m3 (minimum)

l) Sodium silicate/sodium hydroxide = 2.1

m) Aggregate (Fine) = M-Sand

n) Aggregate (Coarse) : 20mm (angular)

o) Liquid to binder ratio = 0.23

Activator Content The maximum amount of water for 1m^3 of concrete as per (IS 10262: 2019) is shown in Table

Nominal size of aggregate(mm)	Maximum water content (kg/m^3)
10	208
20	186
40	165

the amount of water for the nominal maximum size of aggregate is 186 kg for the slump of 50 mm.

To increase the slump to 75 mm, we need to increase it by 25 mm. IS code recommends increasing water by About 3% for every 25 mm slump added. Similarly, 6% for 100mm, so for 25 mm,
we have (3%)
= 186 + 186 × (3/100)
= 191.58 liters = 192 liters

Liquid Binder Ratio From IS 10262-2019, liquid-to binder ratio is taken as 0.48 for compressive strength of 40 Mpa

Binder Material

Fly ash and GGBFS are 2 binder materials used, hence

Binder material (Bm) = Ac / 0.48

= 192 / 0.48 = 400 kg / m3 > 300 kg / m3

Hence OK

A ratio of 50:50 Fly ash and GGBFS hence (200 Kg / m3 each)

Alkaline Activators (AA)

Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) are chosen as activators

Let, Na_2SiO_3 to NaOH = S = 2.1

Then, Quantity of ac = quantity of (Na_2SiO_3 + NaOH)

= quantity of (S X NaOH + NaOH)

= quantity of NaOH (S + 1)

Quantity of NaOH (QNaOH)

= Quantity of ac / (S +1)

= 192 / (2.1+1)

= 62 kg/m3

Quantity of Na_2SiO_3 (Q Na_2SiO_3)

= S × QNaOH

= 2.1 ×62

= 130 kg/m3

Water in Activator Content

The water-to-solid ratio is a critical element in the construction of GPC mixtures. The solid percentage in NaOH and Na_2SiO_3 is taken as 45.5% and 34.5%, respectively.

Let PNaOH and PNa_2SiO_3 be the solids percentages in sodium hydroxide and sodium silicate, respectively.

Water Content = Quantity of water in (NaOH + Na_2SiO_3)

Quantity of water in a sodium hydroxide (QNaOH)

= QNaOH – (PNaOH x QNaOH)

= QNaOH (1- PNaOH)

= 62(1-0.345)

= 40.61 kg/m3

Quantity of water in Sodium silicate (Q Na_2SiO_3)

= QNa2SiO3 – (P Na_2SiO_3 x Q Na_2SiO_3 3)

= QNa2SiO3 (1 -P Na_2SiO_3)

= 130(1-0.455)

= 70.85 kg/m3

Total = quantity of water = ($NaOH + Na_2SiO_3$) = 111.46 kg/m3

21.4 kg of solids has been dissolved in 40.61 kg of water to prepare an 8 Molar solution for the above design mix, and 70.85 kg of water for sodium silicate out of 130 kg has been used. The total water quantity is said to be found at 111.46 kg/m3. Hence the mix design contains 480.55 (400 + 21.4 +130 - 70.85) kg/m3 of concrete. Hence, the water-to-solid ratio is subsequently sustained at 0.23 (111.46/480.55) in this design mix.

Total Aggregates

BM_1 = Binding Material fly ash

BM_2 = Binding Material GGBS

C_v = Concrete Volume

T_v = Total Volume of Aggregates

B_v =Binder Volume

W_{NaOH} = Volume of NaOH

$W_{Na2SiO3}$ = Volume of Na_2SiO_3

W_a = Entrapped Air (1%)

Concrete Volume(C_v) = Total Volume of Aggregates + Binder Volume + Volume of NaOH + Volume of Na_2SiO_3 + Entrapped Air.

Calculating For $1m^3$ Concrete

$T_V + B_V + W_{NaOH} + W_{Na2SiO3} = 0.99$

$T_v = 0.99 – (B_V + W_{NaOH} + W_{Na2SiO3})$

$T_v = 0.73\ m^3$.

M-Sand and Coarse Aggregate Calculation

a% = M-sand Percentage

b% = Coarse Aggregate Percentage

Quantity of M-sand = Sp.Gravity of M-sand * 1000(a% * T_v)

= 2.64 * 1000(0.35 * 0.73)

= 674.52 kg/m^3.

Quantity of Coarse Aggregate = Sp.Gravity of Coarse Aggregate * 1000(b% * Tv)

= 2.74 * 1000(0.65 * 0.73)

= 1300.13 kg/m^3

Hence GPC M 40 Grade Ratio = 1 : 1.68 : 3.24 : 0.48

So We have Cubes Cast for M-40 Concrete Mix design of Various proportions of fly ash and GGBS and check its strength properties of compressive strength,split tensile Strength and flexural strength.

V.Results and Discussion

Compressive strength

Compression tests are performed to characterize the behavior of a material under compressive loading. During the test, pressure is applied to a specimen using compression plates.

Fig 5.1 Compressive strength Test.

Compressive strength of Normal Concrete and Geopolymer Concrete (M 40)

Mechanical Property	Age(days)	Normal Concrete	FA50-GGBS50
Compressive Strength,Fc(Mpa)	7	28.8	40
	28	46	49
	56	49	52.9

Table 5.1 Compressive strength NC AND GPC (FA50-GGBS50) in Mpa.

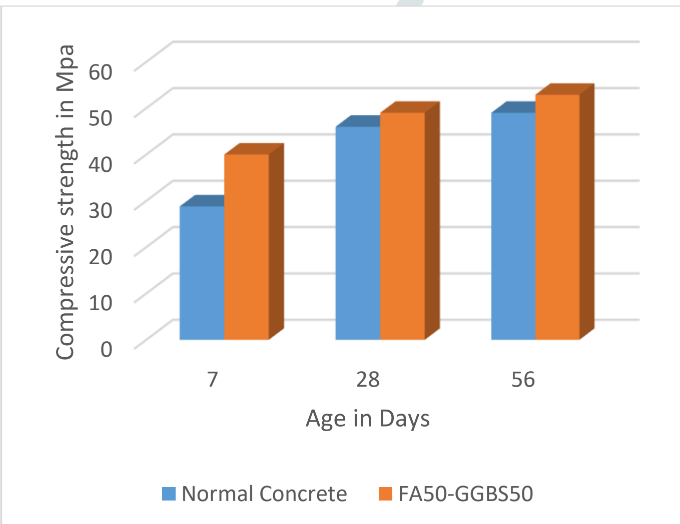

Fig 5.2 Compressive strength NC AND GPC (FA50-GGBS50) in Mpa.

Mechanical Property	Age(days)	Normal Concrete	FA75-GGBS25
Compressive Strength,Fc(Mpa)	7	28.8	21.1
	28	46	30.2
	56	49	35

Table 5.2 Compressive strength NC AND GPC (FA75-GGBS25) in Mpa.

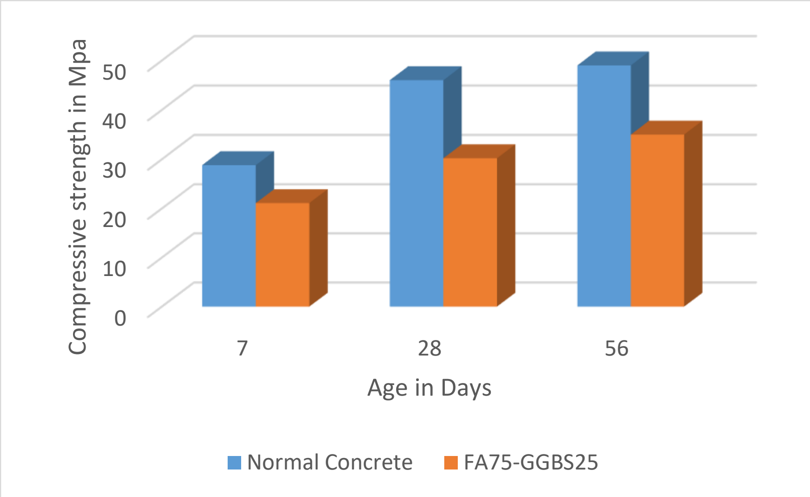

Fig 5.3 Compressive strength NC AND GPC (FA75-GGBS25) in Mpa

Mechanical Property	Age(days)	Normal Concrete	FA100-GGBS0
Compressive Strength,Fc(Mpa)	7	28.8	10.2
	28	46	17.8
	56	49	23.5

Table 5.3 Compressive strength NC AND GPC (FA100-GGBS0) in Mpa

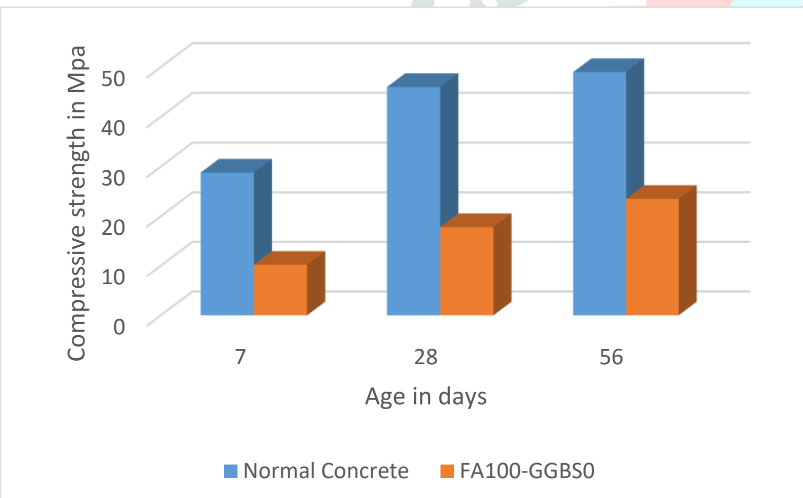

Fig 5.4 Compressive strength NC AND GPC (FA100-GGBS0) in Mpa

Split Tensile Strength

The split tensile test is an indirect way of evaluating the tensile test of concrete. In this test, a standard cylindrical specimen is laid horizontally, and the force is applied on the cylinder radially on the surface which causes the formation of a vertical crack in the specimen along its diameter.

Concrete's tensile strength varies between 300 and 700 psi, i.e., around 2 to 5 MPa. This means, on average, the tension averages about 10% of the compressive strength.

Fig 5.5 Split Tensile strength Test.

Split Tensile strength of Normal Concrete and Geopolymer Concrete (M 40)

Mechanical Property	Age(days)	Normal Concrete	FA50-GGBS50
Split Tensile Strength,Fct(Mpa)	28	2.7	3.2
	56	2.9	3.3

Table 5.4 Split Tensile strength NC AND GPC (FA50-GGBS50) in Mpa

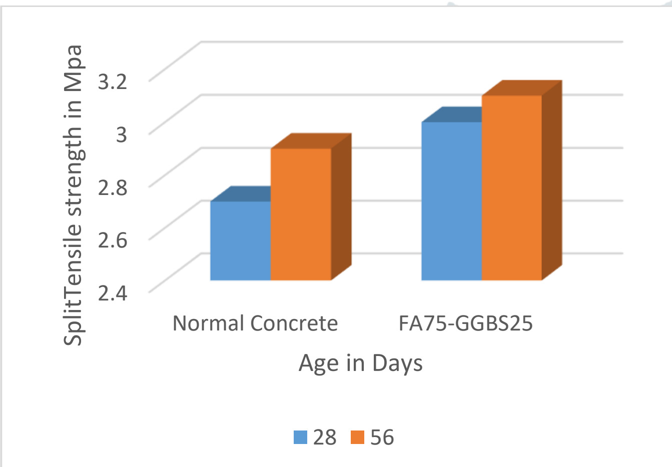

Fig 5.6 Split Tensile strength NC AND GPC (FA50-GGBS50) in Mpa

Mechanical Property	Age(days)	Normal Concrete	FA75-GGBS25
Split Tensile Strength,Fct(Mpa)	28	2.7	3
	56	2.9	3.1

Table 5.5 Split Tensile strength NC AND GPC (FA75-GGBS25) in Mpa

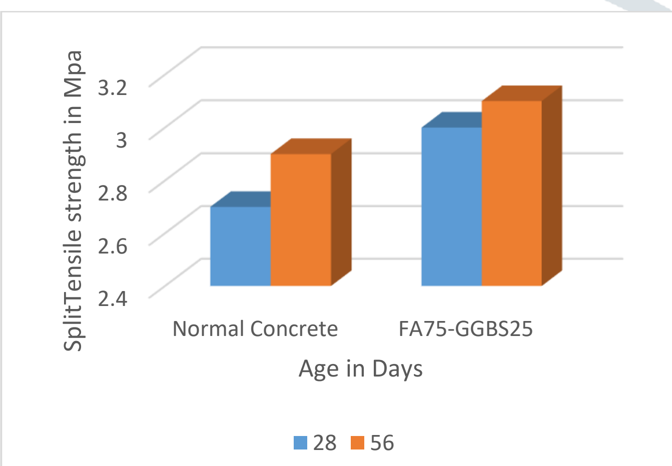

Fig 5.7 Split Tensile strength NC AND GPC (FA75-GGBS25) in Mpa

Mechanical Property	Age(days)	Normal Concrete	FA100-GGBS0
Split Tensile Strength,Fct(Mpa)	28	2.7	2.8
	56	2.9	2.9

Table 5.6 Split Tensile strength NC AND GPC (FA100-GGBS0) in Mpa

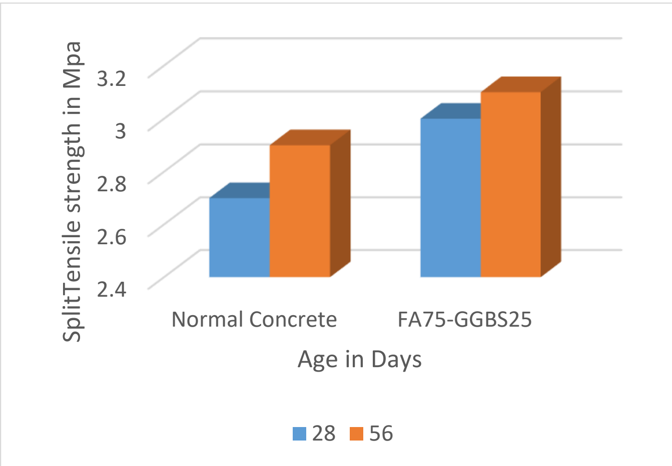

Fig 5.8 Split Tensile strength NC AND GPC (FA100-GGBS0) in Mpa

Flexural Strength

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 6 x 6-inch (150 x 150-mm) concrete beams with a span length at least three times the depth.

Fig 5.9 Flexural Strength Test

Flexural strength of Normal Concrete and Geopolymer Concrete (M 40)

Mechanical Property	Age in Days	Normal Concrete	FA50-GGBS50
Flexural Strength,Fcr(Mpa)	28	4.8	5.3
	56	5	5.9

Table 5.7 Flexural strength NC AND GPC (FA50-GGBS50) in Mpa

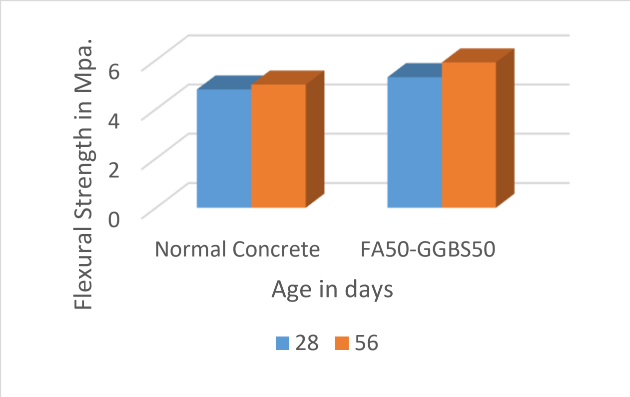

Fig 5.10 Flexural strength NC AND GPC (FA50-GGBS50) in Mpa

Mechanical Property	Age in Days	Normal Concrete	FA75-GGBS25
Flexural Strength,Fcr(Mpa)	28	4.8	5
	56	5	5.3

Table 5.8 Flexural strength NC AND GPC (FA75-GGBS25) in Mpa

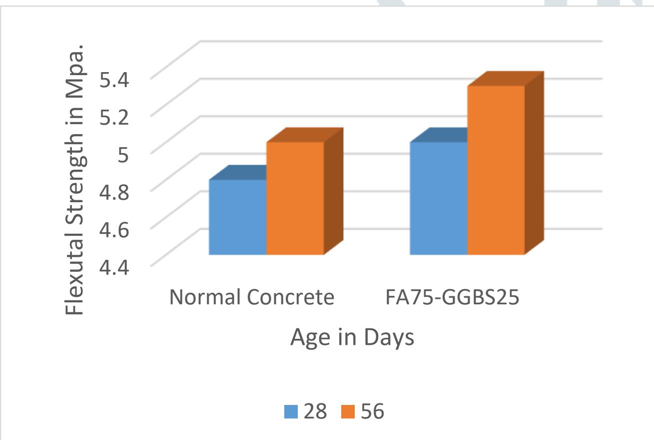

Fig 5.11 Flexural strength NC AND GPC (FA75-GGBS25) in Mpa

Mechanical Property	Age in Days	Normal Concrete	FA100-GGBS0
Flexural Strength,Fcr(Mpa)	28	4.8	4.9
	56	5	5.2

Table 5.9 Flexural strength NC AND GPC (FA100-GGBS0) in Mpa

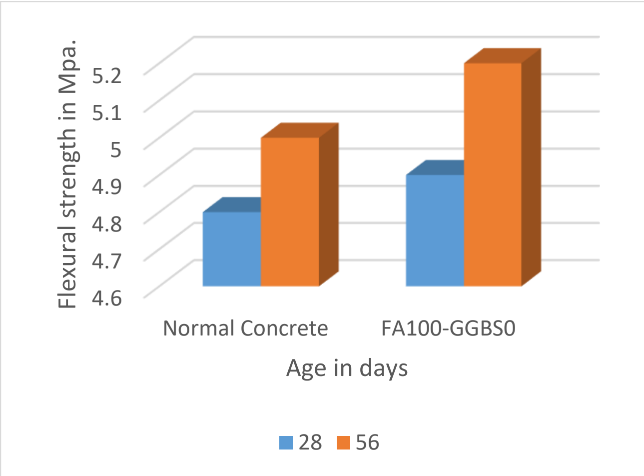

Fig 5.12 Flexural strength NC AND GPC (FA100-GGBS0) in Mpa

VI.CONCLUSION

1. GPC Strength Can be increased with help of increasing Molarity.
2. Though 100% fly ash exhibited decrease in strength it maintains the strength. the cost is also low compared to the 50% GGBS & 50 % fly ash.
3. The Compressive strength of GPC is inversely proportional to the water –to –geopolymer binder ratio similar that of water – to – cement ratio in cement concrete.
4. Suitable Range of water to geopolymer binder ratio is in the range of 0.25 to 0.40.Higher ratio gives the segregated mix while lower ratio gives viscous and dry mix.
5. Fly ash based GPC mixes compared the values of mechanical Properties at room temperature curing at all ages to normal strength.
6. Initial stage of the GPC compressive strength, 7 days strength is less as compared to 28 day strength.
7. Conventional Concrete strength is more than Geopolymer concrete at 7 days.
8. Water to geo polymer binder ratio is maintained at 0.35 which gives better results of workability and compressive strength.

VII.ACKNOWLEDGMENT

The authors would like to thank the Department of civil Engineering,Dr Subhash University for providing the necessary facilities to carry out this research.

REFERENCES

1. D. Hardjito, S.E. Wallah, D.M.J. Sumajouw and B.V.Rangan, "Fly ash-Based Geopolymer Concrete, Construction Material for Sustainable Development", Invited paper, Concrete World: Engineering and Materials, American Concrete Institute, India Chapter, Mumbai, India, 9-12 December 2004.
2. J. Davidovits, "Geopolymers: Man-Made Geosynthesis and the Resulting Development of Very Early High Strength Cement", J. Materials Education Vol. 16 (2&3), 1994, pp. 91-139.
3. Malhotra, V. M., "High-Performance High-Volume Fly Ash Concrete," Concrete International, V. 24, No. 7, July 2002, pp. 1-5.
4. Ganesh, Chithambar and Muthukannan, Muthiah, "A Review of Recent Developments in Geopolymer Concrete," International Journal of Engineering and Technology, vol. 7, no. 2, pp. 696-699, 2018. Crossref, https://doi.org/14419/ijet.v7i4.5.25061
5. Vemundla Ramesh and Koniki Srikanth, "Mechanical Properties and Mix Design of Geopolymer Concrete – A Review," 2nd International Conference on Design and Manufacturing Aspects for Sustainable Energy, vol. 184, no. 6, pp. 1-5, 2020. Crossref, https://doi.org/10.1051/e3sconf/202018401091
6. IS : 3812 ,"Specification for fly ash for used as Pozzolana and admixture ".Bureau of Indian Standards,New Delhi,1981.
7. .IS : 1727 "Methods of test for Pozzolanic materials", Bureau of ndian Standards,New Delhi,1967.
8. A.M. Nevelle,"Properties of Concrete", Published by English Language Book Society, Longman.
9. IS :650 , "Specification for standard sand for testing of cement", Bureau of Indian Standards, New Delhi,1991.
10. D. Hardjito, S.E. Wallah, D.M.J. Sumajouw and B.V.Rangan, "On the development of Fly ash-Based Geopolymer Concrete", ACI Materials Journal, November-December2004, pp 467-472.
11. S.V. Patankar and S.S. Jamkar, "Effect of Various Parameters in Activation of Fly Ash based Geopolymer Mortar",Proceedings of International Conference on Advances in Concrete and Construction, ICACC-2008, 7-9 Feb, 2008, Hyderabad, India pp 270-279.

12. S.V. Patankar, S.S. Jamkar and Y.M. Ghugal, "Effect of Sodium Silicate on Flow and Strength of Fly Ash Based Geopolymer Mortar", The seventh Structural Engineering Convention, SEC-2010, 8-10 Dec., 2010, Annamalai University, Annamalai Nagar, Tamilnadu, India pp 270-279.
13. P.K. Sarker, S. Kelly and Z. Yao, "Effect of exposure on cracking, spalling and residual strength of fly ash geopolymer concrete", Materials and Design Vol. 63, 2014, pp. 584-592.
14. P. Nath and P.K. Sarker, " Effect of GGBS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition", Construction Building Materials Vol. 66, 2014, pp. 163 171
15. P Abhilash, C.Sashidhar "Strength properties of Fly ash and GGBS based Geo-polymer Concrete", International Journal of ChemTech Research, IJCRGG, ISSN: 0974-4290, Vol.9, No.03 pp 350-356**.**