NaOH Molarity's Impacts on SCGC's Workability and Durability with Ecologically Friendly Industrial By-Products

Arun B. R., Nagaraja P.S., Vedamurthy N. H., Srishaila Jagalur Mahalingasharma

Abstract— The objective of the analysis is to investigate the workability and durability properties of self-compacting geopolymer concrete (SCGC) based on fly ash and GGBS on various NaOH molarities. A system of trial and error was employed to achieve the SCGC mix ratio. By conducting workability properties test such as slump flow, T50 slump flow, V-funnel, and L-box and At 28, 56 and 90 days, durability properties such as water absorption, sulphuric acid attack and sorptivity were tested. The specimens have been cured for 24 hours in the oven at 70 ° C, and environmental healing is accompanied by the test days respectively. For all the molarities including 8, 10 and 12 M with a constant binding content of 400 kg / m3, the fly ash mass fraction was changed by GGBS by 0, 30, 50, and 70 per cent by weight. In all molarities, the fluid to binder ratio of 0.47 by mass has been kept constant and the S.P dosage has remained consistent with 0% replacement and 4% with 30, 50 and 70% replacement and the water content has therefore changed accordingly. The experimental result showed lower workability parameters such as slump flow and L-box ratios with increased molarity and GGBS content, increased T50 slump flow and increased V-Funnel with increased molarity and GGBS content, and the whole study was performed as suggested by the EFNARC guidelines. Durability properties such as water absorption and sorptiveness have shown good resistance with an increase of the GGBS content and an increase in molarity. Seventy percent fly-ash replacement by GGBS showed more strength degradation when held at 5percent concentration in the sulphuric acid medium. Hence SCGC can be a better replacement for normal OPC concrete both in terms of strength and durability with reduced CO_2 emission.

Keywords — Self-Compacting Geopolymer Concrete (SCGC), Ground Granulated Blast Furnace Slag (GGBS), Flyash (FA), Molarities (M), Manufactured Sand (M- Sand), Super Plasticizer (S.P)

I. INTRODUCTION

The rapid urbanization and population growth of the world would lead to an increase in the use of concrete & cement production resulting in high CO_2 output levels. Because of its simplicity, strength, and durability, concrete is used on our highways, dams, bridges and buildings.

One ton of cement production results in 780 kg of CO_2. 30% of the overall CO_2 generation comes from energy consumption and 70% from decarbonisation. After coal-fired energy, the concrete output is the next largest greenhouse gas emitter contributing approximately 5percent of anthropogenic global CO_2 emissions annually.

Cement recycling is the first and most important step in reducing energy use and CO_2 emissions. Using Portland cement containing pozzolanic materials such as ground granulated blast furnace slag (GGBS) fly ash, and silica fume are growing significantly. The use of cement in structural applications can be decreased by using by-product cementitious or pozzolanic material as a cement replacement. This leads to a reduction in export demand for cement. Nevertheless, the admixture of these by-products, used as cement substitute material, helps maintain growth in the construction industry, while holding the environmental balance high. One of the main advantages of using pozzolanic concrete materials is increasing the quality of concrete. In the transition zone throughout OPC concrete, the presence of large pores and crystalline substance is significantly reduced by small polymer particles. The decreased permeability increases the long-term longevity and resistance to various forms of concrete construction degradation for all cementitious materials.

It is, therefore, necessary to go beyond the present Cement industry approach to boost OPC replacement levels and maximize the use of industrial by-products as SCMs by means of a comprehensive elimination of OPC by synthesizing fully alternative energy-friendly, sustainable and energy-intensive binders. The new generation, non-conventional, modern OPC free-binders and self-compacts without segregation and blocks and flow into places and blockages with its own weight, in order to fill-up the form, in that direction, the self-compacting geopolymer concrete is a promising area. In this regard.

II. LITERATURE REVIEW

The experimental results on the durability of fly-ash base-geopolymer concrete exposed to 10% sulphuric acid solutions for up to 8 weeks were provided by **Song, et al (2005).** For this analysis, NaOH and Na_2SiO_3 solutions were used. Specimens were either cured for 24 hours at 23^0C or 70^0C. The compressive strength ranged from 53 MPa to 62 MPa at the age of 28 days. The samples were tested for 7, 28 and 56 days after immersion in a 10% sulphuric acid.

Revised Manuscript Received on January 06, 2020.

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Mass losses, reduction in compressive strength and residual alkalinity have been calculated. From their analysis, they found that geopolymer concrete, in terms of extremely low mass loss (less than 3%), is highly resistant to sulfuric acid. In addition, the geopolymer cubes are structurally intact and have significant load capacity despite the fact that all parts have been neutralized by sulphuric acid.

Rajama N.P. et al (2010) The impact and strength of fly ash with an influence on the sulphuric acid resistance of slag-based, environmentally cured geopolymers were investigated.

The findings of the test indicate that the percent loss of weight and strength in specimens from GPC for exposure to 2% sulfuric acid was substantially less than for reference concrete, thereby confirming that GPCs are highly durable for construction. However, in the case of GPCs, partial replacement of GGBS by fly ash caused a reduction in both strength as well as resistance to acid attack.

The mechanical and durable quality of the concrete made using the GGBS as a single binding tool and in contrast to the reference concrete derived from Portland concrete (OPC) is evaluated by **Susan A. Bernal et al. (2011).** The GGBS was activated alkali using a standard sodium silicate solution. The tests were performed on two forms of exercise binders: compression strength test, carbonation test, fast chloride penetration test, total porosity, water absorption test and a capillary sorptiveness test. They found that with comparable binder content the alkaline-activated scale concretes show less water absorption, total porosity and capillarity, which decrease with the increased binder content. Although they found a higher chloride penetration resistance for alkaline-activated concrete, they showed higher carbonation susceptibility.

Jeyaseela J and Vishnuram B.G (2015) assessed the workability and durability properties by replacing the fly ash with OPC by 0-20% with an increment of 5% on a mass basis. The authors identified that as the percentage of OPC increases V-funnel, L-box and J-ring values increased from (7-14) sec, (0.84-1.1) and (6-11) mm. Acid attack immersed in 5% HCl and sulfate attack immersed in 5% $MgSO_4$ was studied with respect to weight loss and it was noticed that as the cement replacement level increases the weight loss decreases 8.068-8.026 and 8.057-8.029 respectively and the reduction in compressive strength was minimum only for 5% replacement of OPC i.e. 0.92 and 0.85 respectively. And the sorptivity of the concrete also shows lower water penetration for 5% replacement of OPC specimen than the other mixes.

III. MATERIALS USED FOR PREPARING SCGC

A. Flyash and GGBS

This research has been performed on class ' F ' fly ash (FA) in compliance with IS 3812-1981 and GGBS IS 12089-1987. Fly ash and GGBS, chemical and physical properties are as shown in Table I. As shown in Fig. 1, the illustrated SEM micrographs reveal that spherical and smooth, hallow spheres called cenospheres (microspheres) and plerospheres are fly ash particles. GGBS particles are long, elongated, and flaky in shape as shown in Fig. 2.

B. Aggregates

The study included the M-sand that verified zone 2, with specific gravity 2.59, 2.2 percent water absorption and fineness modulus 2.68, and the crushed coarse aggregate from the locally crushing site, with a specific gravity of 2.67, 0.65 percent water absorption, and 6.86 modulus fineness.

TABLE-I: Chemical and physical properties of Flyash and GGBS

Contents	Fly ash	GGBS
SiO_2	62.63	33.77
Al_2O_3	23.35	13.24
Fe_2O_3	3.93	0.65
CaO	2.04	33.77
MgO	0.46	10.13
SO_3	1.34	0.23
Na_2O	0.032	…
K_2o	0.03	…
LOI	0.39	0.19
Specific Gravity	2.1	2.9
Specific surface (m^2/Kg)	310	416

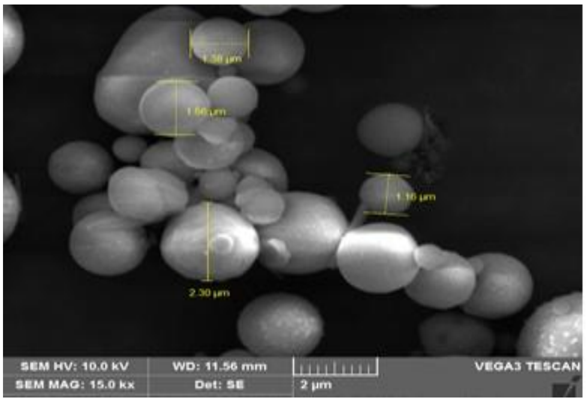

Fig.1. SEM image of Flyash

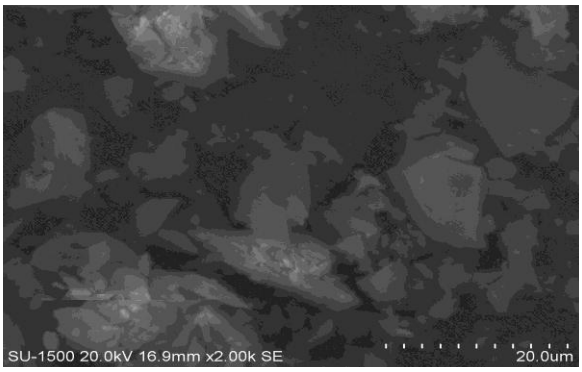

Fig.2.SEM image of GGBS

C. Super Plasticizer (S.P) and Water

Glenium SKY 8233 (S.P) with a specific gravity of 1.08 and a chloride ion content less than 0.2 percent and pH 6 was used in this analysis. For the entire study, tap water was used.

D. Sodium Hydroxide

In this study, commercial sodium hydroxide was used as pellets with a purity of 99% and a specific gravity of 2.13. At the rate of 8, 10, 12 molar concentrations, sodium hydroxide has been dissolved in the water.

It was prepared 24 hours prior to use and finishes at a semi-solid-liquid state if it exceeds 36 hours. The prepared solution was therefore used in this timeframe.

E. Example of Molarity calculation

To provide a solution with the appropriate concentration, solids must be dissolved in water. The concentration of solutions for sodium hydroxide will differ in different molars. The density of NaOH solids in a solution depends on the solution's concentration. For example, a 12-molar sodium hydroxide solution contains 12×40 = 480 grams of sodium hydroxide solids per litre of water, 40 is sodium hydroxide molecular in weight. This volume in 1 litre of water of sodium hydroxide solids is high so that it is reduced to 361 grams for 12 molar concentrations.

F. Sodium Silicate

In this analysis, sodium silicate has been employed in a liquid gel form with 55.52% water and 29.75% SiO_2 and 14.73% Na_2O composition.

G. Alkaline solution preparation

The alkaline solution was prepared in the ratio 1:2.5 at room temperature through a mixture of sodium hydroxide and sodium silicate. When both the solutions are mixed together polymerization takes place and it liberates a large amount of heat so it is left for 20 to 30minutes and thus the alkaline liquid is ready as a binding agent.

H. Mix Proportions

For the present study, twelve mixes with fly ash were replaced with GGBS at 0%, 30%, 50%, and 70% by mass. M1, M2, M3, M4 respectively for 8 Molarity and M5, M6, M7, M8 respectively for 10 Molarity and M9, M10, M11, M12 respectively for 12 Molarity as shown in Table III. The fluid-to-binding ratio (F / B) was maintained by mass for all mixtures to 0.47 and the total binder content was set to 400 kg / m^3. The required working properties of SCGC have been obtained by maintaining the 3% Superplasticizer content for Mix M1, M5 and M9 and 4% S.P content for the rest of the mixture, and by varying the extra water content according to binding mass molarities, as shown in Table III.

I. Preparation of fresh SCGC, Casting, and Curing of Specimens

Initially, a saturated pre-shacked mixture of alkaline solution, superplasticizer and water was rendered to the necessary proportions, then a finely powdered material such as fly ash, GGBS and M-Sand were manually mixed in a pan mixer, then applied to the mixer and mechanically mixed for about 2.5 min. This liquid was applied to the blender at the end of dry mixing and was continued for 2.5 to 3minutes. The freshly mixed concrete mix was then exposed to critical checks for SCC characterisation. For this reason, the slump flow, T50 slump flow, L-box and V-funnel test were performed.

Upon checking SCGC, the fresh concrete was again thoroughly mixed by hand and packed with no compaction into the moulds of the cubes, cylinders and prism so that it could cover all corners of the moulds with its own weight for testing compressive strength, split tensile strength, and flexural strength respectively. All the specimens were kept in the oven for 24hours maintained at a temperature of 70^0c for curing and after 24hours the specimens were taken out of the oven and it was demoulded and it was kept for an environmental cure until the respective check dates as shown in Fig.3.

IV. FRESH PROPERTIES AND TEST RESULTS OF SCGC

A.Properties

Test methods and properties together with their suggested EFNARC values are shown in Table II. And the findings of the SCGC workability test are shown in Table IV.

Table -II: Test method, property and recommended values as per EFNARC

Sl.No	Methods	Workability Property	Acceptance values as per EFNARC Guidelines	
			Minimum	Maximum
1	Slump flow by Abrams cone	Filling ability	650 mm	800mm
2	T50 cm Slump flow	Filling ability	2 Sec	5 Sec
3	V-Funnel	Filling ability	6 Sec	12 Sec
4	L-Box (H2/H1, ratio)	Passing ability	0.8	1

Fig.3. Oven curing at 700C & Ambient curing

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TABLE-III: Mix proportion for SCGC

Mix Proportion	Flyash (Kg/m^3)	GGBS (Kg/m^3)	M-Sand (Kg/m3)	Coarse Aggregate (Kg/m^3)	(F/B) Ratio	Molarity (M)	S.P (%)	Extra Water (%)
M1 (FA 100%)	400	0	872	706	0.47	8M	3	1
M2 (FA 70% & GGBS 30%)	280	153.6	872	706	0.47	8M	4	1
M3 (FA 50% & GGBS 50%)	200	256	872	706	0.47	8M	4	4
M4 (FA 30% & GGBS 70%)	120	358.4	872	706	0.47	8M	4	9
M5 (FA 100%)	400	0	872	706	0.47	10M	3	2
M6 (FA 70% & GGBS 30%)	280	153.6	872	706	0.47	10M	4	2.5
M7 (FA 50% & GGBS 50%)	200	256	872	706	0.47	10M	4	5.5
M8 (FA 30% & GGBS 70%)	120	358.4	872	706	0.47	10M	4	10
M9 (FA 100%)	400	0	872	706	0.47	12M	3	3.5
M10 (FA 70% & GGBS 30%)	280	153.6	872	706	0.47	12M	4	4
M11 (FA 50% & GGBS 50%)	200	256	872	706	0.47	12M	4	7
M12 (FA 30% & GGBS 70%)	120	358.4	872	706	0.47	12M	4	12

TABLE- IV: Workability test results of SCGC

Mix No	Slump Flow (mm)	T50 slump flow (sec)	V-Funnel (sec)	L-Box (H2/H1)
M1	700	4.5	10.25	0.87
M2	690	4.7	10.65	0.85
M3	690	5	11	0.84
M4	685	5	12	0.83
M5	695	4.6	10.5	0.86
M6	685	4.9	11	0.85
M7	682	5.1	13.6	0.83
M8	670	5.3	14.5	0.81
M9	690	4.8	12	0.83
M10	675	5.3	13.5	0.81
M11	670	5.4	15	0.8
M12	660	5.6	16	0.8

B. Test result of SCGC on slump flow

The slump flow test was conducted as per the guidelines given in EFNARC. Table IV displays the results obtained for various molarities, and the same is shown in Fig.4. The results of the test showed a drop in the rate of flow as the content of GGBS increases as the GGBS particles are flat and elongated and have a large area as shown in Fig 2, resulting in high demand for water and thus a reduction of concrete workability but still all values within specified limits. And as sodium hydroxide concentration rises from 8 M to 12 M, it becomes more coherent and decreases the SCGC's working efficiency.

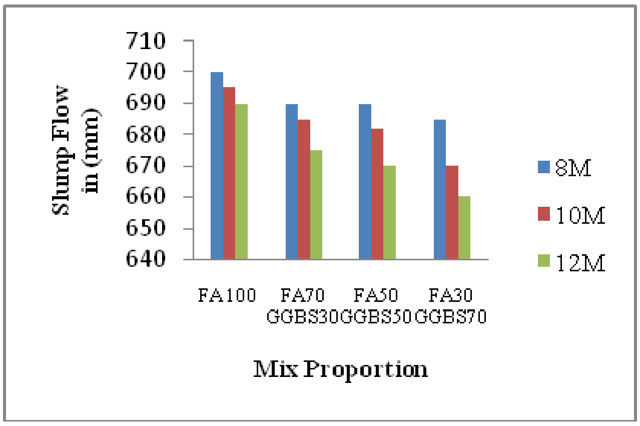

Fig.4. Slump flow test for various molarities.

C. Test result of SCGC on T50 cm slump flow

The T50 cm slump flow check offers an indicator of the relative viscosity and relative evaluation of the unconfined SCC flow rate. A lower flow rate indicates higher flowability and as shown in Fig. 5, the GGBS content increases the flow time as the paste volume with fly ash increases. The flow time is also increased because of the high viscosity of the molarity. Mix 7and 8 of 10M and Mix 10, 11, and 12 of 12M were slightly higher than the specified limit.

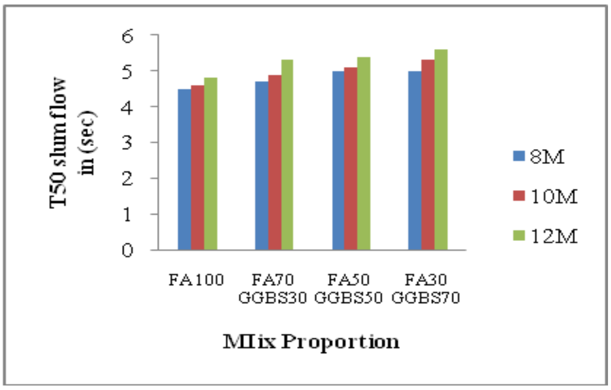

Fig.5. T50 cm slump test flow for various molarities.

D. Test results of SCGC on V- Funnel

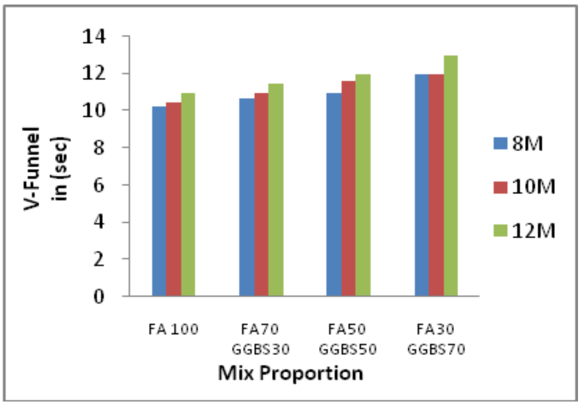

Fig.6. V-Funnel test for various molarities.

This test is used to assess the filling ability of SCC and also used to evaluate the ability of concrete to flow through a continuously reducing section without segregation and blocking. As you can see in Fig 6, as the GGBS content and Molarity are increased the flow time is also increased because due to higher sodium hydroxide concentrations the fluidity and flowability of concrete were decreased resulting in higher V-Funnel flow time. Even here Mix 7 and 8 of 10M and Mix 10, 11, and 12 of 12M were slightly higher than the specified limit.

E. Test results of SCGC on L-Box

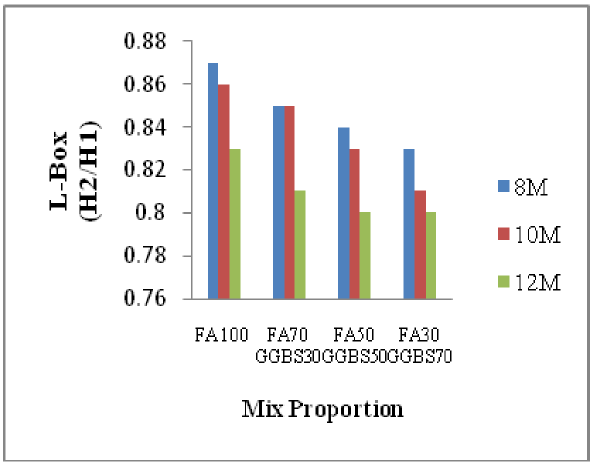

Fig.7. L-Box test for various molarities.

L-box test is used to evaluate the SCGC's ability to fill and pass. As you can see in Fig 7, the blocking frequency (H2/H1is decreased by an increase in GGBS and sodium hydroxide levels. For the L-Box test results, there is also the very same explanation and process regarding slump flow tests.

F. Compression test

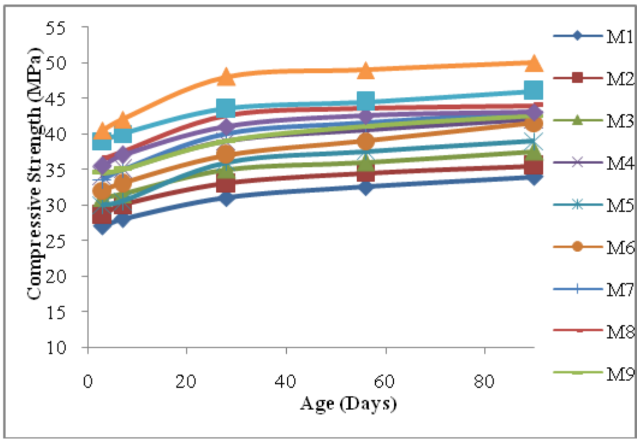

Fig.8. Compressive strength with respect to different binder Components & molarity.

Fig.8 presents the average compressive strength for different ages, binder components and molarity. It was observed that the compressive strength of SCGC increased with an increase in GGBS content implying that GGBS contributes more to the initial strength development. And it is clearly evident that due to more percentage of CaO present in GGBS i.e. 33.77% as shown in Table I which will react with water resulting in the formation of tobermorite leading to higher early strength compare to fly ash. The strength development increased with increase in GGBS from 30% to 70% this is because of its better packing ability and large surface area of around 450 m2/kg as shown in Table III compared to fly ash which is around 310 m2/kg as shown in Table III And also SEM image of GGBS in Fig.2 shows that GGBS particles are flakier and elongated resulting in better packing ability.

In Fig.8 you can also see that, because the strength of the molarity has risen, the sodium hydroxide concentration has increased the liquidation of alumina and silica, leading to a greater geopolymerisation and thus an increase in intensity. Replacement of GGBS by 70% resulted in the highest compressive strength irrespective of any molarity. The percentage increase in strength for (30% - 50% - 70%) replacement of fly ash by GGBS for 8M, 10M and 12M with respect to control mix FA100 at the end of 90days is around (4.41% - 10.30% - 23.53%), (6.41% - 10.25% - 12.82%) and (1.18% - 8.23% - 17.64%) respectively.

The percentage increase in strength from 8M to 10M and from 10M to 12M at the end of 90days for M1 series is 14.70% and 8.97% and for M2 series is 16.90% and 3.61% and for M3 series is 14.66% and 6.97% and for M4 series is 4.76% and 13.63% respectively.

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V. DURABILITY CHARACTERISTICS STUDIES

A.Water absorption test

The water absorption tests are performed to account for the relative porosity and permeability characteristics of the concretes. The water absorption test is carried out as per ASTM C 642-82 [182] at 28days, 56days and 90days by adopting the 24-hour cold-water immersion protocol.

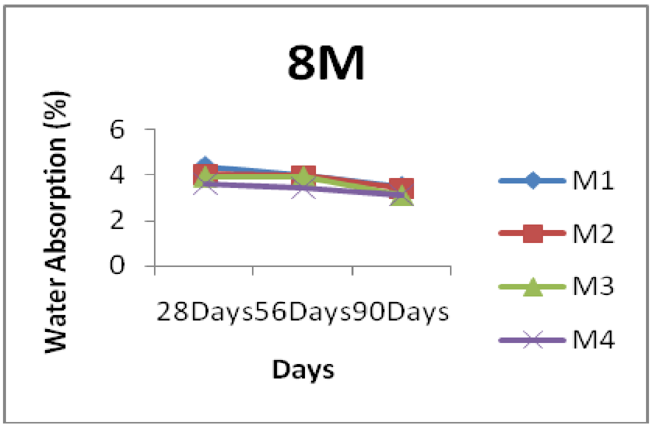

Fig.9

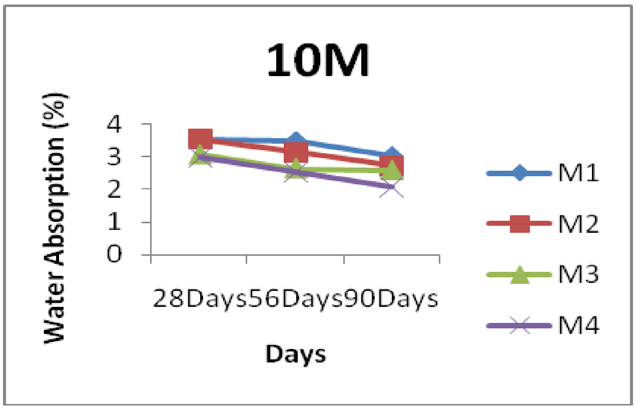

Fig. 10

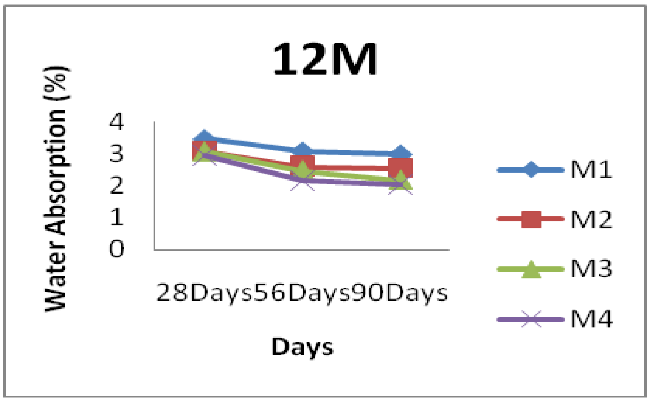

Fig. 11.

Figure 9, 10 & 11. Water Absorptionw.r.t Different Mix Proportion of SCGC for 8M,10M and 12M respectively.

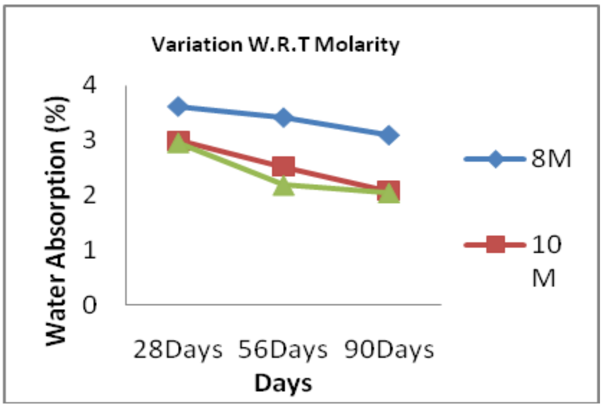

Fig.12. Water Absorption w.r.t Different Molarity for 70% Replacement of Fly ash with GGBS

As the GGBS content increased with respect to control mix water absorption decreased irrespective of any mix and molarities i.e. because as the GGBS content has increased the strength is increased which results in less water absorption and the increase in molarity attributed to the denser structure which resulted in reduced absorption. The 28days water absorption value for 70% replacement of fly ash by GGBS was lowest compared to other replacement levels. And as the days increased from 28 to 90 days water absorption was decreased. These results are consistent with the compressive strength development results which uncover that better permeability resistance is closely related to the compressive strength. Reduced absorption is shown to improve the longevity of the concrete.

The percentage decrease in water absorption from 28days to 56days and from 56days to 90days for 70% replacement of fly ash with GGBS at 24hrs for 8M is 5.5% & 9.3% and for 10M is 15.7% & 17.4% and for 12M is 26.1% & 6.4% respectively. The percentage decrease in water absorption from 8M to 10M and from 10M to 12M for 70% replacement of fly ash with GGBS at 24hrs at 28days is 17.1% & 1.3% and at 56days is 26% and 13.5% and at 90days is 32.6% and 1.9% respectively.

Fig. 13. Absorption test setup

B. Sportivity Test

Sorptivity test is to examine the quality of concrete specimens in terms of density and imperviousness. The experimentation is to estimate the sorptivity of SCGC for different molarities like 8M, 10M and 12M by incorporating mineral admixture like fly ash and GGBS in various proportions.

From the following equation the sorptiveness can be calculated:

Sorptivity $Si= \frac{I}{\sqrt{t}+b}$

Where $I = \frac{\Delta m}{a * d}$

I= water absorption in mm
Δm= change in mass in grams at the time t in sec
A= area of the exposed specimen in mm2
D= density of water in g/mm2
b= points measured up to 6 hours are used

Fig.14.Sorptivity test setup

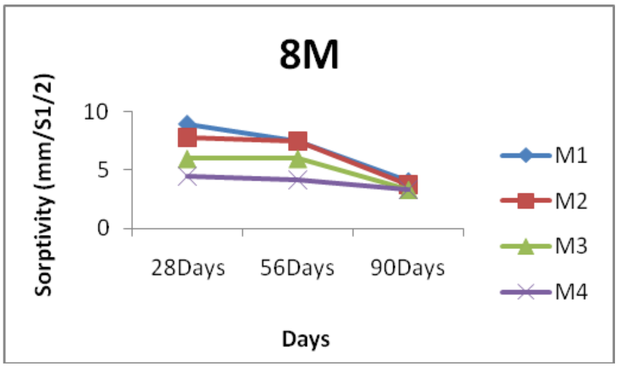

Fig.15

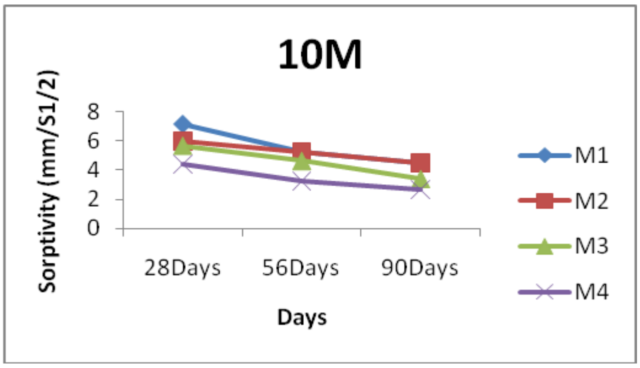

Fig.16

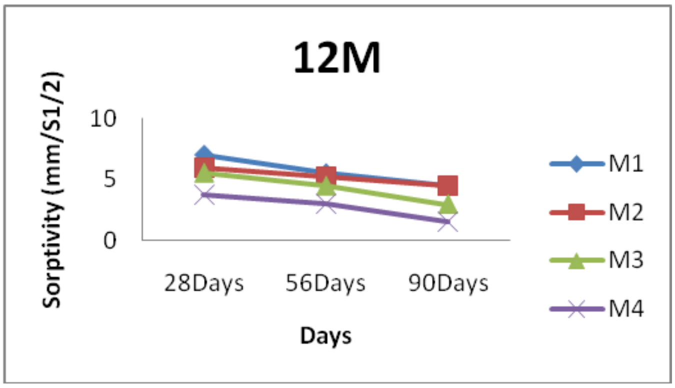

Fig. 17

Figure 15, 16 & 17. Variation in Sorptivity w.r.t Different Mix Proportion of SCGC for 8M, 10M, 12M respectively.

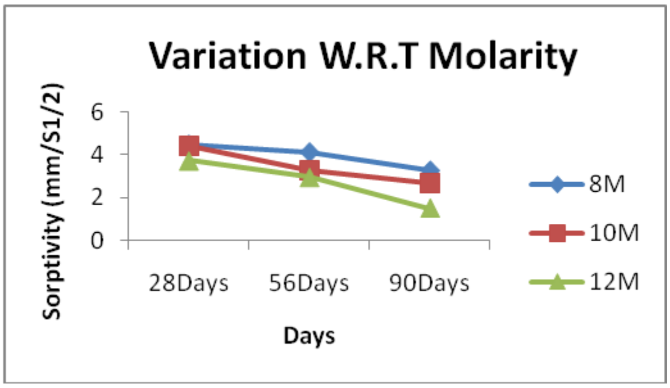

Fig.18. Variation in Sorptivity w.r.t Different Molarity for 70% Replacement of Fly ash with GGBS.

Fig. 15, 16 and 17 show the 6 hours initial sorptivity values of SCGC with the addition of fly ash and GGBS for 8M, 10M and 12M molarity respectively. From the figure, it's clearly evident that as the percentage of GGBS increases the sorptivity values keep on decreasing irrespective of any molarity.

Fig. 18 shows the variation of sorptivity values at 28days for 70% replacement of fly ash with GGBS for different molarities like 8M, 10M and 12M. As the molarity is increased the sorptivity values decreased this is because of the fact that more the compressive strength lesser is the water absorption. The percentage decrease in sorptivity values from 8M to 10M and from 10M to 12M at 90days is 18.29% and 44.4% respectively.

C. Acid Attack Test

The acidic attack is a subject of increasing importance; owing to the spread of the damages due to acid attack on concrete structures in both urban and industrial areas. The experimentation is to evaluate the reduction in compressive strength due to acid attack on fly ash-GGBS based SCGC. Concrete cubes of size 100 mm are immersed in 5% Sulphuric acid (H_2SO_4) solution maintained at pH 5, for 28, 56 and 90 days.

Fig.19.Cubes kept in sulphuric acid medium

D. Weight Changes under Acid Attack

Fig.20 shows the change in weight for different mix proportions of Fly ash GGBS based, SCGC when immersed in 5% solutions of sulphuric acid, for different duration's upto 90 days. The weight loss is due to the erosion of the materials. All the mixes suffered weight loss to a different extent. The weight loss is found to be much higher for 70% replacement of fly ash with GGBS i.e. for M4 mix, irrespective of molarity.

The weight loss increases with the duration of exposure. While the percentage weight loss at 90 days of exposure from 8M to 10M and from 10M to 12M for 70% replacement of fly ash with GGBS is 0.41% and 2.07% respectively.

E. Residual Strength under Acid Attack

Fig.21 presents the variations of residual compressive strength of Fly ash GGBS based SCGC with that of normal compressive strength values and it is evident that all specimens undergo strength deterioration when immersed in 5 % solution of $H_2SO_4$for different mix proportions and for different durations upto 90 days. Fig.21 shows that a decrease in fly ash content in concrete increases the deterioration owing to sulphuric acid compared to GGBS. As the percentage of GGBS increased the reduction in strength kept on increasing irrespective of any days and molarity this may be due to the more percentage of CaO present in GGBS. The strength loss increases gradually till 56days and after 56 days we can see a slight reduction for all the mixes irrespective of any molarity. And as the molarity increased residual strength also decreased.

The more degradation of strength was for 70% replacement of fly ash with GGBS. The percentage decrease in strength from 8M to 10M and from 10m to 12M at the end of 90days is 4.76% & 13.40% respectively.

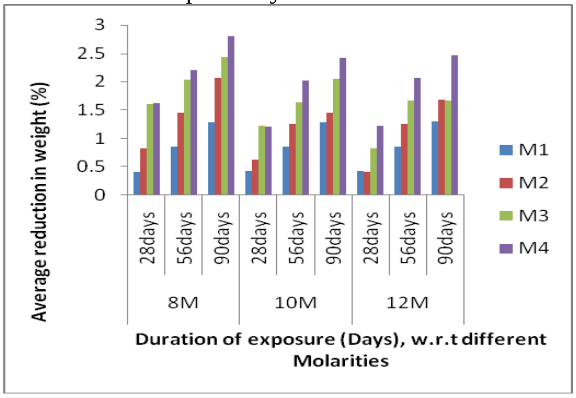

Fig.20. weight loss with duration of exposure.w.r.t different mix proportion and different Molarities under sulphuric acid attack.

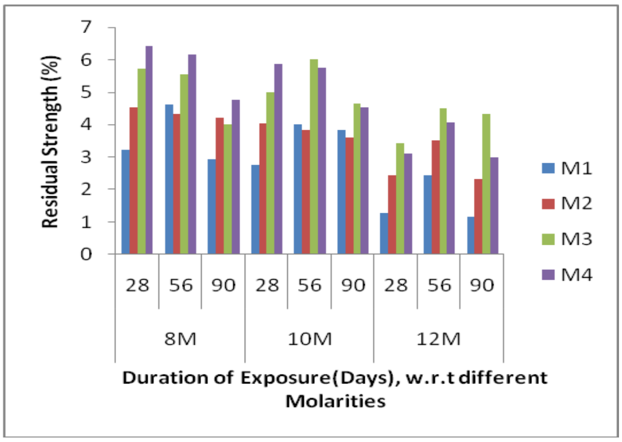

Fig.21: Residual Strength with duration of exposure, wr.t different mix proportion and different Molarities under sulphuric acid attack.

VI. CONCLUSION

1. M-sand can be a fine aggregate alternative to natural sand.
2. With the rise in GGBS content and with an improvement in NaOH concentration from 8M to 12M for the reference mix (fly-ash 100%), workability parameters such as slump flow, L-Box values decreased and T50 slump flow, V-funnel values increased and all values were within EFNARC guidelines limits.
3. In general, Fly-ash/GGBS based oven-cured SCGC attains strength with age, for all binder proportions and for all molarities.
4. With the incremental rise in GGBS content and a corresponding decrease in fly-ash content at all ages, compressive strength increases.
5. The increase in NaOH concentration from 8M to 12M molarity increases the compressive strength irrespective of any mix.
6. The 7th-day compressive strength for all the mixes and molarities was more than 28MPa and 28th day compressive strength for all the mixes and molarities was more than 30MPa which is almost equal to the strength of M30grade concrete. And maximum strength of 50MPa was achieved for 30:70 proportion (fly-ash: GGBS) at 90days for 12M.
7. Water absorption and sorptivity of fly-ash/GGBS based SCGC decreased with increase in GGBS content and as well decreased with increase in molarity due to the denser structure formed and hence resulted in less water absorption.
8. When exposed to aggressive chemicals like 5 % solution of H_2SO_4 for 90 days, fly-ash/GGBS based SCGC exhibits very little mass change. The mass loss was comparatively more for 70% replacement of fly-ash with GGBS compare to other mixes, irrespective of any molarity.
9. As the percentage of GGBS increased the reduction in strength kept on increasing irrespective of any days and molarity this may be due to the more percentage of CaO present in GGBS. The more degradation of strength was for 70% replacement of fly-ash with GGBS.
10. Fly-ash: GGBS proportion in the range of 50:50 irrespective of any molarity seems to be desirable from both performance and economic considerations.

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