An Experimental Study On Strength Characteristics Of Geopolymer Concrete (Gpc) With Different Ggbs And Fly Ash Proportions

J.Srinivas[1] D.Rama Seshu [2] B.Sesha Sreenivas[3]

[1]Research Scholar, Associate Professor in Civil Engineering, Adams Engineering College, Palvancha, affiliated to JNTUH.

[2] Professor of Civil Engineering, NIT, Warangal

[3] Principal and Professor of Civil Engineering, Kakatiya University, Warangal.

***Abstract*:** *This article mainly aims at the study of effect of fly ash (FA) and Ground Granulated Blast Furnace slag (GGBS) on the mechanical properties of Geo Polymer Concrete(GPC) as a replacement for OPC, using Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaoH) solutions as alkaline activators. The proportions of Fly Ash to GGBS Used are (80:20),(60:40),(40:60),(20:80).Alkaline liquid content to Fly ash ratio taken as 0.36 and fine aggregate to total aggregate ratio is taken as 32 percentage[1]. The ratio of Sodium Silicate (Na_2Sio_3) solution to Sodium Hydroxide solution is kept constant as 2.5[1].There identical specimens for each of variation were cast and tested after 7days and 28days ambient curing. Heat curing for polymerization was not necessary due to the presence of GGBS. The experimental results indicate that the mechanical properties, such as Compressive Strength (f_{ck}), Split Tensile Strength (f_{ct}) and Modulus of Rupture, increase with increase in the percentage of GGBS.A parameter called Binder Index (Bi) is introduced to quantify the effect of Fly ash, GGBS and Molarity on the Compressive Strength (f_{ck}), Split Tensile Strength (f_{ct}) and Modulus of Rupture of Geopolymer Concrete at ambient temperature. Effect of GGBS to Fly Ash ratio and Effect of Binder Index[2] on Compressive Strength(f_{ck}) of GPC,Split Tensile Strength(f_{ct}) of GPC and Modulus of Rupture of GPC is calculated.*

Key words: *Geopolymer concrete, GGBS, Fly ash, Sodium silicate, Sodium hydroxide, Compressive strength, Split tensile strength, modulus of rupture.*

I. INTRODUCTION:

Concrete is the most expansive used building construction material in the world and Ordinary Portland Cement (OPC) is the major component used in concrete. The manufacturing of cement releases large amount of carbon dioxide (CO_2) to the atmosphere that significantly contributes to green house gas emissions. It is evaluate that one ton of CO_2 is released into the atmosphere[3] for every ton of OPC produced.

In terms of reducing the global warming, the geopolymer technology could reduce the CO_2 emission to the atmosphere caused by cement and aggregates industries by about 80% . One of the efforts to produce more environmentally friendly concrete is to reduce the use of opc by replacing the cement concrete with geopolymer.

In view of this, there is a need to develop sustainable alternatives to conventional cement materials utilizing the cementitious properties of industrial by-products such as fly ash and ground granulated blast furnace slag. Fly ash is a by-product produced from thermal power stations in large quantities, the safe disposal of which has become very difficult. On the other hand, the abundance and availability of fly ash and GGBS worldwide created an opportunity to utilize these by-products, as partial replacement for OPC.

In 1978, Davidovits [(4)] developed a composite material called geo-polymer to describe an alternative cementitious material which has ceramic-like properties. Geo-polymer concrete is a new technology considered to reduce the use of Portland cement in concrete. Geopolymer is environmental friendly material that does not emit green house gases during polymerization process. Geopolymer can be produced by combining a pozzolanic compound or aluminosilicate source material with highly alkaline solutions [(5)]. Geopolymer are made from source materials with silicon (Si) and Aluminium (Al) content and thus cement can be completely replaced.

II.Experimental Program: The present investigation consisted of determining the Compressive Strength(fck)**,** Split Tensile Strength(fct) and Modulus of Rupture of the GPC, by casting and testing cubes (100mm size), cylinders (100mm X 200mm) and prisms (100mm X100 X500mm) respectively.

2.1 Materials:

Low calcium, Class F dry fly ash, conforming to IS 3812(part 1:2003)[8], is obtained from Kothagudem Thermal power station, Bhadradri Kothagudem Dist, Telangana, India . Ground Granulated Blast furnace slag(GGBS) conforming to IS 12089:1987 is obtained from Blue way exports supplier, from Vijayawada, Andhra Pradesh, India. Specific gravity of fly ash and GGBS are 2.175 and 2.904 respectively. Chemical composition details are shown in Table 1. Natural river sand was used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the sand as per IS 2386 (Part III, 1963)[10] were 2.45 and 1% respectively. The gradation of the sand was determined by sieve analysis as per IS 383 (1970)[9]. Fineness modulus of sand was found to be 2.50. Crushed granite stone aggregate of size 12 mm and 10 mm were used as coarse aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 12 mm and 10mm as per IS 2386[10] (Part III, 1963) were 2.35 and 0.28% respectively. Super Plasticizer Conplast Sp-430 was used to obtain the desired workability. Potable water was used in the experimental work for preparation of alkaline solution.

Table 1, showing the chemical composition of Fly ash and GGBS, percentage by mass

Material	SiO2	Al2O3	Fe2O3	SO3	CaO	MgO	Na2O	LOI
Fly ash	60.12	26.63	4.22	0.32	4.1	1.21	0.2	0.85
GGBS	34.16	20.1	0.81	0.88	32.8	7.69	nd	.

2.2 Alkaline liquid: 8 molarity of sodium hydroxide solution is used in the present investigation. The ratio of sodium silicate solution to sodium hydroxide solution is 2.5. NaOH solution was prepared by dissolving 262 grams of NaOH pellets in potable water of 738 grams. The NaOH solution thus prepared is mixed with Na_2SiO_3 solution. The mixture was stored for 24 hours at room temperature before casting.

Table 2, GPC mix proportions

FA:GGBS	GGBS/FA	Molarity	Materials in Kg/m^3							
			Coarse Agg	Fine Agg	Fly ash	GGBS	NaOH Solution	Sodium Silicate	Super Plasticizer	Extra water (10% of the binder)
0:100	--	8M	1100	517.45	0.000	575.2	59.10	148.25	11.50	57.52
20:80	4.00	8M	1100	517.45	115.04	460.16	59.10	148.25	11.50	57.52
40:60	1.50	8M	1100	517.45	230.08	345.12	59.10	148.25	11.50	57.52
60:40	0.67	8M	1100	517.45	345.12	230.08	59.10	148.25	11.50	57.52
80:20	0.25	8M	1100	517.45	460.16	115.04	59.10	148.25	11.50	57.52
100:0	0.00	8M	1100	517.45	575.2	0.000	59.10	148.25	11.50	57.52

The GPC specimens for Compressive Strength(fck), Split Tensile Strength(fct) and Modulus of Rupture were tested on universal testing machine of capacity 1000KN. The load was increased gradually at constant rate until failure. The prisms were tested under two point loading for modulus of rupture. The maximum loads applied on various specimens were recorded as per IS 516-1956 [11].Three identical specimens with each variation were cast and tested after 7 days and 28 days of ambient curing. A total of 30 cubes, 30 cylinders & 30 prisms using different GGBS/FA ratios (0, 4, 1.5, 0.66, and 0.25) and 8M alkaline activator were cast and tested after 7days & 28 days of ambient curing .The test results are given in table 3.

Table 3 Compressive Strength, split tensile strength and modulus of rupture values for GPC

FA:GGBS	Compressive strength (N/mm^2)			Split tensile strength (N/mm^2)			Modulus of rupture (N/mm^2)		
	fck 7D	fck 28D	7D/28D	fct 7D	fct 28D	7D/28D	fcr 7D	fcr 28D	7D/28D
80:20	13.26	19.06	0.69	0.906	1.49	0.608	1.25	1.95	0.64
60:40	29.83	36.20	0.82	1.869	2.067	0.904	1.6	3.0	0.53

40:60	40.36	48.63	0.83	2.09	2.219	0.941	1.7	3.2	0.53
20:80	43.45	51.12	0.85	2.19	2.35	0.986	1.9	3.65	0.52

III.Results & Discussions:

The effect of GGBS to FA ratio on Compressive Strength(fck), Split Tensile Strength(fct) and Modulus of Rupture for GPC is shown in figures 1,2&3. From figures it is observed that the Compressive Strength(fck), Split Tensile Strength(fct) and Modulus of Rupture of GPC has increased with increase in GGBS to FA ratio for 8M. The rate of increase in Compressive Strength(fck), Split Tensile Strength(fct) and Modulus of Rupture is high for GGBS to FA ratio<1.

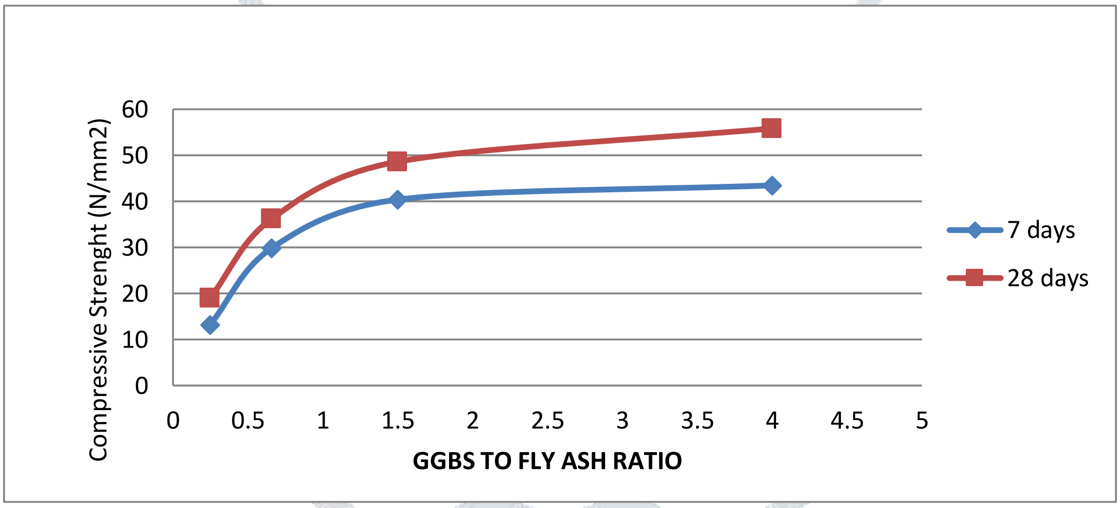

Fig 1: Effect of GGBS to Fly Ash ratio on Compressive strength of GPC

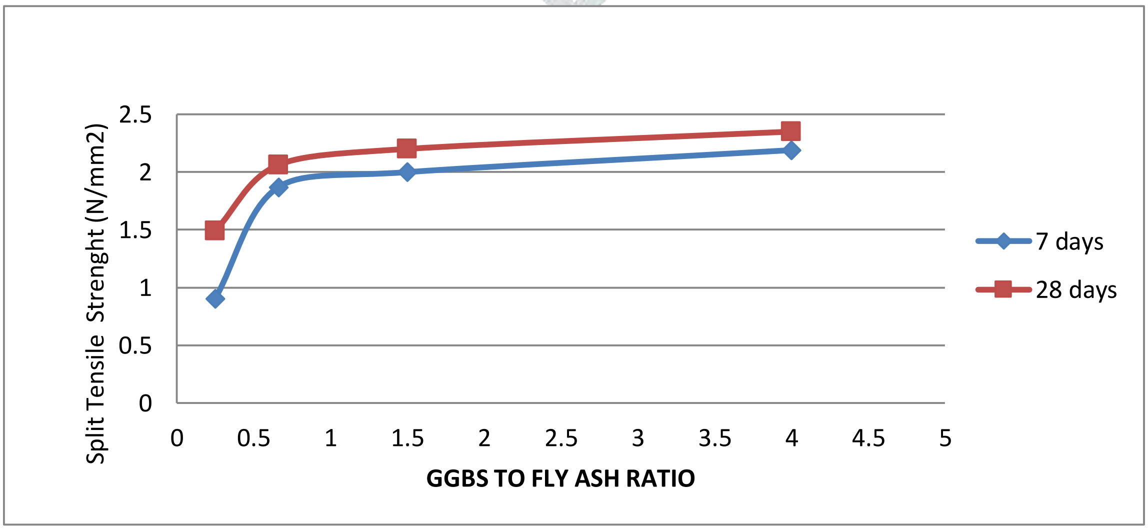

Fig 2:Effect of GGBS to Fly Ash ratio on Split tensile strength of GPC

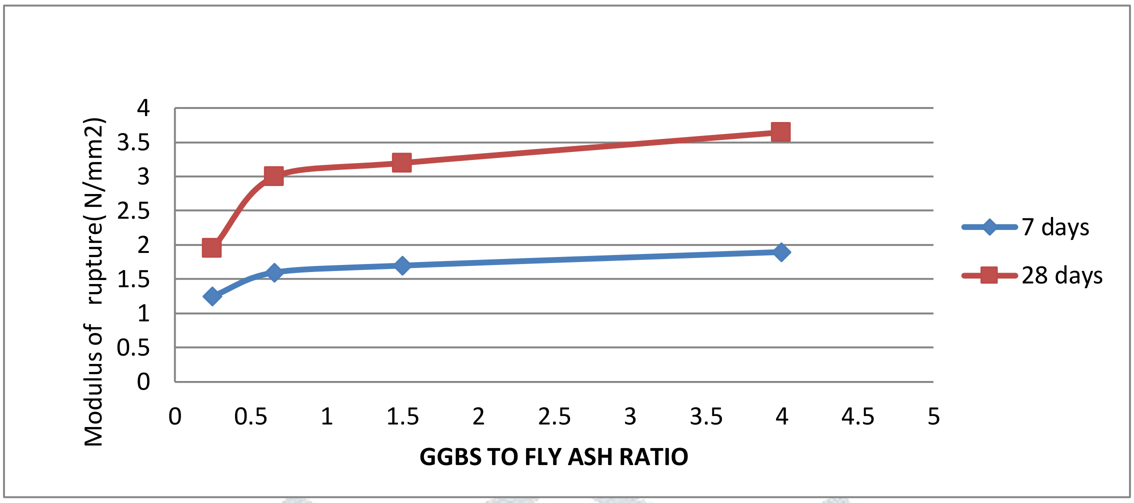

Fig 3:Effect of GGBS to Fly Ash ratio on Modulus of Rupture of GPC

IV.Binder Index: To study the combined effect of GGBS to fly ash ratio and the molarity of alkaline activator, the '**Binder Index (Bi)** (2)' has been used.

Bi = (GGBS/FA) * M, where M = Molarity.

The values of Compressive strength, split tensile strength and modulus of rupture of GPC at 7D and 28D of ambient curing with different levels of Binder Index are given in table 4.

Table 4 Compressive Strength, split tensile strength and modulus of rupture values with B_i

FA:GGBS	Binder Index	Compressive Strength, split tensile strength and modulus of rupture for GPC								
	Bi=M *(GGBS/FA)	fck	fck	7D/28D	fct	fct	7D/28D	fcr	Fcr	7D/28D
		7D	28D		7D	28D		7D	28D	
80:20	2	13.26	19.06	0.69	0.906	1.49	0.608	1.25	1.95	0.64
60:40	5.33	29.83	36.20	0.82	1.869	2.067	0.904	1.6	3.0	0.53
40:60	12	40.36	48.63	0.83	2.09	2.219	0.941	1.7	3.2	0.53
20:80	32	43.45	51.12	0.85	2.19	2.35	0.986	1.9	3.65	0.52

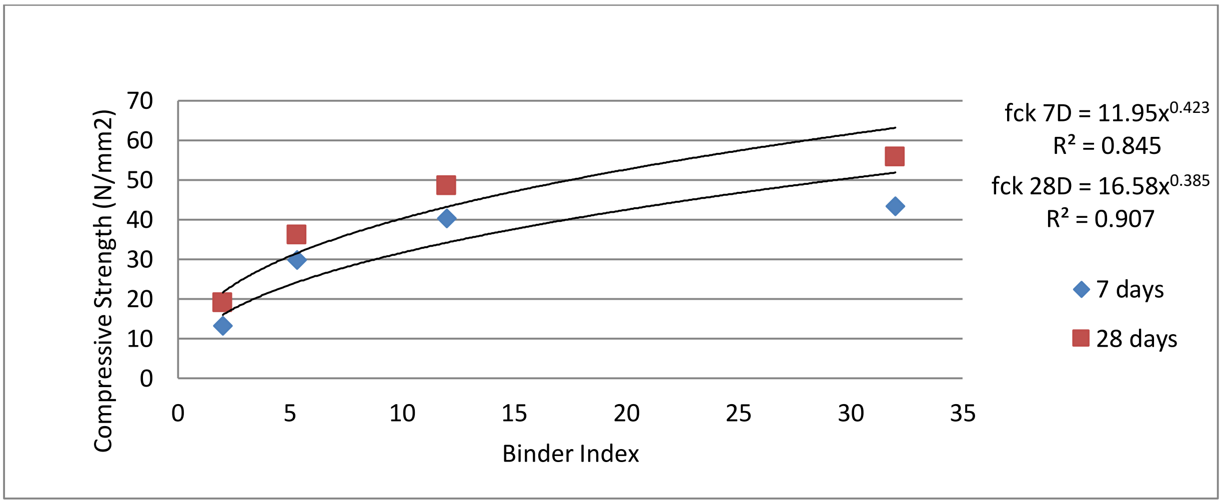

Fig 4:Effect of Binder Index on Compressive strength of GPC

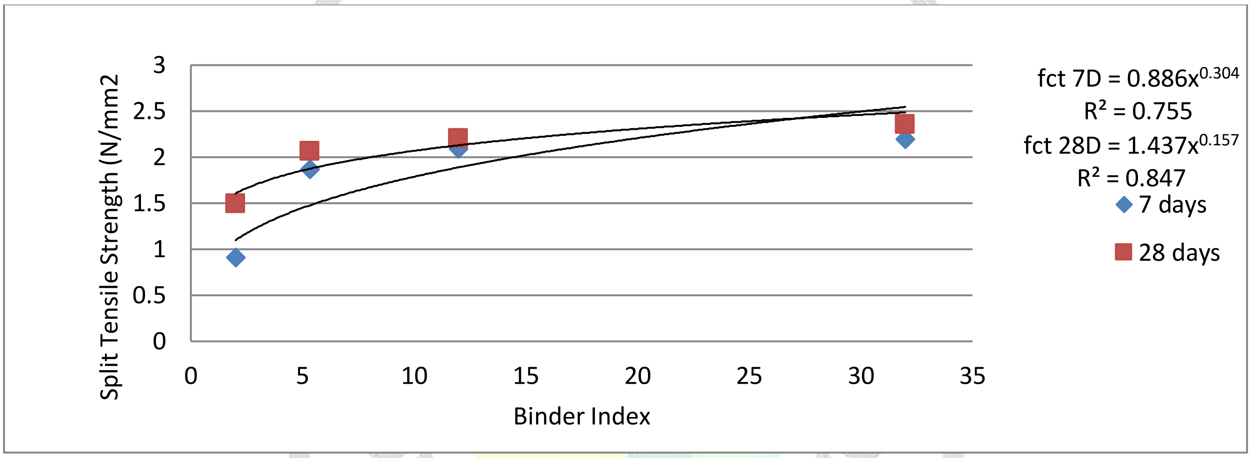

Fig 5:Effect of Binder Index on Split tensile strength of GPC

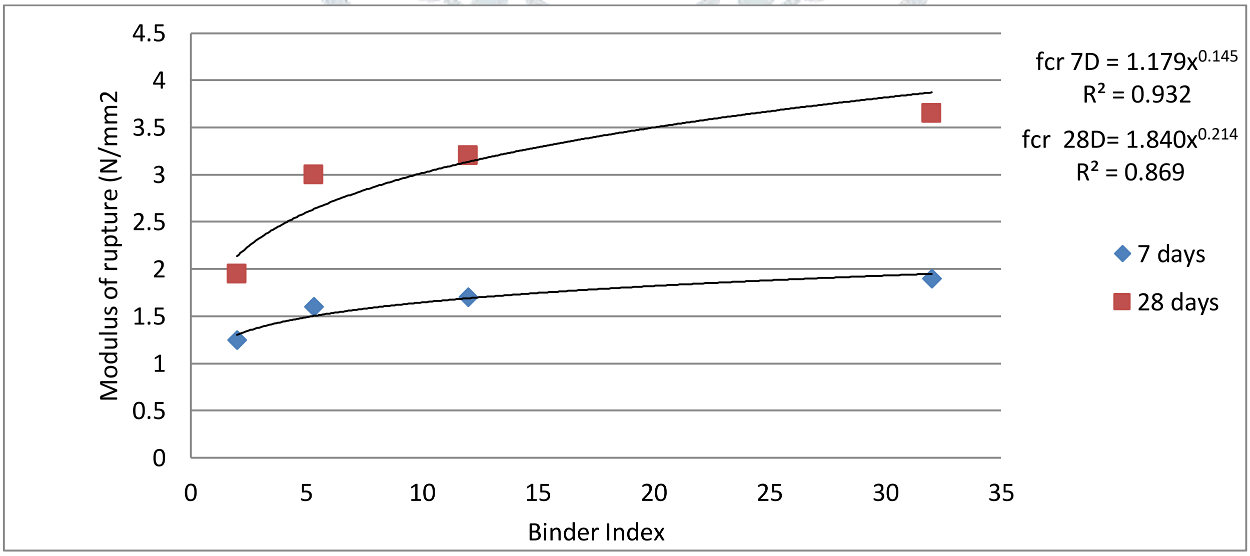

Fig 6:Effect of Binder Index on Modulus of rupture of GPC

The values indicated that both 7D and 28 D values of Compressive strength, split tensile strength & modulus of rupture of GPC increased with increase in Binder Index. The variation of Bi and different strengths in general is non linear. The best fit equations relating the above strengths of GPC at 7D and 28D of ambient curing, with Binder Index (Bi) along with correlation (R^2) are given. From fig 4, 5 and 6.

fcc (7days) $=11.95\ (Bi)^{0.423}$ ------ $R^2 = 0.845$

fcc (28days) $=16.58(Bi)^{0.385}$ ------ $R^2 = 0.907$

fct (7days) $=0.886(Bi)^{0.304}$ ------ $R^2 = 0.755$

fct (28days) $=1.440(Bi)^{0.157}$ ------ $R^2 = 0.847$

fcb (7days) $=1.179(Bi)^{0.145}$ ------ $R^2 = 0.932$

fcb (28days) $=1.84(Bi)^{0.214}$ ------ $R^2 = 0.869$

The variation of (7D/28D) of Compressive Strength(fck), Split Tensile strength(fct) and Modulus of Rupture With Binder index are shown in fig 7, 8 &9.

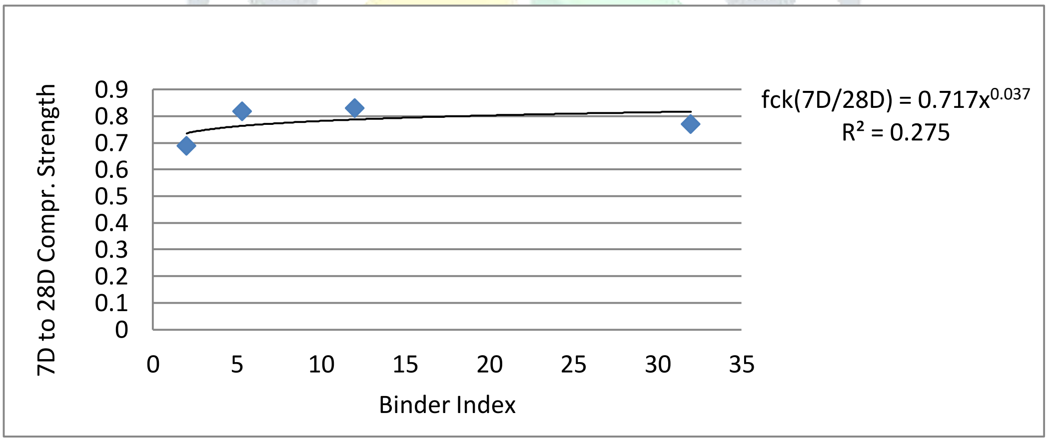

Fig 7:Effect of Binder Index (Bi) on 7D to 28D Compressive Strength(fck) ratio of GPC

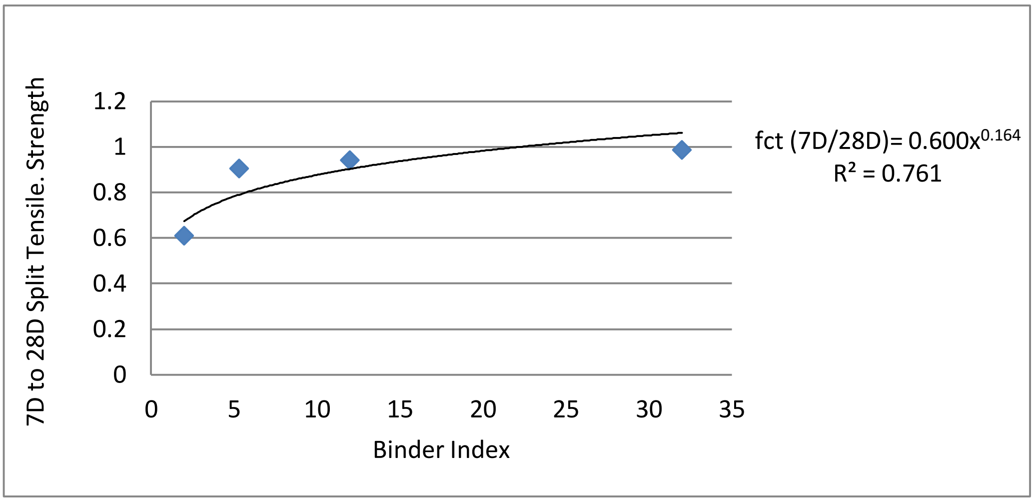

Fig 8:Effect of Binder Index on 7D to 28D Split Tensile Strength(fct) ratio of GPC.

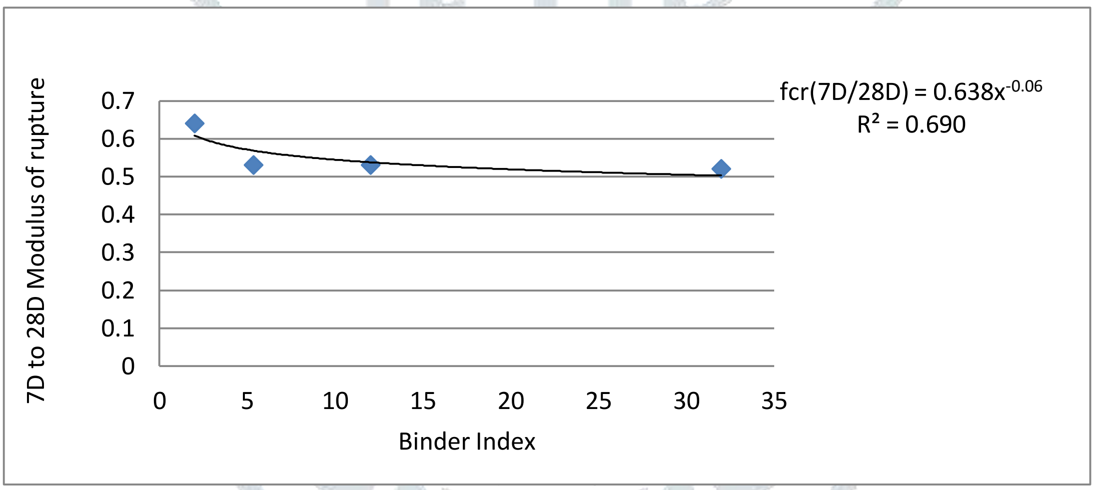

Fig 9:Effect of Binder Index on 7D to 28D Modulus of Rupture ratio of GPC.

V .CONCLUSIONS:

Based on the experimental investigation carried out on geopolymer concrete following conclusions were drawn

1.The Compressive Strength(fck), Split Tensile Strength(fct) and Modulus of rupture at 7 days and 28 days of ambient curing has increased with increase in percentage of (GGBS/FA) ratio.

2. The rate of gain in Compressive Strength(fck), Split Tensile Strength(fct) and Modulus of Rupture is higher for GGBS to FA ratio <1.

3. The Binder Index (Bi), proposed by Shankaraiah et al[3] is observed to combine the effects of GGBS to FA ratio and Molar concentration of activator solution and can be used to predict the Compressive Strength(fck), Split Tensile Strength(fct) and Modulus of Rupture of GPC.

4. The Compressive Strength (fck), Split Tensile Strength (fct) and Modulus of rupture at 7D & 28D have increased with increase in Bi (Binder Index).

5. In general there is a non linear relation between the Bi and the Compressive Strength (fck), Split Tensile Strength (fct) and Modulus of Rupture of GPC.

6. The 7D to 28D Compressive Strength (fck) and Split Tensile Strength (fct) of GPC increased with increase in Binder index (Bi).

7. The 7D to 28D ratio of Modulus of Rupture of GPC decreased with increase in Binder index.

8. The combination of GGBS and FA can be conveniently used for production of GPC avoiding heat curing.

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