International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 10, Issue 8 (August 2021), PP. 01-12

Effect of Sodium Hydroxide and Sodium Silicate on Early Strength Characteristics of GGBS based Geopolymer Concrete

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Abstract
The demand for concrete as a construction material increases exponentially and thereby, there is an increase in the demand for the production of OPC. The environmental issues associated with cement releases around one ton of carbon dioxide to the atmosphere due to the calcinations of limestone and combustion of fossil fuel and cause the global warming condition. In addition, the production of cement is highly energy intensive consuming a large amount of natural resources. To reduce these problems, it is necessary to find out an alternative material for cement. Partial replacement of cement and high volume replacement of OPC with materials having binding properties were studied such as fly ash, GGBS, rice husk ash etc
This project mainly aims at the effect of sodium hydroxide and sodium silicate on GGBS as a complete replacement to cement and investigating the early strength characteristics of geopolymer concrete.
As the demand for pollution control is increasing, use of alternate materials for construction is also increasing, so use of Geopolymer Concrete (GPC) has emerged as a new alternative for conventional concrete.
Keywords: *Geopolymers, GGBS, Geopolymer Concrete, Alternative for Conventional Concrete.*

Date of Submission: 28-07-2021 Date of acceptance: 12-08-2021

I. INTRODUCTION

Construction industry consumes a large amount of concrete; as a result there is an increasing demand for cement. Cement production is energy intensive causing environmental pollution by emitting carbon dioxide at the same consuming natural resources. Concrete is predominantly used material in architectural and construction industry[1] and the overall global production of cement is 2.8 billion tons according.[2] There was a need of alternative other than OPC in order to replace it, in 1970's Davidovits gave a new hope for the

application in construction industry by proposing GPC. Reducing usage of cement lowering amounts of fuel for Manufacturing results in reduced carbon emissions which lowers environmental impact is the primary goal. This can be achieved by using Fly ash, GGBS as a binder.

1.1 Understanding Geopolymer Concrete

Geopolymer is an inorganic polymer similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure of Si-O-Al-O bonds as follows:

$Mn[-(SiO_2)z-AlO_2]n.wH2O$ where, M= the alkaline element or cation such as potassium, sodium or calcium;

The symbol – indicates the presence of a bond, n is the degree of polycondensation or polymerization; z is 1, 2, 3 or higher

1.2 Materials

I) *GGBS*

GGBS (Ground Granulated Blast-furnace Slag) is a cementitious material whose main use is in concrete and is a by-product from the blast-furnaces used to make iron. It is a non-metallic product consisting essentially of silicates and aluminates of calcium. The GGBS used was obtained from Jindal Steel Works, an outlet at hubli. The Table 1 below shows the chemical composition of GGBS with conformance to IS 12089-1987.

Table 1: Composition of GGBS

Parameter	JSW GGBS	As per IS : 1209 - 1987
CaO	37.34%	…..
Al2O3	14.41%	…..
Fe2O3	1.11%	…..
SO_2	37.73%	…..
MgO	8.71%	Max 17.0%
MnO	0.02%	Max 5.5%
Sulphide Sulphur	0.39%	Max 2.0%
Loss of Ignition	1.41%	…..
Insoluble Residue	1.59%	Max 5.0%
Glass Content(%)	92%	Max 86%

II) *Aggregates*

Aggregates are the important constituents in concrete. The aggregates used in normal concrete usually ranges from 75% to 80% of the entire mixture by mass. Therefore in the design of geopolymer concrete, the total aggregate is assumed as 77% of the entire mixture. And the fine aggregate is taken as 30% of aggregates in the mixture. Locally available coarse aggregate of 20 mm size and locally available river sand was used.

III) *Alkaline Liquids*

In geopolymerization, alkaline solution plays an important role and crucial role. The most commonly used alkaline solution is a combination of sodium or potassium hydroxide and silicates. In this project a combination of sodium silicate and sodium hydroxide is being chosen. The sodium hydroxide was taken in the form of pellets. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets in distilled water. Therefore, it is preferred to prepare the Alkaline Activated Solution separately and mix them at the time of casting. Since a lot of heat is generated when sodium hydroxide pellets react with water, the sodium hydroxide solution was prepared a day earlier to cast. The alkaline solution of 8M, 12M and 16M concentration is prepared 24 hours prior to the casting.

IV) *Superplasticizer*

In order to produce a workable concrete a super plasticizer is used. Since adding extra water hampers the workability it is used as the water reducer. BASF MasterPel 777, Robust 2-in-1, waterproofing and water reducing Concreting/Mortar Admixture was obtained from a local chemical store “Sri Sai Engineering Services”, Hubli. The dosage was 2% by weight of the binder.

1.3 Mix Design

Based on the research papers available on geopolymer concrete, the following ranges were selected for constituents of the materials and used in this study:

1. Assuming the density of Geopolymer concrete as 2400kg/m^3.
2. Assuming the total aggregates as 77% of the entire mass in kg/ m^3.
3. Assuming the alkaline solution to the binder ratio as 0.35. **Step 1:**

Calculation of Total Aggregates (Coarse and Fine Aggregates)
Total aggregates = 77% of total mass
= 0.77 x 2400 = 1848 kg/m^3
Coarse Aggregates = 70% of total aggregates
= 0.7 x 1848 = 1294 kg/m^3
Fine aggregate = 30% of total aggregates
= 0.3 x 1294 = 554 kg/m^3 **Step 2:**
Calculation of quantity of Binder and Alkaline solution
Remaining mass = Density of GPC – Total aggregates = 2400 – 1848 = 552 kg/ m^3
Remaining mass = Geopolymer paste = alkaline solution = 552 kg/ m^3
Alkaline solution/Binder = 0.35
Binder = 552/1.35 = 409 kg/m^3
Quantity of alkaline solution = GPC paste **-** Quantity of binder = 552 – 409 = 143 kg/m^3 **Step3:**
Calculation of Proportion of Na2SiO3 + NaOH in Alkaline Solution

Alkaline Solution = Na_2SiO_3 + NaOH
Quantity of NaOH = 143/3.5 = 40.857 kg/m^3
Na_2SiO_3 /NaOH = 2.5
[Molecular weight of NaOH = 40] a)
8M NaOH pellets = 8 x 40 = 340g
NaOH Solids = 320/(1000+320) = 0.2424 x quantity of NaOH
= 0.2424 x 40.857 = 9.9047kg/m^3
Water = 1 - (0.2424 x 40.857) = 30.953 kg/m^3
b)
12M NaOH pellets = 12 x 40 = 480g
NaOH Solids = 480/(1000+320) = 0.3243 x quantity of NaOH = 0.3243 x 40.857 = 13.257kg/m^3
Water = 1 - (0.3243 x 40.857)= 27.6 kg/m^3
c)
16M NaOH pellets = 16 x 40 = 640g
NaOH Solids = 640/ (1000+320) = 0.3902 x quantity of NaOH = 0.3902 x 40.857 = 15.94kg/ m^3 Water = 1 - (0.3902 x 40.857) = 24.91 kg/ m^3
Quantity of Na_2SiO_3 = 143 - 40.85 = 102.14 kg/ m^3
Assuming Na_2O=16.5%
SiO_2 = 33.02%
Water = 50.47%
Total Solids = 49.53%
Water in Na_2SiO_3 = 0.5047 x 102.142 = 51.55 kg/ m^3
Total water content
8M = 30.953+59.55
12 M = 27.6+59.55 = 79.15 16M = 24.91+59.55 = 76.44 **Step 4:**
Calculation of Water required GPC Solids = Binder + NaOH solids + Na_2SiO_3
8M = 409 + 9.904 + 51.55 = 470.454kg/m^3
12M = 409 + 13.25 + 51.55 = 473.8kg/m^3
16M = 409 + 15.94 + 51.55 = 476.49kg/m^3
Water/ Binder = 0.23
8M = 0.23 x 470.454 = 108.2 kg/m^3
12M = 0.23 x 473.8 = 108.974 kg/m^3
16M = 0.23 x 476.49 = 109.6 kg/m^3
Extra water
8M = 108.2 – 82.503 = 25.697 kg/m^3
12M =108.974 – 79.15 = 29.82 kg/m^3
16M =109.6 – 76.44 = 33.16 kg/m^3

Table 2: Weight of Materials Required

Product	Quantity (kg/$m^{3)}$	Volume of Cube(m^3)	No. of Cubes	Quantity (kg)
GGBS	409	0.0034	15	20.85
CA	1294		15	65.99
FA	554		15	28.25
NaOH Solids • 8M • 12M • 16M	9.904 13.25 15.94		5	0.17 0.23 0.271
Na_2SiO_3	50.589		15	2.58

Water • 8M • 12M • 16M	25.697 29.824 33.16		5 5 5	1.4025 1.3456 1.2995
Extra Water • 8M • 12M • 16M	25.697 29.824 33.16		5 5 5	0.4368 0.5070 0.5637
Superplasticizer(2%)			15	0.417

1.4 Methodology

The mixes are designed by trial and error method since there is no standard method for mix design of Geopolymer concrete. In the present work GGBS is used as a binder in designing geopolymer concrete.

I) *Preparation of Alkaline Solution*

The characteristics of Geopolymer concrete is checked for mixes of 8, 12 and 16 molarity of NaOH. The nuclear weight of NaOH is 40. To prepare 8 molarity of alkaline solution, 320gm of sodium hydroxide flakes are weighed and a solution of one litre is prepared with distilled water. NaOH flakes are added continuously to distilled water to prepare a 1 liter solution. In the similar way for 12 and 16 molarity 480gm and 640gm of NaOH flakes are weighed and dissolved in 1 liter distilled water respectively. The ratio of Na2SiO3 to NaOH is taken as 2.5 of 8M, 12M and 16M. The combination of Sodium Silicate (Na2SiO3) and Sodium hydroxide (NaOH) are utilized as basic arrangements [14].

Figure 1: Alkaline Solution prepared 24h before

II) *Preparing of Mixing and Casting*

The test specimens of concrete were altogether blended till uniform consistency was accomplished. After the blending is done, the samples are made by giving appropriate compaction in three layers [13].The cubes were properly compacted and casted as shown in Fig. 2. All the cubes were demoulded after 24 hours and were appropriately cured in ambient curing accessible in the lab at an age of 1 day and 3 days. The specimens of standard cubes (l50 mm X 150 mm X 150 mm) were casted. The concrete cubes were tested for compressive strength test, other results for the split tensile strength, flexural strength and durability studies results were taken from the previous literature investigating the facility with 100% replacement of GGBS with OPC.

Figure 2: Cubes after Casting

III) *Testing*

The slump cone test was conducted for the three mixes to determine the workability as shown in Fig. 3. The workability of 8M, 12M and 16M was 130mm, 120mm and 115mm respectively. The compressive strength is one of the most important properties of hardened concrete. Generally cubes of size 150mm x 150mm x 150mm are used to determine the compressive strength of concrete. The testing was done in a compressive for two specimens and the average value was taken as the mean strength. The test setup is shown in the figure below. Fig. 4 Testing of GPC Cube in CTM testing machine (CTM). The test was conducted.

Figure 3: Slump Cone Test

Figure 4: Testing of GPC cube in CTM

II. RESULT AND DISCUSSION

I) *Compressive Strength Test*

Compressive strength test results of geopolymer cubes for different molarity of alkaline solution at 1 day and 3 days is tabulated in the Table 3 below. Fig. 5 shows the compressive strength versus molarity chart.

Table 3: Compressive Strength Test Result

MOLARITY	Compressive Strength (N/mm^2)	
	1 day	3 days
8M	26.95	32.17
12M	36.07	46.86
16M	32.786	41.8

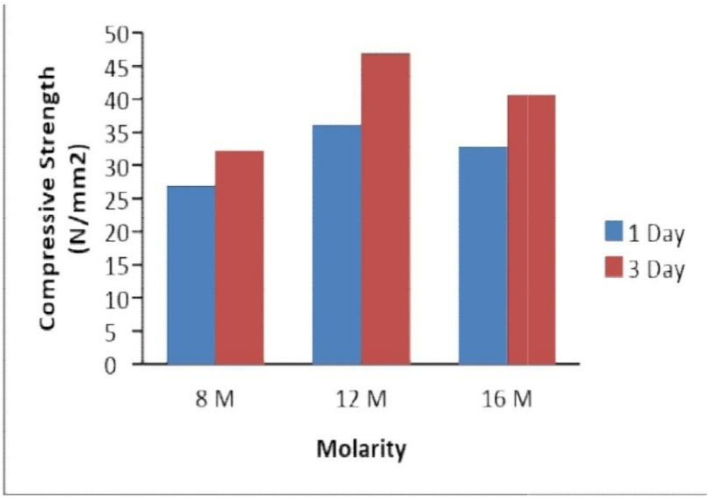

Figure 5: Compressive Strength V/S Molarity

II) *Flexural Strength Test*

Flexural strength test results of geopolymer cubes for different molarity of alkaline solution from the literature are tabulated below. J. Guru Jawahar et.al[8][2015] studied on “Strength properties of fly ash and GGBS based geopolymer concrete”. The Table IV shows the flexural strength of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50;FA25-GGBS75; FA0-GGBS100) at different curing periods at 10M concentration.

Table 4: Flexural Strength Test Result

Mechanical Property	Age (days)	Mix Type (10 M)		
		FA50-GG BS50	FA25-GG BS75	FA0-GGB S100
Flexural strength, fcr (MPa)	28	5.35	5.51	5.76
	56	5.92	6.16	6.34
	112	6.42	6.68	7.12

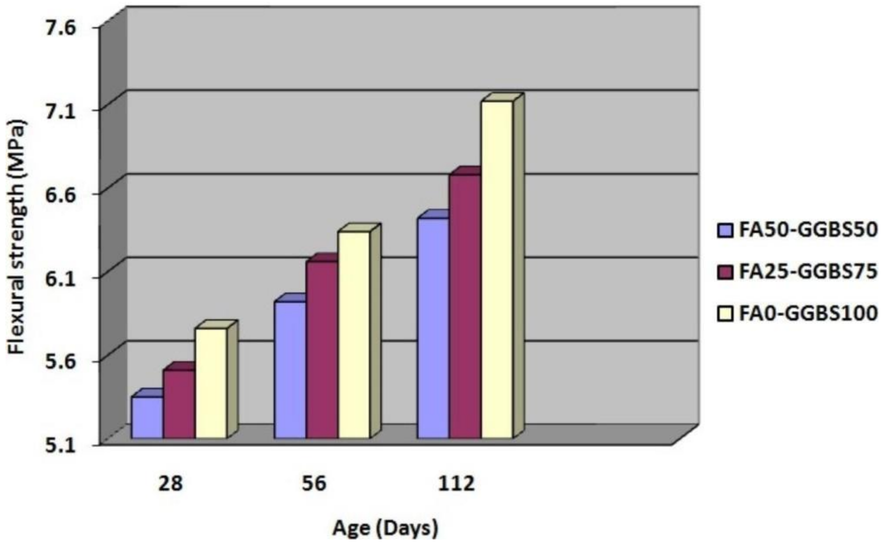

Figure 6: Flexural Strength V/S Age

N. Veerendra Babu**[10]**[2017] study on "Experimental studies on strength and durability properties of GPC with GGBS". The flexural strength values conducted by them are tabulated below as shown in Table 5. Fig 7 Average flexural strength verses molarity curve.

Table 5: Average Flexural Strength Test Results

Molarity	Average Flexural Strength (MPa)		
	3 days	7 days	28 days
6	4.2	5.1	6.2
8	4.5	5.5	6.8
10	4.7	5.8	6.8

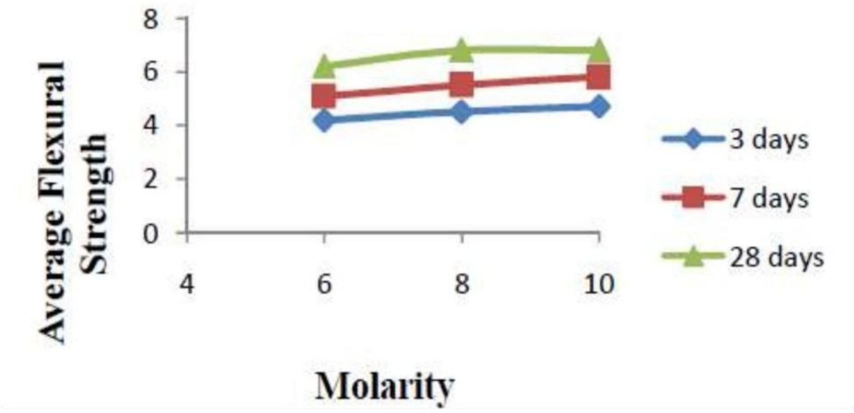

Figure 7: Flexural Strength V/S Molarity

III) *Split Tensile Strength*

Split strength test results of geopolymer cubes for different molarity of alkaline solution from the literature are tabulated below.

J. Guru Jawahar et.al[8][2015] studied the ``Strength properties of fly ash and GGBS based geopolymer concrete". Table 6 shows the splitting tensile strength (STS) of GPC mixes with different proportions of fly ash and GGBS (FA50GGBS50; FA25-GGBS75; FA0-GGBS100) at different curing periods.

Table 6: Split Tensile Strength Test

Mechanical Property	Age (days)	Mix Type (10 M)		
		FA50-GG BS50	FA25-GG BS75	FA0-GGB S100
Split Tensile strength, fcr (MPa)	28	3.25	3.39	3.54
	56	3.38	3.52	3.83
	112	3.52	3.89	4.12

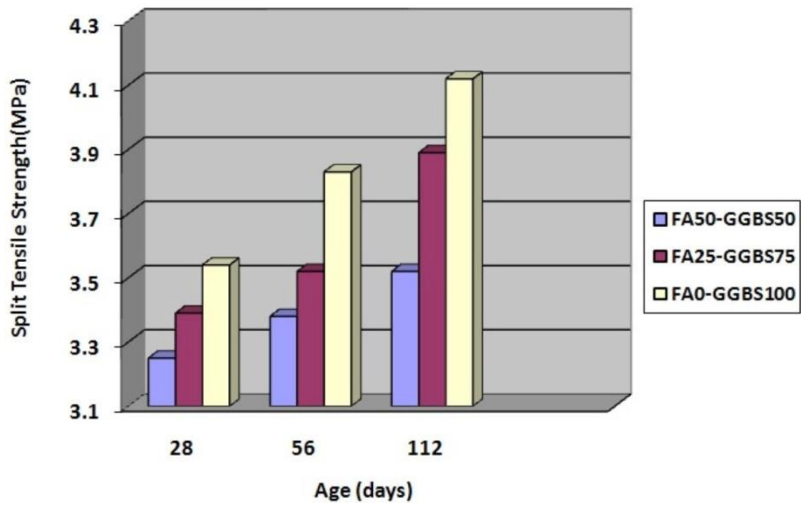

Figure 8: Split Tensile Strength V/S Age

N. Veerendra Babu[10][2017] studied ``Experimental studies on strength and durability properties of GPC with GGBS". The split tensile strength values conducted by them are tabulated below as shown in Table VII. Fig 9 shows the Average split tensile versus molarity curve.

Table 7: Average Split Tensile Strength Test

Molarity	Average Split Tensile Strength (MPa)		
	3 days	7 days	28 days
6	2.5	2.63	2.88

8	2.8	2.9	3.2
10	3	3.2	3.6

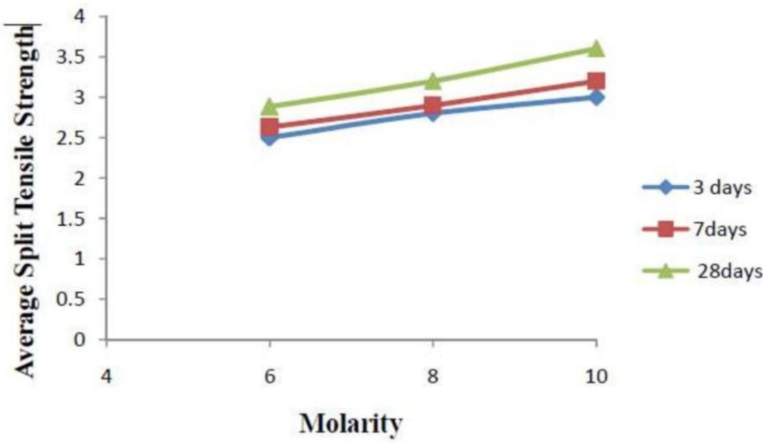

Figure 9: Split Tensile Strength V/S Molarity

IV) *Durability Tests*

N. Veerendra Babu[10][2017] studied "Experimental studies on strength and durability properties of GPC with GGBS". In analyzing the durability parameter of concrete the procedure involves nine polyester tubs of capacity approximately 20 liters which are filled with 2% of chemical solution in 98% distilled water. The concrete cubes are cured for 28 days with each tub three cubes. The chemicals are H2So4, MgSo4 and NaCl. Acid Attack Test results are tabulated in table 8, fig 10 shows the average compressive strength verses molarity graph.

Table 8: Acid Attack Test

Molarity	**Average Compressive Strength (MPa)**		**% loss in compressive strength**
	Before Curing	**After Curing**	
6	36.62	34.44	0.52
8	38.83	36.18	0.53
10	40.54	37.06	0.76

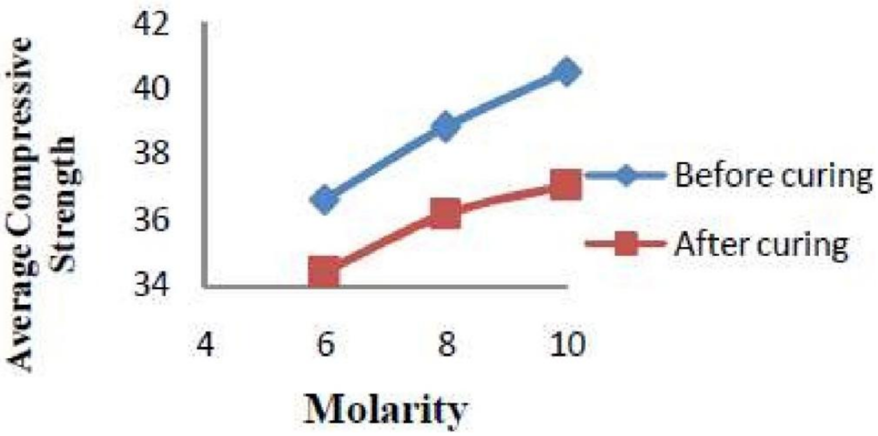

Figure 10: Acid Attack Test

Chloride Attack Test results can be seen in Table 9, Fig 11 shows the average compressive strength verses molarity graph.

Table 9: Chloride Attack Test

Molarity	Average Compressive Strength (MPa)		% loss in compressive strength
	Before Curing	After Curing	
6	36.62	37.49	1.2
8	38.83	40.11	1.25
10	40.54	43.85	1.43

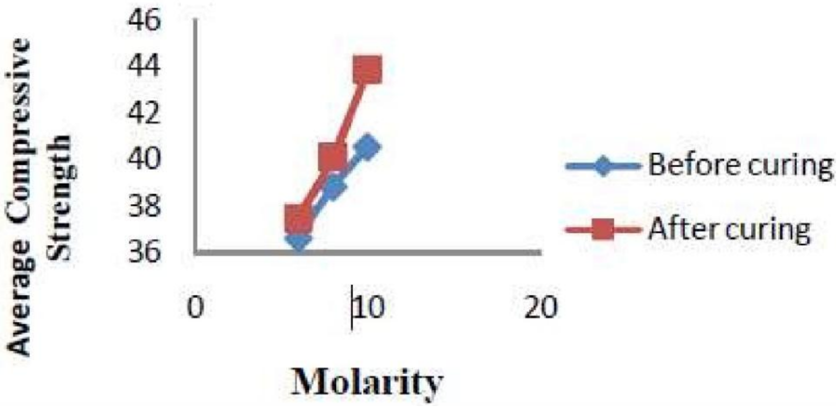

Figure 11: Chloride Attack Test

Sulphate Attack test results are shown below in Table 10, the increase in average compressive strength can be seen in Fig12.

Table 10: Sulphate Attack Test

Molarity	Average Compressive Strength (MPa)		% loss in compressive strength
	Before Curing	After Curing	
6	36.62	37.94	1.13
8	38.83	39.24	0.86
10	40.54	42.29	1.41

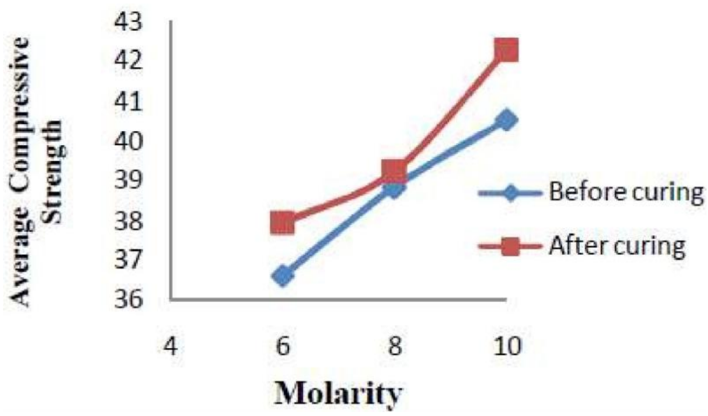

Figure 12: Sulphate Attack Test

V) *Validation*

It was observed that there was a significant increase in compressive strength with the increase in molarity of alkaline solution from 8M to 12M but again decreased at 16M as seen in fig 6 and fig 7 in all curing periods. It can be concluded that the increase in alkaline concentration enhances strength improvement in

Geopolymers. The GPC with 100% GGBS sample exhibited compressive strength values of 26.95 MPa, 36.07 MPa and 32.78 MPa for 8, 12 and 16 molarity at 1 day of curing respectively at ambient room temperature. And 32.17 MPa, 46.86 MPa and 40.55 MPa for 8, 12 and 16 molarity at 3 days of curing respectively at ambient room temperature as seen in Table 3, Table 4 and Table 5.

As seen in the literature review, Harsha Vardhan K et.al[2013][2]obtained that the specimen tested after 1day, 7days and 28 days with 100% of GGBS showed an increase in strength since the first day result. Here, the same results were achieved. The maximum compressive strength for 1 days was found to be 32.07 N/mm2 for 12M and maximum 3 days strength was observed 46.86 again for 12M specimens.

As we all know molarity is one of the parameters which affects the strength of geopolymer concrete.Several studies and tests have been carried out to study the effect of molarity on the compressive strength of geopolymer concrete. Sandeep L Hake et.al[2016][9]studied the effect of fly ash based geopolymer concrete in oven curing at 80ºC varying 8M to 16M. the optimum result was observed at 16M. Compressive strength increases with increase in molarity. But in this study you can see that at 12M highest compressive strength has been achieved. Madheshwaram C. K et al. [2013][6] concluded that higher concentration of sodium hydroxide solution yielded higher compressive strength and split tensile strength. Also, with increase in GGBS the strength increased and a maximum of

60MPa was observed for 100% GGBS. While, the results obtained in this study showed highest strength at 12M and again a decrease in strength at 16M.

In the paper published by J. Guru Jawahar et.al[8][2015] studied on "Strength properties of fly ash and GGBS based geopolymer concrete" it was observed that there was a significant increase in flexural strength with the increase in percentage of GGBS from 50% to 100% in all curing periods as shown in Fig. 8. It can be concluded that the increase in GGBS replacement level refines the pore structure of GPC thus improves the flexural strength of GPC. The GPC with 100% GGBS sample exhibited flexural strength values of 5.76 MPa, 6.34 MPa and 7.12 Mpa after 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 6. Also, there was a significant increase in splitting tensile strength with the increase in percentage of GGBS from 50% to 100% in all curing periods as shown in Fig. 8. The GPC with 100% GGBS sample exhibited splitting tensile strength values of 3.54 MPa, 3.83 MPa and 4.12 MPa after 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 8.

In the study of N. Veerendra Babu[10][2017] on "Experimental studies on strength and durability properties of GPC with GGBS", when molarity is raised there is an increase in compressive strength, split tensile strength and flexural strength. And, when geopolymer concrete gets in contact with magnesium sulphate ($MgSO_4$) there is an increase in compressive strength. When geopolymer concrete gets in contact with hydro sulphuric acid (H_2SO_4) there is a decrease in compressive strength. When geopolymer concrete gets in contact with sodium chloride (NaCl) there is an increase in compressive strength. From the results it is revealed that GGBS based GPC mixes attained enhanced mechanical properties at ambient room temperature curing itself without the need of water curing. Because the bonding of geopolymer paste and aggregates is so strong that tends to increase the mechanical properties of GPC.

III. CONCLUSION

I) *Conclusion*

Based on the results of this experimental investigation, the following conclusions can be drawn:

- GGBS blended FA based GPC mixes attained enhanced mechanical properties at ambient room temperature curing itself without the need of heat curing as in the case of only FA based GPC mixes.
- The increase in GGBS replacement in GPC mixes enhanced the mechanical properties at ambient room temperature curing at all ages.
- Keeping in view of savings in natural resources, sustainability, environment, production cost, maintenance cost and all other GPC properties, it can be recommended as an innovative construction material for the use of construction.
- Compressive strength of geopolymer concrete increases with increase in molarity to an extent and then drops.
- The workability of geopolymer concrete does not get affected with GGBS content.
- The dosage of super plasticizer can add up to workability to some extent, although retarders can give long time retention.
- Water to binder ratio of 0.23 as said being optimum ratio proved to be optimum with gaining of strength.
- Super plasticizer is a must to use in order to achieve required workability.

II) *Future Scope*

The present study can be extended by varying GGBS content with other alternative cementitious material.

- The geopolymer concrete can be studied with variation of alkaline solution to binder ratio in order to investigate regarding the 100% replacement of GGBS with cement.
- The durability characteristics of 100% GGBS based geopolymer concrete can be studied in order to prove it to be a better option than conventional concrete

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