The Effect of Age on Alkali-Activated Geo Polymer Mortar at Ambient Temperature

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Abstract

In this research an investigation on effect of age on Compressive strength of Alkali-activated Geopolymer Mortar (GPM). GPM cubes were (70.7 mm cube) prepared by using industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS) and Silica fume (SF). These binders are adopted as full replacement to Ordinary Portland cement (OPC). However, Quartz sand is used as a fine aggregate as full replacement to river sand. A small quantity of Gypsum is added to control the setting times of the mix in the presence of alkaline medium. The alkaline liquid is a combination of Sodium Hydroxide Solution (NaOH) and Sodium Silicate Solution (Na_2SiO_3). Various salient parameters were studied to investigate the effect of age on compressive strengths of GPM. Those were Molarity of NaOH (9M, 13M and 19M), concentration of Na_2SiO_3 (20%, 35% and 50%) and age of specimen (7, 28, and 56 days). A constant binder-to-fine aggregate (B: FA) ratio of 1:5 and alkaline solution-to-binder (A/B) ratio of 0.8 is adopted. These Mortar cubes cured under ambient air temperature. Results show that Mortar incorporating GGBS and SF had higher compressive strength at 56 days with 13M NaOH, 35% Na_2SiO_3. These results are most promisingfrom both strength and environmental point of view.

Keywords: *Geopolymer Mortar, Compressive strength, GGBS, Silica fume, Alkali activated, Ambient air temperature.*

I. INTRODUCTION

Mortar strength is the most important and predominant factor that affects the strength of concrete. In the current day scenario, Concrete is the most widely used material next only to water in this world [1].Generally, Ordinary Portland cement (OPC) is used as primary binder to produce traditional mortar. The demand for mortar/concrete is increasing day-to-day for the need of development of infrastructure facilities [2].

Mortar and Concrete are the most abundant construction materials and Portland cement is used as a primary binder. Annually 2.8 billion tons of the Greenhouse gas emissions iscaused by the contribution of global Cementitious industries [3]. The production of ordinary Portland cement requires a large-scale input of energy meanwhile, it produces the huge quantity of Carbon-di-Oxide (CO_2) due to the occurring of calcination reaction during the manufacturing process. Approximately one ton of Carbon-di-oxide (CO_2) is released into the atmosphere for every one ton of Ordinary Portland Cement produced [4-5].The global warming and greenhouse effect is caused by the emission of greenhouse gases. Such gases like Carbon-di-oxide (CO_2) contribute about 65% of global warming. Portland cement production leads the sources that produce Carbon-di-oxide (CO_2) and release into the atmosphere. The cement production industries are responsible for about 6% of all Carbon-di-oxide (CO_2) gas emissions [6].

On the other hand, it is essential to find an eco-friendly material as an alternative to the primary binder to produce Mortar/concrete. This has led to an adoption of Ground Granulated Blast Furnace Slag, Silica Fume and fly ash as replacements to binders to preserve the global world environment from the impact of cement production. The production of Slag results in release up to 80% less greenhouse gas emissions than the emission of greenhouse gases due to the production of Portland cement [7].However, fly ash releases up to 80-90% lesser greenhouse gases than OPC. The Carbon-di-oxide emissions will rise by about 50% from the current levels due to the production of ordinary Portland cement by the year 2020 [8-9].

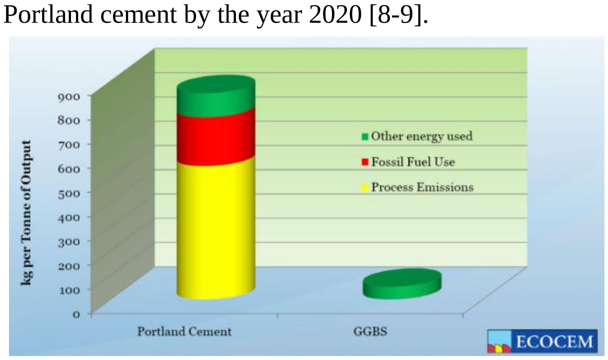

Fig. 1 Typical CO_2 Emissions for OPC and GGBS Production [10]

Two-third of CO_2 emissions are produced from the Portland cement production and remaining one-third produced from the combination of combustion of fossil fuels and other energies

In 1978, Joseph Davidovits coined the term “Geopolymer” and proposed that binders could be produced by a polymeric reaction of alkaline liquids with Silicon (Si) and Aluminium (Al) in source materials of geological origin or by-product materials such as Rice Husk Ash (RHA) and Fly ash. He termed these binders as Geopolymers [11]. In 1999, Paloma et.al.Suggested that pozzolans such as Ground Granulated Blast Furnace Slag might be activated to form a binder and hence totally replace the use of OPC in mortar The Geopolymersare developed by combination of source material and alkaline activate liquid. The source material should be rich in silica and alumina materials such as Ground Granulated Blast Furnace Slag, Silica Fume, fly ash, Rice husk ash (RHA), and Metakaolin [12].

II. MATERIALS

A. GGBS

Ground Granulated Blast Furnace Slag was first cementitious material activated by alkaline liquid and it is different to other supplementary cementitious materials due to its latent hydraulic properties. Ground Granulated Blast furnace is obtained from a by-product of iron manufacturing industry.Granulated Blast Furnace Slag (GGBS). Sustainability of GGBS reports that manufacturing of cement process would require 5000 MJ energy approximately at the same time produces 0.95 ton of Co_2 equivalent. Although, the production of one-ton GGBS would generate only 0.07 ton Co_2 equivalent consumes energy 1300 MJ of energy only.

B. Silica Fume

Silica Fume (SF) is also known as a micro silica and it is a by-product of the smelting process in the manufacturing of silicon alloy and Ferrosilicon alloy industries. In this process involves the reduction of high-purity Quartz to silicon (SiO_2) in an electric arc at temperatures up to 2000^oC. Silica Fume is an ultra-fine powder consisting primarily of spherical particles or microspheres of a mean diameter of less than 1μm and it is 100 times smaller than an average cement grain.

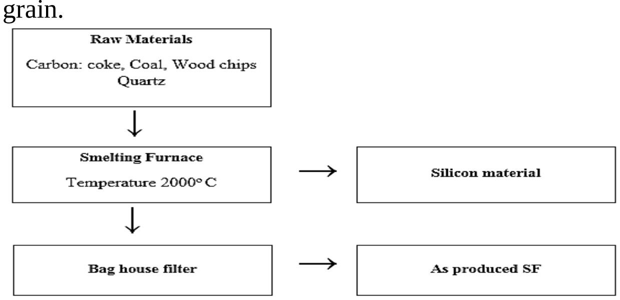

Fig. 2 Schematic Representation of Silica Fume production

Most of the fume from the furnace condenses into spherical particles of Silica Fume and these are drawn through cooling pipes into a pre-collector for removing coarse particles thenfiltered, batched and packaged. By-products of the production of Ferro silicon alloys and silicon metals having silicon content is about to 75%. Generally, Silica Fume powder in grey colour and somewhat likewise to ordinary Portland cement. It can exhibit both pozzolanic and cementitious properties. It is collected in very large baghouse filters and then made available for use in Mortar. Vitreous Silica Fume in the nature of Cristobalite form. It has a very high content of amorphous (Non-crystalline) silicon-di-oxide (SiO_2) and consists of very fine spherical particles. The chemical composition of SF mainly contains more than 90% SiO2 and small amounts of magnesium, iron, and alkali oxides are also found.

C. Alkaline Liquid

The most common alkaline solution used in process of Geopolymerisation is a combination of Sodium Hydroxide Solution (NaOH) or potassium hydroxide solution (KOH) and Sodium Silicate or potassium silicate type of alkaline activating liquid plays an important role in Geopolymerisation[15-16] High rate reactions occur when the alkaline liquid contains soluble silicate, either Sodium Silicate or potassium silicate when compared use of only alkaline hydroxides. Alkaline liquid enhances the reaction between source material and liquid due to the inclusion of Sodium Silicate Solution to the Sodium Hydroxide Solution**.**

D. Quartz Sand

Quartz is a Metamorphic Rock and it is formed when Quartz-rich Sandstone has been exposed to high pressures and temperatures. Quartz is the most important sand forming mineral because of it is resistant to both physical and chemical weathering. Quartz sand is rich in silicates (Si) and has a high resistance to being crushed. Its hardness is 7 on the Mosh scale which is harder than most other natural substances. As such it is an excellent abrasive material.

E. Gypsum

Gypsum is used as a retarder to control the setting time and should be used in appropriate amount of quantity to develop the Geopolymer Mortar. To meet the desired setting qualities in the finished product, a quantity of 5% of gypsum (usually calcium sulphate or anhydrite) to binder is added to the mix. The excess use of gypsum may cause the unwanted expansion and indefinite delay in the setting of mortar.

III. EXPERIMENTAL PROGRAMME

There is no special code for practicing the mix design of Geopolymer Mortar (GPM)

A. Preparation of Alkaline Solution

The Alkaline solution is prepared by the experimental investigation is a combination of Sodium Hydroxide (NaOH) solution and Sodium Silicate (Na_2SiO_3). Potassium hydroxide (KOH) and Potassium silicate (K_2SiO_3) can be used as a preparation of alkaline solution it becomes expensive when compared to Sodium Hydroxide (NaOH) solution and Sodium Silicate (Na_2SiO_3). The alkaline solution was prepared one hour prior to the mix preparation. Entire study Sodium Silicate to Sodium Hydroxide value (SH/SS) = 2.5 was maintained.

Unlike the conventional mortar, there is no code to develop a procedure of designing GPM. Using molarity and final mix proportions of GPM can only be determined. Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) solutions are used to make GPM. In the preparation of GPM, 9M, 13M and 19M NaOH and 20%, 35%, and 50% Na_2SiO_3 are used which is calculated by the following equations. Normally the solution in soapy nature, Care should be taken while handling the Sodium Hydroxide (NaOH) solution with moist hands may cause serious irritation to the skin.

B. Mix Details of GPM

In this entire study binder to fine aggregate ratio was maintained with 1:5 at the same time GGBS to SF maintained with 0.8: 0.2 and alkalinity to binder ratio is 0.8. A small quantity of Gypsum 5% is added to the GPM mixture. The different molarities of Sodium Hydroxide (9M, 13M, and 19M) with different concentrations of Sodium Silicate Solution (20%, 35% and 50%) were used. The Table 1, 2 summarize the mix proportions of GPM

Table 1Mix design of Geopolymer Mortar

GGBS:SF Ratio	GGBS (kg/m^3)	Silica Fume (kg/m^3)	Gypsum (kg/m^3)	Quartz (kg/m^3)
0.8:0.2	266.00	66.50	17.50	1750.00

Table 2 Mix design of Geopolymer Mortar

MIX ID	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Water (kg/m^3)	Alkaline liquid (kg/m^3)
A1	22.48	40	217.52	280
A2	22.48	70	187.52	280
A3	22.48	100	157.52	280
B1	30.15	40	209.84	280
B2	30.15	70	179.84	280
B3	30.15	100	149.84	280
C1	39.60	40	200.40	280
C2	39.60	70	170.40	280
C3	39.60	100	140.40	280

C. Sample preparation of GPM

Geopolymer Mortar is developed by using Ground Granulated Blast Furnace Slag with Silica Fume as binders, Quartz sand is used as fine aggregate. The alkaline solution was used for alkali activation of source materials to develop Geopolymerisation. Alkaline solution preparation and development of equations based on different molarities and concentrations of the Na2SiO3 solution. In binders, GGBS and Silica Fume contains 80% and 20% respectively and a small quantity of Gypsum 5% added to the binder, then conventional river sand is completely replaced by Quartz sand. However, NaOH and Na2SiO3 were used as alkali activator.

Fig.3 Preparation of GPM

Before going to the preparation of GPM Mortar the mortar moulds (70.7 mm^3) were cleaned then applied grease for smooth de-moulding. The alkaline solution was prepared one prior to the mix. In this experimental work, the influence of different parameters on compressive strength of Mortar was studied. A total of 9 combinations carried out for this study. For each combination, 9 cubes were cast for testing of compressive strength of different ages (7, 28, and 56 days) each age carries 3 cubes. Ambient air curing technique was adopted for all the specimens.

Fig. 4 Cubes After Casting

It was observed that very quick setting of mortar mixes when compared to traditional mortar development and it is overcomes by fast mixing of materials until it turns into paste or mortar and it is filled with three layers into mortar moulds. Each layer consists approximately equal proportion of mortar and it was maintained as 25 blows to complete the layer with mortar in the mould. After completed the compacting of the top layer, a trowel used to finish off the surface level with the top of the mould, and excess material should be removed. After 24hr, the mortar specimens were demoulded and it is allowed for ambient air curing in order to provide adequate circulation of air and also maintain the adequate space between the cubes. Proper care should be taken to avoid damages to the cubes. It causes the reduction of strengths of Mortar

D. Compressive Strength Test on GPM

The mortar cube specimens tested according to IS 516-1959. The Geopolymer Mortar cubes were tested at the age of 7 days, 28 days, and 56 days. Compressive strength test is an utmost important mechanical property, and it gives the clear idea to analyse characteristics of either mortar or concrete. This test is conducted on hardened mortar specimens. It is easy to perform and analyse the desirable characteristic properties of Mortar are quantitatively related to compressive strength. By this single test, it can judge the whether the mortar is suitable for construction or not. Mortar specimens are used to determine the compressive strength of mortar. The mortar specimens size 70.7*70.7*70.7mm3 was uniformly maintained throughout the study. Compression testing machine was used to conduct the compressive strength of Geopolymer Mortar. The entire study was maintained the rate of loading is 1.2 KN/sec. In this experimental work to study the influence of different parameters on Compressive strength such as molarity, the concentration of Na_2SiO_3, mix proportion, alkaline to binder ratio, and age of the specimen. In order to develop a model based on different parameters as above mentioned to predicting the approximate characteristic strength of Mortar.

$$\textbf{Compressive strength} = \frac{\text{Ultimate compressive load (N)}}{\text{Area of cross section (mm square)}}$$

IV. RESULTS AND DISCUSSION

Table 3 Compressive Strength Test Results of GPM mix 1:5

NaOH	Code	Na_2SiO_3	Age of Mortar		
			7 Days	28 Days	56 Days
9M	A1	20%	17.9	18.9	19.9
	A2	35%	10.1	11.7	13.4
	A3	50%	12	12.3	20.3
13M	B1	20%	22.1	24.6	27.1
	B2	35%	19.5	20.5	28.2
	B3	50%	20.2	20.4	28.1
16M	C1	20%	14.6	26.7	27.8
	C2	35%	18.1	22	23.2
	C3	50%	21.7	23.3	21

Table 3 give the compressive strength results reported for the GPM mortar specimens for all mixes. Table 4 gives the percentage of strength development of GPM for all mixes.

The figure 5 represents the compressive strength results of 9M NaOH GPM mixes with 20%, 35%, and 50% concentration of Na_2SiO_3 at the ages of7, 28, and 56 days respectively in these results A3 give high compressive strength value of 20.3 MPa @56days whereas A2 give low compressive strength value 10.1MPa. In 9M NaOH, 20% concentration of Na_2SiO_3 give good results when compared to other two concentrations. It shows that the compressive strength increases with increasing the age of specimen of GPM.

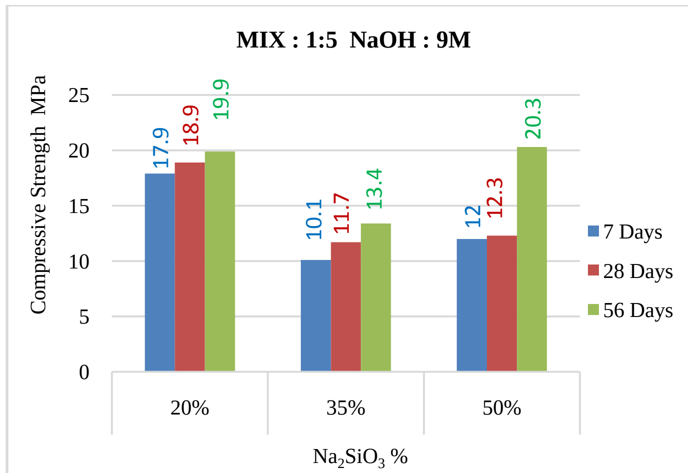

Fig. 5 Effect of Na_2SiO_3 % on Compressive Strength of GPM with 9M

Table 4 Percentage of Strength Developed at Given age with Respect to 56 days Strength

MIX NaOH	Code	Na_2SiO_3	Age of Mortar		
			7 Days	28 Days	56 Days
1:5 9M	A1	20%	89.9	95	100%
	A2	35%	75.4	87.3	100%
	A3	50%	59.1	60.6	100%
1:5 13M	B1	20%	81.5	90.8	100%
	B2	35%	69.1	72.7	100%
	B3	50%	71.9	72.6	100%
1:5 19M	C1	20%	52.5	96	100%
	C2	35%	78	94.8	100%
	C3	50%	92.4	111	100%

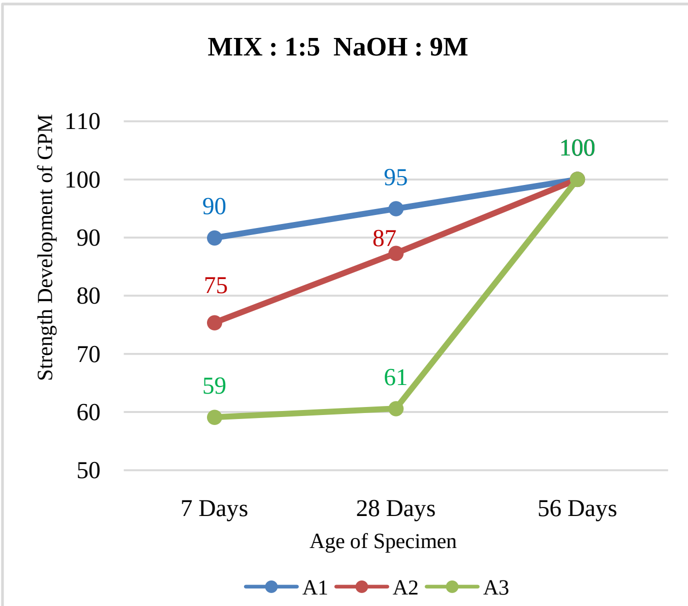

Fig. 6 Strength Development of GPM with 9M NaOH

The figure 6 represents the percentage of strength development of GPM from 7 days to 56 days. In 7days, GPM mortar gains 90%, 75% and 60% of Strength however in 28 days, 95%, 87%, and 60% of strength gains to the total strength attained in 56 days in 20%, 35% and 50% concentration of Na_2SiO_3 respectively.

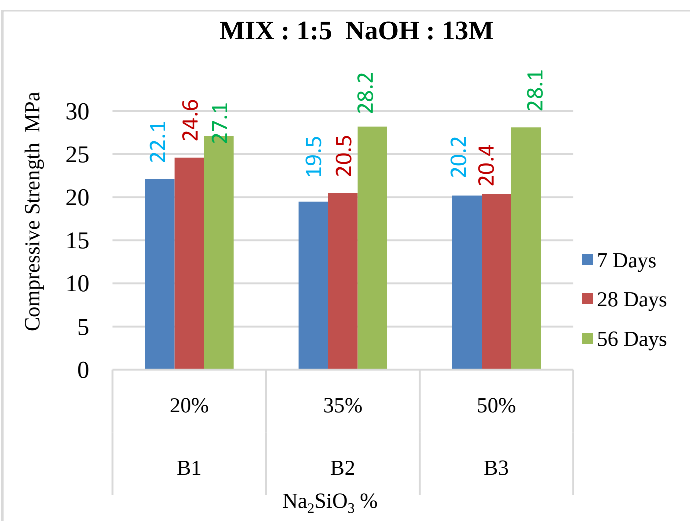

Fig.7 Effect of Na_2SiO_3 % on Compressive Strength of GPM with 13M

The figure 7 represents the compressive strength results of 13M NaOH GPM mixes with 20%, 35%, and 50% concentration of Na_2SiO_3 at the ages of7, 28, and 56 days respectively in these results B3 give high compressive strength value of 28.1 MPa @56days whereas B2 give low compressive strength value 19.5 MPa.

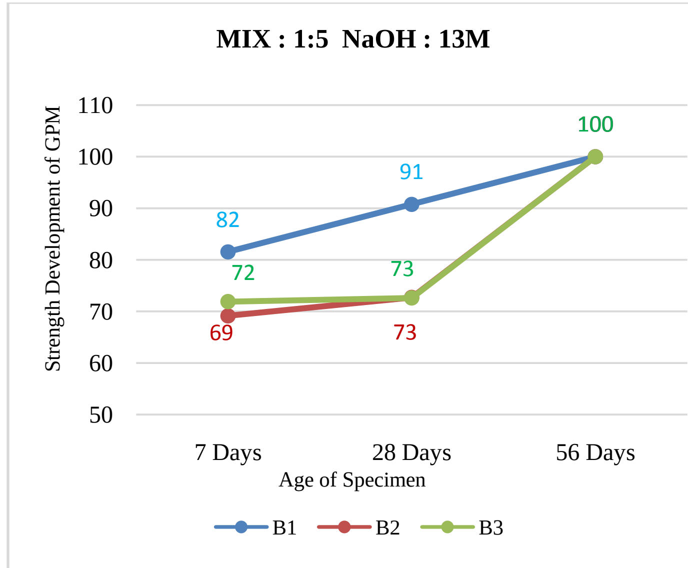

Fig 8: Strength Development of GPM with 13M NaOH

In 13M NaOH, 35% and 50% concentration of Na_2SiO_3 are look-alike it shows that similar strengths attained in 7 days, 28 days and 56 days respectively. It shows that the compressive strength increases with increasing the age of specimen of GPM. The figure 8 represents the percentage of strength development of GPM from 7 days to 56 days. In 7 days, GPM mortar gains 82%, 69%, and 72% of Strength however in 28 days 90%, 73%, and 73% of strength gains to the total strength attained in 56 days in 20%, 35% and 50% concentration of Na_2SiO_3 respectively.

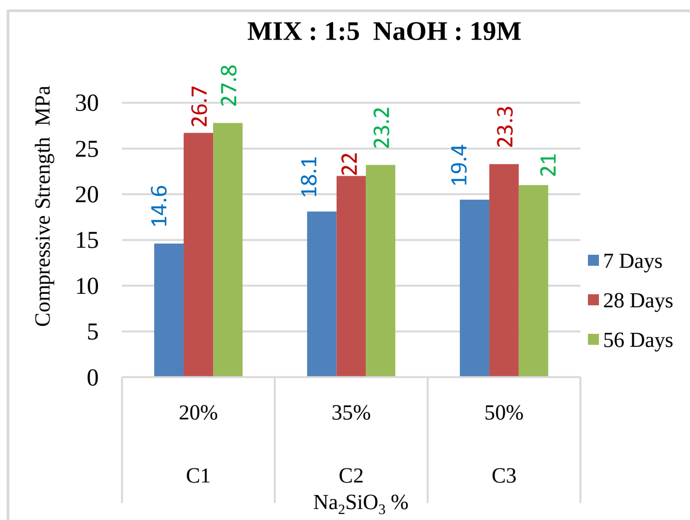

Fig. 9 Strength Development of GPM with 13M NaOH

The figure 9 represents the compressive strength results of 19M NaOH GPM mixes with 20%, 35%, and 50% concentration of Na_2SiO_3 at the ages of7, 28, and 56 days respectively in these results C1 give high compressive strength Value of 27.8 MPa @56days at the same time it give low compressive strength value 14.6 MPa @ 7 days. It shows that the compressive strength increases with increase in the age of specimen of GPM except in C3. In that C3 the compressive strength increases with an increase of age from 7 days to 28 days then it decreases from 28 days to 56 days.

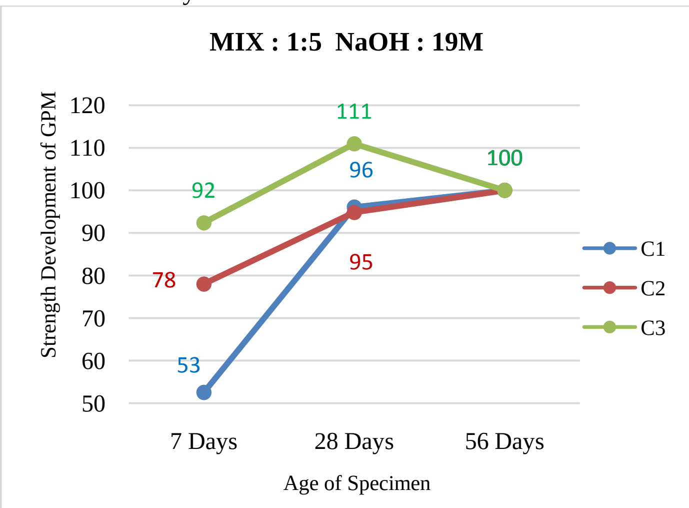

Fig. 10 Strength Development of GPM With 19M NaOH

The Figure 10 represents the percentage of strength development of GPM from 7 days to 56 days. In 7 days, GPM mortar gains 53%, 78%, and 92% of Strength however in 28 days 96%, 95%, and 110% of strength gains to the total strength attained in 56 days in 20%, 35% and 50%

V. CONCLUSION

Based on experimental work reported in this study, the following results were developed.

1. The appropriate percentage of GGBS and Silica Fume were finalized with 80% and 20% respectively on the basis results of various trial mixes.
2. The compressive strength increases with the increasing age until 56 days in all mixes except C3 mix of GGBS with SF based Geopolymer Mortar.
3. Geopolymer Mortars gain by the average 75% and 90% of strength in 7 days and 28 days respectively with respect to the total strength attained in 56 days.
4. In these results 20% concentration of Na_2SiO_3 givegood results when compared to other two concentrations.
5. In 1:5 mixes, 13M NaOH gives high compressive strengths results than other two molarities of NaOH.
6. Among all the mixes of GPM, B2 mix (1:5, 16M NaOH, 35% Na_2SiO_3, 0.8 A/B, and @56) gives high compressive strength value of 28.2 MPa and A2 mix (1:5, 9M NaOH, 35% Na_2SiO_3, 0.8 A/B, and @28) gives low compressive strength value of 10.1 MPa.
7. The GGBS with SF based Geopolymer Mortars can be used as mortar for plastering, manufacture of bricks and also as concrete in Geopolymer reinforced concrete.

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