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Effect of Alkaline Liquid to Silica fume and SiO_3 to OH ratio on Compressive Strength of Geopolymer Concrete

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Abstract: The exposure of alumino silicate materials such as fly ash, rice husk ash, silica fume etc., under goes thermal activation along with alkaline environment forms an environment friendly material called geopolymer. These materials not only contribute reduction in emission of carbon dioxide gas to the atmosphere but also these modern materials act as a substitute for cement to meet with the future demand. In this study an attempt has been made to produce silica fume based geopolymer concrete and to find out its compressive strength characteristics by considering the parameters such as ratio of alkaline liquid (AL) to silica fume (SF), ratio of silicate to hydroxide (SiO_3/OH) and the age of geopolymer concrete with constant percentage of silica fume. Detailed experimental investigations were carried out to assess the effect of the above mentioned parameters on compressive strength. From the results it was understood that with AL/SF = 0.30, SiO_3/OH= 1.5, for thermal curing temperature of 60°C, for curing period of 56 days and 80% replacements of silica fume, yielded better compressive strength when compared to conventional concrete under normal curing. Hence use of silica fume based geopolymer concrete is recommended for construction.
Keywords: Silica fume, Alkaline liquid, geopolymer concrete, thermal curing, Curing period and Compressive strength.

Introduction

Geopolymeric materials represent a new innovative technology which has been developed in the construction industry, although this technology has been considered new but it can produced from ancient building materials[1-3]. This geopolymer concrete has been developed from any byproduct or pozzalano materials such as fly ash, rice husk ash, silica fume, slag etc., which is rich in silica and alumina which can be dissolved in alkaline solution which involves chemical reaction to form geopolymers[3].The chemical reaction involves polymerization process which involves reaction between silica and alumina along with alkaline solution produces three dimensional polymeric ring structures[4]. The presence of calcium in source material in larger amount disturbs the polymerization process and also the microstructure of concrete[5]. The source material with alkaline liquid subjecter to thermal curing at temperature 60º to 90ºC increases the compressive strength[6-12].

The thermal curing of geopolymer concrete enhances the compressive strength and it facilitates any one of the form as such as Poly (sialate), Poly (sialate-siloxo), and Poly (sialate-disiloxo) as a repeating units[13]. Also the compressive strength value not only depends upon chemical reaction but also depends upon the concentration of sodium hydroxide (NaOH) solution[14-15]. Hence to produce eco friendly concrete has to be produced from partial replacement of cement with byproduct material silica fume and parameters taken for present study are effect of AL/SF,effect of sodium silicate to sodium hydroxide solution (Na_2SiO_3/NaOH) and effect of age on compressive strength of concrete.

Experimental Investigations

Materials used

Silica fume

Silica fume is a byproduct material obtained in the production of ferrosilicon industry and also from silicon metal. The silica fume material was supplied by Oriental Trexim Pvt Ltd. Typical particle size is <1µm and of very small particle size that plays a significant role in enhancing the strength at early ages. The specific gravity of silica fume used is 2.26. Silica and alumina constitutes around 80 to 85% by mass. The presence of silica in greater percentage improves the microstructure of concrete. In the present work cement was replaced with silica fume of about 80%.

Cement

The cement used for this study is Ordinary Portland Cement (OPC) of 43 grade. The silica fume based geopolymer concrete is designed for characteristic compressive strength of 25 MPa.

Fine aggregate

The type of fine aggregate used for the present study is natural river sand and it was screened and washed to remove all organic and inorganic compounds before its use that are likely to present in it. Sand passed through 2.36 mm sieve and retained on 600 µ was taken for study. The specific gravity of fine aggregate used for the present work is 2.63.

Coarse aggregate

Granite stones were used as coarse aggregate and are of size 12.5 mm. The aggregates were washed to remove dust & dirt and were dried to surface dry condition. The specific gravity of coarse aggregate used is 2.6.

Super plasticizer

To improve the workability of the silica fume based geopolymer concrete, conplast SP430 super plasticizer which was obtained from FOSROC Constructive Solutions Company was used in the present work. It served as a high range water reducer. The color of the conplast is brown liquid and dosage of conplast added as 4% by weight of silica fume for all the mixes.

The chemical composition of the materials used for the present study is given in Table 2.

Alkaline liquid

The alkaline liquid is soluble alkali metals usually sodium or potassium based. The sodium based liquid has more reactivity and it is easily soluble than potassium based solution. A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. The sodium hydroxide solids were a technical grade in flakes form with a specific gravity of 2.13 with 98% purity. The chemical composition of sodium silicate solution was Na_2O is 23.3%, SiO_2 is 20.8% and water 55.9% by mass.

Table 1 Chemical composition of concrete materials

Description	Coarse Aggregate (%)	Cement (%)	Silica fume (%)
SiO_2	58.54	24.5	97.36
Al_2O_3	17.81	7	0.53
CaO	6.17	63	0.14
Fe_2O_3	6.07	0.55	0.15
Na_2O	4.2	0.4	0.06
MgO	2.91	2	0.79
K_2O	2.65	0.6	0.29
TiO_2	0.66	-	0.01
P_2O_5	0.38	-	0.09
BaO	0.15	-	-
SO_3	0.14	1.5	0.51
SrO	0.07	-	
MnO	0.06	-	0.01
Cl	0.06	0.05	-
ZrO_2	0.06	-	-
Cr_2O_3	0.04	-	100 ppm
NiO	0.01	-	-
ZnO	89 ppm	-	70 ppm
Rb_2O	46 ppm	-	-

Table 2 Mix Proportion for geopolymer concrete

Water	Cement	Fine Aggregate	Coarse Aggregate
202.395 kg/m^3	459.98 kg/m^3	508.23 kg/m^3	984.26 kg/m^3
0.44	1	1.1	2.1

Methodology

Preparation of alkaline liquid

Sodium hydroxide (NaOH) and Sodium silicate (Na_2SiO_3) were used as alkaline liquids. The molarity of NaOH used for the present study was 14. The ratios of Na_2SiO_3 to NaOH selected were 0.5, 1.5, and 2.5 respectively. Alkaline liquid (AL) to Silica Fume (SF) ratio were taken as 0.25, 0.30, and 0.35. A solution of 14M of sodium hydroxide is prepared by dissolving 560g of sodium hydroxide pellets in a liter of water and stored separately. For particular ratio of alkaline liquid to silica fume and sodium silicate to sodium hydroxide ratio were taken and mix the two solutions in the beaker one day before casting of specimens.

Casting of Geopolymer concrete specimens

Concrete mix proportion for a characteristic compressive strength of 25 MPa and required ingredients per m^3 is shown in Table 2. The size of the specimens used for the present study was 100 mm x 100 mm x 100 mm. Silica fume was mixed with sand, coarse aggregates and the alkaline liquid (combination of Sodium silicate and sodium hydroxide) were poured to dry mix and mixed thoroughly to form homogenous mixture for a period of 3 min approximately. The required quantity of super plasticizer was added as 4% by mass of silica fume. The quantities of alkaline solutions are shown in Table 3. Once the mixing process was over the mould was filled by the fresh concrete in three layers and compacted well. In each mix three specimens were cast to test the compressive strength of concrete. A total number of 108 specimens were cast for the present study.

Table 3 Quantity of alkaline liquid used for the present work

NaOH ml	Na_2SiO_3 ml	AL ml	AL/SF	Na_2SiO_3/ NaOH
914	457	1028	0.25	0.5
1096	548	1233	0.3	0.5
1278	640	1439	0.35	0.5
548	822	1028	0.25	1.5
658	987	1233	0.3	1.5
768	1151	1439	0.35	1.5
392	979	1028	0.25	2.5
470	1173	1233	0.3	2.5
548	1370	1439	0.35	2.5

Curing of Geopolymer concrete specimens

After the specimens were cast they were kept in hot air oven properly wrapped by a polyethylene with a constant temperature of 60°C for a period of 6 hours. Then the specimens were taken out and kept in room temperature for the desired rest period. The specimens were cast for three different AL/SF ratios of 0.25, 0.30 and 0.35 respectively to study the effect of AL/SF ratio and for three different ratios of Na_2SiO_3/NaOH such as 0.5, 1.5 and 2.5 respectively to study the effect of SiO_3/OH ratio on compressive strength of concrete. All the specimens cast for the above said ratios were tested for its compressive strength at the ages of 3, 7, 28 and 56 days. For all the mixes cement was replaced with 80% of Silica fume to study its effect. The molarity used for the present study was kept constant as 14. Since alkali activators were used for the study the specimens were kept in hot air oven for thermal curing to a temperature of 60^{o} C and after that the specimens were cured at ambient temperature for the desired rest periods. The proportions of cement, silica fume mixture for M25 grade concrete is given in Table 2.

Results and Discussion

Effect of Alkaline liquid to silica fume ratio on compressive strength

Figure 1 to 3 represents the results of compressive strength of geopolymer concrete to for AL/SF ratios of 0.25, 0.30 and 0.35 respectively to understand the effect of AL/SF ratio. The result clearly shows that there was an increase in compressive strength with increase in AL/SF ratio and with increase in age of concrete. It was revealed that for a particular AL/SF ratio there was an increase in strength with increase in Na_2SiO_3/NaOH ratio from 0.5 to 2.5. The rate of increase in compressive strength due to increase in AL/SF ratio from 0.25 to 0.30 were varied from 1 to 3% for all the ages of concrete for Na_2SiO_3/NaOH ratio as 0.5. Similar values for Na_2SiO_3/NaOH = 1.5 these values were 1 to 2% and for Na_2SiO_3/NaOH = 2.5 these values were around 1%. Similar trend was observed for AL/SF ratio from 0.3 to 0.35 also. It was also observed that rate of increase of compressive strength was more for AL/SF ratio from 0.25 to 0.30 than 0.30 to 0.35. The important point to be noted was with no water addition to concrete, no water curing and with 80% replacement of cement with silica fume the concrete was able to develop 30, 60 and 80% of characteristic compressive strength for which it was designed. Replacement of 80% of cement with waste product from silicon industries not only minimizes the CO_2 emission problem but also solves the disposal problem of such waste with little bit compromise in compressive strength.

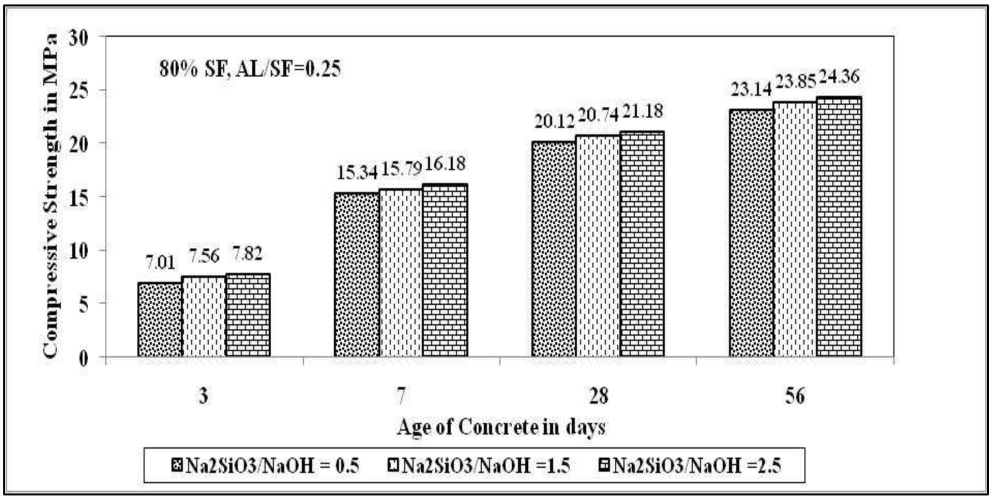

Figure 1 Effect of Compressive strength for AL/SF ratio = 0.25

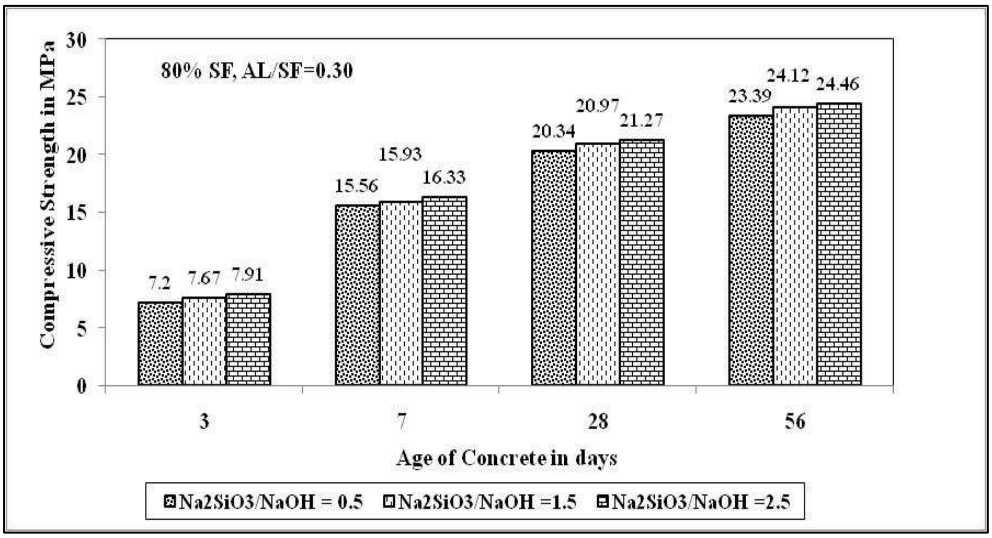

Figure 2 Effect of Compressive strength for AL/SF ratio = 0.30

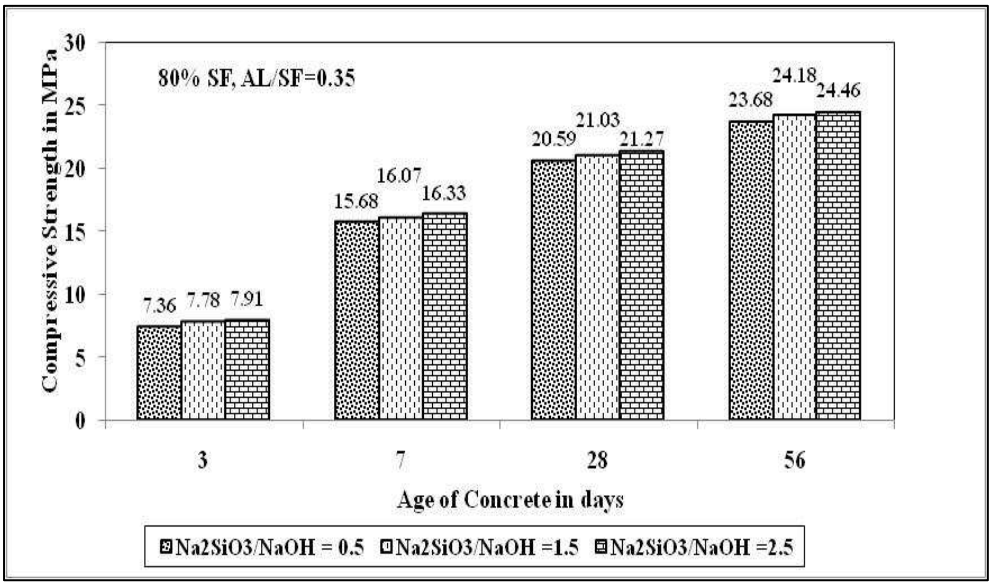

Figure 3 Effect of Compressive strength for AL/SF ratio = 0.35

Effect of Sodium silicate to sodium hydroxide ratio on compressive strength

Figure 4 to 6 depicts the results of compressive strength of geopolymer concrete for three different Na_2SiO_3/NaOH ratios of 0.5, 1.5, and 2.5 respectively to understand the effect of Na_2SiO_3/NaOH ratio. The result revealed that for a particular Na_2SiO_3/NaOH ratio and particular age of concrete there is an increase in compressive strength of silica fume based geopolymer concrete. A similar trend was observed when ratio of Na_2SiO_3/NaOH increases from 0.5 to 1.5 and 1.5 to 2.5 for all the ages of silica fume based geopolymer concrete. It was also noted that for a particular Na_2SiO_3/NaOH ratio there was an increase in strength with increase of AL/SF ratio from 0.25 to 0.30 and 0.3 to 0.35 ratios. The rate of increase in compressive strength due to increase in Na_2SiO_3/NaOH ratio from 0.5 to 1.5 was from 3 to 8% for different ages of concrete and AL/SF ratios. The rate of increase of compressive strength was more for Na_2SiO_3/NaOH from 0.5 to 1.5 than 1.5 to 2.5.

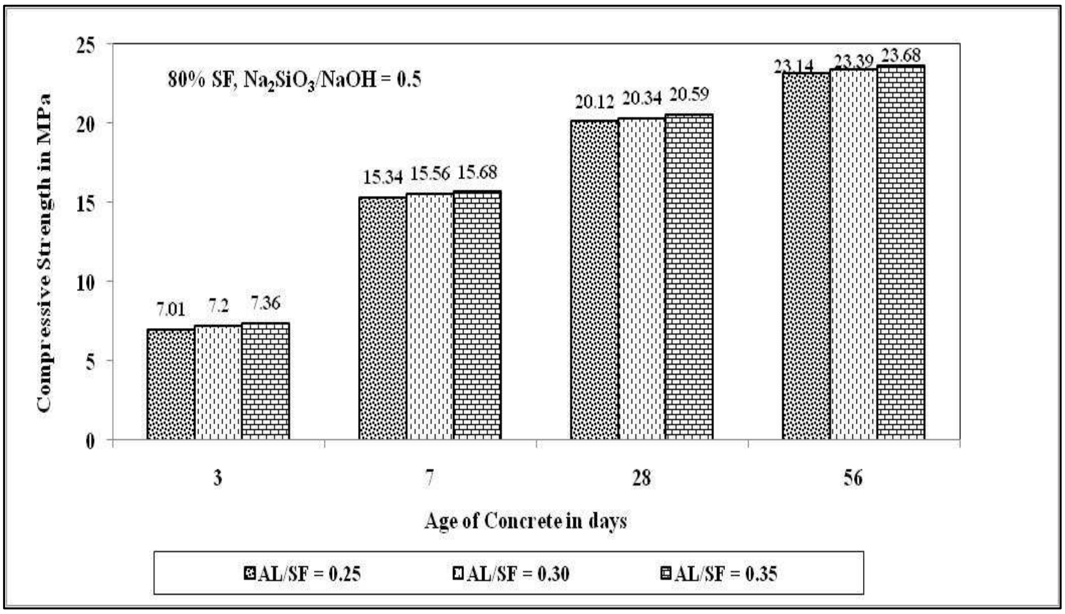

Figure 4 Effect of Compressive strength for Na_2Sio_3/NaOH ratio = 0.5

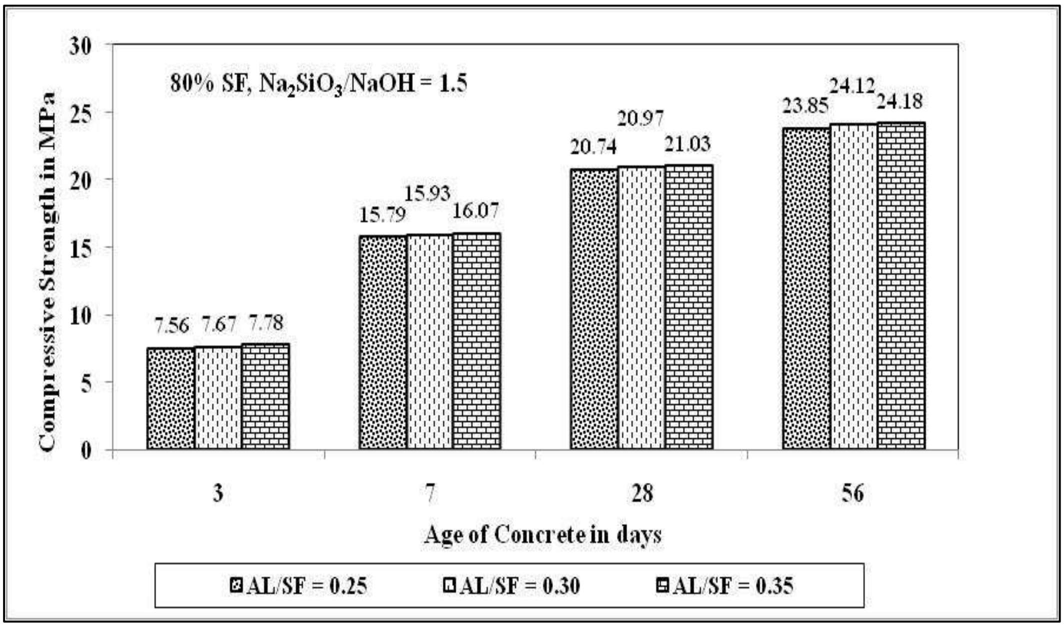

Figure 5 Effect of Compressive strength for Na_2Sio_3/NaOH ratio = 1.5

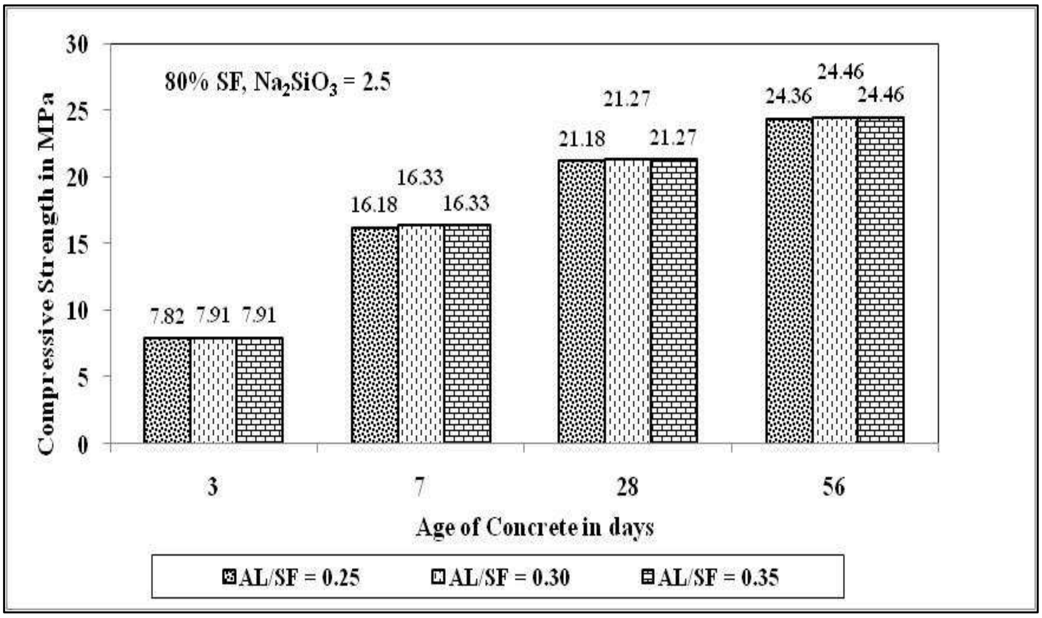

Figure 6 Effect of Compressive strength for Na_2Sio_3/NaOH ratio = 2.5

Effect of age on compressive strength

The results of compressive strength of geopolymer concrete for four different ages of 3,7,28 and 56 days are shown in figure 7 to 9 to understand the effect of age of concrete. All the specimens were subjected to thermal curing with a constant temperature of 60^o C for 6 hours and age of concrete was nothing but rest period. Rest period was the period during which the specimens were kept with ambient temperature (room temperature). The rate of increase in compressive strength for the age from 3 to 7 days was around 50 to 54%, for the age from 7 to 28 days was around 24% and for the age from 28 to 56 days it was found to be 13% for all the AL/SF ratios and Na_2SiO_3/NaOH ratios. Even though gain in compressive strength observed in early ages but optimum percentage of gain in strength was observed for AL/SF = 0.30 and Na_2SiO_3/NaOH = 1.5 ratio at all the ages of specimens and hence they can be taken as optimum ratio in the respective category.

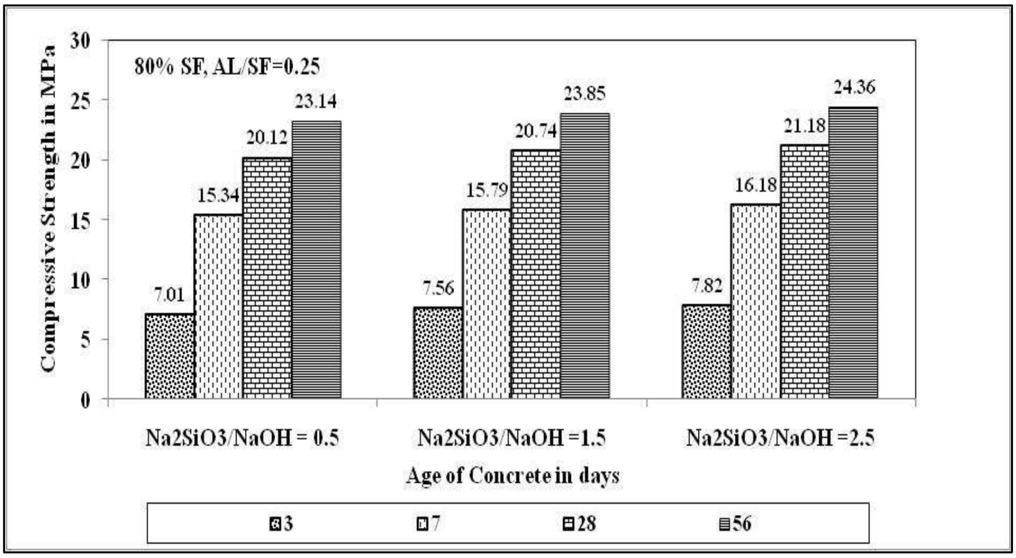

Figure 7 Effect of age on Compressive strength for AL/SF ratio = 0.25

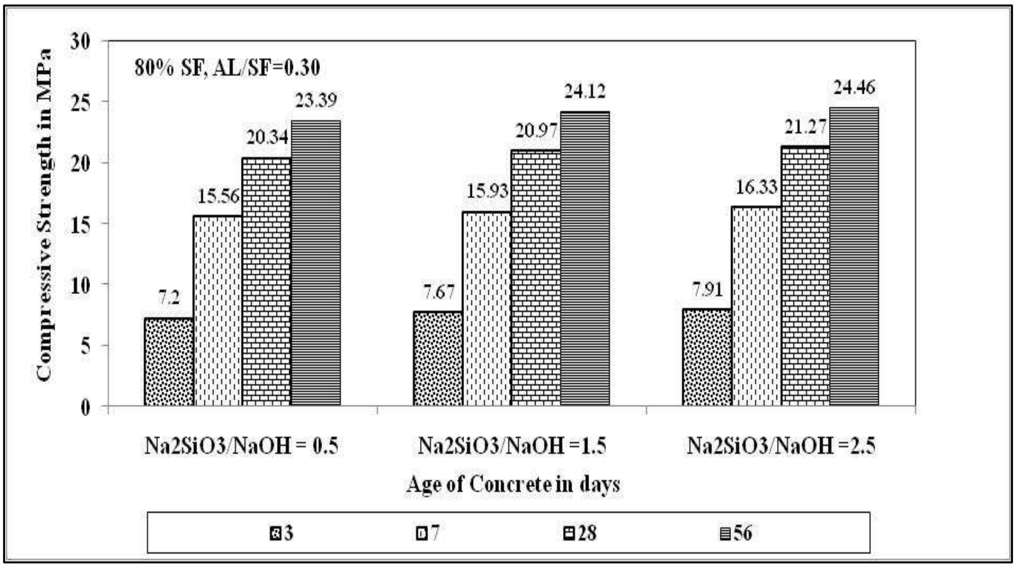

Figure 8 Effect of age on Compressive strength for AL/SF ratio = 0.30

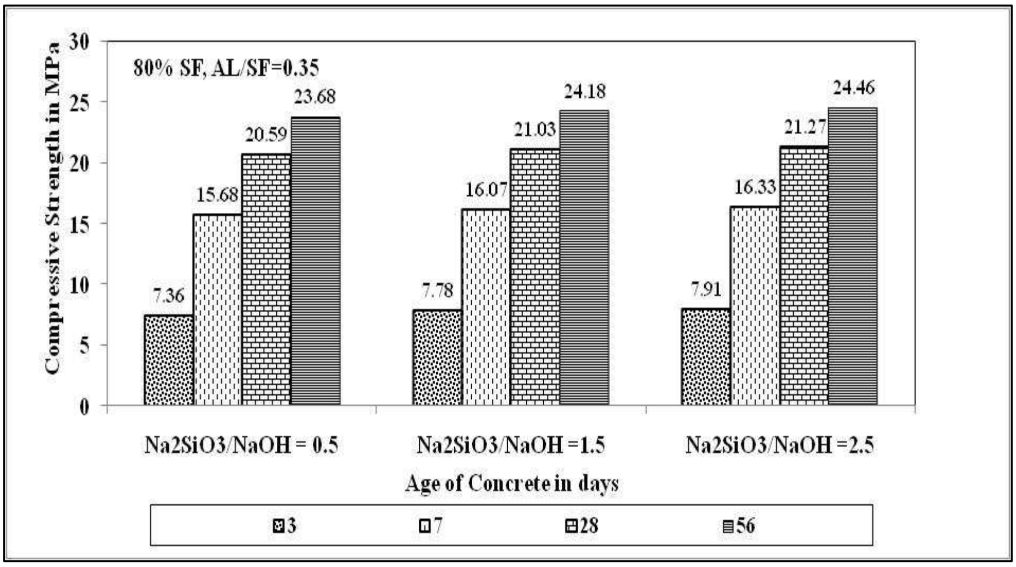

Figure 9 Effect of age on Compressive strength for AL/SF ratio = 0.35

Conclusions

A sincere attempt has been made to produce silica fume based geopolymer concrete and found that it was feasible. Following are the conclusions from the study.

1. Replacement of 80% of cement with silica fume made possible with little bit compromise in compressive strength. The development of compressive strength of silica fume based geopolymer concrete at par with control concrete.

2. Silica fume was effective in modifying the microstructure of geopolymer concrete and in the geopolymerisation process. It also developed very good bondage with alkaline liquids to yield a better strength and alkali activation process.

3. From the limited experiments conducted, it was found that AL/SF = 0.30 and $Na_2SiO_3/NaOH$ = 1.5 were the optimum ratios in preparing silica fume based geopolymer concrete.

4. This type of geopolymer concrete not only replaces the cement to a larger extent and making use of industrial waste to minimize its disposal problem but also suited for precast concrete where thermal curing is possible and needs higher degree of quality control.

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