An Experimental Study on Split Tensile Strength (f_{ct}) of Steel Fibre Reinforced Geopolymer Concrete (SFRGPC)

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Abstract*:* The Geopolymer is a concrete where there is no cement is used instead fly ash and GGBS is used as the binding material and these materials does not pollute the environment and so it is green and eco-friendly, GGBS is obtained by a bye product of iron and steel in blast furnace that produce a glassy, granular product, that is then dried and ground in to a fine powder. Fibre reinforced concrete is the concrete with addition of Steel Fibres targeting the improvement of the propriety of this material. This paper presents the results of an experimental investigation on Split Tensile Strength (fct) of Steel Fibre Reinforced geopolymer concrete (SFRGPC).The effect of steel Fibres, Fly ash, GGBS, Alkaline liquid (combination of Sodium silicate and Sodium hydroxide) on Split Tensile Strength of SFRGPC is presented. Two different proportions of fly ash and GGBS (40%F:60%G) and (60%F:40%G0 with different volume fraction[1] of hooked end steel fibers (0,0.5,0.7,0.9,1.1 %) and 8M alkaline activator are consider in the present study. In the experimental program total of 60 cylinders of its size 100mm dia 200 length were cast. Split tensile strength of SFRGPC increases with increase in % of GGBS and % of fibers. The effect of Binder Index (B_i) Vs Split tensile strength(fct) and effect of Modified Binder Index [2] (Bmi) Vs Split tensile strength is studied. The fiber effect is incorporated in the Modified Binder Index.

***Key words:** Geopolymer concrete; Fly ash; Ground Granulated Blast furnace slag; Alkaline Liquid; Steel fibers; Split tensile strength; Binder Index (Bi); Modified Binder Index (B mi)*

I. INTRODUCTION

Geopolymer concrete is a cementitious concrete material, better another possibility to avoid the water curing, better mechanical properties and also the production, supply and construction of Portland cement emits large amount of Co_2 released in to the air. The production of one ton of Portland cement discharges about 1 ton of carbon dioxide to the air[3]. Therefore to reduce the emission of the Co_2 in to the air (atmosphere) by reducing the cement production and usage. Geopolymer concrete is get from the industrial by product of fly ash and GGBS which are eco friendly another possibility to opc based concrete. Ordinary Portland cement concrete (opc) are less durable (Neville-2005). 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 Geometric shape of testing fibers is also important. They can be a circular or flat .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. EXPERMENTAL INVESTIGATION

Experimental Program: The present investigation consisting of determining of the split tensile strength of the SFRGPC, based on **GGBS** and Fly ash by casting and testing of cylinders of size 100mmx200mm.

A. Materials:

Low calcium, Class F dry fly ash, conforming to IS 3812(part 1:2003)[3] , is obtained from Kothagudem Thermal power station, Bhadradri Kothagudem Dt,

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Telangana, India . 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.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)[4] were 2.45 and 1% respectively. The gradation of the sand was determined by sieve analysis as per IS 383 (1970)[5]. Fineness modulus of sand was found to be 2.50. 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) 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	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	.

B.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 grms.The NaoH solution thus prepares is mixed with Na2sio3 solution. The mixture was stored for 24 hr at room temperature before casting.

C.Fibres: An experimental investigation hooked end steel fibers are used. These Steel fibers to increase the tensile strength of the concrete. Hooked end steel fibres having an aspect ratio of 50 was used. The tensile strength of the wire is 1450Mpa and Modulus of elasticity 2 x10^5Mpa.

Table 2: FRGPC Material Mix Proportions are shown in the Table 2&Table 3 (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**	**575.2**	**59.10**	**148.25**	**11.50**	**57.52**
20:80	4	**8M**	**1100**	**517.45**	**115.04**	**460.16**	**59.10**	**148.25**	**11.50**	**57.52**
40:60	1.5	**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**

Table 3: Fiber mix proportions in SFRGPC (wt/vol))

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

D. Preparation of SFRCPC:

The investigation 8M alkaline solution (combination of Sodium silicate Na_2Sio_3 and Sodium Hydroxide NaoH) is prepared one day. To find the split tensile strength of Steel fibre reinforced geopolymer concrete (SFRGPC) by adding addition of steel fibers with two mix proportions are prepared, first mix proportion fly ash is 40% and GGBS is 60% and second mix proportion is fly ash 60% and GGBS is 40% with four different percentages of fibers (0.5%, 0.7%, 0.9% and1.1%) added to the mix. The dry materials along with fibres as per the mix proportions were weighed. The weighted materials were mixed by adding alkaline solution, added water and the super plasticizer were premixed 3 to 5min, for obtaining the homogeneous mix. Immediately after mixing the SFRGPC was casted in cylinders. The cylinders were remolded after 24 hours and kept for ambient curing. For split tensile strength (fct) test with different age 7 days and 28 days was tested with and without fibers. Calculation of percentage increase in Split Tensile Strength (fct) with effect of Binder Index (Bi) and Modified Binder Index (Bmi) on SFRGPC is presented.

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III. RESULT AND DISCUSSIONS

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

A. Split Tensile Strength

In present Investigation split tensile strength was obtained by testing cylinders with two different proportions of fly ash and GGBS (40%F:60%G) and (60%F:40%G) with different volume fraction of hooked end Steel fibers (0,0.5,0.7,0.9,1.1 %) and 8M alkaline activator are consider in the present study. The increase in split tensile strength at 40%GGBS with fiber variation of 0.0%,0.5%,0.7%,0.9% and 1.1% is 8.77,18.38, 17.69,17.64,16.37.The increase in split tensile strength at 60% GGBS with fiber variation 0.0%,0.5%,0.7%,0.9% and 1.1% is 6.07,18.16,7.44, 13.52,7.69 %. The Split Tensile Strength (fct) is increased with the increase in the volume fraction of Steel fibres from 0.5% to 1.1%.The Values are shown in table 4 and fig 1 and 2.

Table: 4 Comparison variations of GGBS and Fibers Split tensile strength 7days and 28 days:

% Of fiber	Ratio of (GGBS/Fly Ash)	Split Tensile Strength at 40% GGBS		Split Tensile Strength at 40% GGBS 7Days / Ratio	Split Tensile Strength at Ratio of GGBS/Fly Ash	Split Tensile Strength at 60% GGBS		Split Tensile Strength at 60% GGBS 7Days / Ratio
		7 days (mpa)	28 days (mpa)			7days (mpa)	28 day (mpa)	
0.0	0.667	1.869	2.067	0.904	1.5	2.092	2.219	0.943
0.5	0.667	3.062	3.625	0.845	1.5	3.485	4.118	0.846
0.7	0.667	3.142	3.698	0.85	1.5	3.936	4.229	0.931
0.9	0.667	3.349	3.94	0.85	1.5	4.356	4.945	0.881
1.1	0.667	4.44	5.167	0.86	1.5	5.708	6.147	0.928

B. Effect of fibres on Split Tensile Strength

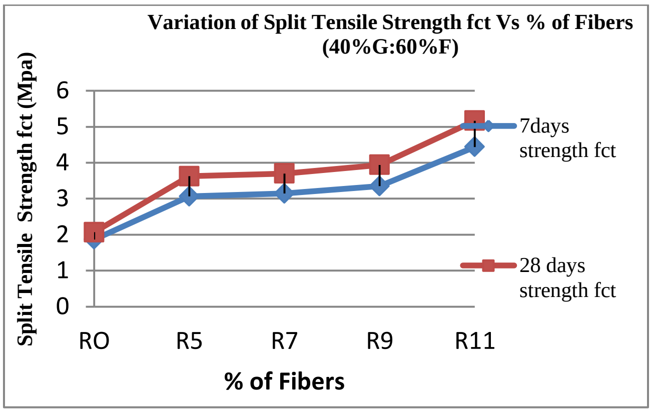

Fig : 1 The Variation of Split Tensile strength with % of Fibers (40%G:60%F)

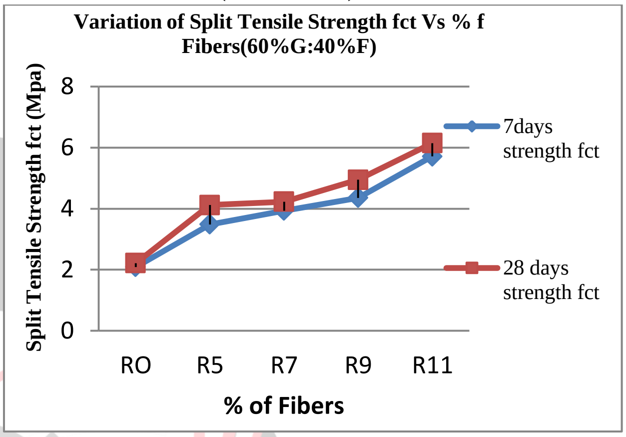

Fig : 2. Variation of Split Tensile strength with % of Fibers (60%gG:40%F)

C.Discussion: Table 4 and fig 1 and 2 it is observed that for constant molarity of alkaline activator and GGBS TO Fly ash ratio the 7 days and 28 days Split Tensile Strength of SFRGPC is increased with icrease in volume fraction of dibres it also observed that for any choosen GGBS to Fly ash Ratio with constant Alkaline Activator for 7days and 28 days Split Tensile strength (fct) of SFRGPC is increased with increase in volume fraction of fibres .

D.Effect of Binder Index on strength of GPC:

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.

BINDER INDEX =((GGBS / (GGBS+FLY ASH)) X MOLARITY

Table:5 Split tensile Strength and Binder Index without Fibres

% of GGBS	(GGBS/ Fly ash)Ratio	Binder Index	fct	fct
		Bi	7 Days	28 Days
20%	0.25	1.6	0.906	1.49
40%	0.667	3.2	1.869	2.067
60%	1.50	4.8	2.09	2.219
80%	4.0	6.4	2.19	2.35

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Table 6: Split tensile Strength and Binder Index with Fibres

% of fibre	Binder Index	60% Fly ash:40% GGBS	
	(GGBS/GGBS+ FlyAsh)xMolarity	7 days stress (mpa)	28 days Stress (mpa)
0.0	3.2	1.869	2.067
0.5	3.2	3.062	3.625
0.7	3.2	3.142	3.698
0.9	3.2	3.349	3.94
1.1	3.2	4.44	5.167
% of fibre	Binder Index	40% Fly ash: 60% GGBS	
	(GGBS/ GGBS+ Fly Ash)x Molarity	7days strength (mpa)	28 days Strength (mpa)
0.0	4.8	2.092	2.219
0.5	4.8	3.485	4.118
0.7	4.8	3.936	4.229
0.9	4.8	4.356	4.945
1.1	4.8	5.708	6.147

The values of compressive strength of GPC at 7 days and 28 days of ambient curing with the level of binder index (BI) are given table 6.Fig 3 shows the variation of Split tensile strength with binder index. However, the increase in Split Tensile Strength(fct) is not proportional to the increase of binder index. There is a non linear vartion between binder index and compressive strength of geopolymer concrete.

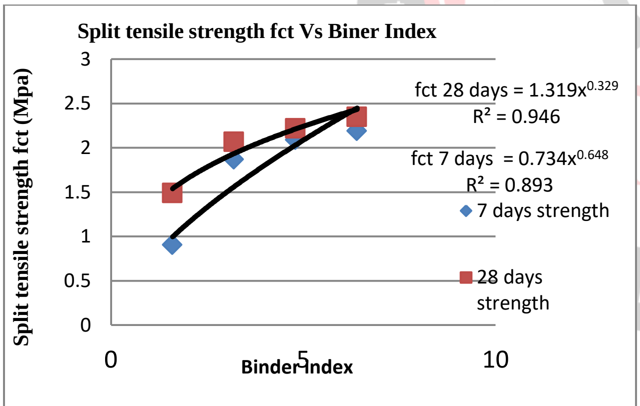

Fig: 3 Effect of Binder Index (Bi) on Split tensile strength

The values indicated that both 7D and 28 D values of split tensile strength of 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 Split Tensile Strength (fct) of SFRGPC at 7D and 28D of ambient curing, with Binder Index (Bi) along with correlation (R^2) are given. From fig 3.

fct (7days) = 0.0734 Bi $^{0.0648}$ -- R^2 = 0.893 eq --1

fct (28days) = 1.319 Bi $^{0.0329}$ ---- R^2 = 0.946 eq –2

E. Modified Binder Index (B_{mi}): An experimental investigation Modified Binder Index is obtained by using an empirical formula connecting the fiber effect and Binder Index. Fiber effect is incorporated multiplying the volume fraction of steel fiber and tensile stress of Steel fibers. Modified Binder Index(Bmi) combining the effects Binder index(Bi)multiply the square root of fiber effect. Fiber effect is increases with increasing the volume of the fibers.

The Modified Binder Index (Bmi) is formulated as follow

(B_{mi})or P = B_i x ($\sqrt{f_{eff}}$) **$f_{eff} = f_{tr} \cdot V_{fr}$**

(where f eff = Fiber effect) Vfr = Volume fraction of steel fiber f tr = Tensile stress of steel fiber

(Hooked end fiber value 1450 mpa)

Table :7 Fibre effect f $_{effect}$

sl.no.	%oFiber	Fibre Designation	$f_{eff} = f_{tr} \cdot V_{fr}$	($\sqrt{f_{eff}}$)
1	0	R0	1450x0=0	0.0
2	0.5	R5	1450x(0.5/100) =7.25	2.692
3	0.7	R7	1450x(0.7/100)=10.15	3.185
4	0.9	R9	1450x(0.9/100)=13.05	3.612
5	1.1	R11	1450x(1.1/100)=15.95	3.993

Table 8: An experimental investigation Modified Binder index (Bmi) is calculated as

% Fibre	Fibre Desig na tion	Binder Index	Modified Binder Index	GGBS (40 % and 60 %	
		(GGBS/GGBS+ Fly Ash)x Molarity		7 days Strength (mpa)	28 days Strength (mpa)
0.0	R0	3.2	0	1.869	2.067
0.5	R5	3.2	8.614	3.062	3.625
0.7	R7	3.2	10.192	3.142	3.698
0.9	R9	3.2	11.558	3.349	3.94
1.1	R11	3.2	12.777	4.44	5.167
0.0	R0	4.8	0.0	2.092	2.219
0.5	R5	4.8	12.922	3.485	4.118
0.7	R7	4.8	15.288	3.936	4.229
0.9	R9	4.8	17.337	4.356	4.945
1.1	R11	4.8	19.166	5.708	6.147

F. Modified Binder Index:

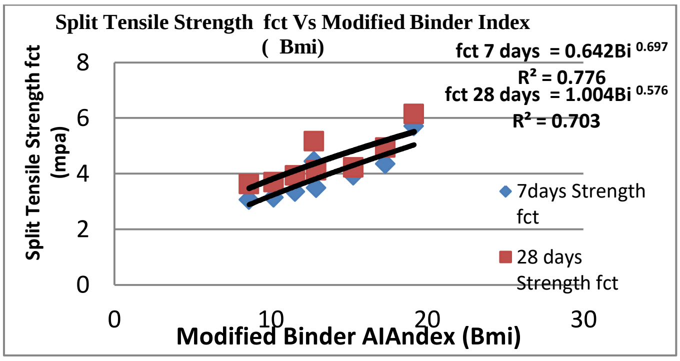

Fig : 5 Effect of Modified Binder Index(Bmi) on Split tensile strength(fct)

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From table 8 and Fig 5,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 Split Tensile Strength (fct). The following best fit equations give the relation between the Split Tensile Strength (fct) at 7days and 28 days of air curing with Modified Binder Index along with the correlation coefficient (R^2).

$$f_{cr}\ 7days = 0.642\ (B_{mi})^{0.697} \text{ ------- eq -3}$$

(where B_{mi} = Modified Binder Index)

$$f_{cr}\ 28\ days = 1.004\ (B_{mi})^{0.576} \text{ ------ eq- 4}$$

Split Tensile Strength (fct) of SFRGPC increased with increase in the proportion of fibers. Split Tensile Strength (fct) of SFRGPC increased with increase in the Binder index and Modified Binder Index.

IV. CONCLUSIONS

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

1. The Split Tensile Strength (fct) of Steel Fibre Reinforced Geopolymer Concrete **(SFRGPC)** improves slightly with the addition of Steel Fibres at variours volume fractions.

2. Inclusion of Steel fibres in Geopolymer Concrete shows considerable increase in Split Tensile Strength (f_{ct}) of GPC with respect to GPC without fibres.

3. The Split tensile Strength (f_{ct}) of Geopolymer Concrete (GPC) increased with increase of Binder Index **(Bi).**

4.The 7 days and 28 days Split Tensile Strength (f_{ct}) of Steel Fibre Reinforced Geopolymer Concrete **(SFRGPC)** increased with increase in Binder index**(Bi)** at constant molarity 8M.

5. The Modified Binder Index proposed combining the tensile strength of fibers, its volume fraction and Binder **Index (Bi)** found to give reasonably good prediction of the Tensile Strength.

6. The Split tensile Strength (fct) of Steel Fibre Reinforced Geopolymer Concrete **(SFRGPC)** increased with increase in the percentage of volume fraction of steel fibres from 0.5% to 1.1%.

7. There is a non linear relation between the Modified Binder Index **(Bmi)** and the Split Tensile Strength **(fct)** of Steel Fibre Reinforced geopolymer Concrete.

8. The Split Tensile Strength (f_{ct}) of Steel Fibre Reinforced Geopolymer Concrete **(SFRGPC)** both 7days and 28 days is higher for Fly ash to GGBS proportions (F40%: GGBS 60%) compared to (F60%:GGBS40%).

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