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Experimental Study on Workability and Strength Characteristics of Fly ash and GGBS based Self-Compacting Geo polymer Concrete

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Abstract: - Self compacting Geo polymer Concrete (GPSCC) is an innovative material and is produced by complete elimination of ordinary Portland cement (OPC) by industrial waste materials such as Fly ash and Ground Granulated Blast Furnace Slag (GGBS). Alkaline solutions such as sodium hydroxide (NaOH) and sodium silicate are used to make the binder necessary to manufacture the concrete. This paper reports the laboratory tests conducted to investigate on the fresh and hardened properties of self-compacting geo-polymer concrete. The experiments were conducted by varying concentration of sodium hydroxide from 8M to 12M, binder material such as fly ash and GGBS are taken with 100:0, 70:30, 50:50, 30:70 and 0:100 proportions. Mixtures were prepared with alkaline liquid to binder ratio of 0.5 and the ratio of sodium silicate to sodium hydroxide solution was kept 2.5 for all mix proportions. The test methods on fresh properties to access the workability characteristics such as slump flow test, $T50_{cm}$ slump flow, V–funnel test, L-box test, and J-ring test on SCGPC were carried out. The test specimens were cured for about 7, 28 and 56 days at ambient room temperature. The compressive strength test was carried out at the age of 7, 28 and 56 days, flexural and split tensile strength tests were carried out at 28 days. Based on the test results the workability of fresh concrete was slightly reduced with increase in the molarity of sodium hydroxide solution. However the strength properties were increased with high concentration of NaOH of GGBS based SCGPC

Keywords:- Fly ash, GGBS, Self Compacting Geo polymer concrete, Workability, Compressive Strength, Split Tensile Strength, and Flexural Strength

I. INTRODUCTION

The economic strength of any country is reflected by the growth rate of the infrastructures and is high lightened by the production rate of concrete. Worldwide utilization of concrete as a major construction material, results in cement industry using large amount of natural non-renewable resources in environment to prepare Ordinary Portland Cement (OPC) the main constituent. The production of OPC increases the possibility of forming global warming potentially and a non-eco-friendly material, due to its emission of carbon dioxide gas to the surrounding atmosphere, finally leading to environmental impact.

Due to growing environmental concerns, usage of OPC has to be altered by substituting other binder materials. Binder materials are indispensable for enhanced strength and durability performance. A new innovative material in this direction is Self compacting Geo polymer concrete which uses waste materials like Fly ash, and Ground granulated blast furnace slag as binder materials, which are less pollutant and improve the concreting operation not requiring any vibration for compacting.

Geo polymer concrete & Self compacting Geo polymer concrete

In this regard, the geo polymer concrete (GPC) is one of the revolutionary related to novel material developed as an alternative to the OPC resulting in low-cost and environmentally friendly innovative binder material. It is demonstrated that the geo polymeric cement generates 5-6 times less CO_2 than OPC. Therefore the use of geo polymer technology not only significantly reduces the CO_2 emissions by the cement industries, but also utilizes the industrial wastes and/or by-products of alumina-silicate composition to produce added-value construction materials.

Self compacting Geo polymer concrete (SCGPC) is a relatively a new concept and can be regarded as the most revolutionary development in the field of concrete technology. SCGPC is an innovative type of concrete that does not require vibration for placing it and can be produced by complete elimination of ordinary Portland cement. And also it serves as eco-friendly material.

II. RESEARCH SIGNIFICANCE

The present investigation is to study Self Compacting Geo Polymer Concrete (SCGPC) with varied mix proportion of fly ash and Ground granulated blast furnace slag with different Molarities of alkaline solution to examine its basic physical and mechanical properties. This research is to develop SCGPC by utilizing locally available constituent materials that would satisfy the requirements of self compacting concrete both in fresh and hardened state.

III. EXPERIMENTAL WORK

A. Materials

a. Fly Ash:

In this research study, Low calcium Fly ash obtained from Bellary thermal power station, Bellary, Karnataka, India, was used for the production of SCGPC. The specific gravity of fly ash is 2.02 and the chemical composition of fly ash as shown in table I.

Table I: Chemical Composition Of Fly Ash

Parameters	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	K_2O	SO_3	Loss on ignition % by mass	Bulk density
Content (% by mass)	62.63	23.35	3.93	2.04	0.032	0.46	0.030	1.34	0.39	1.11gm/cc

b. Ground granulated blast furnace slag:

Slag is taken from Jindal steel plant, Bellary, Karnataka, India. The specific gravity of GGBS is 2.72 The chemical composition as shown in table II

Table II: Chemical Composition Of Ggbs

Oxide	SiO_2	Al_2O_3	FeO	CaO	MgO	Others
Mass percentage (%)	35.47	19.36	0.8	33.25	8.69	3.25

c. Aggregates:

A good quality of locally available crushed granite stone, well graded coarse aggregate of maximum size 12.5 mm was used and natural river sand confirming to zone II was used in this research work.

Table III: Basic Properties Of Aggregates

Properties	Coarse aggregate	Fine aggregate
Specific Gravity	2.76	2.6
Water absorption	0.8%	0.1%
Max size (mm)	12.5	4.75
Fineness modulus	6.5	3.6
Unit weight (Kg/m^3)	1620	1610

d. Alkaline solutions:

In geo polymerization, alkaline solution plays an important role. The most common alkaline solution used in geo polymerization is a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). A combination of sodium silicate solution and sodium hydroxide solution is used. The sodium silicate solution is obtained from local supplier, S.P Enterprises, Bangalore.

Table IV: Specifications of Sodium Silicate

Specific gravity	1.50
Sodium oxide (Na_2O)	11
Sulphur dioxide (SO_2)	31.25
(Na_2O): (SO_2)	1:2.84
Iron content	<100ppm

The sodium hydroxide (NaOH) in flakes or pellets from with 97%-99% purity. The NaOH solids were dissolved in water to make the solution. The sodium hydroxide solids were of commercial grade in flakes form (3 mm), with a specific gravity of 2.130, 99% purity, and obtained from S.P Enterprises Bangalore.

Table V: Specifications of Sodium Hydroxide Flakes

Sodium hydroxide (as NaOH) % by mass	99.79
Sodium carbonate (as Na_2CO_3) % by mass	0.177
Sodium chloride (as NaCl) % by mass	0.017
Sodium sulphate (as Na_2SO_4) % by mass	0.005
Silicate (as SiO_2) % by mass	0.001
Iron (as Fe) ppm	4.0
Copper (as Cu) ppm	<2
Manganese (as Mn) ppm	<1
Water insoluble in water % by mass	0.005

e. Water: Portable fresh water free from organic matter was used for preparation of alkaline solution and as extra water added for the concrete to get workability.
The Physical and chemical analysis of water is shown in the table VI

Table VI: Test Results of Water

PH	7.92
Acidity	NIL
Specific conductance	835 micro/mhos
Total Hardness	274 mg/litre
Chloride	105 mg/litre
Turbidity	1 NTU
Sulphate	63 mg/litre
Calcium	109 mg/litre
Magnesium	17 mg/litre
Na^+	10 mg/litre
K^+	2 mg/litre
Alkalinity	260 mg/litre
TDS	500 mg/litre
Iron	0.04 mg/litre
Fluoride	0.7 mg/litre
Nitrate	07 mg/litre

f. Chemical admixture:

i) Super plasticizer (SP) Modified poly carboxylic ether base Master Glenium Sky 8233, supplied by BASF was used in the production of SCGPC.

Table VII: Specifications of Master Glenium Sky 8233

Aspect	Light brown liquid
Relative density	1.08 ± 0.01at 25˚c
pH	≥6
Chloride ion content	<0.2%

ii) Viscosity modifying admixture (VMA): Glenium stream 2 is a premier used, liquid, organic VMA specially developed for producing concrete with enhanced viscosity and controlled rheological properties supplied by BASF was used in the production of SCGPC

Table VIII: Specifications of Glenium Stream-2

Aspect	Colorless free flowing liquid
Relative density	1.01 ± 0.01at 25˚c
pH	≥6
Chloride ion content	<0.2%

B. Preparation of Alkaline solution:

The mass of NaOH solids in a solution varies depending on the concentration of the solution. The sodium hydroxide (NaOH) solution was prepared by dissolving either the flakes or the pellets in water. The concentration (which is measured in terms of molarities) of sodium hydroxide solution is kept as 8M. NaOH solution with a concentration of 8M consists of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per liter of the solution. (40 being molecular weight of NaOH), similarly solutions will be prepared for 10M, and 12M consisting of 400 grams, and 480 grams of NaOH respectively. It is recommended that the alkaline liquid is prepared by mixing sodium silicate and sodium hydroxide solution together at least 24 hours prior to use.

C. Mix proportions:

In this study, Flyash-GGBS based Geo-polymer was used as the binder instead of ordinary Portland cement based paste to produce concrete. The manufacture of SCGPC was carried out by using the traditional trial and error concrete technology methods. In the beginning, numerous trial mixtures of SCGPC were manufactured. A total of fifteen (15) mixtures were made to assess the workability characteristics and strength properties. Binder materials such as Fly ash and GGBS are taken with 100:0, 70:30, 50:50, 30:70 and 0:100 proportions for 8M, 10M, and 12M respectively. The alkaline solution to binder ratio was kept constant at 0.5 whereas the ratio of sodium silicate to sodium hydroxide solution was kept 2.5 for all mix proportions. The details of mix proportion for 8M, 10M and 12M are given in table IX.A, IX.B & IX.C

Table XI.A: The Various Mix Proportions for 8m

MIXES	GGBS	FLYASH	COARSE AGG.	FINE AGG.	SODIUM HYDROXIDE		SODIUM SILICATE	SUPER PLASTICIZER		VMA		EXTRA Water	
	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(Kg/m^3)	Mol	(Kg/m^3)	(Kg/m^3)	%	(Kg/m^3)	%	(Kg/m^3)	%
100%GGBS & 0%FLYASH (MIX1)	522	-	794	793	76.8	08	115.2	5.22	1	2.61	0.5	193.14	37
70% GGBS & 30%FLYASH (MIX2)	365	117	794	793	76.8	08	115.2	4.82	1	2.41	0.5	159.06	33
50%GGBS & 50%FLYASH (MIX3)	261	195	794	793	76.8	08	115.2	4.56	1	2.28	0.5	145.92	32
30%GGBS & 70%FLYASH (MIX4)	157	273	794	793	76.8	08	115.2	4.3	1	2.15	0.5	90.3	21
100%FLYASH (MIX5)	-	390	794	793	76.8	08	115.2	3.9	1	1.95	0.5	78	20

Table IX.B: The Various Mix Proportions For 10m

MIXES	GGBS	FLY ASH	COARSE AGG.	FINE AGG.	SODIUM HYDROXIDE		SODIUM SILICATE	SUPER PLASTICIZER		VMA		EXTRA Water	
	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(Kg/m^3)	Mol	(Kg/m^3)	(Kg/m^3)	%	(Kg/m^3)	%	(Kg/m^3)	%
100%GGBS & 0%FLYASH (MIX1)	**522**	**-**	**794**	**793**	**76.8**	**10**	**115.2**	**5.22**	**1**	**2.61**	**0.5**	**193.14**	**37**
70% GGBS & 30%FLYASH (MIX2)	**365**	**117**	**794**	**793**	**76.8**	**10**	**115.2**	**4.82**	**1**	**2.41**	**0.5**	**159.06**	**33**
50%GGBS & 50%FLYASH (MIX3)	**261**	**195**	**794**	**793**	**76.8**	**10**	**115.2**	**4.56**	**1**	**2.28**	**0.5**	**145.92**	**32**
30%GGBS & 70%FLYASH (MIX4)	**157**	**273**	**794**	**793**	**76.8**	**10**	**115.2**	**4.3**	**1**	**2.15**	**0.5**	**90.3**	**21**
100%FLYASH (MIX5)	**-**	**390**	**794**	**793**	**76.8**	**10**	**115.2**	**3.9**	**1**	**1.95**	**0.5**	**78**	**20**

TABLE IX.C: THE VARIOUS MIX PROPORTIONS FOR 12M

MIXES	GGBS	FLYASH	COARSE AGG.	FINE AGG.	SODIUM HYDROXIDE		SODIUM SILICATE	SUPER PLASTICIZER		VMA		EXTRA Water	
	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(Kg/m^3)	Mol	(Kg/m^3)	(Kg/m^3)	%	(Kg/m^3)	%	(Kg/m^3)	%
100%GGBS & 0%FLYASH (MIX1)	**522**	**-**	**794**	**793**	**76.8**	**12**	**115.2**	**5.22**	**1**	**2.61**	**0.5**	**193.14**	**37**
70% GGBS & 30%FLYASH (MIX2)	**365**	**117**	**794**	**793**	**76.8**	**12**	**115.2**	**4.82**	**1**	**2.41**	**0.5**	**159.06**	**33**
50%GGBS & 50%FLYASH (MIX3)	**261**	**195**	**794**	**793**	**76.8**	**12**	**115.2**	**4.56**	**1**	**2.28**	**0.5**	**145.92**	**32**
30%GGBS & 70%FLYASH (MIX4)	**157**	**273**	**794**	**793**	**76.8**	**12**	**115.2**	**4.3**	**1**	**2.15**	**0.5**	**90.3**	**21**
100%FLYASH (MIX5)	**-**	**390**	**794**	**793**	**76.8**	**12**	**115.2**	**3.9**	**1**	**1.95**	**0.5**	**78**	**20**

D. Mix Procedure and Test Set up:

Mixing process was done in two stages. Initially, fine sand, crushed coarse aggregate in saturated surface dry condition and Flyash - GGBS were mixed together in 100 liter capacity concrete mixer for about 2.5 minutes. At the end of this dry mixing, a well-shaked pre-mixed liquid mixture containing alkaline solution, super plasticizer should be added in the concrete mixer and the wet mixing continued for another 3 minutes. Fresh concrete mix was then hand mixed for further 2 to 3 minutes to ensure the mixture homogeneity. The freshly prepared concrete mixture was then assessed for the essential workability tests required for characterizing SCC. The fresh concrete mixture was then casted in 150 mm x150 mm x150 mm steel cube moulds, 150mmØ x 300mm cylinder moulds and 100mm x100mm x500mm prism moulds.

E. Workability characteristics:

A concrete mix can only be categorized as Self Compacting Concrete (SCC) if the requirements for all the three workability properties are fulfilled. The three essential fresh properties required by SCC are filling ability, passing ability and resistance to segregation. A number of test methods have been developed to measure and assess these properties; however, no single test method is capable of assessing all the workability properties at once. As these properties are interrelated, most tests indirectly measure more than one property at a time. The European Guidelines EFNARC has proposed five test methods to fully characterize an SCC mix such as slump flow test, T50cm slump flow, V-funnel test, L-box test, and J-ring test respectively. The European Guidelines EFNARC has proposed five test methods to fully characterize an Self Compacting Concrete (SCC) mix. Table X lists the test methods along with their recommended values given by EFNARC.

Table X: Test Methods And Recommended Limits As Per Efnarc Guide Lines

SL.No.	Test	Permissible limits as per EFNARC Guide lines	
1	Slump flow by Abrams Cone (Filling ability)	650 mm	800 mm
2	T50 cm Slump flow (Filling ability)	2 sec	5 sec
3	V-funnel (Passing ability)	6 sec	12 sec
4	L-Box (H2 /H1) (Passing ability)	0.8	1.0
5	J-Ring (Passing ability)	0 mm	10 mm

F. Curing:

After casting the specimens, they were kept in rest period for one day and then they were demoulded. The term ‘Rest Period’ was coined to indicate the time taken from the completion of casting of test specimens to the start of curing under ambient conditions at room temperature for 7, 28 and 56 days respectively.

G. Testing:

The specimens were tested in laboratory as per IS 516:1957 and the compressive strengths were calculated for 7, 28, and 56 days, Flexural and Split strength is calculated for 28 days and the results were tabulated.

IV. RESULTS AND DISCUSSIONS

Workability:

The following are the results obtained for different mix proportions which satisfies the EFNARC guidelines and are shown in table XI

Table XI: Workability Results

Sl.no	Test Conducted	NaOH (M)	Mix-1	Mix- 2	Mix- 3	Mix-4	Mix-5
1		8M	670	680	680	700	710
	Slump flow(mm)	10M	670	670	680	700	700
		12M	660	670	670	690	700
2		8M	4.5	3.5	3.5	3.5	3.5
	T_{50} Slump (sec)	10M	4.5	4	3.5	3.5	4
		12M	5	4	4	4	4
3		8M	10.5	9	9	8.5	7.5
	V-Funnel (sec)	10M	11	10	9.5	9	8
		12M	11	10	10	9	8
4		8M	7	7	6	6	5
	J- Ring(mm)	10M	8	8	7	7	6
		12M	9	9	8	8	7
5		8M	0.91	0.92	0.94	0.95	0.97
	L-Box (H_2/H_1)	10M	0.9	0.92	0.94	0.95	0.96
		12M	0.88	0.9	0.92	0.94	0.96

Compressive Strength:

Table XII: Compressive Strength Results Obtained For 8m

Mixes	Molarity	Density (kg/m^3)	Compressive strength, MPa		
			7th day	28th day	56th day
Mix-1 (100% GGBS)	8M	2380	30	32	36
Mix-2 (70% GGBS & 30% FLYASH)	8M	2430	28	30	33
Mix-3 (50% GGBS & 50%FLYASH)	8M	2450	23.32	29.28	32.17
Mix-4 (30% GGBS & 70% FLYASH)	8M	2415	20.15	22.35	28.5
Mix-5 (100% FLYASH)	8M	2512	6.92	8.48	10.32

Table XIII: Compressive Strength Results Obtained For 10m

Mixes	Molarity	Density (kg/m^3)	Compressive strength, MPa		
			7th day	28th day	56th day
Mix-1 (100% GGBS)	10M	2415	30	35	38
Mix-2 (70% GGBS & 30% FLYASH)	10M	2386	29.2	31	33.15
Mix-3 (50% GGBS & 50%FLYASH)	10M	2434	24.5	30.18	33.46
Mix-4 (30% GGBS & 70% FLYASH)	10M	2448	22.18	24.52	29.18
Mix-5 (100% FLYASH)	10M	2378	8.12	10.24	12.38

Table XIV: compressive strength results obtained for 12m

Mixes	Molarity	Density (kg/m^3)	Compressive strength, MPa		
			7th day	28th day	56th day
Mix-1 (100% GGBS)	12M	2386	28.8	36.5	40
Mix-2 (70% GGBS & 30% FLYASH)	12M	2435	26.15	32	34.0
Mix-3 (50% GGBS & 50%FLYASH)	12M	2468	26.3	31	34.0
Mix-4 (30% GGBS & 70% FLYASH)	12M	2464	25.12	28.49	33.49
Mix-5 (100% FLYASH)	12M	2418	10.25	12.92	15.89

Table XV: Split Tensile Strength Results

		Split tensile strength @ 28 Days in N/mm^2	
MIXES	**8M**	**10M**	**12M**
MIX 1 (100% GGBS)	**2.263**	**2.54**	**3.536**
MIX 2 (70% GGBS+30% Flyash)	**2.122**	**2.405**	**3.2538**
MIX 3 (50% GGBS+50% Flyash)	**1.556**	**2.122**	**2.829**
MIX 4 (30% GGBS+70% Flyash)	**1.4147**	**1.98**	**2.6879**
MIX 5 (100% Flyash)	**1.13**	**1.273**	**1.4147**

Table XVI: Flexural Strength Results

		Flexural strength @ 28 Days in N/mm^2	
MIXES	**8M**	**10M**	**12M**
MIX 1 (100% GGBS)	**2.9**	**3**	**3.2**
MIX 2 (70% GGBS+30% Flyash)	**2.5**	**2.8**	**3.1**
MIX 3 (50% GGBS+50% Flyash)	**2.4**	**2.4**	**2.6**
MIX 4 (30% GGBS+70% Flyash)	**1**	**1.2**	**1.2**
MIX 5 (100% Flyash)	**0**	**0**	**0**

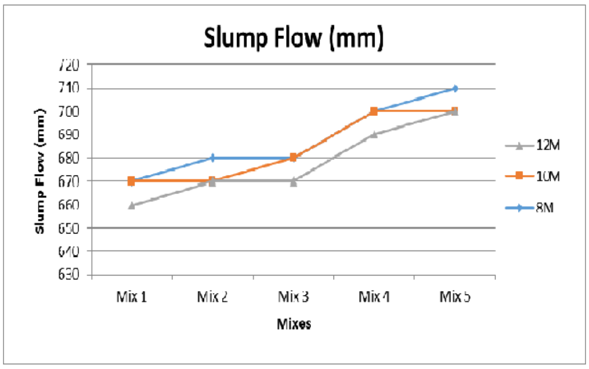

Chart 1: Slump flow for different mix proportions

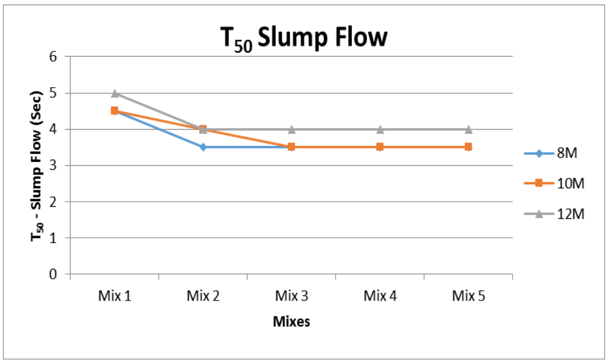

Chart 2: Slump flow at T50cm for different mix proportions

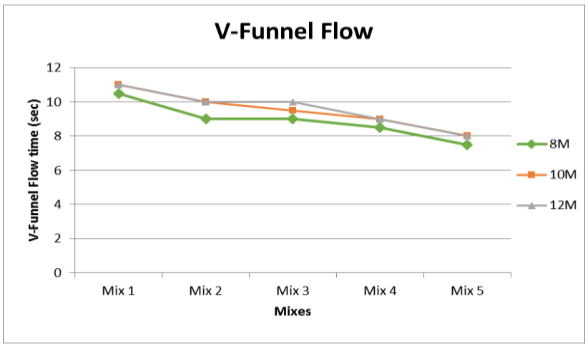

Chart 3: V-funnel results for different mix proportions

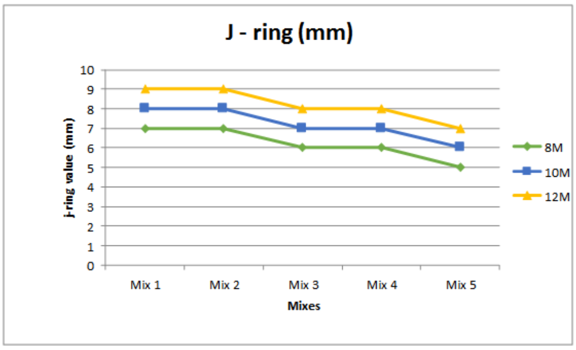

Chart 4: J-ring results for different mix proportions

Chart 5: L-box results for different mix proportions

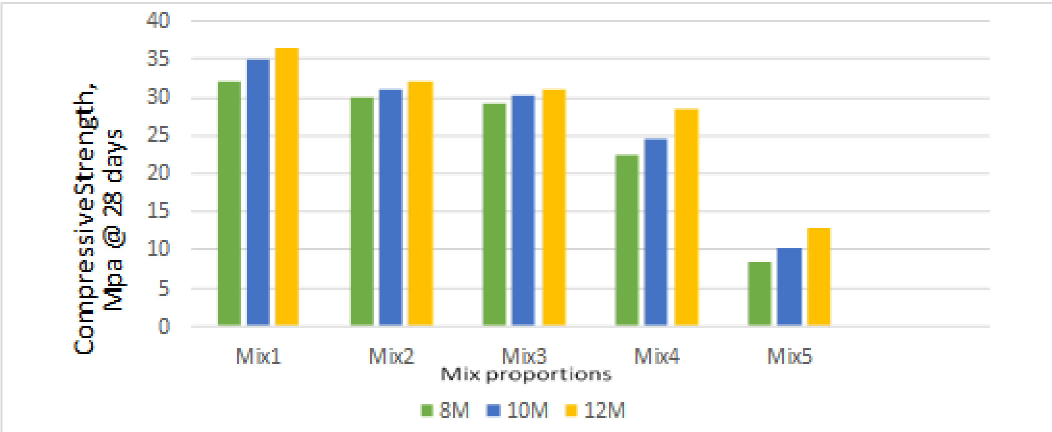

Chart 6: Compressive strength of various mixes and different molarities at 28 days

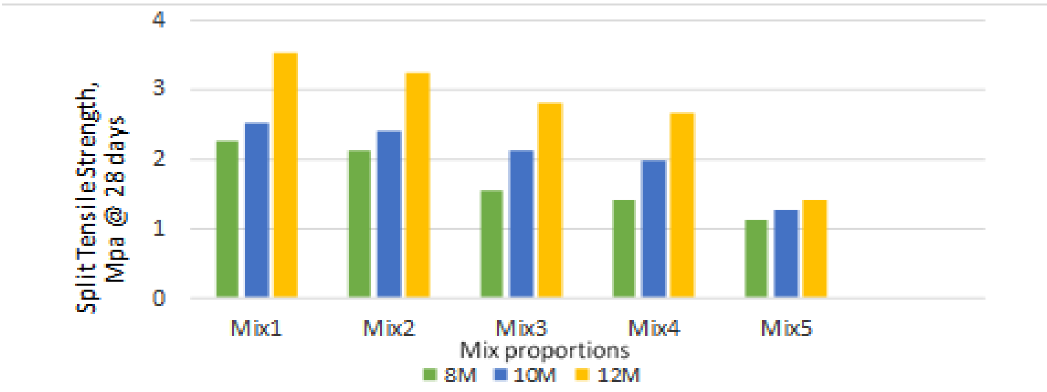

Chart 7: Split Tensile strength of various mixes and different molarities at 28 days

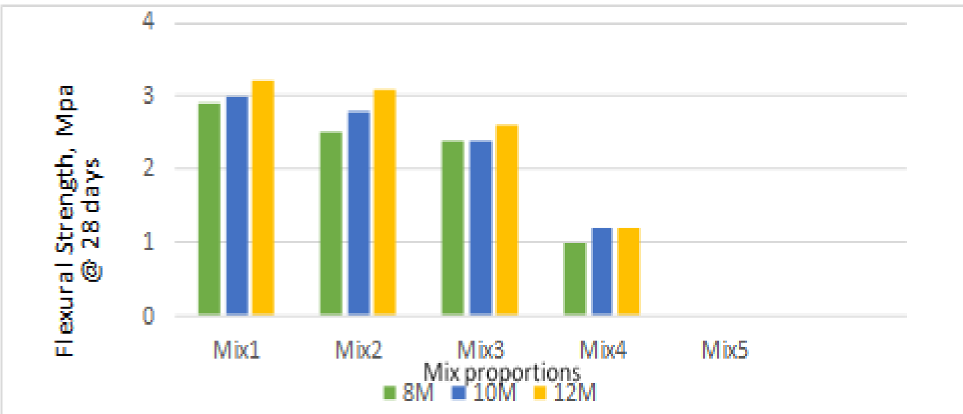

Chart 8: Flexural strength of various mixes and different molarities at 28 days

V. CONCLUSION

The following conclusions can be drawn from this study based on the results obtained:

[1]. Longer curing duration improves the process of Geo-polymerization resulting in higher compressive strength. The compressive strength is more when the specimens were cured for 56 days.

[2]. Higher concentration of molarities will results in higher compressive strength. In the present study, compressive strength is gradually increased from 8M to 12M.

[3]. The GGBS SCGPC at ambient temperature will have higher compressive strength rather than fly ash based SCGPC.

[4]. The 56 days compressive strength of GGBS based SCGPC for 12M at ambient temperature was found to be 40.00MPa, whereas for Fly ash based SCGPC was found to be 15.89MPa.

[5]. The percentage of GGBS and Fly ash in the mix will affects the workability characteristics and compressive strength of SCGPC.

[6]. The consumption of extra water is more for GGBS based SCGPC and it reduced gradually as we reduced GGBS percentage in the mix

[7]. In the present study, the result obtained from GGBS is having good initial strength and also a good binder material rather than compare to FA based SCGPC.

[8]. The split tensile strength and flexural strength is high for GGBS based SCGPC compared to fly ash based SCGPC.

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