



An Experimental Study on Modulus of Rupture of Steel Fibre Reinforced Geopolymer Concrete (SFRGPC)

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Abstract: Steel Fibre reinforced geopolymer concrete (SFRGPC) may be defined as a composite materials made with ground granulated blast furnace slag (GGBS), Fly ash, Alkaline liquid, aggregates and incorporating hooked end steel fibres. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions as alkaline activators. Two different proportions of Fly ash and GGBS, different volume fraction of steel fibers (0%, 0.5%, 0.7%, 0.9%, 1.1%) and 8M alkaline activator are used for making the SFRGPC. In the experimental program 60 prisms of 100X100X500 mm size were cast and tested after 7 days and 28 days ambient curing. Modulus of rupture increased with increase in percentage of GGBS and percentage of fibers. The effect of Binder Index (B_i) and Modified Binder Index² (B_{mi}) on Modulus of Rupture (f_{cr}) is studied. The fiber effect is incorporated in the Modified Binder Index (B_{mi}) fiber effect.

Key words: Geopolymer concrete; Fly ash; Ground Granulated Blast furnace slag; Alkaline Liquid; Modulus of rupture; Binder Index; Modified Binder Index.

I. Introduction

Geopolymer concrete is an inorganic polymer. Joseph Davidovits (1978) Proposed that an alkaline liquid could be used to react with silicon (Si) and aluminum (Al) as source material of geological origin with by product material fly ash and rice husk ash to produce binders³. Since the chemical reaction that is taking place in this case is a polymerization process and the precursors are of geological origin, these binders were named as "Geopolymer"¹. Geopolymer concrete is gaining importance world over as the carbon emission and consequent global warming has become the major concern of the entire countries world over. Concrete is a relatively brittle material when subjected to normal and impact load practically weak in resting tensile forces. The purpose of the fiber is to control cracking and to increase the fracture toughness in Geopolymer concrete. Fiber is a small piece of Reinforcing material possessing certain characteristic properties. The fiber is often described by a parameter called aspect ratio. The aspect ratio of the fiber is the ratio of its length to its diameter. Fiber reinforced concrete is used industrial floors, pre cast panels road and air port run ways, underground structures repair and renovation activities, machine foundations and other elements exposed to under vibrating or changing loading.

II. Experimental Investigation

Experimental Program: Consisted of determining of modulus of rupture of the GPC, based on GGBS and Fly ash by casting and testing with and without steel fibers total cylinders (100mmx200mm) no's 60, prisms (100mmx100x500mm), no's 60 are prepared in this investigation with constant molarity of 8M respectively.

A. Materials:

Ground Granulated Blast furnace slag conforming to IS 12089:1987 was used, is obtained from Blue way exports supplier, from Vijayawada, Andhra Pradesh, India. Specific gravity of fly ash and GGBS are 2.17 and 2.90 respectively. Chemical composition details are shown in Table 1. Low calcium, Class F dry fly ash, conforming to IS 3812(part 1:2003)⁷, is obtained from Kothagudem Thermal power station, Bhadradi Kothagudem Dt, Telangana, India. 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)⁸ 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 2.50¹. Crushed granite stones 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 (Part III, 1963)⁸ were 2.35 and 0.28% respectively. Potable water was used in the experimental work for preparation of alkaline solution. Super Plasticizer Conplast Sp-430 was used to obtain the desired workability. Hooked end steel fibers conforming to ASTM A820 has a length of 30 mm and diameter 0.6 mm thus giving an aspect ratio of 50 were used. Tensile strength of the hooked end fibers is 1450Mpa.

B. Alkaline liquid: The molarity of sodium hydroxide solution used is 8M,. Alkali liquid to fly ash ratio was fixed 0.36 and also Na_2SiO_3 and NaOH ratios is taken as 2.5¹; the mix solution was stored for 24 hours at room temperature, before it was used for casting. The sodium hydroxide pellets used for preparation of NaOH solution is given in table 3.

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

Material	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	Na_2O	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	.

Table 2: Fiber Mix Proportions in SFRGPC

Fiber designation	Volume fraction (%)	Weight(kg/m^3)
R0	0.0	0.00
R5	0.5	39.25
R7	0.7	54.95
R9	0.9	70.65
R11	1.1	86.35

Table: 3 Alkaline Liquids

(8Molarity)	8 moles/L
Sodium hydroxide pellets (NaOH), (grams)	262
Water (grams)	738

GPC mix proportions: SFRGPC Material Mix Proportions are shown in the Table 4

Table 4: FRGPC (with out Fibers)

FA:GGBS	GGBS/FA	Materials in Kg/m^3								
		Molarity	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	575.2	59.10	148.25	11.50	57.52
20:80	4.0	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	0.666	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

C. Preparation of SFRGPC:

Alkaline solutions is prepared one day before by mixing sodium silicate (Na_2SiO_3) with Sodium Hydroxide (NaOH) 8 molarity. The solids constituents of the Geopolymer concrete were dry mixed for about three minutes and then liquid part of the mixture i.e. the alkaline solution, added water and the super plasticizer were premixed then added to the solids. The Compaction of fresh Geopolymer concrete in the beam moulds (Prisms) was done in three equal layers, followed by compaction on a vibration table for ten seconds. The demoulding was done after 24 hours and kept for ambient curing.

The Geopolymer concrete specimens for Modulus of rupture were tested on Universal Testing Machine of capacity 1000KN. The maximum loads applied on various specimens were recorded as per IS 516-1956. Three identical specimens with each variation were cast and tested after 7 days and 28 days of ambient curing. A total of 60 prisms of 100X100X500mm size using different Fly ash to GGBS proportions and constant molarity (8M) were cast and tested after 7days and 28 days of ambient curing .The test results are given in table 5.The **Binder Index (B_i)** and **Modified Binder index** has been used to study the combined effect of GGBS, Fly ash, molarity of alkaline activator and fiber effect on SFRGPC

$$\text{Binder Index } (B_i) = \text{Molarity} \times [\text{GGBS} / (\text{GGBS} + \text{Fly ash})] \dots \text{eq (1)}$$

D. Results and Discussions:

Three identical specimens with each variation were cast and tested after 7 days & 28 days of ambient curing. A total 60 prisms using different GGBS/FA ratios (0, 4, 1.5, 0.66, and 0.25) with addition of different percentages (0.5,0.7,0.9,and 1.1%) of steel fibres and 8M alkaline activator were tested. The test results are given in table.5.

III. Modulus of Rupture

In the present Investigation Modulus of rupture was obtained by testing prisms with two different proportions Fly ash and GGBS (F40%:GGBS60%) and (F60%:GGBS40%) with different volume percentages of steel fibers

(0.0%, 0.5%, 0.7%, 0.9% and 1.1%). The Modulus of Rupture was increased with the increase in the volume fraction of steel fibers from 0.5% to 1.1%. The values are shown in table 5 and fig 1 and 2.

Table 5: Comparison variation of GGBS and Modulus of rupture 7 days and 28 days:

% of Fibers		Ratio of (GGBS/FLY ASH)	Modulus of Rupture for 40% GGBS at 7 Days mpa	Modulus of Rupture for 40% GGBS at 28 Days mpa	Modulus of Rupture for 40% GGBS (7days/28D days ratio)	Ratio of (GGBS/Fly	Modulus of Rupture for 60% GGBS at 7Days Strength mpa	Modulus of Rupture for 60% GGBS at 28 Days mpa	Modulus of Rupture for 60% GGBS at (7days/28 days ratio)
0.0	R0	0.667	1.60	3.00	0.533	1.5	1.7	3.20	0.531
0.5	R5	0.667	4.55	5.05	0.901	1.5	4.7	5.20	0.903
0.7	R7	0.667	5.05	5.75	0.878	1.5	5.3	6.00	0.883
0.9	R9	0.667	5.55	6.40	0.867	1.5	6.1	6.50	0.938
1.1	R11	0.667	6.65	7.40	0.898	1.5	6.9	7.70	0.896

Fig :1 The Variation of Modulus of Rupture with % of Fibers (40%G:60%F)(40%G:60%F)

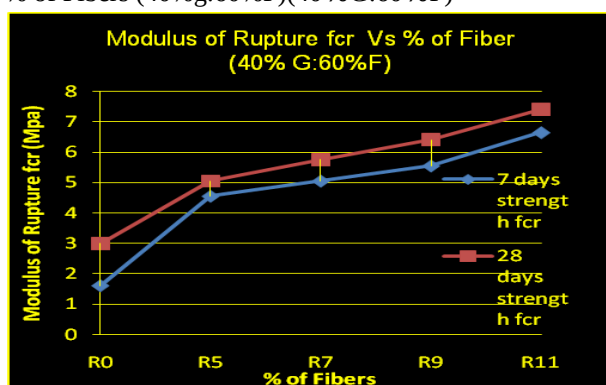
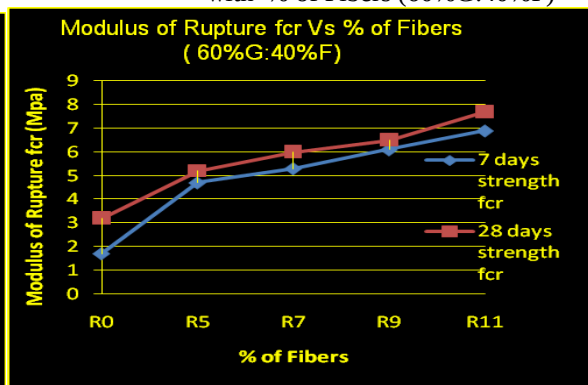


Fig :2 The Variation of Modulus of Rupture with % of Fibers (60%G:40%F)



From table 5 and fig 1 and 2, the 7 days and 28 days Modulus of Rupture of Steel Fibre Reinforced Geopolymer concrete increased with increase in volume fraction of steel fibres.

IV. Effect of Binder Index on Modulus of rupture of GPC

A. Binder index: proposed by authors Hathiram..et al., has been used to study the combined effect of GGBS to fly ash ratio and molarity (m) concentration of activator solution. The binder index was defined as the product of GGBS to (Fly ash + GGBS) ratio and molarity concentration of activator solution.

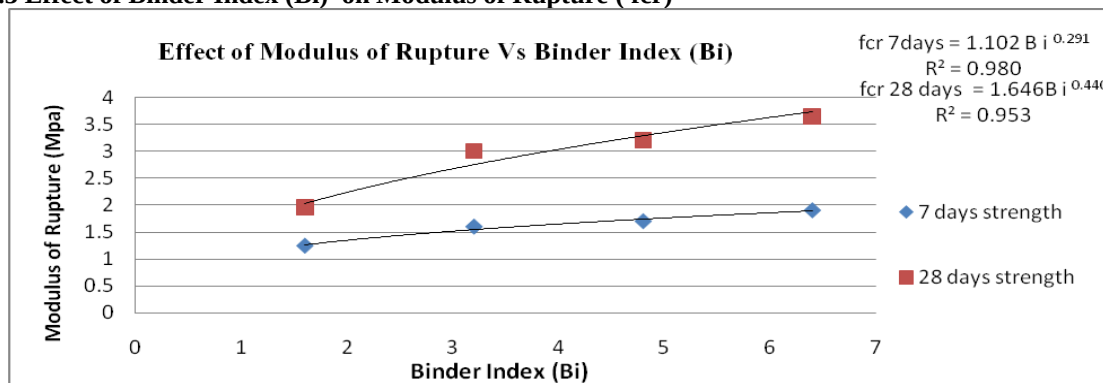
$$\text{BINDER INDEX} = ((\text{GGBS} / (\text{GGBS} + \text{FLY ASH})) \times \text{MOLARITY})$$

Table 6: Binder Index

% OF GGBS	GGBS/FLY RATIO	ASH	Binder Index	7D	28D
20%	0.25		1.6	1.25	1.95
40%	0.667		3.2	1.6	3.0
60%	1.50		4.8	1.7	3.2
80%	4.0		6.4	1.9	3.65

The values of Modulus of rupture of GPC at 7 days and 28 days of ambient curing with the level of binder index (B_i) are given in table 6. Fig 4.1 shows the variation Modulus of Rupture with Binder Index. However the increase in Modulus of Rupture is not proportioned to the increase of Binder Index (B_i). There is a non linear variation between binder index and modulus of rupture of fibre Reinforced Geopolymer Concrete.

Fig.3 Effect of Binder Index (B_i) on Modulus of Rupture (fcr)



The values indicated that both 7D and 28 D values of Modulus of rupture SFRGPC increased with increase in Binder Index. The variation of Bi and different strengths in general is non linear. The best fit equations relating the Modulus of Rupture of GPC at 7D and 28D of ambient curing, with Binder Index (Bi) along with correlation (R^2) are given. From fig 3.

$$\begin{aligned} \text{fcr (7days)} &= 1.102 \text{ Bi}^{0.291} \quad \text{-----} \quad R^2 = 0.980 \\ \text{fcr (28days)} &= 1.646 \text{ Bi}^{0.440} \quad \text{-----} \quad R^2 = 0.953 \end{aligned}$$

V. Effect of Modified Binder Index (B_{mi}) on Modulus of Rupture

An experimental investigation the modified Binder index is obtained by using an empirical formula connecting the fiber effect and binder index. The Fiber effect is incorporated multiplying the volume fraction of steel fibre with tensile strength of Steel fibers. The Modified Binder Index (B_i) is formulated as follows.

$$\begin{aligned} \text{Vfr} &= \text{Volume fraction of Rigid fiber} \\ (\text{B}_{mi}) \text{ or } P &= B_i \times (\sqrt{f_{eff}}) \quad f_{eff} = f_{tr} \cdot V_{fr} \quad (\text{where } f_{eff} = \text{Fiber effect}) \\ &(\text{Hooked end fiber value } 1450 \text{ mpa}) \quad f_{tr} = \text{Tensile stress of Rigid fiber} \end{aligned}$$

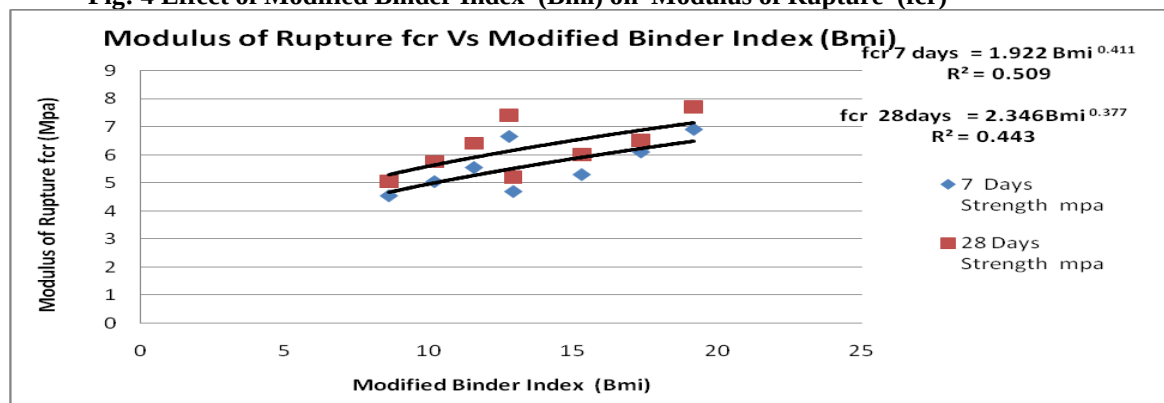
Table: 7 Fibre effect

sl.no.	%ofFiber	$f_{eff} = f_{tr} \cdot V_{fr}$	$(\sqrt{f_{eff}})$
1	0	$1450 \times 0 = 0$	0.0
2	0.5	$1450 \times (0.5/100) = 7.25$	2.692
3	0.7	$1450 \times (0.7/100) = 10.15$	3.185
4	0.9	$1450 \times (0.9/100) = 13.05$	3.612
5	1.1	$1450 \times (1.1/100) = 15.95$	3.993

Table 8: Modified Binder Index(B_{mi})

% of fiber	Binder Index	Modified Binder Index	40% GGBS	
	(GGBS/GGBS+Fly Ash)xMolarity	(B _{mi})	7 Days Strength mpa	28 Days Strength mpa
0.0	3.2	0	1.6	3
0.5	3.2	8.614	4.55	5.05
0.7	3.2	10.192	5.05	5.75
0.9	3.2	11.558	5.55	6.4
1.1	3.2	12.777	6.65	7.4
0.0	4.8	0.0	1.7	3.2
0.5	4.8	12.922	4.7	5.2
0.7	4.8	15.288	5.3	6
0.9	4.8	17.337	6.1	6.5
1.1	4.8	19.166	6.9	7.7

Fig: 4 Effect of Modified Binder Index (B_{mi}) on Modulus of Rupture (f_{cr})



A. Result and Discussions graphs: From table 8 and Fig 4, it is observed that the proposed Modified Binder Index (B_{mi}) combine the effects of Binder Index (B_i), Molarity and fibre effect reasonably well in predicting the Modulus of Rupture. The following best fit equations give the relation between the Modulus of Rupture at 7 days and 28 days of air curing with Modified Binder Index along with the correlation coefficient (R^2).

$$f_{cr \text{ 7days}} = 1.922 (B_{mi})^{0.411} \quad (\text{where } B_{mi} = \text{Modified Binder Index})$$

$$f_{cr} \text{ 28 days } = 2.346 (B_{mi})^{0.377}$$

Modulus of Rupture of SFRGPC increased with increase in the proportion of fibers. Modulus Rupture of SFRGPC increased with increase in the Binder index and Modified Binder Index

VI. Conclusions

Based on the experimental investigation carried out following conclusions were drawn.

1. The Modulus of Rupture of geopolymer concrete increased with increase of Binder Index.
2. The both 7 days and 28 days Modulus of Rupture of SFRGPC increased with increase in Binder index with constant molarity 8M.
3. The Modified Binder Index proposed combining the tensile strength of fibers, its volume fraction and Binder Index found to give reasonably good prediction of the Modulus of Rupture.
4. The Modulus of Rupture of SFRGPC increased with increase in the percentage of volume fraction of steel fibres from 0.5% to 1.1%.
5. There is a non linear relation between the Modified Binder Index (B_{mi}) and the Modulus of rupture of Steel Fibre Reinforced geopolymer Concrete.
6. Modulus of rupture of SFRGPC both 7 days and 28 days has higher value for Fly ash to GGBS mix proportions (F40%:GGBS 60%) compared to (F60%:GGBS 40%)

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