The effect of Molarity and Steel fibers on Compressive strength of Fiber Reinforced Geopolymer Concrete

J.Srinivas, B.Sesha Sreenivas, D. Rama Seshu

Abstract: This article contains the effect of different alkaline activators [1] (8M, 10M and 12M) on Compressive Strength of Steel fiber Reinforced Geopolymer Concrete (SFRGPC). Two different proportions of Ground Granulated Blast Furnace Slag (GGBS) and Fly ash (60%GGBS: 40%F and 40% GGBS: 60%F) were used in the present study. The combination of sodium Hydroxide (NaoH) and Sodium Silicate (Na_2Sio_3) are used as a alkaline activators. SFRGPC is produced by adding different volume fractions of Hooked end steel fibres to the GPC. The Hooked end steel fibres were added to the Geopolymer concrete(GPC) in the volume fractions[2] of 0%,0.5%,0.7%,0.9% & 1.1% (R_0,R_5,R_7,R_9,&R_{11}) of Geopolymer concrete. Three identical cube specimens of size 100mm, for each variation, were cast and tested after 7 days and 28 days of ambient curing for average strength. The Modified Binder Index (B_{mi})[3] is introduced to quantify the effect of Binder Index(Bi)[4] and steel fibre effect(f_{eff}) on compressive strength of Steel Fibre Reinforced Geopolymer Concrete. The effect of molarity , GGBS:Fly Ash ratio and the steel fibers on compressive strength of SFRGPC is presented in this paper.

Index Terms: Alkaline Activator, Binder Index, Compressive Strength, Fly ash, Ground Granulated Blast furnace slag (GGBS), Steel Fibres.

I. INTRODUCTION

The production of OPC worldwide emitted about 7% of green house gasses of the total emissions to the earth atmosphere contributing greatly to the global warming. It is necessary to reduce use of cement and replace it by alternative materials like fly ash, GGBS, silica fume etc., Fly ash is a byproduct of burning coal in the thermal power plants. Every year about 220 million tons of Fly ash is produced of which about 35-50% is utilized. Hence a huge quantity of Fly ash is disposed on land as a waste material. The Geopolymer was introduced to the world by Joseph Davidovits in year 1978. Geopolymer are obtained by polymerization of fly ash and alkaline solutions. In Geopolymer technology 100% replacement of cement is possible by using the source material and alkaline liquids, the most commonly used source material are fly ash and GGBS.

Revised Manuscript Received on April 25, 2019.

Dr. D.Rama Seshu, Professor of Civil Engineering, NIT, Warangal. Hanamkonda, Telangana

Dr.B. Sesha Sreenivas . Professor of Civil Engineering & Principal, University College of Engineering

Mr. Jetty Srinivas, Scholar,Kakatiya University Warangal. BE Vasavi College of Engineering(OU) M.Tech Hyderabad, Telangana

II. EXPERMENTAL INVESTIGATION

Experimental Program Consisted of casting and testing cubes of size 100mm for determining the Compressive Strength of the SFRGPC, based on GGBS and Fly ash. Two different Fly ash to GGBS proportions (40%F:60%GGBS & 60%F:40%GGBS) are used. The ratio of Sodium silicate solution to Sodium hydroxide solution is kept as 2.5[5]. Alkaline liquid content to fly Ash Ratio is taken as 0.36[6] and fine Aggregate to total Aggregate ratio is taken as 32%. In the present investigation NaoH, Na_2sio_3 are used as alkaline activators. Three different molarities of NaoH solution (8M, 10M and 12M)[1] were considered to prepare different GPC Mixes. The average 7days and 28days (f_{ck}) of SFRGPC is obtained by testing the cubes after 7days and 28days of ambient curing.

A.Materials

Ground Granulated Blast furnace slag conforming to IS 12089:1987, is obtained from Blue way exports supplier, 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.

Table 1. Chemical composition

Material	Fly ash	GGBS
SiO2	60.1	34.1
Al2O3	26.6	20.1
Fe2O3	4.2	0.8
SO3	0.32	0.88
CaO	4.1	32.8
MgO	1.21	7.69
Na2O	0.2	--
LOI	0.8	--

Low calcium, Class F dry fly ash, conforming to IS 3812[7](part 1:2003) , is obtained from Kothagudem Thermal power station, Bhadradri Kothagudem District, 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], are 2.45 and 1% respectively. The gradation of the sand was determined by sieve analysis as per IS 383 (1970)[9].

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

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)[8] are 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 having 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 steel fibers is 1450MPa.

B. Preparation of Alkaline Solutions

In the present Investigation three different molarities of NaoH solutions (8M,10M and 12M) were prepared one day before casting. The alkaline activators were prepared by mixing NaoH (8M, 10M and 12M) with Na2Sio3 solution. The solution thus mixed was stored for 24hours at room temperature before casting. The NaoH pellets used for preparation of NaoH solution is given in Table.2.

Table 2: Mix Proportions of Alkaline Liquids (NaoH Solution Preparation)			
Alkaline liquids	8M	10M	12M
Sodium hydroxide pellets (NAOH),(grams)	262	314	361
Water (grams)	738	686	639

C. Figures

The Mix proportions were given in table 4. The Density of Geopolymer concrete is assumed as 2400 kg/m^3. Alkali liquid to fly ash ratio was fixed as 0.36[6] and also Na_2 Sio_2 and NaoH ratio is taken as 2.5. The quantities of all ingredients are given in Table 3.

Table 3. Quantity of Materials used

FA:GGBS	GGBS/FA		Materials in Kg/m^3							
		Molarity	Coarse Agg	Fine Agg	Fly ash	GGBS	NaoH Solution	Sodium Silicate	Super Plasticizer	(10% of the binder)
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
40:60	1.5	10M	1100	517.45	230.08	345.12	59.10	148.25	11.50	57.52
60:40	0.666	10M	1100	517.45	345.12	230.08	59.10	148.25	11.50	57.52
40:60	1.5	12M	1100	517.45	230.08	345.12	59.10	148.25	11.50	57.52
60:40	0.666	12M	1100	517.45	345.12	230.08	59.10	148.25	11.50	57.52

The hooked end Steel Fibres were added in` the volume fractions of 0%, 0.5%, 0.7%, 0.9% & 1.1% (R_0, R5, R7, R9 & R11) of Geopolymer concrete.(Table:4)

Table 4: Fiber Proportions in SFRGPC:

Fiber 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

III. Casting of GPC

The solid constituents of the Geopolymer concrete were dry mixed for about three minutes and then liquid part of the mixture i.e. the alkaline solution, additional water and the super plasticizer were premixed then added to the solids. The mixing is done for about 5-6 minutes for obtaining a uniform mix. The Compaction of fresh Geopolymer concrete in the cube moulds was done 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.

.

IV. Testing and Discussion of Results

A. Testing

The Geopolymer concrete specimens for Compressive Strength were tested on Universal Testing Machine of capacity 1000KN. The maximum loads applied on various specimens were recorded as per IS 516-1956[10]. Three identical specimens with each variation were tested for average compressive strength. A total of 180 cubes using different Fly ash to GGBS proportions, different molarities (8M, 10M and 12M) and different volume fractions of steel fibres were cast and tested after 7 days and 28 days of ambient curing. The test results are given in table 5,6 and 7.

B. Discussion of Results

The variation of compressive strength of Steel fiber reinforced Geopolymer concrete (SFRGPC) with increase in volume fraction of Steel fibres from (0.0 %, 0.5%, 0.7%, 0.9%, 1.1%) for different molarities and GGBS: Fly ash ratio are shown in fig. 1 to fig. 8. From figures 1 to 4, it is observed that for different molarity of alkaline activator and GGBS to fly ash ratio, the 7 days and 28 days Compressive Strength (fck) of SFRGPC increased with increase in volume fraction of fibres.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The compressive strength in general increased with increase in molarity and increase in GGBS proportion.

Table 5. Compression strength test results

Sl. No.	Mix	Molarity (M)	R0			R5			R7			R9			R11		
			7D	28D	7/28 R	7D	28D	7/28 R	7D	28D	7/2 8 R	7D	28D	7/28 R	7D	28D	7/28 R
1	(Fly Ash 60 % : GGBS 40%)	8M	29.8	36.2	0.82	34.9	42.26	0.83	37.3	45.0	0.83	39.9	48.2	0.83	45.5	50.5	0.90
		10M	41.8	47.0	0.89	48.6	52.8	0.92	50.0	54.2	0.92	52.6	56.5	0.93	56.3	59.3	0.94
		12M	45.5	48.5	0.94	55.2	59.7	0.93	59.2	61.8	0.95	62.6	65.7	0.95	66.6	69.7	0.96
2	(Fly Ash 40%:GGBS 60 %)	8M	40.3	48.6	0.83	44.9	54.1	0.83	51.9	56.2	0.92	54.9	58.2	0.94	57.2	59.4	0.96
		10M	44.0	50.4	0.87	54.3	59.6	0.91	55.2	62.8	0.88	61.3	65.1	0.94	64.3	67.4	0.95
		12M	50.2	56.0	0.90	56.6	62.2	0.21	60.3	64.5	0.94	65.8	67.5	0.98	68.4	72.1	0.95

Table 7 The values of the Compressive strength 7days and 28days and Modified Binder Index

S.NO	% GGBS	% Fibres	Molarity (M)	Binder Index (Bi)	Modified Binder Index (B_{mi})	7 Days Compressive Strength(**Mpa)**	28Days Compressive Strength(**Mpa)**
1	40%	0.0	8	3.2	0.0	29.83	36.20
2	40%	0.5	8	3.2	8.614	34.93	42.26
3	40%	0.7	8	3.2	10.19	37.30	45.06
4	40%	0.9	8	3.2	11.55	39.93	48.20
5	40%	1.1	8	3.2	12.77	45.56	50.57
6	60%	0.0	8	4.8	0.00	40.36	48.63
7	60%	0.5	8	4.8	12.92	44.96	54.16
8	60%	0.7	8	4.8	15.28	51.90	56.26
9	60%	0.9	8	4.8	17.33	54.93	58.20
10	60%	1.1	8	4.8	19.16	57.20	59.46
11	40%	0.0	10	4	0.00	41.86	47.06
12	40%	0.5	10	4	10.76	48.66	52.88
13	40%	0.7	10	4	12.74	50	54.26
14	40%	0.9	10	4	14.44	52.66	56.5
15	40%	1.1	10	4	15.97	56.33	59.3
16	60%	0.0	10	6	0.0	44	50.4
17	60%	0.5	10	6	16.15	54.33	59.66
18	60%	0.7	10	6	19.11	55.26	62.8
19	60%	0.9	10	6	21.67	61.33	65.1
20	60%	1.1	10	6	23.95	64.33	67.47
21	40%	0.0	12	4.8	0.0	45.5	48.5
22	40%	0.5	12	4.8	12.92	55.27	59.7
23	40%	0.7	12	4.8	15.28	59.2	61.8
24	40%	0.9	12	4.8	17.33	62.6	65.74
25	40%	1.1	12	4.8	19.16	66.6	69.7
26	60%	0.0	12	7.2	0.0	50.2	56
27	60%	0.5	12	7.2	19.38	56.66	62.2
28	60%	0.7	12	7.2	22.93	60.33	64.5
29	60%	0.9	12	7.2	26.00	65.8	67.5
30	60%	1.1	12	7.2	28.74	68.4	72.1

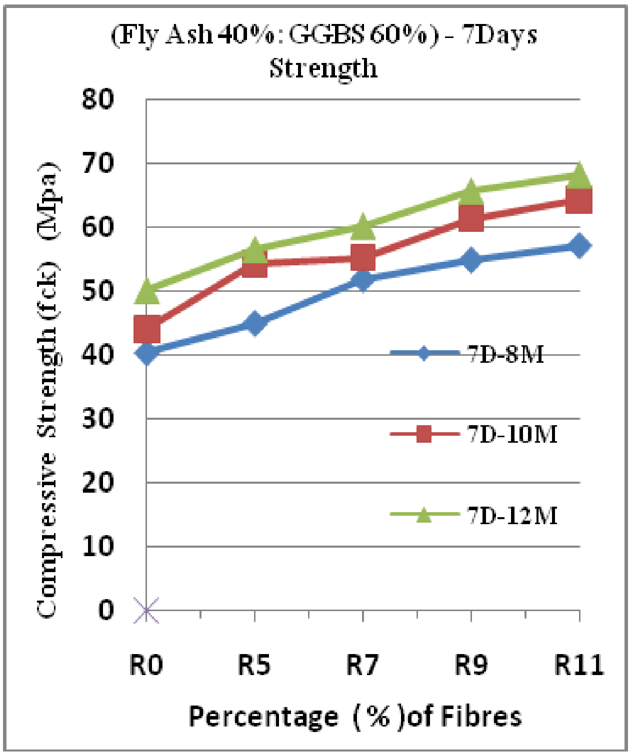

Fig 1.The Variation of7days Compressive Strength (fck With % of Fibres (Different Molarity 8M, 10M and 12M)

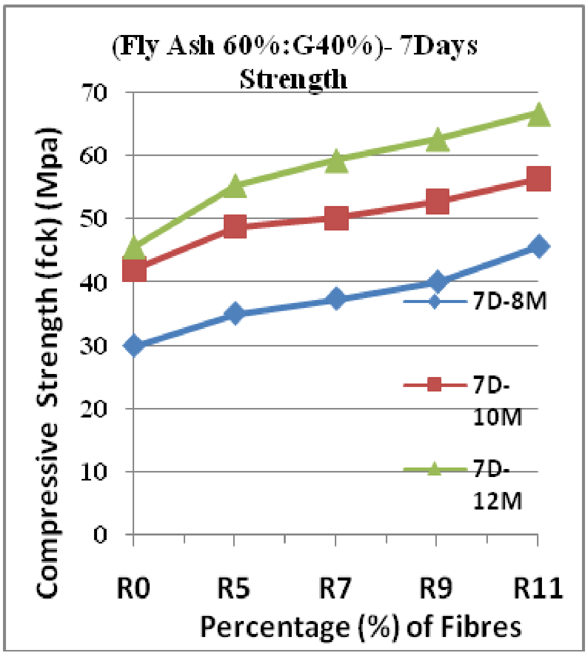

Fig 3.The Variation of7days Compressive Strength(fck) With % of Fibres (Different Molarity 8M,10M and 12M)

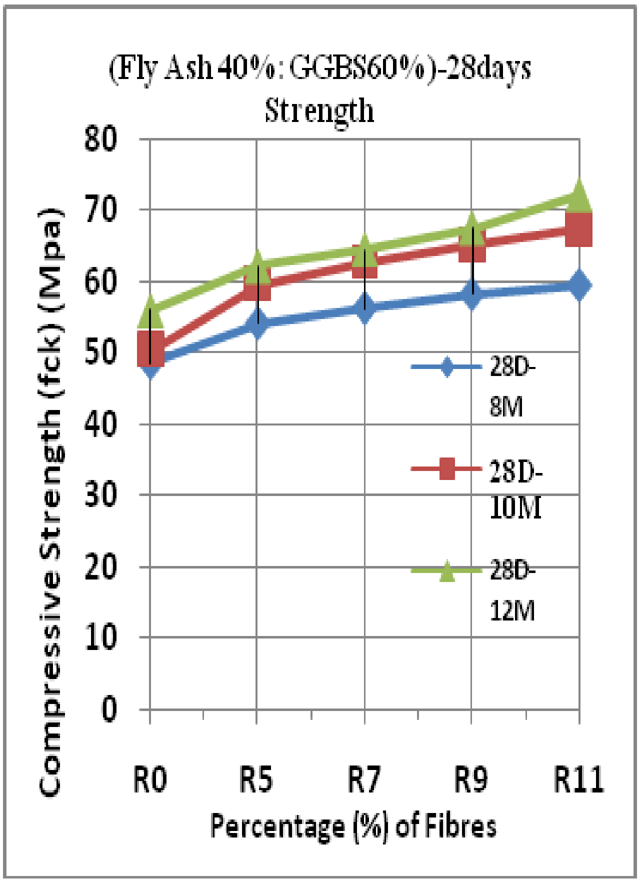

Fig 2.The Variation of 28 days Compressive Strength (fck) with % of Fibres (Different Molarity 8M, 10Mand 12M)

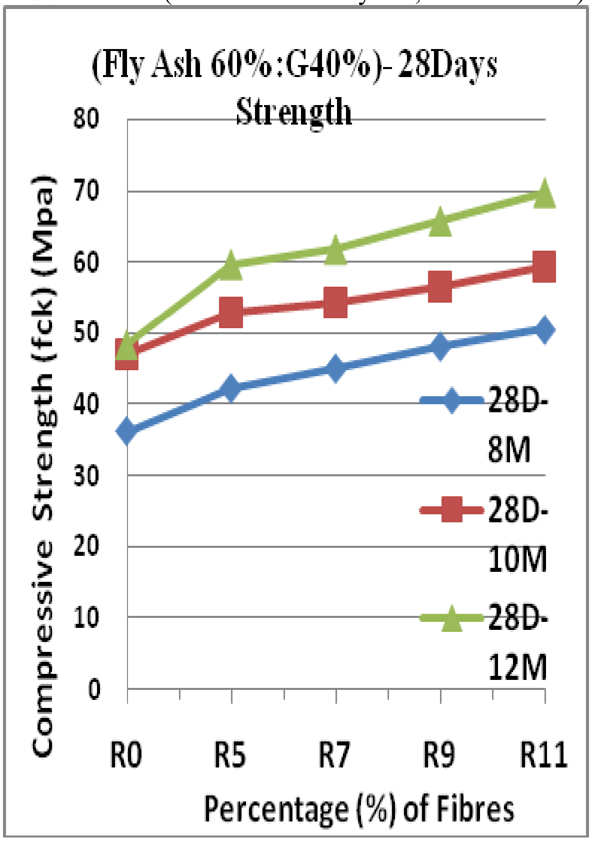

Fig 4.The Variation of28 days Compressive Strength(fck) With % of Fibres (Different Molarity 8M,10M and 12M)

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

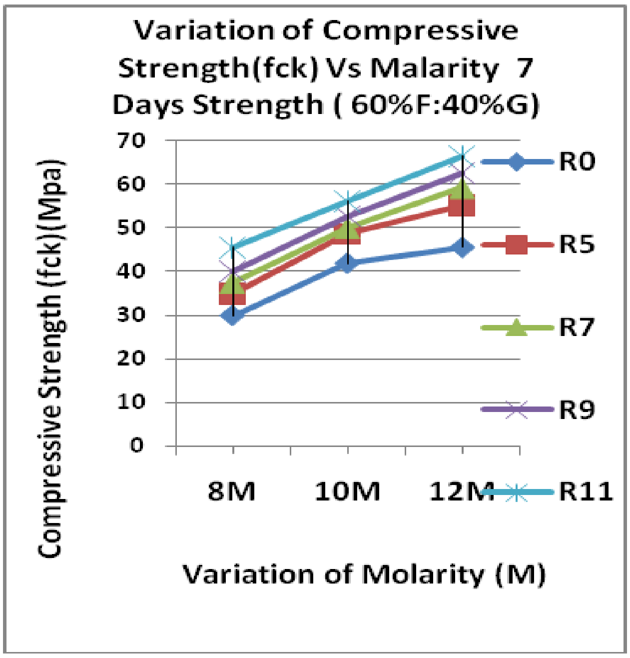

Fig 5.The Variation of 7Days Compressive Strength (fck) Vs Molarity (M) (60%F:40%G)

Table 6.Fiber index

Sl.No.	% of Fibre	$f_{eff} = f_{tr} \times V_{fr}$	$(\sqrt{f_{eff}})$
1	0	1450x0=0	0.0
2	0.5	1450x(0.5/100) =7.25	2.692
3	0.7	1450x(0.7/100)=10.15	3.185
4	0.9	1450x(0.9/100)=13.05	3.612
5	1.1	1450x(1.1/100)=15.95	3.993

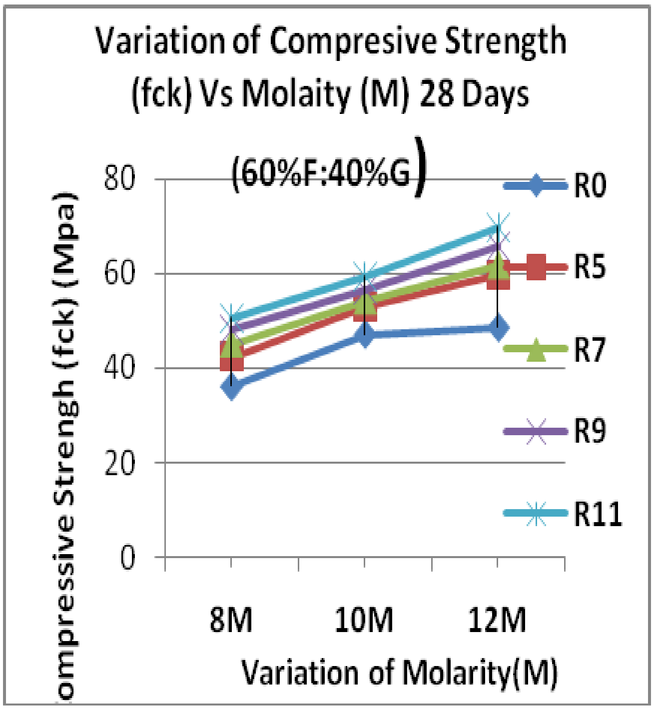

Fig 6.The Variation of 28-Days Compressive Strength (fck) Vs Molarity(M) (60%F:40%G)

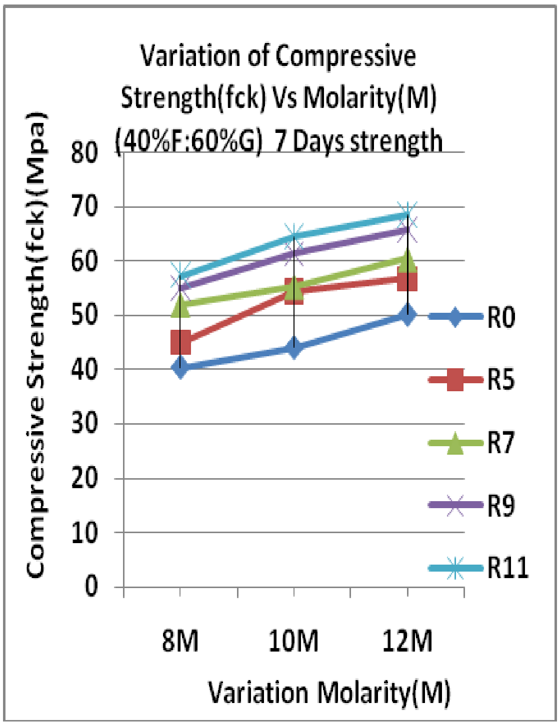

Fig 7 The Variation of 7Days Compressive Strength (fck) Vs Molarity (M) (40%F:60%G)

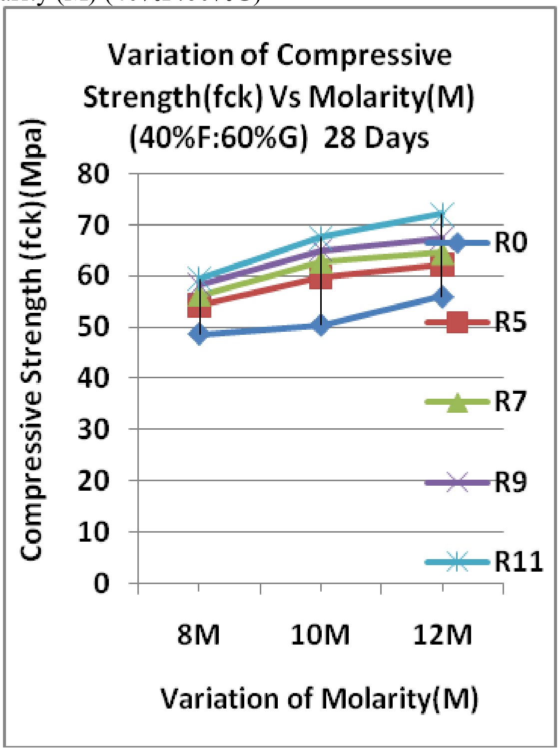

Fig 8.The Variation of 28-Days Compressive Strength (fck) Vs Molarity(M) (60%F:40%G)

From figures 5 to 8 it is observed that for different molarity (8M,10M and 12M) of alkaline activators and any chosen GGBS to Fly ash ratio the 7 days and 28 days Compressive Strength (f_{ck}) of SFRGPC is increased with increase in molarity .

C. Binder Index (Bi)

The binder index was defined as the product of Molarityof alkaline activator solution and GGBS to (Fly ash + GGBS) ratio.

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

In the present study the Modified Binder index(Bmi)[3] has been used to study the combined effect of GGBS, Fly ash, molarity of Alkaline Activator and Fiber effect on SFRGPC.

D . Modified Binder Index (B_{mi})

The Modified Binder index is an empirical formula connecting the fibre effect and binder index. Fibre effect is incorporated multiplying the volume fraction of steel fibre and tensile strength of Steel fibre. The Modified Binder Index (B_{mi}) is formulated as follows.

$$(B_{mi}) = B_i \text{ x } (\sqrt{f_{eff}}) ;$$

Where

$f_{eff} = f_{tr} \text{ x } V_{fr}$ (where f_{eff} = Fibre effect)

V_{fr} = Volume fraction of Rigid fibre

f_{tr} = Tensile Strength of steel fibre

The values of 7 days and 28 days Compressive strength and Modified Binder Index (B_{mi})were ploted as shown in fig.9. From fig.9 it is observed that the compressive strength and Modified Binder Index(B_{mi}) have a non linear relation.

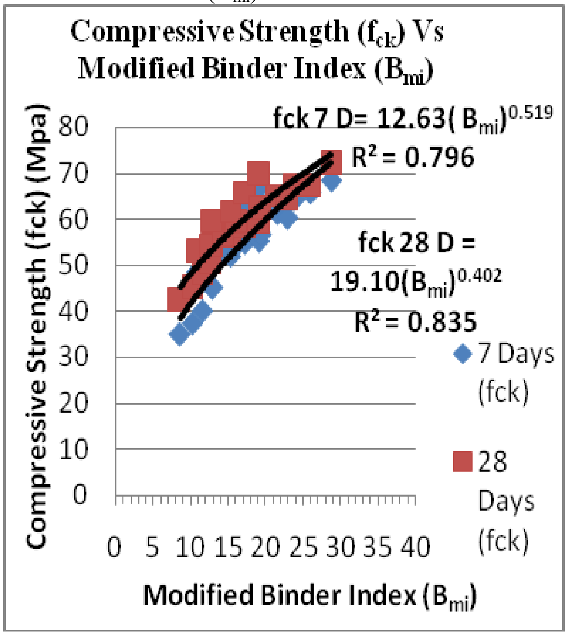

Fig.9. Effect of Modified Binder Index (B_{mi}) on Compressive Strength (f_{ck}) of Fibre Reinforced Geopolymer Concrete

It is observed that the Modified Binder Index combined the effects of Binder index (Bi) and Fibre effect (feff) reasonably well in predicting the Compressive Strength(fck). The following best fit curve equations 2 and 3 give the relation between the7days and 28days Compressive Strength (fck) with Modified Binder Index (Bmi) along with the correlation coefficient (R^2).

$$f_{ck7} = 12.63(B_{mi})^{0.519} \text{..........eq (2)--------} R^2 = 0.796$$

$$f_{ck28} = 19.10(B_{mi})^{0.40} \text{.........eq (3)--------} R^2 = 0.835$$

IV. Conclusions:

1. The compressive Strength (f_{ck}) of Geopolymer concrete is higher for Fly Ash to GGBS proportions 40:60 compared to 60:40.

2. The 7 days and 28 days Compressive Strength (f_{ck}) of Geopolymer Concrete increased with increase in Molarity.

3. The 7days and 28 days Compressive Strength (f_{ck}) of Steel Fibre Reinforced Geopolymer Concrete increased with increase in Molarity of Alkaline Activator.

4. The Compressive Strength (f_{ck}) of Steel Fibre Reinforced Geopolymer Concrete is higher for Fly Ash to GGBS proportions (40:60) compared to (60:40).

5 There is a non linear relation between Modified Binder Index (B_{mi}) and Compressive Strength (f_{ck}) for Steel Fibre Reinforced Geopolymer Concrete.

6. The Modified Binder Index (B_{mi}) which combines the effect of Molarity, GGBS to Fly Ash ratio and Fibre effct give good prediction of Compressive Strength (f_{ck}) of FRGPC.

References:

1. **1.** S. Selva Kumar, Jose Ravindra raj. B , " Strength and Durability of 8m 12m and 10m Geopolymer Concrete " International Journal of Innovations in Engineering and Technology (IJIET) volume 8 Issue 3 , June 2017 , Issn2319- 1058 .
2. Rekha.K.P, Hazeena R "Strength and Durability of Fibre Reinforced Geopolymer Concrete,(International Journal of Scientific and Engineering Reearch,Volume5,Issue7,july2014.
3. HathiRam Gugulothu,B.Sesha Sreenivas,D.Rama Seshu "Experimental Investigation of Compressive Strength of Combined Fibre Reinforced Geopolymer Concrete"2018 JETIR ,December 2018,volume 5 , (ISSN-2349-5162).
4. D. Rama seshu, R. Shankaraiah, B.Sesha Sreenivas, 2017, a study on the effect of Binder index on compressive strength of Geopolymer concrete, CWB-3/2017, pages 211-215.
5. **5.** Rohith Zende, Mamatha. A, Study and Fly Ash GGBS Based Geopolymer Concrete under Ambient Journal of Engineering Technology's and Innovative Research (JUTIR) Volume 2, Issue 7 July 2015.
6. V.Bhikshma, M.koti Reddy, and T.Srinivas Rao, "An Experimental Investigation on Properties of Geopolymer Concrete, (Asian journal of civil engineering (Building and Housing) v0l 13, No.6 (2012).
7. Is 3812(part-1) 2003,(pulverized Fuel Ash –Specification For use As Pozzolana on cement Mortar and Concrete.
8. Is 2386-1963, "Methods of testing for aggregate for concrete"
9. Is 383-1970, Specification for Coarse and fine Aggregate from Natural sources for concrete .Bureau of Indian Standards, New Delhi.
10. Is 516-1956Indian Standard methods of test for Strength of Concrete

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

11. **11.**Madheswaram C.K, Gnanasundar.G, Gopalakrishnan .N "Effect of Molarity in Geopolymer Concrete"International Journal of Civil and Structural Engineering, Volume4, No.2, 2013.
12. Y.Emilius Sebastian Antony, Experimental investigation of Replacement of GGBS for Fly Ash in Steel Fibre Reinforced Geopolymer Concrete (SFRGPC)
13. J.srinivas,B.Sesha sreenivas,D.RamaSeshu, "An Experimental Study on Compressive Strength of Steel Fibre Reinforced Geopolymer Concrete(SFRGPC) with Different GGBS and flyashProportions.IJRARJanuary 2019,volume 6,Issue 1.
14. C.D. Budh and N.R Warhade, Effect of Molarity on Compresive strength Geopolymer Motor nternational Journal of Civil Engineering Research Volume 5 November 2014 Issn2278- 3652.
15. Pallavi Jakate, Sanjeev Verma, Sourabh Asange."Effects of Varying Molarity in fly Ash Based Concrete.(International Journal of latest Technology in Engineering,Management and Applied Science,Vol VI,Issue VIIIs,August 2017,Issn2278-2540.
16. 16. Is 1199-1959, Indian Standard Methods of sampling and analysis of concrete. Bureau of Indian Standards, New Delhi, 1959.

AUTHORS PROFILE

	**First Author** **Mr. Jetty Srinivas,** Reaserch Scholar,Kakatiya University Warangal. BE Vasavi College of Engineering(OU) M.Tech JNTUH his working as Associate Proff in Civil Engineering Department & HOD at Adams Engineering College palvancha. Mail.id. civil.adams@gmail.com
	**Second Author** **Dr.B. Sesha Sreenivas** . Professor of Civil Engineering & Principal, University College of Engineering In his 35 Years of Service he has several Publication in the areas of his research interest. Mail.id. bseshasreenivas@yahoo.co.in
	**Third Author** **Dr. D.Rama Seshu,** Professor of Civil Engineering, NIT, Warangal. He has more than 30 years of service. His areas of interest include new concrete making materials, He has published more than 50 papers in national and international journals and guided 4 PhD Scholors. Mail.id. ramadrs@gmail.com