Experimental investigation on Compressive Strength of Combined fiber reinforced Geopolymer concrete

HathiRam Gugulothu[1] B. Sesha Sreenivas[2] D.Rama Seshu[3]
[1] Research Scholar, Kakatiya Univ., Warangal, India
[2] Professor and principal, University College of Engg, Kothagudem, Kakatiya Univ., India.
[3] Professor of Civil Engineering, National Institute of Technology, Warangal, India.

ABSTRACT : Ordinary Portland cement (OPC) production produces substantial CO_2 emissions, which is a green house gas causing global warming. To address the environmental constraints due to cement production, strength properties of high-calcium fly ash based geopolymer concrete have been explored in this research article. This research article is aimed at finding the effect of combination fibers (Soft and Rigid) on compressive strength of Geo polymer concrete. Two different Ground Granulated Blast Furnace Slag (GGBS) to Fly Ash (FA) ratios (60:40 and 40:60) and three molarity of alkaline activators 8, 10 and 12 are used. Fiber combinations R0S10, R2S8, R4S6, R6S4, R8S2 and R10S0 are used. Three identical specimens of size 100 mm were used for each variation were cast and tested for 7 days and 28 days ambient curing. A parameter called ''Modified Binder Index' is introduced to quantify the effects of molarity of alkaline activator, GGBS to fly ash ratio and fiber effect on compressive strength of Combined Fiber Reinforced Geo Polymer Concrete is presented.

Key words: Combination fibers (soft and rigid fibers), Fly ash (FA), Ground Granulated Blast furnace slag (GGBS), alkaline solution, Modified binder index, Compressive strength, ambient curing.

1.0 INTRODUCTION:

The increase for demand of Portland cement has resulted in depletion of natural resources and environmental pollution. The environmental issues associated with the production of ordinary Portland cement (OPC) are well known. The amount of the carbon dioxide released during the manufacture of ordinary Portland cement due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the amount of energy required to produce ordinary Portland cement is only next to steel and aluminium. On the other side, the abundance and availability of fly ash worldwide create opportunity to utilize this by-product of burning coal [1]. Pozzolanas such as blast furnace slag and fly ash may be activated using alkaline liquids to form a binder and hence totally replace the use of ordinary Portland cement in concrete. Davidovits (1999) in 1970 has patented the use of waste material like fly ash and GGBS and stated that these binders can be produced by a polymeric synthesis of the alkali activated material from geological origin or by-product materials such as fly ash and rice husk ash[2]. Many researchers have done extensive study on proportioning the materials used in making Geo polymer concrete. Keeping in view of the past research work done on plain and fiber reinforced Geo polymer concrete the present study is focused on finding the effect of combination fibers on compressive strength of combined fiber reinforced geopolymer concrete(CFRGPC). Two different Ground Granulated Blast Furnace Slag (GGBS) to Fly Ash (FA) ratios (60:40 and 40:60) and three alkaline molar activators 8, 10 and 12 are used. Fiber combinations R0S10, R2S8, R4S6, R6S4, R8S2 and R10S0 are used. Three identical specimens of size 100 mm were cast and tested for each variation for 7 days and 28 days ambient curing. A parameter called **''Modified Binder Index'** is introduced to quantify the effects of alkaline molar activator, GGBS to fly ash ratio and fiber effect on compressive strength of Fiber Reinforced Geo Polymer Concrete is presented.

2.0 MATERIALS:

Fly ash is obtained from Kothagudem Thermal Power Station, Bhadradri Kothagudem Dist, Telangana, India. GGBS is obtained from Blue way exports supplier, from Vijayawada, Andhra Pradesh, India. Specific gravity of FA and GGBS are 2.17 and 2.90 respectively. Chemical composition details of FA and GGBS are shown in Table 1. Natural river sand confirming to grading zone II of IS 383:1970 was used. Specific gravity and fineness modulus of sand used were 2.32 and 2.81 respectively. Coarse aggregate of maximum size 12mm from local source was used. A hooked end steel fiber of aspect ratio 60 with tensile strength 1100 Mpa is used. Polypropylene fiber (Recron 3S) of length 12mm and diameter 20 microns with tensile strength 490.3 Mpa is used. The molarity of alkaline activators of sodium hydroxide solution used are 8, 10 and 12.The sodium hydroxide pellets used for preparation of NaOH solution is given in table 2. The NaOH solution thus prepared is mixed with Na_2SiO_3 solution. The ratio of sodium silicate solution to sodium hydroxide solution is fixed as 2.5 [3, 4, 5]. The mixture was stored for 24 hours at room temperature before casting. Super Plasticizer Conplast Sp-430 is used to obtain the desired workability.

Table 1. Chemical composition of FA 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. Materials used for NaOH solution preparation.

	8 moles/L	10 moles/L	12 moles/L
Sodium hydroxide pellets (grams)	262	314	361
Potable Water (grams)	738	686	639

2.1 MIX PROPORTIONS: The Unit weight of Geopolymer concrete is taken as 2400 kg/m^3. The materials used for making combined fiber reinforced Geopolymer concrete (GPC) are calculated and tabulated in table 3 and 4.

Table 3. GPC mix proportion

FA:GGBS	Molarity(M)	Geopolymer concrete materials Composition (Kg/m^3)							
		Coarse Aggregate	Fine Aggregate	Fly Ash	GGBS	NaOH Solution	Sodium Silicate	Super Plasticizer(2% of the Binder)	Extra water (7.5% of the Binder)
60:40	8	1100	517.45	345.10	230.10	59.10	148.25	11.50	43.15
60:40	10	1100	517.45	345.10	230.10	59.10	148.25	11.50	43.15
60:40	12	1100	517.45	345.10	230.10	59.10	148.25	11.50	43.15
40:60	8	1100	517.45	230.10	345.10	59.10	148.25	11.50	43.15
40:60	10	1100	517.45	230.10	345.10	59.10	148.25	11.50	43.15
40:60	12	1100	517.45	230.10	345.10	59.10	148.25	11.50	43.15

Table 4. Fiber mix proportion

@ 1st letter indicates the Rigid fiber designation (R), 2nd letter indicates the volume fraction percentage for Rigid fiber (0,0.2,0.4,0.6,0.8 and 1), 3rd letter indicates the Soft fiber designation (S) and 4th letter indicates the volume fraction percentage for Soft fiber (1,0.8,0.6,0.4,0.2 and 0).

Combined fiber proportions				
@fiber designation.	Rigid fiber volume fraction (%)	Soft Fiber volume fraction (%)	Rigid fiber weight (Kg/m^3)	Soft fiber weight (Kg/m^3)
R0S10	0	1	0	9.5
R2S8	0.20	0.80	15.7	7.6
R4S6	0.40	0.60	31.4	5.7
R6S4	0.60	0.40	47.1	3.8
R8S2	0.80	0.20	62.8	1.9
R10S0	1	0	78.5	0

2.2 CASTING OF COMBINED FIBER REINFORCED GEOPOLYMER CONCRETE SPECIMENS (CFRGPC):
The solid constituents of the CFRGPC i.e. the aggregates and the fly ash, fibers (soft and rigid) were dry mixed for about three minutes. The liquid part of the mixtures i.e. the alkaline solution, added extra water and the super plasticizer were premixed then added to the solids. The wet mixing usually continued for another four minutes. The fresh CFRGPC concrete was dark in colour and shiny in appearance. The mixtures were usually very cohesive. The workability of the fresh CFRGPC was measured by means of the conventional slump test. Compaction of fresh concrete in the cube moulds was done by applying 25 manual strokes per layer in three equal layers followed by compaction on a vibration table for ten seconds. The cubes were demoulded after 24 hours and kept for ambient curing.

2.3 COMPRESSIVE STRENGTH:
The compressive strength tests on hardened CFRGPC cubes were performed on a 1000 kN capacity universal testing machine in accordance to the relevant Indian Standard code IS:516[6]. Three 100 mm x 100 mm x 100 mm CFRGPC cubes were tested for every compressive strength test. The results given in the various figures and tables are the mean of these values. A parameter called Modified Binder Index is introduced to quantify the effects of molarity of alkaline activator, GGBS to fly ash ratio and fiber effect on compressive strength of Fiber Reinforced Geo Polymer Concrete. Binder index is taken as the product of molarity of alkaline activator and binder's ratio as given below [7].

Binder Index = Molarity x [GGBS / (GGBS + Fly Ash)]......eq (1).

3.0 RESULTS AND DISCUSSIONS

Table 5. Compressive strength values of Combined fiber reinforced geopolymer concrete (CFRGPC)

FA:GGBS	Molarity (M)	Binder Index	Compressive strength values of combined fiber reinforced geopolymer concrete(CFRGPC) (Mpa)					
			R0S10	R2S8	R4S6	R6S4	R8S2	R10S0

			7D	28D	7D	28D	7D	28D	7D	28D	7D	28D	7D	28D
60:40	8	3.2	38.1	42	39.5	47.4	42	50.4	43.5	51.3	47.2	54.9	51.9	62.3
60:40	10	4	40.1	48.2	42.1	51.4	45.3	55.7	46.5	57.5	51.9	69.9	58.2	76.5
60:40	12	4.8	42.5	52.2	45	56	48.7	63.8	51.8	65	61.2	79.5	67.1	88.5
40:60	8	4.8	39	45	40.1	49	43	52	44.8	55.9	49.3	61.2	55.3	69.3
40:60	10	6	41	50.1	43.5	54.4	46.5	59.9	48.9	64.5	58.4	74.2	63.8	86.2
40:60	12	7.2	43.5	53.9	45.5	59.8	49	65	52.5	71.2	63.1	83.1	68	91.1

Modified Binder Index (P):

To know the effect of combination fibers on compressive strength of combined fiber reinforced geopolymer concrete (CFRGPC) modified binder index combining the effects of binder index, tensile strength and volume fraction of fibers shall be calculated for each fiber combination. To account for the reduced effect of soft fibers in combination fibers a factor 0.85 has been introduced while evaluating modified binder index.

Modified binder index (P) = B_i x ($\sqrt{F_{ef}}$).....eq(2)

Where F_{ef} is fiber effect.

$F_{ef} = (F_{tr}$ x V_{fr} + F_{ts} x V_{fs}).....eq(3)

F_{tr} = Tensile strength of Rigid fiber = 1450 Mpa, V_{fr}=Volume fraction of rigid fiber.

F_{ts} =Tensile strength of soft fiber =490.33 Mpa, V_{fs}=Volume fraction of soft fiber.

Modified binder index (P_{cf}) = B_i x [$\sqrt{RF_{ef}}$ +0.85 $\sqrt{SF_{ef}}$] ..For combination fibers...eq(4)

Table 7. Fiber effect for Combination fibers

fiber designation	fiber designation	fiber designation	Binder index	$\sqrt{RF_{ef}}$	$\sqrt{SF_{ef}}$	0.85 $\sqrt{SF_{ef}}$	$\sqrt{RF_{ef}}$ +0.85 $\sqrt{SF_{ef}}$
R0S10	R0	S10	3.2	0	2.21	1.88	1.88
R2S8	R2	S8	4	1.70	1.98	1.68	3.38
R4S6	R4	S6	4.8	2.40	1.72	1.46	3.86
R6S4	R6	S4	4.8	2.95	1.96	1.2	4.15
R8S2	R8	S2	6	3.40	0.98	0.83	4.23
R10S0	R10	S0	7.2	3.80	0	0	3.80

Table 8. Modified Binder Index for Combination fibers

Molarity	Binder Index	Combination of fibers					
		P_{cf} = B_i x [$\sqrt{RF_{ef}}$ + 0.85$\sqrt{SF_{ef}}$]					
		R0S10	R2S8	R4S6	R6S4	R8S2	R10S0
8	3.2	6.01	10.816	12.352	13.28	13.536	12.16
10	4	7.52	13.52	15.44	16.6	16.92	15.2
12	4.8	9.02	16.224	18.528	19.92	20.304	18.24
8	4.8	9.02	16.224	18.528	19.92	20.304	18.24
10	6	11.28	20.28	23.16	24.9	25.38	22.8
12	7.2	13.54	24.336	27.792	29.88	30.456	27.36

Table 9. Binder index Vs Compressive strength

S.No	Binder Index	Modified binder index	Compressive strength of CFRGPC		Ratio of 7 day strength to 28 day strength of CFRGPC
			7 days	28 days	7D/28D
1	3.2	6.01	38.1	42	0.907
2	4	7.52	40.1	48.2	0.832
3	4.8	9.02	42.5	52.2	0.814
4	4.8	9.02	39	45	0.867
5	6	11.28	41	50.1	0.818

6	7.2	13.54	43.5	53.9	0.807
7	3.2	10.816	39.5	47.4	0.833
8	4	13.52	42.1	51.4	0.819
9	4.8	16.224	45	56	0.804
10	4.8	16.224	40.1	49	0.818
11	6	20.28	43.5	54.4	0.800
12	7.2	24.336	45.5	59.8	0.761
13	3.2	12.352	42	50.4	0.833
14	4	15.44	45.3	55.7	0.813
15	4.8	18.528	48.7	63.8	0.763
16	4.8	18.528	43	52	0.827
17	6	23.16	46.5	59.9	0.776
18	7.2	27.792	49	65	0.754
19	3.2	13.28	43.5	51.3	0.848
20	4	16.6	46.5	57.5	0.809
21	4.8	19.92	51.8	65	0.797
22	4.8	19.92	44.8	55.9	0.801
23	6	24.9	48.9	64.5	0.758
24	7.2	29.88	52.5	71.2	0.737
25	3.2	13.536	47.2	54.9	0.860
26	4	16.92	51.9	69.9	0.742
27	4.8	20.304	61.2	79.5	0.770
28	4.8	20.304	49.3	61.2	0.806
29	6	25.38	58.4	74.2	0.787
30	7.2	30.456	63.1	83.1	0.759
31	3.2	12.16	51.9	62.3	0.833
32	4	15.2	58.2	76.5	0.761
33	4.8	18.24	67.1	88.5	0.758
34	4.8	18.24	55.3	69.3	0.798
35	6	22.8	63.8	86.2	0.740
36	7.2	27.36	68	91.1	0.746

The variation of compressive strength with combination fibers is shown in fig 1. To fig 6.

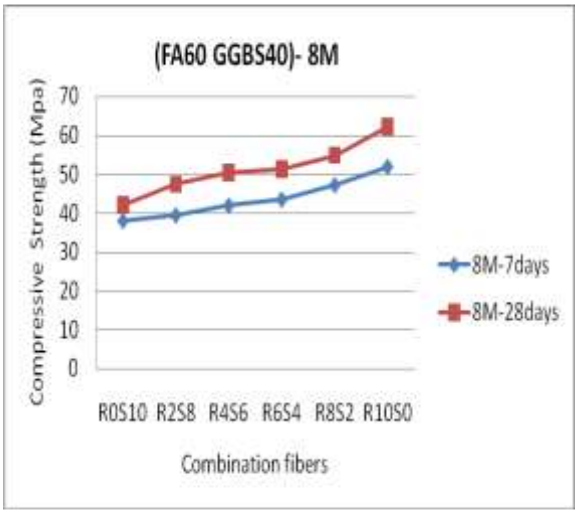

Fig.1 Combination fiber effect on compressive strength of CFRGPC

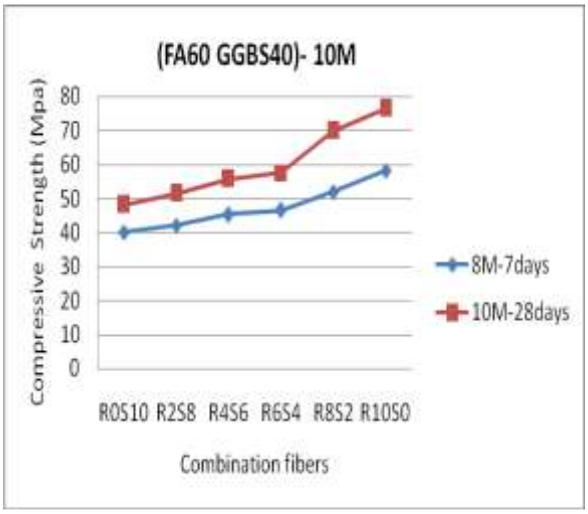

Fig.2 Combination fiber effect on compressive strength of CFRGPC

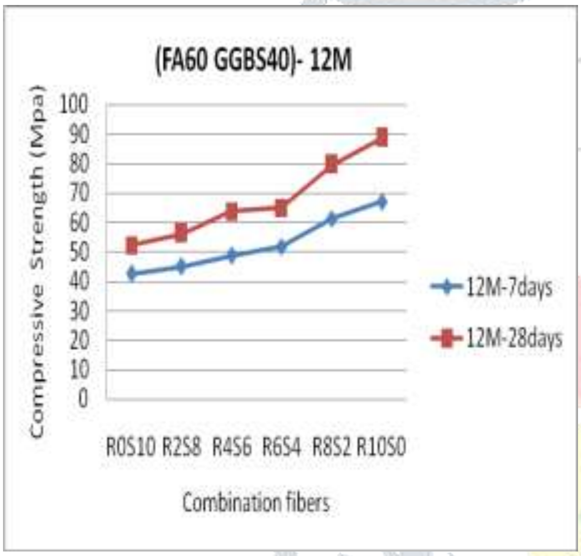

Fig.3 Combination fiber effect on compressive strength of CFRGPC

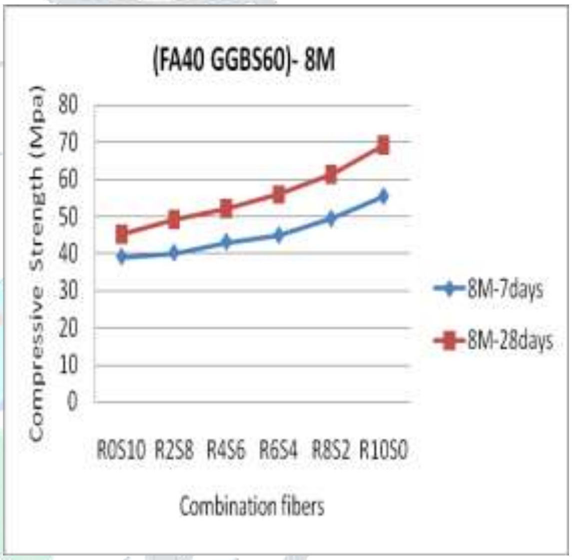

Fig.4 Combination fiber effect on compressive strength of CFRGPC

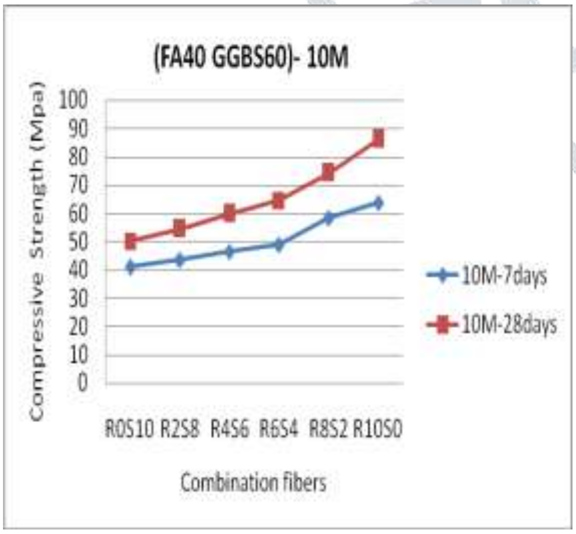

Fig.5 Combination fiber effect on compressive strength of CFRGPC

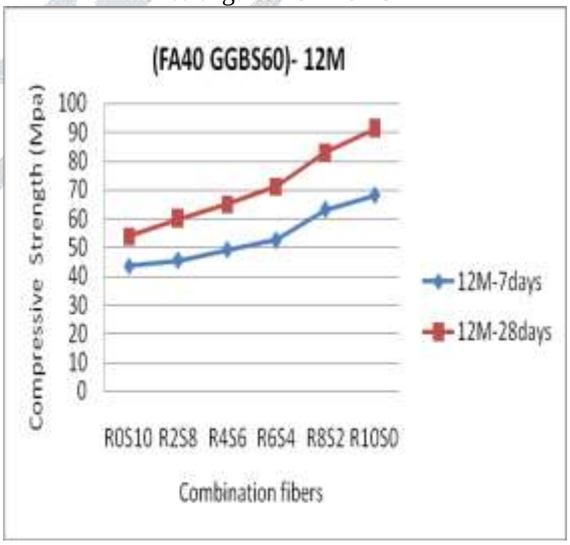

Fig.6 Combination fiber effect on compressive strength of CFRGPC

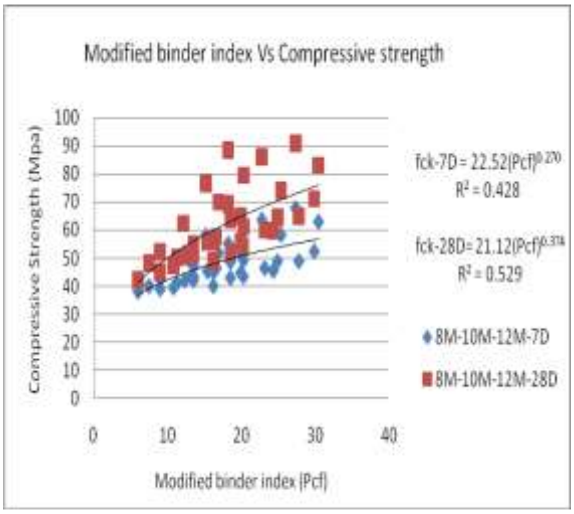

Fig.7 Modified binder index effect on compressive strength of Combined fiber reinforced geopolymer concrete.

3.1 Effect of molarity of alkaline activator on compressive strength of combined fiber reinforced geopolymer concrete

The effect of molarity of alkaline activator for different fiber combinations is shown in fig 1 to fig 6. In general as the molarity increased the compressive strength of combined fiber reinforced GPC is increased.

3.2 Effect of fiber combinations on compressive strength of combined fiber reinforced geopolymer concrete

From fig 1 to fig 6, it is observed that for any choosen molarity of alkaline activator and GGBS to FA ratio, the 7 days and 28 days strength of combined fiber reinforced geopolymer concrete is increased with increase in rigid fiber proportions.

3.3 Effect of binder index on the compressive strength of combined fiber reinforced geopolymer concrete.

From table 5, it is observed that the compressive strength of combined fiber reinforced geopolymer concrete is increased with the increase in binder index values.

3.4 Effect of modified binder index on the compressive strength of combined fiber reinforced geopolymer concrete

From table 9 and fig 7, it is observed that the proposed modified binder index combine the effects of binder index, molarity and fiber effect resoanably well in predicting the compressive strength. The following best fit equations give the relation between the compressive strength at 7 days and 28 days of air curing with modified binder index along with the correlation coefficient (R^2).

$Fck\text{-}7D=22.52(P_{cf})^{0.270}$
$R^2 = 0.428$
$Fck\text{-}28D=21.12(P_{cf})^{0.374}$
$R^2 = 0.529$
Where ' P_{cf} ' is modified binder index for combination fibers.

4.0 Conclusions

From the analysis of experimental results the following conclusions were drawn.

1. The 7 days and 28 days compressive strength of combined fiber reinforced geopolymer concrete increaed with increase in molarity of alakaline activator for any chosen fiber combination.
2. The 7 days and 28 days compressive strength of combined fiber reinforced geopolymer concrete is increased with increae in rigid fiber proportions for any chosen molarity of alkaline activator.
3. The 7 days and 28 days compressive strength of combined fiber reinforced geopolymer concrete is increased with the increase in binder index values.
4. The modified binder index which combines the effect of molarity, GGBS to Fly ash ratio and fiber effect can be considered as a unique parameter in characterizing the compressive strength of Combinded fiber reinforced geo polymer concrete.
5. There is a non linear relation between the modified binder index and compressive strength of combined fiber reinforced geopolymer concrete.
6. The 7 days and 28 days Compressive strengths of combined fiber reinforced geo polymer concrete is increased for fly ash to GGBS proportion 40:60compared to 60:40.

5.0 References

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