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EFFECTS OF FLY ASH AND BLAST FURNACE SLAG ON THE PERFORMANCE OF SELF-COMPACTING GEO-POLYMER CONCRETE

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ABSTRACT

Multiple studies had created better understanding about the behavior of self-compacting concrete and in the last decade it had gained wider usage when it comes to congested reinforcement. Experiments were conducted to observe the impact of replacing Cement by fly ash and ground granulated blast furnace slag (GGBS) by keeping the molarity of sodium hydroxide from 8M to 12 M, Binding materials used in this study are fly ash and GGBS which were taken in varying proportions.A 0.5 liquid to binder ratio was considered where the proportions of sodium silicate and sodium hydroxide solutions were kept constant as 2.5. Workability characteristics of fresh concrete were studied.When the molarity of the sodium hydroxide was reduced, there was significant reduction in the workability of the concrete. Moreover, high concentration of NaOH and GGBFS had showns an increase in the hardened concrete properties.

Key words: alkaline solution; geo-polymer concrete; GGBS; fly ash; self-compacting concrete

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1. INTRODUCTION

Civil engineering structures are becoming complicated day by day and the load carrying capacity per m^2 of every structure is increasing steadily. This is mostly achieved by increasing the reinforcement in reinforced concrete (RC) to limit state level, thereby achieving highest possible strength which leads up to congested reinforcement. Pouring concrete in this form work is becoming difficult which lead to the creation of Self-Compacting Concrete which has high flowability with required strength. It is mostly made up of a binder, aggregate with rheological enhancement by addition of various fluids such as Viscosity modifiers and super plasticizers in the required volume. It is found that fresh SCC flows into its place by going around the obstructions due to its own weight itself and filling the formwork fully in a self-compacting mode without any sort of segregation or blocking. Real time elimination of compaction leads to high quality concrete with good workability condition, mostly SCC is made with higher filler content than aggregate and ends up in excessive compressive strength (Bouzoubaa, and Lachemi, (2001); Sonebi, (2004))

Many waste materials were used as admixtures or fillers in SCC such as fly ash (Bouzoubaa, and Lachemi, (2001); Sonebi, (2004)), fibers (Sahmaran,and Yaman, (2007), slag (Kuder, ,2012), silica fume and high volume fly ash (Yazıcı, (2008) etc. pulvirised fuel ash (Liu, M. (2010);Tyre rubber waste (Bignozzi, and Sandrolini, (2006), coarse and fine recycled aggregate (Kou, and Poon, (2009, basalt fiber (Sateshkuma and Gobinath, 2017)), glass fibers (Sathanandham et al., 2015;Sureshkumar, 2015)), coir fiber (Sureshkumar et al., (2015), saw dust (Shobana et al., 2014).

Bouzoubaa, and Lachemi (2001) investigated the SCC made of high volume fly ash, they had produced nine different SCC mixtures with one variety as control concrete. In their experimentation, the cementitious material is kept constant in the range of 0.35 to 0.45 and its replaced by using fly ash by 40%, 50%, and 60%. The SCC produced by them gave a compressive strength of from 26 to 48 MPa through which its observed that usage of SCC is economical. The following studies (Karthik et al, 2017; Awoyera, 2015a, b;Malhotra et al., 2002) had observed new techniques and materials have been introduced for concrete production focusing in reducing the use of cement as a binding material. (Hardjito et al., 2005) Thus a pozzolonic material which is termed to be a waste material or a byproduct from the power generation plants have been introduced in the replacing cement. Since last decade, many researches have been done using fly ash because of its silica and alumina content. Consequently, the use of geopolymer has many benefits such as it helps in reducing CO_2 emission, utilization of waste materials in an effective way and also it produces an ecofriendly construction. (Neville, 2000). During concreting compaction and reduction in void ratio plays an vital role in predicting the strength increase of the concrete mix (Okamura et al., 2003) The workability of concrete in its fresh state should ensure better flow of concrete. The primary aim of self-compacting concrete is to minimize the entrapped air and to enhance the compaction characteristics of concrete by itself. Xie et al. (2002) and Khatib et al. (2008) studied the properties of SCC made with low calcium fly ash (Class F). Nuruddin et al. (2010) explored the workability, strength and durability characteristics in a self-compacting concrete containing fly ash as partial replacement for cement. Fly ash addition into the concrete enhanced the workability and strength of the concrete. Cover materials are essential for upgraded quality and solidness execution. Another creative material toward this path is SCGC solid which utilizes squander materials like Fly fiery remains, and Ground granulated impact heater slag as fastener materials, which are less poison and enhance the cementing operation not requiring any vibration for compacting.(Thangaraj Sathanandam et al., 2017) has reported that there was generous increment in elasticity of geopolymer because of expansion of glass fiber. Split rigidity has expanded by 5-10% in glass fiber-reinforced geopolymer concrete, containing 0.1-0.5% of glass fiber and 16 M NaOH when contrasted with the unreinforced geopolymer concrete.

Kou and Poon (2009) through their study presented the mechanical properties of SCC which contains low-lime and high-lime fly ash (FA). Five different contents of high-lime FA and low-lime FA is used as a replacement of (30, 40, 50, 60 and 70 % by weight) with a control concrete which does not contains any FA. Results obtained confirmed that producing SCC with even upto 70% cement replaced with fly ash is possible without compromising its strength. Liu, (2010) also confirmed the same by replacing cement with 80% fly ash in producing SCC. They had also shown that addition of fly ash will have negative effect on passing ability, consistency retention and will have impact on hardened properties of concrete.

Katib (2008) studied the influence of fly ash in various properties of SCC by replacing Portland cement with 0-80% fly ash by keeping water to binder ratio as 0.36 for all types of mixes adopted. He studied various properties including workability, compressive strength, adsorption and linear shrinkage and nondestructive testing. His results indicated that high volume fly ash can also be used in SCC to produce a concrete which has lesser shrinkage. It is found that there is systematic reduction in shrinkage with the increasing fly ash content and at 80% fly ash content it reduced to two thirds original value. Also, it is obtained that the correlation between strength and adsorption shows sharp decrease in strength when the adsorption increases from 1 to 2% and after that the strength reduces at a very lower rate.

Fareed Ahmedet al., (2011) studied in self-compacting geopolymer concrete by mixing fly ash and ground granulated blast furnace slag (GGBS), and they found the usage more beneficial.

Li and Zhao (2003) investigated the influence of fly ash and ground granulated blast-furnace slag on high strength concrete which is found to be a contrast study. They had assessed the concrete mixes both on short and long-term performance and also studied the acid attack on the concrete. It is concluded that this combination will improve both short and long-term properties of concrete.Srishaila et al., (2014) investigated SCGPC utilization with the locally available construction materials that helps the concrete in both it's fresh and hardened states. Also, this study has been used to promote and creating an awareness among the construction methods and utilization of FA in SCGPC. GGBS proved to be a viable admixture to enhance corrosion resistance in concrete and research suggests that more corrosion resistance can be achieved, if volume of GGBS added is high in Type 1 cement rather than Type V cement (Yeau, and Kim, 2005).

2. EXPERIMENTAL WORK

Materials

Fly Ash

Materials were selected according to the specifications that meet the requirements of British Standards and EFNARC guidelines. Fadhil Nuruddin et al. (2011) used the base material in this study is a dry low calcium Fly ash, which was sourced from a thermal power Plants in Talminadu. American Standard Testing and Material (ASTM C618) classifies the Fly ash into two types based on the constituent of CaO in it named as Class F and Class C. In this research Class F Fly ash has been used. The specific gravity of the fly ash, obtained using apycnometer is 2.02. Table 1 shows the chemical composition of the fly ash. .

Table 1 Chemical composition of flyash

Parameters	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	K_2O	SO_3	LOI	Bulk density
Concentration (%)	62.63	23.35	3.93	2.04	0.032	0.46	0.030	1.34	0.39	1.11gm/cc

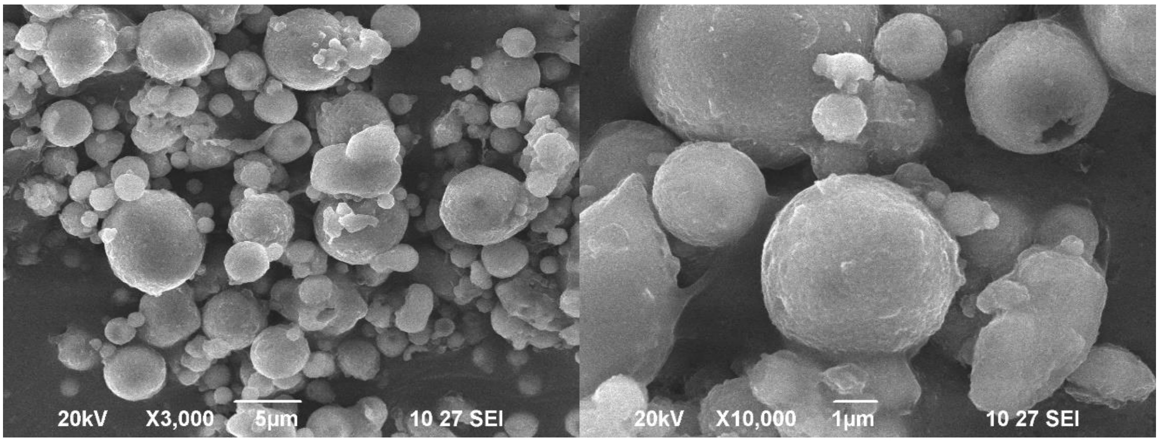

Figure 1 SEM images of fly ash particles (a) low magnification (b) high magnification

Ground Granulated Blast Furnace Slag

GGBS was sourced from Jindal Steel Plant located in Bellary, Karnataka, India. It has a specific gravity of 2.72. Table II presents the chemical composition of the GGBS. The dominant oxides in the GGBS areSiO_2, Al_2O_3, and CaO, which are the major contents to aid pozzollanic reaction in a cement based material (Awoyera et al., 2017).

Table II Chemical composition of GGBS

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Concentration (%)	35.47	19.36	0.8	33.25	8.69

Aggregates

A well graded coarse aggregate with uniformity in size obtained from a locally available crushed granite stone is used and the sand conforming to the standards of zone II were used in this study.

Table III Properties of the aggregates used

Properties	Coarse aggregate	Fineaggregate
Specific gravity (SG)	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

Alkaline Solutions

Komljenovi´c et al. (2010) prepared geopolymerization, addition of fly ash and incorporating a self compacting medium involves proper selection alkaline solution. The most used alkaline solution is a mixture ofsodium hydroxideor potassium hydroxidewithsodium silicate or potassium silicate. The most suitable alkaline solution is the combination of NaOH and sodium silicate, because this material combination partially polymerized silicon in it, which aids the reaction, and also significantly enhances the characteristics of mortar (Xu et al., 2000). Again, the material combination also help the process of geopolymerization (Palomo et al., 1999). In normal geopolymer concrete as showed by, (Fadhil Nuruddin et al., 2011) was evident that the higher the alkaline content doesn't involve better performance. By results it is seen that the 12M of NaOH concentration has a better performance than 18M of NaOH concentration due to the excess of OH^- Concentration in the system.

Table IV Properties of the sodium silicate used

SG	1.50
Na_2O	11
SO_2	31.25
(Na_2O): (SO_2)	1:2.84
Iron content	<100ppm

The NaOH solution is made by mixing the commercial grade of NaOH flakes of purity 97% - 99% in water with a proper dilution of the flakes. The SG of the pellets is 2.13 with a purity of 99%.

Table V Properties of the sodium hydroxide used

Sodium hydroxide	99.79
Sodium carbonate	0.177
Sodium chloride	0.017
Sodium sulphate	0.005
Silicate	0.001
Iron	4.0
Copper	<2
Manganese	<1
Water insoluble in water % by mass	0.005

Water

A potable water, having some amount of dissolved salt was used for the preparation of alkaline solution.Afterthe addition of alkaline solution ordinary water is also added for better workability of concrete. Both the physical and the chemical properties of the water used is presented in Table VI.

Table VI Properties of the water used

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

Chemical Admixture

(Fadhil Nuruddin et al., 2011) added super plasticizer (conflast 430) to influence and improve the workability of the concretefor a certain extent for self compacting of geopolymerconcrete.(FareedAhmedet al., 2011)The ordinary drinking water available in concrete laboratory was used for this purpose.

Preparation of Alkaline Solution

(Srishaila et al., 2014) prepared the mass of NaOHsolidin depends uponthe concentration of the solution.Yhesolutionis prepared by mixingflakes of NaOHin water .The concentrationof NaOH is set as 8M increasing upto 12M.For a solution of concentration of 8M it consist of 320 grams(8x40) of NaOH solid. Similarly, the 10M, and 12M NaOH solutionof 400 grams and 480 grams were prepared.The solution was left for 24 hours after preparation before use so as to enhance its reactivity.

Mix Proportions

In this study, a geo-polymer is prepared by mixingFly ash and GGBS in the form of a paste and used as a partial replacement for OPC. The production of SCGC was done by utilizing the conventional experimentation of innovation techniques. In the first place, various trial mix of SCGPC were fabricated. Fifteen (15) mixes were produced to determinetheworkability attributes and quality properties. Cover materials, for example, Fly ashandGGBS arebroughtwith 100:0, 70:30, 50:50, 30:70 and 0:100extentsfor8M, 10M, and 12M separately. The basic answer for fastener proportion was kept steady at 0.5 though the proportion of sodium silicate to sodium hydroxidearrangementwas kept 2.5for all mixes. Thedetails of mix proportions forsamples containing molarities 8M, 10M and 12Mare given in Tables IX.A, IX.B and IX.C, respectively.

Mixing of Constituent Materials

The concrete mixing was performed at two stages, first fine sand coarse aggregate are mix dry with a saturated rough dust free surface Then fly ash and GGBS are mixed together ina 100litcapacity concrete mixer for 2 minutes in the other hand separately at the end superplasticizer is added and mixing is continued for another 3 minute then the gelatinous solution of geopolymer is mixed with the dry sand and coarse aggregate mix . the mix is continued for ensuring the concrete mix homogeneity. Subsequently, th eworkaiblity characteristics of the SCC, following standard procedures, were determined. Then, concrete cubes of 150 mm sizes, cylinders of 150 mm x 300 mm, and prisms of 100 mm x 100 mm x 500 mm were cast, for the assessment of the compressive, split-tensile, and flexural strengths of the concrete samples, respectively.

Workability Characteristics

(Obonyo et al., 2011) studied that workability of a concrete mix plays an important characteristic in SCC It is a main property that predicts the compaction rate of the concrete. It also aids the determination of the hardened property of the concrete.The workability of the concrete,slump flow test, J-Ring test, V-Funnel, L-box tests were carried out.Table X shows the recommended values for the workability of a self-compacting concrete using the guidelines of the European standards.

Table X Recommended ranges of values using EFNARCguide lines

SL.No.	Test	Recommended ranges based on EFNARC criteria	
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

Strength Tests

The concrete was tested using IS516:1957, and the strength properties were determined after 7,14, and 28days, however, flexural and split-tensile strength was calculated for 28 daysand the results were tabulated.

In this study, compressive strength test was performed in accordance withBS EN12390-3:2002 using 2000 KN Digital Compressive and Flexural Testing Machine in the Concrete Laboratory of Civil Engineering Department University Technology PETRONAS. A set of three cubes for eachmixwere testedon the 1-day after specified curing period. The average compressive strength ofthe three cubes for all mix composition is presented inTableXII.

3. RESULTS AND DISCUSSIONS

Workability

The workability properties, slump flow, T_{50} flow, V-funnel flow time, J-ring value, and L-box ratio of the tested concrete mixtures are presented in Figures 2, 3, 4, 5, and 6 respectively.The workability properties of all the tested mixtures fell within the recommended limits of EFNARC. Higher slump flow are obtainable when the molarity of the alkaline solution is 8M. For all the mixtures, the slump flow reduced as the molarity increased. However, for the T_{50} flow, V-funnel, J-ring, and L-box flows, higher molarity of the alkaline solution enhanced the flowability of the concrete mixes.

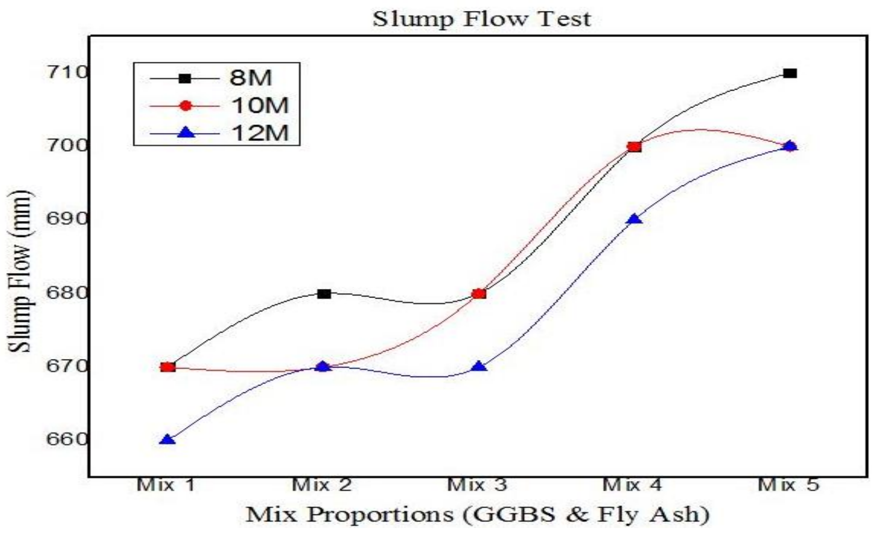

Figure 2 Slump flow

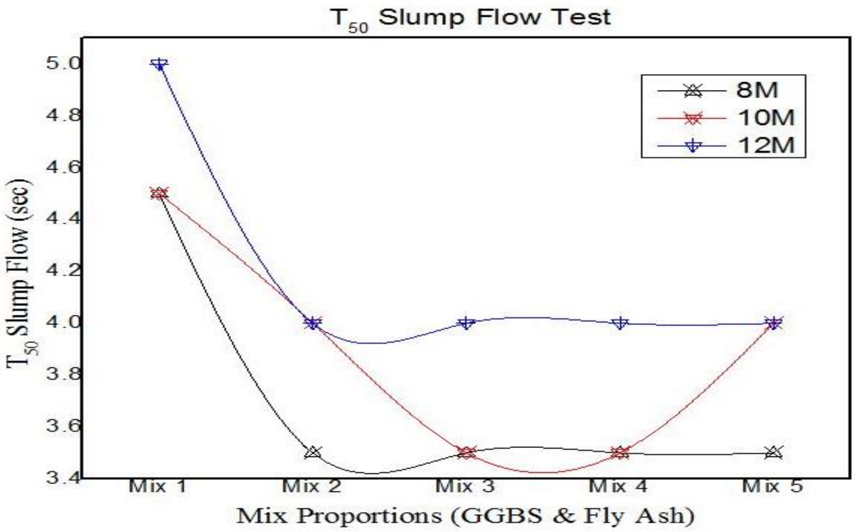

Figure 3 T_{50} slump flow

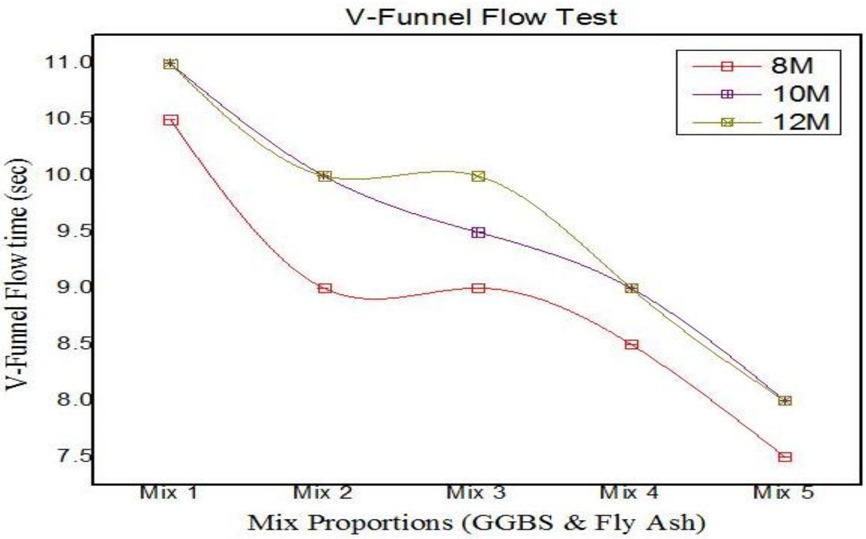

Figure 4 V-funnel flow

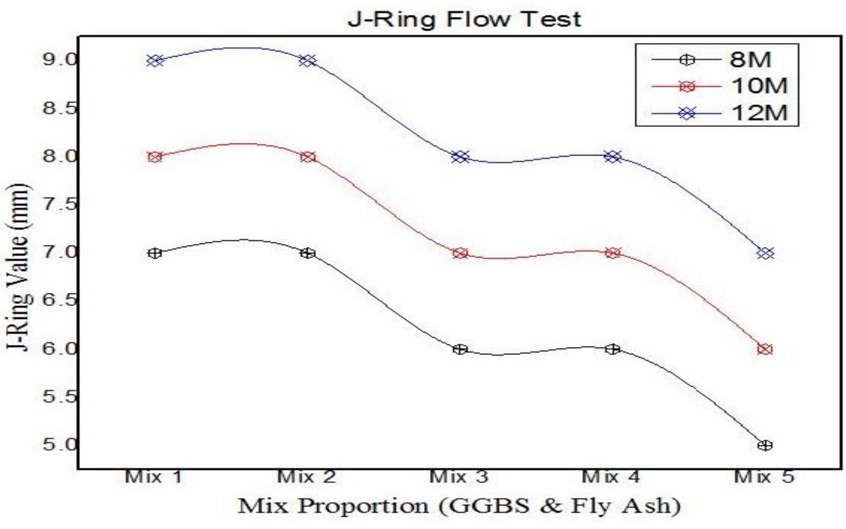

Figure 5 J-ring value

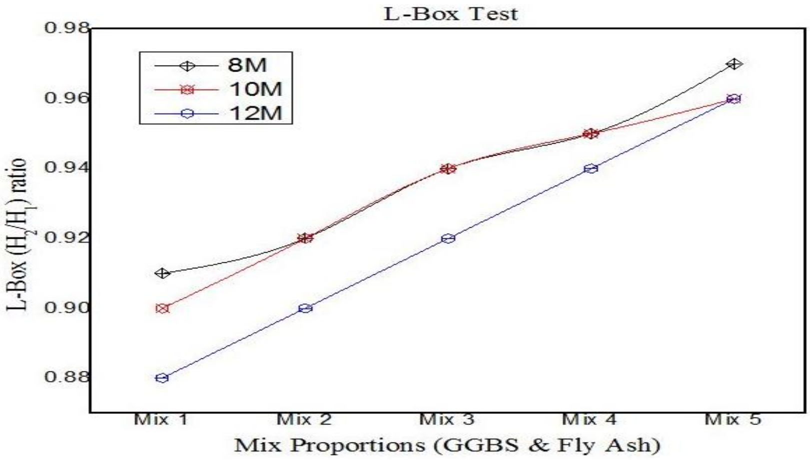

Figure 6 L-box ratio

4. COMPRESSIVE STRENGTH

Figures 7, 8, and 9 show the compressive strength development for the concrete mixtures at 7, 28, and 56 days respectively. There was significant improvement in the strength of the mixtures from 7 to 56 days curing period. The compressive strength was best at a molarity of 12M, however, the compressive strength generally increased with increasing molarity of the alkaline solution.

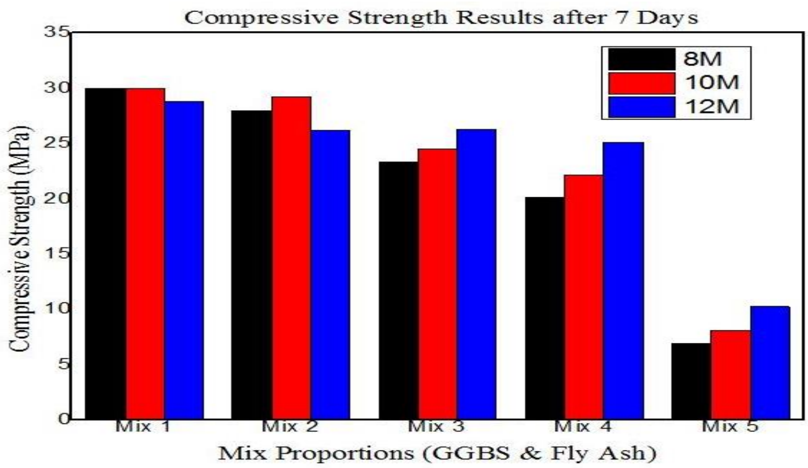

Figure 7 Compressive strength development per mix after 7 days curing

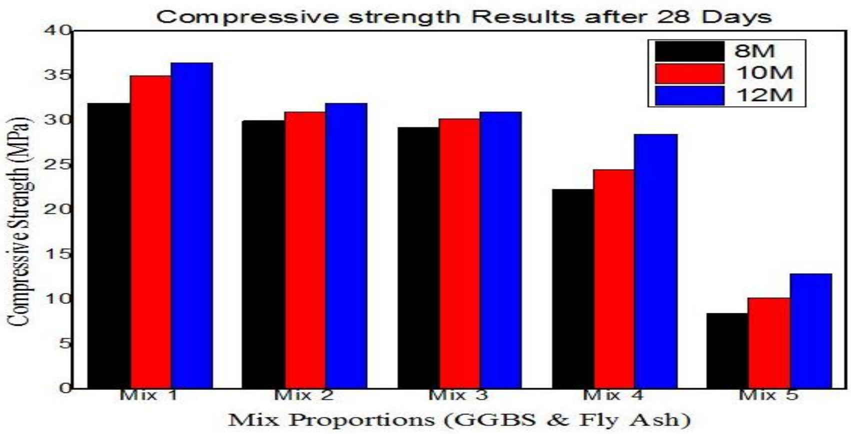

Figure 8 Compressive strength development per mix after 28 days curing

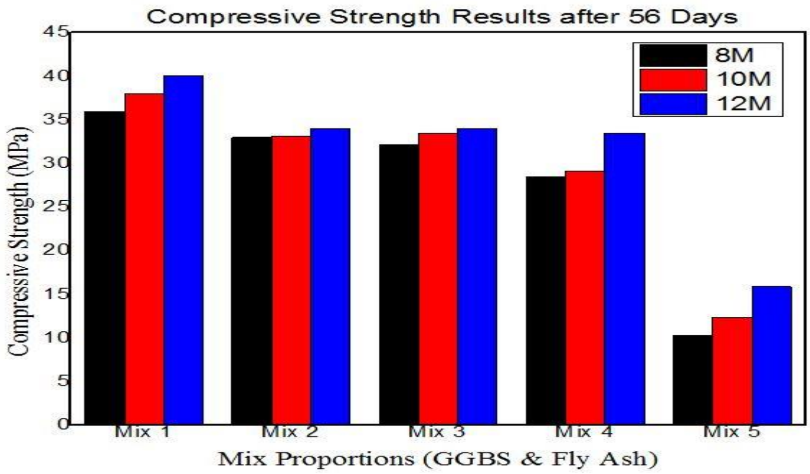

Figure 9 Compressive strength development per mix after 56 days curing

The split tensile strength and flexural strength of the concrete mixtures, obtained after 28 days curing, are presented in Figures 10 and 11.Both strength properties increased with increasing alkaline solution molarity. Again, a 12M molarity of alkaline solution enhanced the tensile and the flexural strength characteristics of the concrete.

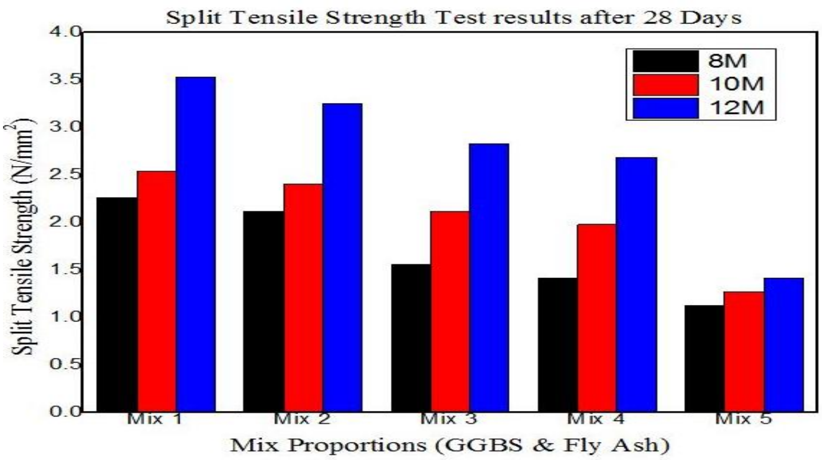

Figure 10 Split-tensile strength development per mix after 28 days curing

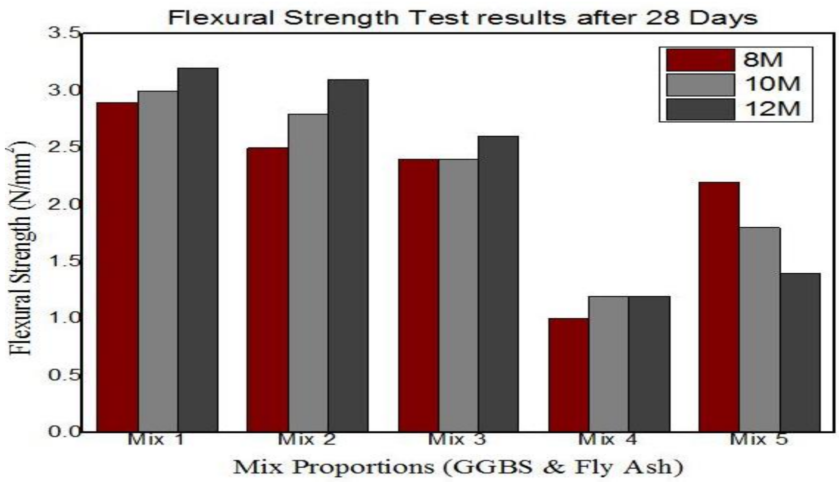

Figure 11 Flexural strength development per mix after 28 days curing

5. CONCLUSIONS

This study explores the performance of SCGC by replacing GGBS with fly ash. The following conclusions were drawn;

- There was an appreciable increment in compressive strength; this was traced to be as a result of longer curing duration of the concrete, which improved geo-polymerizationprocess.
- Increasing the molarities of the concrete also enhanced the compressive strength.
- The GGBS based SCGC developed increased compressive strength much more than fly ash basedSCGC.
- The GGBS based SCGC required more waters thanSCGPC containing fly ash during mixing.

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