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Effect of Alkaline Activators, Binders and Fibers on Strength Development of Geopolymer Mortar

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Abstract— ***Nowadays Environmental pollution is the major problem faced by the world. The emission of pollutants by construction industry during production of Portland cement are the main causes for environmental pollution. With the increase in use of industrial by products in our construction industry the pollution effect on environment can be reduced. Geopolymer is the one which uses by products and are environmentally friendly. In the present study to produced geopolymer the Portland cement is replaced with fly ash and fine aggregate is replaced with quarry dust and for binding materials alkaline are used. In this study for polymerization the alkaline solutions used are sodium hydroxide (NaOH) and Sodium silicate (Na2Sio3) solution. To prepare different mixes different molarities of sodium hydroxide solution i.e. 6M and 8M and comprehensive strength is calculated for each mix. The size of cube specimen considered are 150 mm x 150mm x 150mm.The comprehensive strength of geopolymer concrete specimen are tested at the age of 7,28 and 56 days. Mixes of different molarities 6M and 8M are prepared by varying the sodium hydroxide flakes amount in grams which are then cured in lab atmosphere and their strengths are calculated for 7,28 and 56 days. The results show that with the increase of the molarity of sodium hydroxide solution the comprehensive strength increases.***

Index terms: Fly-Ash,Mortar, Fine aggregates, NaOH, Na_2Sio_3.

I. INTRODUCTION

Concrete is widely used as a building material as well as it is essential in the construction for infrastructure applications such as roads, bridges, dams, and highways. The future demand for concrete is predicted to increase dramatically with the rise of developing countries such as China and India. The most common ingredient used as the binder in concrete is ordinary Portland cement (OPC), and this will continue to be the primary binder used in the future. However, the creation of OPC utilizes large amounts of natural resources and energy during its manufacturing and releases large amounts of CO2 into the atmosphere. The cement industry is one of the largest carbon-emitting industries behind only the steel and energy industries. To overcome this issue, replacement to OPC based concrete is required.

Thus, it is necessary to produce ecological replacements to avoid traditional cement and use cementations fly ash properties, ground granulated blast furnace slag properties which are industrial by-products. Without any compromise a quality/performance, the production industry is the source where large amount of unwanted materials is utilized efficiently. Even though the usage of Portland cement is still particular unless, in the upcoming days, various steps are carried out for less utilization of Portland cement in concrete, one such step is partial cement replacement with the production and use of blended cement containing a high volume of fly ash cement. The efforts also comprise a utilization of complementary cementing property materials for example silica fume, rice-husk ash, fly ash, and metakaolin as substitute binders to Portland cement. To accomplish ultimately cement replacement, a new binder material, called geopolymer which has been developed in the mid-1970s by Davidovits, were Geo-polymeric alumina-silicate gel performs the binder role. Geopolymer is produced by alkali activation of primary silicon and anAluminium materials of the geographical origin or byproduct materials such as fly-ash, slag, etc. Geopolymers are regarded as NO CEMENTcomposites with the ability to use large quantities of fly ash.

Unlike ordinary Portland /pozzolana cement, geopolymer for matrix formation and strength does not ensure the form calcium silicate hydrates gels, but it uses the polymerization/polycondensation of silica and alumina in the source material such as fly ash, GGBS, Silica fume, specific. Generally, source materials are activated by an alkaline solution which mixture of sodium silicate and sodium hydroxide. The polymerization process is usually aided by the application of heat then monitored by drying. In order to form the geopolymer mortar/geopolymer concrete the role of geopolymer gel tends to bind the fine aggregates and loose coarse aggregate.Curing is one of the essential steps of geopolymer synthesis between 400C and 1000C for 4 to 48 hours in dry or steam conditions. However, when it is mixed with moderately low-alkali solution and cured in a reasonable time at ambient temperature, it is essential as per practical application. There are no widespread applications of geopolymer although there are wide-ranging attributes listed above. Although several geopolymer systems are suggested, many of them are challenging to work as it requires much attention during production. Synthesis of manageable geopolymer cement which may be used under the similar conditions that are appropriate for Portland cement is the present effort worldwide researchers.

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The production of such adaptable, economical geopolymer cement which can be assorted and hardened permanently alike Portland cement represents an improvement and modernization in the construction industry.

Sungwon Choi et al., [1] examined the various environmental influences on the concrete beams reinforcement with carbon fiber (CFRP = Carbon fiber reinforcement fibers). To assist the overall environmental impact on the durability of interfacial bonds between concrete and carbon fiber, various commercial carbon composite systems were tested under different exposure conditions using the new test which is previously proposed in their work. Chindaprasirt et al., [2] studied well on the synthesis of many high-strength geopolymers. The effect of fillet fineness on the crystallization of the geopolymer pastes process capabilities on drying on the solution of geopolymers which is obtained from the thin flies classified by the high level of calcium was studied. Fly ash in the air classifications with three main differences such as large, medium, and fine was used in Mae Moh. Cured geopolymer is thermally activated by sodium silicate and sodium hydroxide. Moreover, the weight is added in a small amount to enable the process. Debaiky et al., [3] experimentally investigated the tensile strength, ultimate elongation at break, and elastic modulus that are urgently needed. Fiberglass reinforcement (GRF) has an initially low modulus of elasticity and should not decrease significantly over time during loading. Otherwise, the performance of an element containing, and it will be degraded.

Akuthota et al., [4] the use of CFRP has been studied to improve the aging of concrete structure. In the discovery of cracks and ligaments between the CFRP elements and concrete substrates is an essential matter in this field. Since the presence of these defects affects the reinforcement. Therefore, the development of non-destructive testing to sense this type of imperfections in this area is very interesting.Morsy et al., [5] experimentally studied the influence of sodium-silicate and sodium-hydroxide on the possibility of synthesizing a geopolymer using fly ash for 80 0C temperature. Sodium-silicate and sodium-hydroxide (S/N) ratios value of 0.5, 1, 1.5, and 2.5 are investigated. Erdogan [6] studied the stability of mixtures containing only particle powders activated with sodium-hydroxide/sodium-silicate solution at a temperature of room or when cured in an oven. The resulting geopolymer structure was investigated through infrared spectroscopy with Fourier transform, diffraction of X-ray, and nuclear magnetic resonance. Heat resistance and acid resistance of the mixture were evaluated. A mixture of activated sodium silicate slowly reaches medium strength at room temperature, but mixtures activated with sodium hydroxide do not generate strength regardless of the concentration of activator. Kardon et al., [7] reviewed the polymer history between the mixture with building material such as cement, whenever the polymer fiber is not arranged or reinforcing of the mesh. Nevertheless, results in hydrated cement paste due to the arrangement of the polymerized matrix.

Heard [8] presented the results of three laboratory experimental series by conducting in to depict, enumerate, and innovative rapid sets, field curable geo-polymer concrete improved the response of tensile failure that represents the different advantages throughout other cementitious composites. They conducted the experiments for a geo-polymer concrete to achieve a compressive strength of 44 MPa for 24-hours, and 62 MPa for 28 days in ambient temperatures for a single fiber pull-out, individual fiber, and direct uni-axial tensile load without any further curing process.

Shi et al., [9] experimentally investigated the behavior of bond among the substrate of limited concrete and basalt fiber reinforced polymer sheet (BFRP) to a influences of coupled of sustained load and freeze-thaw cycling. Test variables are the types of sustained load levels, freeze-thaw cycles, and adhesive. They used double lap shear-specimen for a test and a mainly intended reactions loading system that was utilized to apply the sustained load during freeze-thaw cycles. Topark-Ngarm[10] investigated the time setting, compressive/tensile strength, and adhesive of geopolymer concrete at high calcium fly ash. The fly ash was used from the northern Thailand of Mae-Moh power plant. The sodium hydroxide/silicate solutions are utilized as activators of alkali in each single mix sodium hydroxide (NaOH) solution concentrations of 10 M, 15 M and 20 M, and the ratio of sodium-silicate to the sodium-hydroxide at 23 ± 2 °C were utilized. Ren et al., [11] used the waste material like concrete for recycling purpose with the collection of fines from the crushing in order to form the fresh material concrete via polymerization. As per the literature work and because of the work of the new geopolymer concrete contents the 75% of class-F fly-ash and 25% of concrete waste fines are utilized as the geopolymer source material of cement. The sodium-hydroxide and sodium-silicate solutions as the activation of alkaline and the coarse and fine concrete wastes are used to get the total values of new concrete.

Zhen et al., [12] experimentally presented the use of fly ash which depends on geo-polymers for the loess stabilization with the 2-dissimilar forerunners are hired for the examination. They found that a higher unconfined strength compression load reduces by potassium hydroxide rather than sodium-hydroxide to a prepared specimen once the use of similar fly-ash and loess-ratio was employed. Laskar et al., [13] experimentally investigated the geopolymer mortars set from ultrafine blast-furnace slag of ground granulated. Geo-polymer mortars were set with activators of alkali composed of sodium-silicate and sodium-hydroxide, and only a sodium-hydroxide solution, and tested to study the setting time, workability, and strength-gain behavior. Zabihi et al., [14] experimentally studied the geopolymer concrete through high amounts of wastes of agricultural solid by way of byproduct materials possibility of producing structural rice shell ash. Prepared testes samples were reinforced by polypropylene fiber. Then a result of tested specimen specified that replacement by rice shell ash-based on geopolymer, 100% replaced and enhanced the concrete material properties through geo-polymer.

Dong et al., [15] experimentally studied on the bond durability of bars-basalt fiber reinforced polymer (BFRP), steel-fiber reinforced polymer (FRP) composite bars (SFCB), and steel bars embedded in seawater sea-sand concrete (SWSSC) and subject to a simulated ocean environment.

They studied the impacts of the type of environment, experience period and reinforcement type on adhesive durability. Vafaei et al., [16] used alkali activation of a binary mix of fly ash and calcium aluminate cement in order to produce a high-strength geopolymer binder. The calcium aluminate cement has been partially substituted with the fly-ash in order to increase the source materials reactive phases and activated the resulting blends through an aqueous solution of sodium-hydroxide, and sodium-silicate integrated with different sodium oxide and S/N ratios are cured hydrothermally at 95 °C for 20 hours. The geopolymer mortar compressive strength increased up to 59 MPa through enhancing monitor variations in a physical to mechanical properties of the mortars.

In this article, industrial wastages such as fly ash and GGBFS are used feasibly. In various amounts and marginal materials like quarry dust is used as fine aggregates. Fine aggregates have been examined experimentally to produce geopolymer mortar, which is cured at ambient conditions, without any traditional cement and traditional curing system, and then the strength response is evaluated about compressive strength. The effect of alkaline activators, binders, and fibers effect on the strength of the compression load of geo-polymer mortar is studied.

II. EXPERIMENTAL INVESTIGATION

The resource materials that are used in the present investigation for the prepared specimens are the fly ash-based geopolymer composites that are low calcium dry fly-ash and sources material-GGBS type of material, quarry dust as fine aggregate, coarse aggregate, water, and alkaline liquid.

A. Fly-Ash

In thermal power plant during the production of electricity, coal is burnt while burning coal the gases are produced from that gases fly ash a fine and glassy powder is obtained. Fly ash is also stack emission from coal-fired thermal power plants. It is by-product which must be landfilled or used as complementary cementing material as replacement to cement. Fly ash particles are typically spherical, ranges in diameter from less than 1µm but not higher than 15µm, better than the Portland cement and lime. Based on combustion methods, physical and chemical characteristics are defined. Theparticle shape depends on the type of coal burnt. Fly ash is categorized as Class C and Class F.

B. Class-C Fly-Ash

Fly ash basically produced by burning of younger lignite or sub-bituminous coal with the addition of having pozzolanic properties. Class c fly ash gets harder and gains strength by adding water. Normally, fly ash has 10 % lime. r. Alkali and sulfate contents are high in class C fly ash. They donot require captivators as they are self-cementing.

C. Class-F Fly-Ash

Class F fly ash basically produced by the burning anthracite or bituminous coal. This fly ash has less than 5% lime and have pozzolanic. Propertiesthat produce cementitious compounds in order to react. In presence of water the gassy Silica and Alumina of class F fly ash require a cementing agent such as Portland cement, quicklime or hydrated lime. The addition of chemical activator such as sodium silicate water glass to a Class F fly ash results in the formation of a Geopolymer. In the present study class F fly ash from Ratnagiri used as one of the source materials. The fly ash which is used for the current experimental studies is shown in figure 1.

Figure 1 Physical and chemical properties of fly ash are given in table 1 and 2

Table 1 Physical composition of fly ash

Specific Gravity	2.4
Loss of ignition(%)	1-1.5

Table 2 Chemical composition of fly ash

Characteristics	Fly ash (% weight)
Silica	55-65
Iron oxide	5-7
Aluminum oxide	22-25
Calcium oxide	5-7
Magnesium oxide	<1
Titanium oxide	<1
Phosphorous	<1
Sulphates	0.1
Alkali oxide	<1

D. Ground Granulated Blast Furnace Slag

Granulated blast furnace slag is a sand-type slag, which is industrially produced by spraying high-pressure water on blast-furnaces molten slag. The slag is sold to domestic and overseas markets. It is also supplied as a cement material for civil engineering and construction work. The product is called "ground granulated blast furnace slag," which is used to blend with Ordinary Portland cement to enhance the concrete as mortar. In the present investigation, GGBFS obtained are from JSW Steel, Bellary, which is used as another source material. The Ground Granulated Blast Furnace Slag is shown in figure 2. Physical and chemical composition of Ground Granulated Blast Furnace Slag
are shown in table 3 and 4.

Figure 2 Ground Granulated Blast Furnace Slag

Table 3Physical composition of GGBS

Specific Gravity	Fineness	Loss of ignition (%)
2.91	377	0.19

Table 4 Chemical Composition of GGBS

Chemical Requirements	Test Results
Manganese Oxide (MnO) %	0.09
Magnesium Oxide (MgO) %	7.75
Sulphide Sulphur(S) %	0.51
Sulphate (as SO3)	0.24
Insoluble Residue (I.R) %	0.33
Chloride Content %	0.008
Glass Content %	92
Loss on Ignition (L.O.I) %	0.22
Moisture Content %	0.03
CaO+MgO+1/3Al2O3/(SiO2+2/3 Al2O3)	1.12
CaO+MgO+Al2O3/SiO2	1.96

E.Alkaline Liquids

The alkaline activators which were used are a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution was bought in bulk quantity through local supplier. The solutions properties are described in table 5. The sodium hydroxide (NaOH) flakes with 97-98 % purity was bought through a local supplier in bulk quantity.

Table 5Properties & Chemical Composition of Sodium Silicate

S No	Properties	Values
1	Sp Gravity	1.57
2	Na2O	14.11 %
3	SiO2	31.97 %
4	Na20: SiO2	1.2.26

F. Preparation of Liquid

In a solution, the amount of sodium hydroxide solids changes based on the concentration of the solution. By dissolving flakes in distilled water, the NaOH solution was prepared. The concentrations of sodium hydroxide solution which is measured as molarity are kept as 6M and 8M. Based on molarity of the solution and molecular weight, for every liter of water 196 grams and 262 grams of NaOH pellets were dissolved for 6M & 8M respectively. One day before the solution of sodium hydroxide was prepared and kept ready for use. On the day of casting alkaline solution is prepared by mixing sodium hydroxide and sodium silicate solution. The sodium silicate solution to sodium hydroxide ratio for concrete is 1:1.5 is used in the study.

G.Preparation of 6M of NaOH solution

In one liter of water 196 g of NaOH, flakes are dissolved to form 6M NaOHsolution. Similarly, 262 gm of NaOH flakes is dissolved to form 8M NaOHsolution. Figure 3 shows the sodium hydroxide which is utilized in current research work.

Figure 3 Sodium Hydroxide Flakes

H.Fine Aggregates

For ecological development, quarry dust is used as fine aggregate as an alternative for natural sand. Quarry dust which is a by-product produced by crushing stone industry which can be brought from local supplier. In saturated surface dry condition fine aggregates were used. Figure 4 shows the used fine aggregates which is obtained from the local supplier in order to prepare a test specimen. The test specimens prepared in several blocks (or cubes) and specified a code to easily recognize during the experimental work. Moreover, the prepared specimen used for only compressive test under uniform loading conditions.

Figure 4Fine aggregates

- Sieve analysis of fine aggregates

Material Information: Total weight of fine aggregates taken: 1000 Gms

Table 6 Sieve analysis and Fineness modulus of fine aggregate

I.S Sieve Designation	Weight retained (gms)	% Weight retained	Cumulative % Weight retained
4.75mm	7	0.7	0.7
2.36mm	7	0.7	1.4
1.18mm	280	28.0	29.4
600μ	207	20.7	50.10
300μ	195	19.5	69.6
150μ	135	13.5	83.10
75 μ	159	15.9	99.10
Pan	10	1.0	100
Total=	**1000**		**433.4**

Calculations:Fineness modulus = (Summation of cumulative % weight retained)/100 = 433.4/100 = 4.334

I. Micro Steel Fibers

The micro steel fibers with brass coated of grade C76-78D is used to increase the strength of mortar. They are available in different sizes. Figure 5 shows the micro steel fibers.

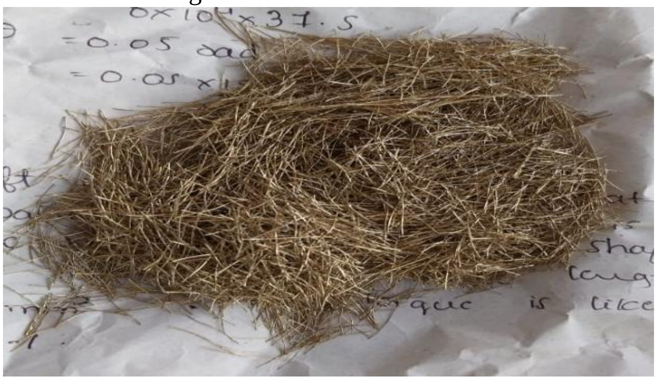

Figure 5 Micro steel fibers

It is obtained from Fiber Zone India of Ahmadabad Chemical, and Physical composition of Micro steel fibers is shown in Table 7 and 8, respectively.

Table 7 The Chemical composition of Micro steel fibers

Specifications	Standard values	Test results
% C.	0.72-0.8	0.76
% Min.	0.5-0.8	0.65
% Si.	0.1-0.3	0.19
% S. Max	0.035	0.015
% P. Max	0.035	0.030
% Ni. Max	0.2	0.12
% Cr. Max	0.15	0.11
% Mo. Max	0.05	0.01
% Cu. Max	0.25	0.19
% Al. Max	0.01	-

Table 8 The Physical composition of Micro steel fibers

Specifications	Standard value	Test results
DIA (mm)	0.2	13
UTS (N/mm^2)	2200-2850	2800
LENGTH (mm)	6mm & 13 ± 10%	13

III. RESULTS AND DISCUSSION

The preparation of Geopolymer mortar is discussed in this chapter and its strength development, using Fly ash and GGBS as source materials activated by alkaline solution. Total of 180 mortar specimens of 75×75×75 mm was casted out of which 90 specimens were without fibers, and 90 specimens were with 1% steel fibers by weight of binder were casted. For suitable workability superplasticizer from BASF Chemicals, i.e., Master Polyhued 8146 was used, 1% by weight of binder. The specimens were ambient cured and tested for compressive strength at 7, 28, and 56 days respectively. In this chapter we will discuss in detail the preparation and test results of mortar cubes. The mix proportions are illustrated in table 9.

Table 9 Mix Proportions

Fluid binder : M Sand	1:3
Fluid binder ratio	0.475
Binder Proportion(Fly Ash:GGBS)	60:40, 70:30, 80:20
Molarity	6M and 8M
NaOH: Na2Sio3	1:1.5

A. Manufacture of Fresh Mortar Casting

The fly ash-based geopolymer mortar solid constitutes are fly ash, aggregates, and GGBS which are dry mixed for about three minutes manually in the predetermined proportions. The sodium hydroxide and sodium silicate which are liquid parts of the mixture is added to the solids. The mixture was mixed continuously for four minutes. The product after mixing, i.e. fresh geopolymer mortar is dark in color and appears shiny as shown in figure 6. The mixtures were usually cohesive.

Figure 6Fresh geopolymer mortar

The moulds can be used after they are cleaned and fitted. The mould were greased with oil at inner surface before casting the specimen. The prepared fresh mortar was casted in three layers into the moulds straightaway after mixing for all specimens. The vibration was done for 12 to 15 seconds on a vibrating table to achieve compaction of the specimens.

B. Curing of Specimens

The Specimens are Demoulded and kept for ambient curing, i.e., without thermal curing until the time for testing. All prepare mortar specimen specified with alphabetic code which is shown in figure 7.

Figure 7Demoulded Geopolymer Mortar Specimens

C. Compression Strength

Compressive strength test was conducted in CTM at 7, 28, and 56 days with five specimens for each proportion. The specimens were tested by IS Compression strength = (Load/Area) in MPa. The results of the are shown in table 10. Figure 8 shows the test case which depicts during experimental work conducted.

Table 10Compressive strength results of geopolymer mortar

S No	Code	Strength in MPa 7 Days	Strength in MPa 28 Days	Strength in MPa 56 Days
1	6GC 60:40	19.52	21.8	25.25
2	6GC 70:30	19.17	20.82	21.22
3	6GC 80:20	17.7	19.69	20.1
4	8GC 60:40	24.029	25.39	26.87
5	8GC 70:30	20.97	24.35	25.14
6	8GC 80:20	17.18	23.99	24.09
7	6FGC 60:40	20.08	22.53	26
8	6FGC 70:30	19.55	21	24.93
9	6FGC 80:20	17.8	19.75	22.09
10	8FGC 60:40	25.51	26.01	27
11	8FGC 70:30	24.29	25.04	26.32
12	8FGC 80:20	19.55	24.03	25.74

Figure 8Failure mode of mortar cube

D. Variation of Strength with Molarity

The strength development of ambient cured geopolymer mortar is discussed in this chapter with reference to the factors measured at the selected levels. The experimental results achieved are represented in the form of graphs to ease the discussions.

The figure 9 to 11 depicts that the strength of geopolymer mortar for all binder proportions was optimum for 6M ratios. However, the literature survey explains that with an increase in molarity the strength increases, we achieved promising results with six molar NaOH solution. Further, the study can be enhanced and improved in detail by XRD analysis.

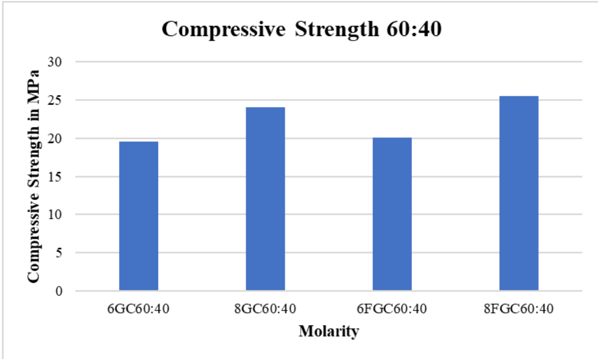

Figure 9Compressive Strength vs. Molarity of NaOH Solution

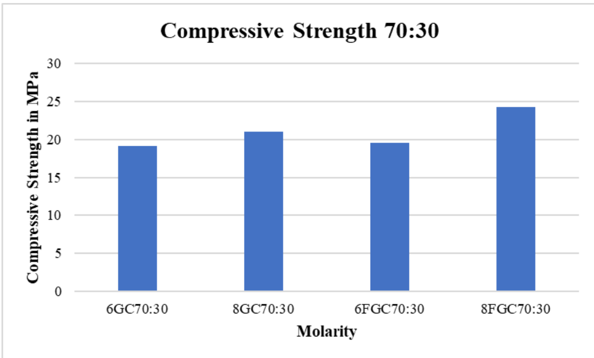

Figure 10Compressive Strength vs. Molarity of NaOH Solution

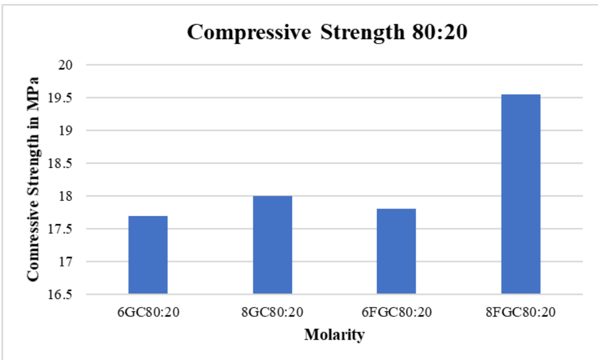

Figure 11Compressive Strength vs. Molarity of NaOH Solution

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E. Variation of Compressive Strength with Binder Preparation

Figure 12 and 13 represents the compressive strength variation with binder proportion of 6M (6 Molarity). In ambient cured geopolymer mortars for both 6M & 8M ratios increase in GGBFS increases strength. Geopolymer of fly ash-based gain strength in higher temperatures than to achieve ambient curing GGBFS is necessary for strength gain. If fly ash content is more significant, the workability is better because of the ball bearing effect, and if GGBFS content higher, the strength gain is better at ambient temperatures.

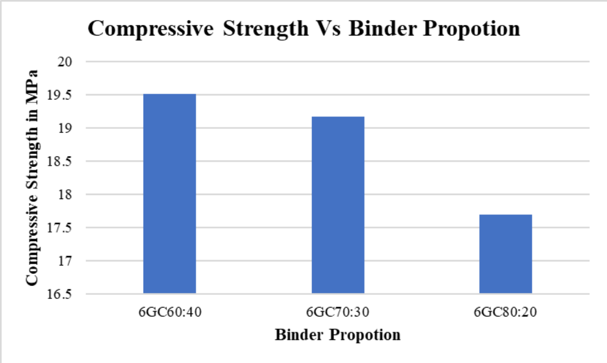

Figure 12Compressive Strength vs. Binder Proportion

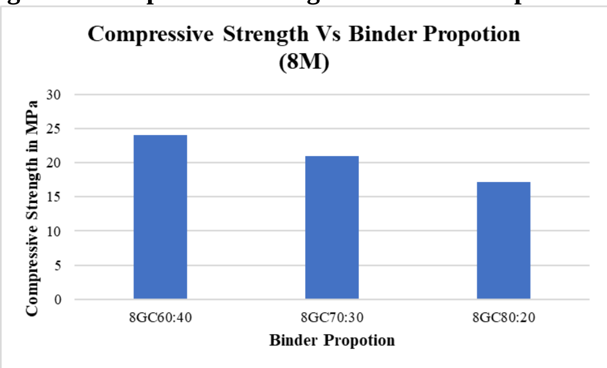

Figure 13Compressive Strength vs. Binder Proportion

F. Variation of Compressive Strength with Fibers

Figure 14 and 15 represents the compressive strength variation with fibers. The literature survey recommends that with the fiber'saddition the mechanical properties of concrete increases. However, there is negligible increase in strength, but there will be moderate increase in flexural strength and ductility. The present study was limited to test compressive strength, and there is an increase up to 27 MPa as mortar specimens were casted and microfibers of length 13mm was used.

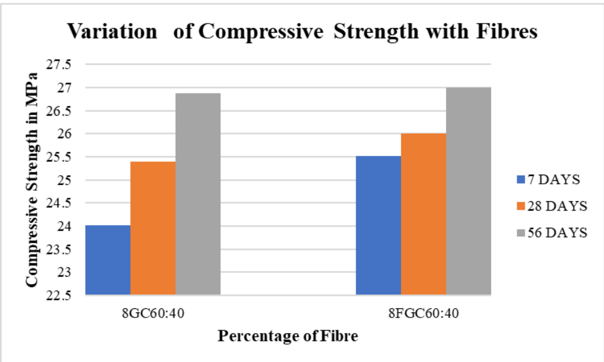

Figure 14Compressive Strength with Fibers

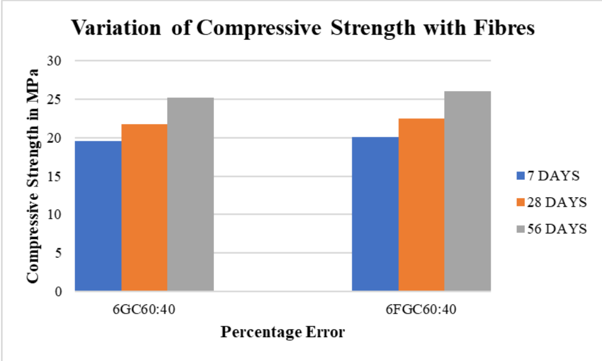

Figure 15Compressive Strength with Fibers

Figure 16 represents the variation of compressive strength with the different binder properties. According to the results, it has been found that if the number of days increases the strength with some ratio like 60:40. It has also been observed that besides fiber, there is a chance of increase in strength.

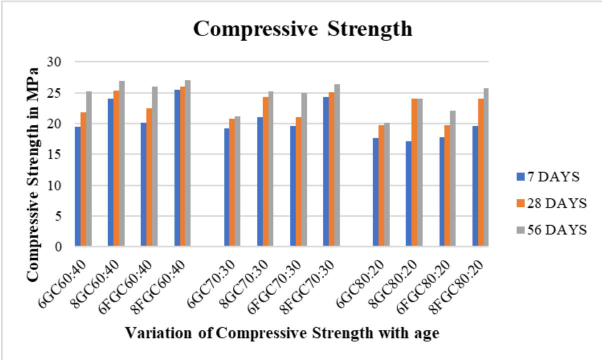

Figure 16Variation of Compressive Strength with Age

IV. CONCLUSION

The present study, concludes the following points

- The optimal molar concentration of NaOH solution is 6M. When strength increases with increasing molar concentration to 14 moles, the study shows encouraging results for 6 moles solutions, which also reduces the cost of the geopolymer composites.
- Fiber-geopolymer solutions have better compressive strength than fiber-free solutions.
- Over time, performance does not improve significantly. Achieve supply strength in fly ash/GGBS geopolymer solutions.
- An increase in GGBS improves strength in the surrounding compressed geopolymer solution:

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