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Optimization of Molarity on Workable Self-Compacting Geopolymer Concrete and Strength Study on SCGC by Replacing Flyash with Silica fume and GGBFS

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Abstract: Two kinds of system have been considered in this study. 100% replacement of cement by flyash and 100% replacement of river sand by manufactured sand. The workability of Self Compacting Geo polymer Concrete (SCGC) for various molarities and hardened properties of SCGC were investigated in this paper. The work focused on the concrete mixes with a fixed water-to-geopolymer solid (W/Gs) ratio of 0.33 by mass and a constant total binder content of 450 kg/m^3. The workability related fresh properties for molarity of 8M, 10M, 12M, and 14M of SCGC were assessed through slump flow,T_{50cm} Slump flow**,** V-funnel, L-box and U-Box test methods. According to EFNARC (European Federation of National Associations Representing for Concrete) guidelines the mix proportions are arrived. Based on the results taken from workability tests the optimized molarity is chosen for SCGC. The hardened properties of concrete are conducted by replacing flyash with silica fume and GGBFS.

Keywords: *Fly ash, Manufactured sand, Self Compacting Geopolymer Concrete, Alkaline Liquids, Silica fume, GGBFS*

Introduction:
Geopolymeric materials have become the focus of interest and received the considerable attention because of the environmental benefits, such as the reduction in consumption of natural resources and the decrease in production of CO_2. Unlike ordinary Portland cement, the production of raw materials for geopolymers does not require a high level of energy consumption because the high temperature calcining is not required. It is demonstrated that the geopolymeric cement generates 5-6 times less CO_2 than Portland cement. Therefore, the use of geopolymer concrete technology not only significantly reduces CO_2 emissions but also utilizes the industrial waste and/or by-product, converting a potentially hazardous material to a valuable construction material. To save our rivers from sand mining and to sustain our environment M – sand is used. The Manufactured sand was used as fine aggregate since the demand and cost of river sand is high. Self-compacting concrete, also referred to as Self-consolidating concrete can flow and consolidate under its own self weight and de-aerated almost completely while flowing in the formwork. It is cohesive enough to fill the spaces of almost any size and shape without segregation or bleeding. This makes Self-compacting concrete particularly useful wherever placing such as in heavily reinforced concrete members or in complicated formworks. Self-compacting concrete can save labor, eliminate consolidation noise and lead to innovative construction methods.
SCGC (Self Compacting Geopolymer Concrete) is relatively a new concept and can be regarded as the revolutionary development in the field of concrete technology. It is an innovative type of concrete that can achieve the combined advantages of both geopolymer concrete and SCC. Literature review indicated that, up to date, no research has been conducted on SCGC. This research study was therefore intended to explore the feasibility and potential of SCGC made with locally available constituent materials by examining its basic physical and mechanical properties,
The present work investigated the workability related fresh properties of SCGC through slump flow,T_{50cm} Slump flow**,** V-funnel, L-box and U-Box test methods.Rashida A Jhumarwala, et.al (2013)studied that It is observed that maximum compressive strength of self compacting geopolymer concrete is achieved at elevated temperature cured concrete, and as molarity increases the strength goes on decreasing but after 14M the strength again increases at 16M and at 8M maximum strength is observed. Fareed Ahmed, et.al (2011) [2] has reported that the addition of extra water improved the workability characteristics of concrete mixtures; however, the inclusion of water beyond certain limit resulted in bleeding and segregation of fresh concrete and decreased the compressive strength of the concrete. The compressive strength of SCGC was significantly decreased as the amount of extra water exceeded 12% by mass of FA [4].

Experimental Work:
The materials used for making self compacting Geopolymer concrete specimens are low calcium fly ash as the source material, manufacture sand, coarse aggregate as the filler, alkaline such as sodium hydroxide solution, sodium silicate solution were as binder and water & super plasticizer as workability measure. In this investigation, class F type of fly ash is obtained from Metur power plant with fineness

modulus and specific gravity were 7.86 and 2.21 respectively. The fineness modulus and specific gravity were 2.85 and 2.64. The sodium hydroxides (NaOH) are available in solid state in the forms of pellets. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. In this investigation 94 to 96% purity NaOH is used. Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In present investigation the ratio between sodium hydroxide and sodium silicate is taken as 1:2.5.

GGBFS is a by-product from the blast-furnaces used for manufacturing iron with specific gravity and fineness modulus of 2.9 and 450 to 550kg/m3 respectively with three grades 80,100,120. The way of its production is that the blast-furnaces are fed with carefully controlled mixtures of iron-ore, coke and limestone, with temperatures of about 1500^{o} C. Silica fume is the another type of pozzolana and its merit being the ‘Silica Fume Concrete’ produced high compressive strength which is 2 to 3 times the strength of Portland Cement Concrete (PCC) with specific gravity and fineness of 2.2 - 2.3 and 22 sq.m/g respectively.

Glenium B233 is an admixture of a new generation based on modified polycarboxylic ether. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required. It is free of chloride & low alkali. It is compatible with all types of cements. The hyper plasticizer shall be Glenium B233, high range water reducing, Super plasticizer based on polycarboxylic ether formulation. The product shall have specific gravity of 1.09 & solid contents not less than 30% by weight. Optimum dosage of Glenium B233 should be determined with trial mixes. As a guide, a dosage range of 500 ml to 1500ml per 100kg of cementitious material is normally recommended.

Preparation of Self Compacting Geopolymer Concrete:

A. Sodium Hydroxide

Sodium hydroxide pellets are taken and dissolved in water. Sodium hydroxide should be prepared 24 hours prior to use and also if it exceeds 36 hours it terminate to semi solid liquid state. So the prepared solution should be used within this time. To find the best molarity various calculations where done. The mass of NaOH solids in solution varied depending on the concentration of the solution expressed in terms of molarity (M) is shown in table 1.

Table I Mass of NaOH per Liter

NaOH	% of solids	Solids(grams)	% of water
8M	26.23	262	73.77
10M	31.37	314	68.63
12M	36.09	361	63.91
14M	40.43	404	59.57

B. Example Molarity Calculation

The solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution can vary in different molar. The mass of NaOH solids in a solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 12 molar consist of 12x40 =480grams of NaOH solids per litre of water, were 40 is the molecular weight of NaOH. This amount of NaOH solids in one litre of water will be large of its volume so it reduces to 361grams for 12 molar concentrations.

C. Alkaline Liquid

Generally alkaline liquids are prepared by mixing of sodium hydroxide solution and sodium silicate at the room temperature. When the solutions mixed together the both solution start to react with each other there polymerization process take place. It liberate large amount of heat so it is recommended to leave it for about 20 minutes thus the alkaline liquid is ready as binding agent.

D. Preparation of Fresh SCGC

For the production of fresh SCGC, fine powdered materials (i.e., fly ash, and fine aggregate) were firstly placed in a pan mixer and blended manually. Afterwards, the coarse aggregate in saturated surface dry condition was added to the mixer and mixed mechanically for about 2.5 min. At the end of this dry mixing, a well-shacked premixed liquid mixture, containing alkaline solution, Super plasticizer, and extra water, was added in the mixer. This duration was not less than 3 min. The freshly prepared concrete mix was then assessed for the essential workability tests required for characterizing SCC. Slump flow, V- funnel, and L-box tests were performed for this purpose.

Mix Design of Self Compacting Geopolymer Concrete for Various Molarities:

The mix design in the case of self-compacting geopolymer concrete is reverse to that of conventional concrete. The design is made by the help of EFNARC guidelines as shown in table II. For this study, proportions of water and solids foe various molarities like 8M, 10M, 12M, 14M are taken as shown in table III. The water to geopolymer solids (W/G’s) ratio by mass for all the mixes was maintained at 0.33 and the total powder content was fixed at 450 kg/m3. To obtain the requested workability characteristics of SCGC, a water content of 12% and super plasticizer dosage of 6% by mass for the binder were used. Based on the above discussions mix proportions has been arrived for Fresh SCGC as shown in table IV.

Table II. Typical range of SCC constituents suggested by EFNARC

Constituent	**Typical range by mass (kg/m^3)**	**Typical range by volume (liters/m^3)**
Powder	380 – 600	
Paste		300 - 380
Water	150 – 210	150 - 210
Coarse aggregate	750 – 1000	270 - 360
Fine aggregate (sand)	Content balances the volume of the other constituents, typically 48 – 55% of total aggregate weight.	
Water/Powder ratio by Volume		0.85 – 1.10

Table III Mix Proportions for various Molarity

NaOH Molarity (M)	**NaOH (57) (kg/m^3)**		**Na_2SiO_3 (143) (kg/m^3)**		**Added H_2O (kg/m^3)**	**Total (kg/m^3)**		
	Solids	**H_2O**	**solids**	**H_2O**		**H_2O**	**solids**	**W/G**
8	14.9	42.0	63.0	79.9	52.2	174.2	527.9	0.33
10	17.8	39.1	63.0	79.9	56.1	175.2	530.9	0.33
12	20.5	36.4	63.0	79.9	59.7	176.1	533.6	0.33
14	23.0	33.9	63.0	79.9	60.0	176.9	536.0	0.33

Table IV Mix Proportions for fresh SCGC

Mix	**Fly ash (kg/ m^3)**	**FA (kg/m^3)**	**CA (kg/m^3)**	**NaOH (kg/ m^3)**	**Na_2SiO_3 (kg/ m^3)**	**W/G**	**SP**	**Extra water**
8M	450	850	1000	57	143	0.33	6%	12%
10M	450	850	1000	57	143	0.33	6%	12%
12M	450	850	1000	57	143	0.33	6%	12%
14M	450	850	1000	57	143	0.33	6%	12%

CA = Coarse aggregate, FA = Fine aggregate, SP = Super plasticizer

Fresh properties and test results of SCGC:

Fresh properties of SCGC mixes were evaluated based on three key characteristics of SCC: filling ability, passing ability, and resistance to segregation. These characteristics were measured using, Slump Flow Test, T_{50cm} Slump Flow, V-Funnel Test, L-Box Test and U-Box Test.

A. Slump Flow Test

This is the simplest and most widely used test method for evaluating the flow ability of SCC. The basic equipment used in this test is the traditional slump cone used for the conventional slump test; however, the concrete placed into the mould is not tamped. To perform the test, slump cone is placed on a rigid and non-absorbent leveled plate and filled with concrete without tamping. After filling the slump cone, it is raised vertically and concrete is allowed to flow out freely. The diameter of the concrete in two perpendicular directions is measured and the average of the two measured diameters is recorded. There is no standardized threshold limit for the slump flow value, however, according to EFNARC guide lines, SCC is assumed of having a good filling ability and consistency if the diameter of the spread is in the range of 650mm to 800mm. The test is performed and results are shown in figure 1.

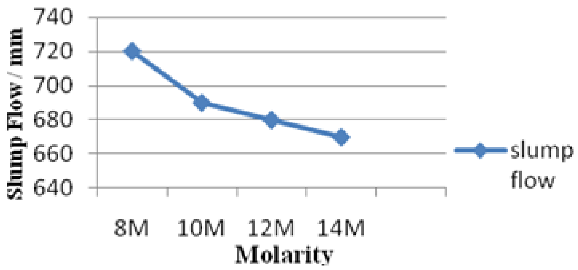

Fig 1 Slump Flow Test for Various Molarity

T_{50cm} Slump Flow

At the time of performing the slump flow test, the time taken in seconds from the instant the cone is lifted to the instant when the flow spread reaches a 500 mm circle is recorded. This flow time, termed as $T_{50\ cm}$ Slump flow, gives an indication of the relative viscosity and provides a relative assessment of the unconfined flow rate of the SCC. A lower time indicates greater flow ability. It should be noted that T_{50} times will be less meaningful and perhaps more variable for highly viscous mixes than for mixes with lower T_{50} times. This test generally not be used as a factor in rejection of a batch of SCC but rather as a quality control diagnostic test. The test is performed and results are shown in figure 2.

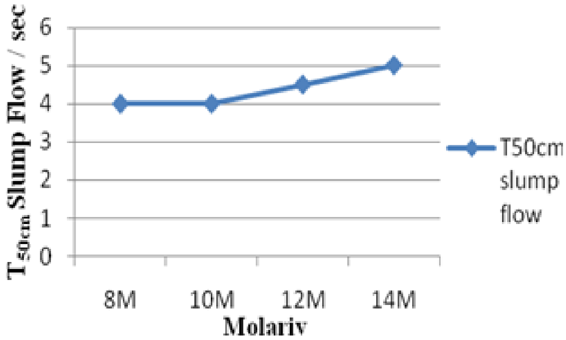

Fig 2 T_{50cm} Slump Flow Tests for Various Molarity

B. V-Funnel Test

This test is primarily used to measure the filling ability (flow ability) of SCC and can also be used to evaluate segregation resistance. The equipment used in this test consists of a V-shaped funnel. To perform this test about 12 litres (0.4 ft3) of concrete is needed and the funnel is completely filled with concrete without tapping or compaction. After filling the funnel with concrete, the trap door at the bottom is opened and concrete is allowed to flow out under gravity and the time taken for the concrete to flow out completely through the orifice is recorded as the V-funnel flow time. The funnel flow time between 6-12 seconds is generally desired for SCC. The test is performed and results are shown in figure 3 vertical section (H1) are measured to compute the blocking ratio (H2/H1). The test is performed and results are shown in figure 4.

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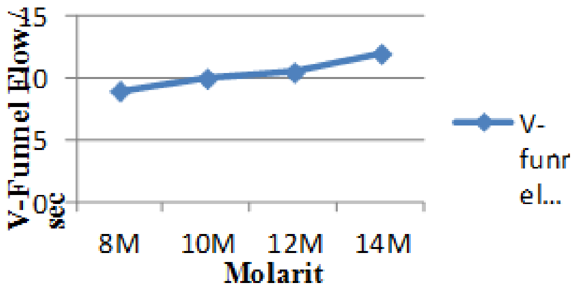

Fig 3 V-Funnel Tests for Various Molarity

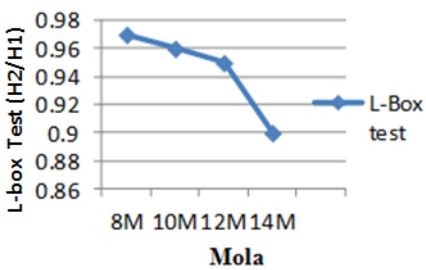

Fig 4 L- Box Tests for Various Molarity

L-Box Test

The L-box test is used to assess the filling and passing ability of SCC. The L-box test apparatus consists of a rectangular-section box in the shape of L, with a vertical and horizontal section, separated by a moveable gate, in front of which vertical reinforcement bars are fitted. Before commencing the test, the L-box is set on a firm levelled ground and inside surfaces of the box. After that, the vertical section of the box is filled with concrete and the gate separating the vertical and horizontal compartments is then lifted and the concrete is allowed to flow through closely spaced reinforcing bars at the bottom into the horizontal section of the box. When the concrete stops flowing, the heights of the concrete at the end of the horizontal section (H2) and in the

C. U-Box Test

The U-Box test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments. An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacing of 50 mm. This creates a clear spacing of 35 mm between the bars. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water Fill the one compartment of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the other compartment. After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (H1). Measure also the height in the other compartment (H2). The whole test has to be performed within 5 minutes. The test is performed and results are shown in figure 5.

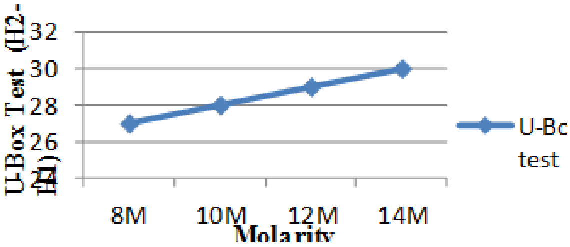

Figure 5 U-Box Tests for Various Molarity

D. Discussions

Based on workability tests for various molarities, the results are within the limits of EFNARC Guidelines. The workability of 8M concentration is high compared to all the other molarity. It is mainly due to the concentration of NaOH. It was observed that concrete mixes containing higher concentration of NaOH were more Cohesive and results in reduction of workability of SCGC.

Strength Study on SCGC:

A. Mix Design of Self Compacting Geopolymer Concrete

The mix design in the case of self compacting geopolymer concrete is inverse to that of conventional concrete. The design is made by the help of EFNARC guidelines. For this study, seven mixtures M1, M2, M3, M4, M5, M6, M7 are taken. Fly ash was replaced with GGBFS at the contents of 0%, 10%, 20%, and 30% by mass for M1, M2, M3 and M4 respectively and fly ash is replaced by Silica fume at the contents of 5%, 10%, 15% by mass for M5, M6, M7 respectively. The water to geopolymer solids (W/G's) ratio by mass for all the mixes was maintained at 0.33 and the total powder content was fixed at 450 kg/m3. To obtain the requested workability characteristics of SCGC, a water content of 12% and super plasticizer dosage of 6% by mass for the binder were used as shown in table 5.

Table V Mix Proportions for fresh SCGC

Mix proportion	**Fly ash (kg/m^3)**	**Silica Fume**	**GGBFS (kg/m^3)**	**FA (kg/m^3)**	**CA (kg/m^3)**	**Sodium hydroxide (kg/m^3)**	**Sodium silicate (kg/m^3)**	**W/G**	**SP**	**Extra water**
M1 (0% replacement by GGBFS &SF)	450	-	0	850	1000	57	143	0.33	6%	12%
M2 (10% replacement by GGBFS)	405	-	45	850	1000	57	143	0.33	6%	12%
M3 (20% replacement by GGBFS)	360	-	90	850	1000	57	143	0.33	6%	12%
M4 (30% replacement by GGBFS)	270	-	180	850	1000	57	143	0.33	6%	12%
M5 (5% replacement by SF)	427.5	22.5	-	850	1000	57	143	0.33	6%	12%
M6 (10% replacement by SF)	405	45	-	850	1000	57	143	0.33	6%	12%
M7 (15% replacement by SF)	382.5	67.5	-	850	1000	57	143	0.33	6%	12%

B. Casting of Test Specimen

The test moulds were all set and oil is applied inside, before mixing. The ingredients for SCGC were weigh batched. The concrete mixing were done using mixer machine. The concrete is taken in buckets and then poured into the moulds without any tamping or compaction. The top surface is kept smooth.

C. Curing of Specimens

In this project the ambient curing was done for periods of 7, 14 & 28 days. After casting the specimens were kept for heat curing for 48 hours then the specimens were kept in the ambient temperature till the test day.

D. Compression Test

Compression test is the most common test conducted on hardened concrete, because it is an easy test to perform and most desirable characteristic properties of concrete are qualitatively related to its compressive strength. The compression test is carried out on specimen in cubical or in cylindrical shape. Table 6 shows the compressive strength for various mixes.

Table VI Compressive strength for various Mixes

Mix	**Compressive strength in Mpa**		
	7 days	**14 days**	**28 days**
M1 (0% replacement by GGBFS & SF)	32	32.89	34.67
M2 (10% replacement by GGBFS)	31.56	32.44	35.92
M3 (20% replacement by GGBFS)	29.98	32	36.26
M4 (30% replacement by GGBFS)	28.88	31.11	38.55
M5 (5% replacement by SF)	32.89	33.33	36
M6 (10% replacement by SF)	34.67	35.56	37.38
M7 (15% replacement by SF)	32.89	33.78	35.56

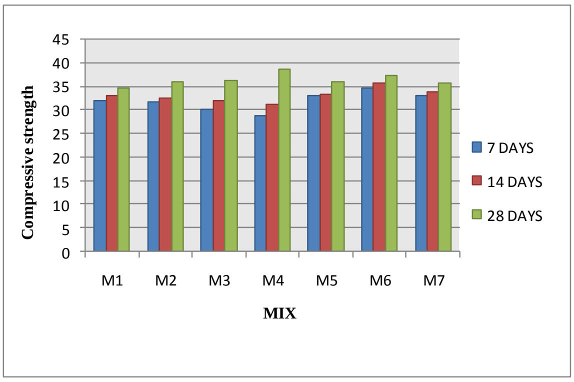

Fig 6 Compressive Strength for Various Mixes

A. Split Tensile Strength

The test was carried out on diameter of 150mm and length 300mm in size cylinder. The test results were tabulated in table 7.

Table VII Split Tensile Strength For Various Mixes

Mix	**Split Tensile Strength In Mpa**	
	14 days	**28 days**
M1 (0% replacement by GGBFS&SF)	3.25	4.2
M2 (10% replacement by GGBFS)	3.11	4.44
M3 (20% replacement by GGBFS)	2.97	4.56
M4 (30% replacement by GGBFS)	2.83	4.62
M5 (5% replacement bySF)	3.51	4.2
M6 (10% replacement bySF)	3.88	4.4
M7 (15% replacement bySF)	3.62	4.38

Mixes:

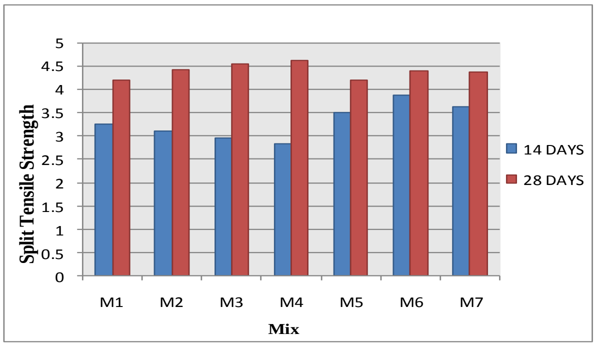

Fig 7 Split Tensile Strength for Various mixes

Flexural Test

Concrete as we know is relatively strong in compression and weak in tension. Tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other results. Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the "pull" applied to the concrete beam rest are found to be measure the flexural strength property of concrete. The test was carried out on 100 x 100 x 500 mm size prism. The test results were tabulated in table 8 using the stress values the flexural strength of binder.

Table VIII Flexural Strength For Various Mixes

Mix	Flexural Strength In Mpa 14 days	Flexural Strength In Mpa 28 days
M1 (0% replacement by GGBFS&SF)	3.86	4.2
M2 (10% replacement by GGBFS)	3.71	4.43
M3 (20% replacement by GGBFS)	3.5	4.63
M4 (30% replacement by GGBFS)	3.26	4.82
M5 (5% replacement by SF)	4.1	4.28
M6 (10% replacement by SF)	4.4	4.6
M7 (15% replacement by SF)	4.2	4.3

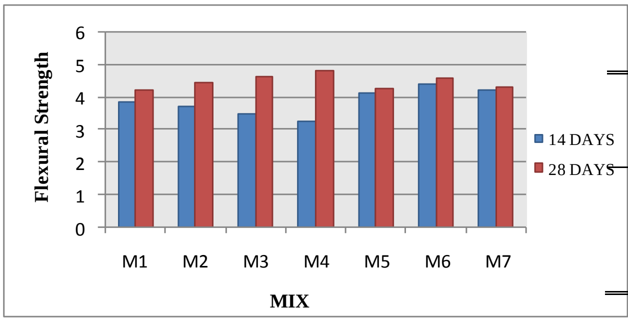

Fig 8 Flexural Strength for Various Mixes

B. *Compressive Strength for Various Molarities*

The test was carried out in 150x150x150mm size cubes. The test results were tabulated in table 9 using the stress values the compressive strength of binder (Fly ash and GGBFS). Compressive strength in Mpa=maximum load /cross section area of the cube.

Table IX Compressive Strength For Various Molarities

Molarity	Compressive Strength In Mpa 7 days
8M	28.3
10M	29
12M	33.4
14M	35.8

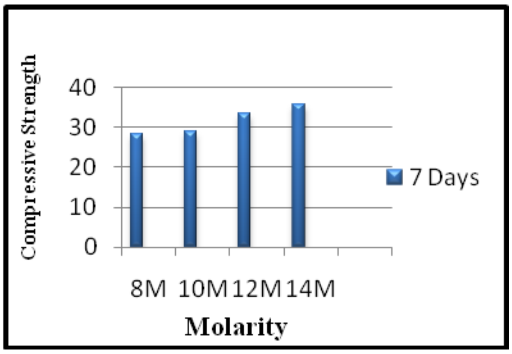

Figure 9 Compressive Strength for Various Molarity

Discussions and Conclusions:

- According to the workability test results the sodium hydroxide (pellet) molarity concentration is kept as 12M since it yield both good workability and compressive strength.
- The replacement of GGBFS with 30% (Mix 4) and replacement of Silica fume by 10% (Mix 6) shows high compressive strength, split tensile strength and flexural strength then other percentage of replacement.
- The Material achieves early strength when heat curing is adopted instead of ambient curing.
- If the replacement of GGBFS and Silica fume increases more than 30% and 15% respectively, it does not satisfy the workability requirements of SCGC.
- Based on workability tests for various molarities, the results are within the limits of EFNARC Guidelines. The workability of 8M concentration is high compared to all the other molarity. It is mainly due to the concentration of NaOH. It was observed that concrete mixes containing higher concentration of NaOH were more Cohesive and results in reduction of workability of SCGC.

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References:

[1] EFNARC, European guidelines for Self-compacting Concrete, Specification, Production and Use. (May-2005).
[2] Fareed Ahmed Memon, MuhdFadhilNuruddin, Samuel Demie and NasirShafiq "Effect of Curing Conditions on Strength of Fly ash-based Self-Compacting Geopolymer Concrete" International Journal of Civil and Environmental Engineering. pp 183-186, 2011.
[3] Ilangovana. R "strength and durability properties of concrete containing quarry dust as fine aggregate" ARPN Journal of engineering and applied science, vol 3, NO 5, pp 20-26, 2008.
[4] IS 3812: 1981 Specification for fly ash for use as pozzolana and admixture Bureau of Indian Standards, New Delhi, India.
[5] IS 383: 1970 "Specification for coarse and fine aggregates from natural sources for concrete" Bureau of Indian Standards, New Delhi, India.
[6] Rashida A Jhumarwala, P. S. Rao and T. N. Patel "Experimental Investigation on Self Compacting Geopolymer Concrete (SCGC)" Research Paper, S.V.I.T, Vasad, 2013.