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Compressive Strength of Silica Fume Based Geopolymer Concrete

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ABSTRACT

The increasing worldwide production of cement to meet the future development in the infrastructure industry indicates the concrete is the most important ingredient in the modern construction materials. It is well evident that production of Ordinary Portland Cement (OPC) not only consumes larger quantity of natural resources but also emits larger quantity of carbon dioxide gas to the atmosphere. An effort has been taken to reduce the emission of carbon dioxide gas and also to produce an environment friendly material in the development of inorganic alumino silicate polymer called geopolymer, which is obtained from materials of geological origin or a byproduct materials such as fly ash, Silica fume, Ground Granulated Blast furnace Slag (GGBS) along with alkaline liquid. Geopolymer concrete (GPC) is a new innovative eco-friendly material which can be produced by partial replacement of cement in ordinary concrete by a mineral admixture such as Silica fume, Fly ash and Ground Granulated Blast furnace Slag along with alkaline liquid. In this study an attempt has been made to produce silica fume based geopolymer concrete and to find out its strength characteristics by considering the parameters such as ratio of alkaline liquid to silica fume, ratio of silicate to hydroxide and for different ages of geopolymer concrete with constant percentage of silica fume. The experiments were conducted to study the above mentioned parameters. From the results it is understood that with AL/SF = 0.25, SiO_3/OH = 0.5, for thermal curing temperature of 60°C, for curing period of 56 days and 60% 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.

Key words: Silica fume, alkaline liquid, geopolymer concrete, thermal curing, curing period, compressive strength

INTRODUCTION

The contribution of Ordinary Portland Cement (OPC) production world wide to green house gas emissions to be approximately 2.6 billion tones per year and growing at 5% annually. In 1991-1994 Davidovits stated that geopolymers are a new class of inorganic polymers. These polymers will be formed by a three dimensional alumino silicate materials. It can be produced by polymerization process of alkaline liquid along with geological origin materials or a byproduct material such as fly ash, silica fume and GGBS. These polymers are a new innovative materials which replaces the use of OPC in concrete. This polymerization reaction involves formation of three dimensional polymeric chain by the Si-Al minerals to form a ring structure which consist of Si-O-Al bonds.

Palomo *et al.* (1999) suggested that pozzolans such as blast furnace slag might be activated using alkaline liquids to form a binder and hence replace the use of OPC in concrete. Cioffi *et al.* (2003) also suggested that the fast chemical reaction will takes place when Si-Al minerals reacts with alkaline condition under polymerisation process. This results in a formation of three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds: $Mn[-SiO_2)Z-AlO_2].n.wH_2O$ (Davidovits, 1999). The rate of increase in the formation of polymer compounds alumina and silica substantially increases the strong bond between the geopolymers (Provis *et al.*, 2005). Products arising from geopolymeric reaction will have high mechanical properties and resist high temperature and other chemical reagents (Yunsheng *et al.*, 2010). Hence these are subjected to heat curing with a range of temperatures, 60 to 90°C (Palomo *et al.*, 1999; Puertas *et al.*, 2000; Brough *et al.*, 2001; Phair and van Deventer, 2002; Bakharev, 2005; Provis *et al.*, 2005). Kovalchuk *et al.* (2008) concluded the compressive strength values geopolymer concrete are very much influenced by molar ratio. Rattanasak and Chindaprasirt (2009) and Guo *et al.* (2010) also suggested that the concentration of NaOH solution influences the strength characteristics of GPC. Hence in order of reducing the impact of unwanted by products of industry and by lowering the rate of material consumption the effort to produce more environmentally friendly concrete is to partially replace the amount of ordinary portland cement in concrete with by product material such as silica fume in the production of silica fume based geopolymer concrete. It was decided to study the effect of ratio of sodium silicate to sodium hydroxide ratio, effect of alkaline liquid to silica fume ratio and effect of age of geopolymer concrete on compressive strength of silica fume based geopolymer concrete.

MATERIALS AND METHODS

Materials

Silica fume: Silica fume is a by product in the production of ferrosilicon industry and also of silicon metal. The silica fume was supplied by Oriental Trexim Pvt Ltd. Typical particle size is <1 μm. The specific gravity of silica fume used is 2.26. Silica and alumina constitutes around 80 to 85%. The presence of silica in greater percentage improves the microstructure of concrete. In the present work cement was replaced with silica fume to a value of 60%.

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 strength M25 grade concrete. The proportions of cement, silica fume mixture for M25 grade concrete is given in Table 1.

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 and dirt and were dried to surface dry condition. The specific gravity of coarse aggregate used is 2.6.

Super plasticizer: To improve the work ability of the silica fume based geopolymer concrete, conplast SP 430 super plasticizer which is obtained from FOSROC Constructive Solutions Company and it 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.

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.

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 16 M. 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 16 M of sodium hydroxide is prepared by dissolving 640 g 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 M25 grade and required ingredients m^{-3} is shown in Table 1.

The size of the specimens used for the present study is 100×100×100 mm as per IS standard code (IS 2386). Silica fume were mixed with sand and aggregates and the alkaline liquid (combination of sodium silicate and sodium hydroxide) were poured to dry mix and mix thoroughly to form homogenous mixture for 3 min, approximately. The required quantity of super plasticizer is added as per the Table 2. Once the mixing process gets over the mould was filled by the concrete in three layers and compaction is done by hand using rod. For taking the compressive strength three specimens were casted for 16 M concentration of sodium hydroxide, three different ratios of sodium silicate to sodium hydroxide, three different alkaline liquid to silica fume ratio and four different periods of curing. Totally 108 specimens were casted.

Table 1: Mix proportion for M 25 grade GPC

Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (L)
459.98	508.23	984.26	202.40
1.0000	1.10	2.10	0.44

Table 2: Results of 40% replacement of cement with 60% replacement of silica fume for 16 molarity concentration of NaOH solution

SF (kg)	CEM (kg)	FA (kg)	CA (kg)	NaOH (mL)	Na_2SiO_3 (mL)	AL (mL)	AL/SF	Na_2SiO_3/NaOH
4.1	2.76	7.54	14.4	684.00	342.00	1026.00	0.25	0.5
4.1	2.76	7.54	14.4	821.33	410.66	1231.99	0.30	0.5
4.1	2.76	7.54	14.4	958.00	479.00	1437.00	0.35	0.5
4.1	2.76	7.54	14.4	410.40	615.60	1026.00	0.25	1.5
4.1	2.76	7.54	14.4	492.80	739.20	1232.00	0.30	1.5
4.1	2.76	7.54	14.4	575.20	862.20	1437.40	0.35	1.5
4.1	2.76	7.54	14.4	293.00	732.20	1025.20	0.25	2.5
4.1	2.76	7.54	14.4	273.30	683.33	956.63	0.30	2.5
4.1	2.76	7.54	14.4	410.57	1025.73	1436.30	0.35	2.5

Curing of geopolymer concrete specimen: After the specimens are casted they were kept in hot air oven properly wrapped by a polythene bags and kept for a constant temperature of 60°C for a period of 6 h, then the specimens are taken out and kept in room temperature until the period of testing. The specimens were tested for its compressive strength at 3, 7, 28 and 56 days. Parameters considered for study of the compressive strength characteristics are as follows:

- Silica fume (%) = 60%
- Cement (%) = 40%
- Concentration of sodium hydroxide = 16 M
- Sodium silicate to sodium hydroxide ratio = 0.5, 1.5, 2.5
- Alkaline liquid to silica fume ratio = 0.25, 0.3, 0.35
- Curing temperature is at 60°C
- Age of concrete = 3, 7, 28, 56 days

Based on the above parametric study the results are tabulated in Table 2.

RESULTS AND DISCUSSION

Effect of alkaline liquid to silica fume ratio: The specimens are casted and tested for its compressive strength with three different ratios of alkaline liquid to silica fume. The ratios taken for the present study were 0.25, 0.30 and 0.35, respectively. The results are shown in Fig. 1a-c, result reveals that for a particular Na_2SiO_3/NaOH ratio and particular age of concrete there is an respectively. The result reveals that there is an increase in compressive strength when AL/SF ratio

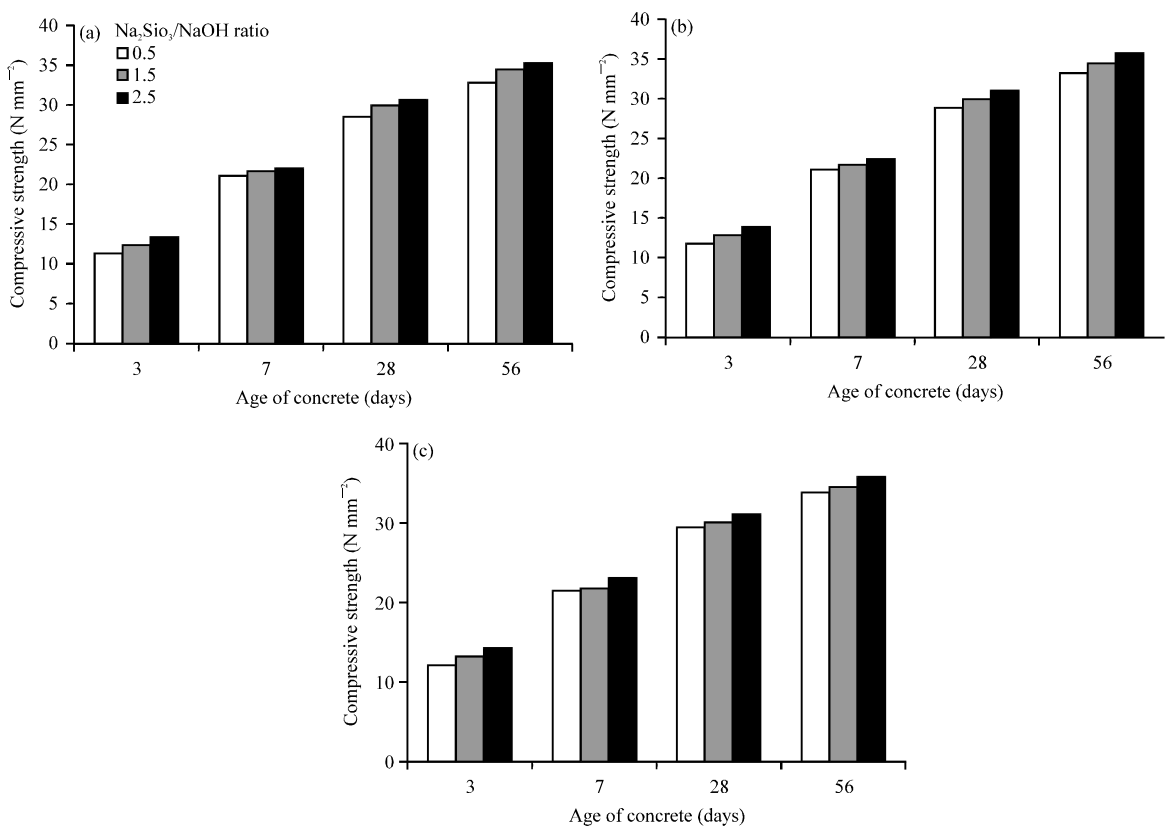

Fig. 1(a-c): Effect of compressive strength for AL/SF ratio (a) 0.25, (b) 0.30 and (c) 0.35

increases irrespective to the age of concrete. It reveals that there is an increase in the compressive strength when alkaline liquid ratio increases from 0.25 to 0.30 and 0.30 to 0.35 irrespective of age of concrete. It is also noted that for a particular AL/SF ratio there is an increase in strength with increase in Na_2SiO_3/NaOH ratio from 0.5 to 1.5 and 1.5 to 2.5 ratios. The rate of increase in compressive strength due to increase in AL/SF ratio from 0.25 to 0.30 were 3.51, 1.33, 1.51 and 1.50% for 3, 7, 28 and 56 days, respectively with Na_2SiO_3/NaOH ratio as 0.5. Similar values for Na_2SiO_3/NaOH = 1.5 these values are 2.65, 0.32, 0.74 and 0.70% and Na_2SiO_3/NaOH = 2.5 these values are 2.99, 1, 1.14 and 1.14%, respectively. Similar trend has been observed for AL/SF ratio from 0.3 to 0.35 and these were 3.05, 0.56, 2.32 and 2.32% for 3, 7, 28 and 56 days, respectively with Na_2SiO_3/NaOH ratio as 0.5. Similar values for Na_2SiO_3/NaOH = 1.5 these values are 3.05, 0.78, 0.4 and 0.41%, respectively. For Na_2SiO_3/NaOH = 2.5 these values are 1.01, 2.87, 0.78 and 0.79%, respectively. The rate of increase in compressive strength of silica fume based geopolymer concrete is 1.00 to 3.5% for all the ages of geopolymer concrete and for all the Na_2SiO_3/NaOH ratios when tested. Although the magnitude of AL/SF ratio increases by 0.25 to 0.30, the magnitude of compressive strength for AL/SF = 0.25 is lesser than the values for AL/SF = 0.30. The alkaline solution to flyash ratio increases there is an increase in the compressive strength of GPC of about 1.5 times that of M25 grade controlled concrete (Raijiwala and Patil, 2011). Hence AL/SF ratio of 0.25 is the optimum proportion among the three different ratios in the present study.

Effect of sodium silicate to sodium hydroxide ratio: The silica fume based geopolymer concrete were casted for three different ratios of Na_2SiO_3/NaOH. The ratio for Na_2SiO_3/NaOH is 0.5, 1.5 and 2.5 have taken for the present study. The results are shown in Fig. 2a-c, respectively. The

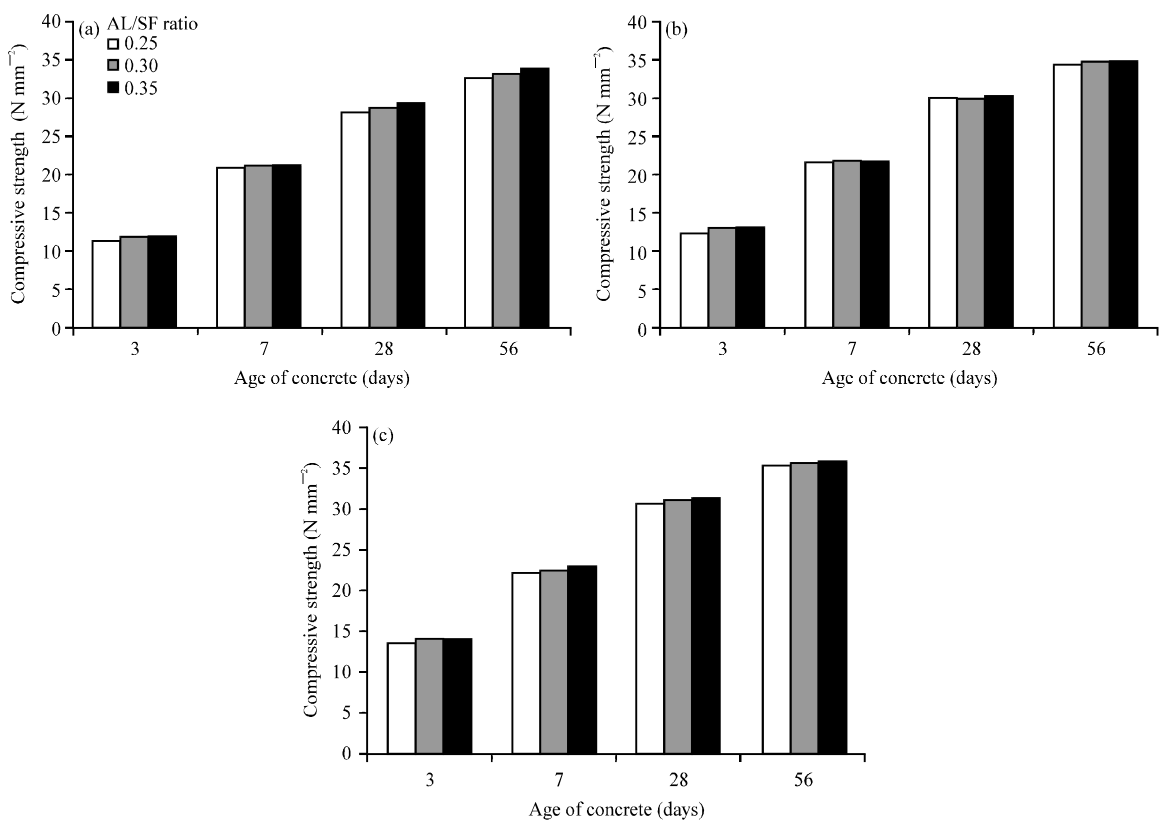

Fig. 2(a-c): Effect of compressive strength for Na_2Sio_3/NaOH ratio (a) 0.5, (b) 1.5 and (c) 2.5

result reveals 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. It shows a similar trend 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 is also noted that for a particular Na_2SiO_3/NaOH ratio there is 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 is 9.39, 2.95, 4.85 and 4.86% for 3, 7, 28 and 56 days respectively with AL/SF ratio as 0.25. Similar values for AL/SF = 0.30 these values are 8.47, 1.93, 4.05 and 4.03% and AL/SF = 0.35 these values are 8.47, 2.15, 2.10 and 2.09% respectively. Similarly for 1.5 to 2.5 are 7.46, 1.94, 2.61 and 2.59%, respectively. Similar trend has been observed for Na_2SiO_3/NaOH from 1.5 to 2.5 and these values are 7.46, 1.94, 2.61 and 2.59% for 3, 7, 28 and 56 days with AL/SF = 0.25. Similar values for AL/SF = 0.30 and these values are 7.81, 2.63, 3.03 and 3.04%, respectively. For AL/SF = 0.35 these values are 5.69, 4.76, 3.41 and 3.43%, respectively. The rate of increase in compressive strength is 2 to 9% for 0.5 to 1.5 ratio and 2 to 7% for 1.5 to 2.5 ratios. The increase in concentration of NaOH solution and increase in the ratio of Na_2SiO_3/NaOH solution results in increase in compressive strength of GPC (Chindaprasirt *et al*., 2007). Hence for three different ratios of Na_2SiO_3/NaOH tested for different ages of concrete, it reveals that Na_2SiO_3/NaOH = 0.5 is an optimum one in terms of strength increase.

Effect of age on compressive strength of silica fume based geopolymer concrete: The results for the different ages of silica fume based geopolymer concrete are shown in Fig. 3a-c, respectively. Since the silica fume based geopolymer concrete are subjected to thermal curing for a period of 6 h and kept in a room temperature for a desired period until the period of testing of

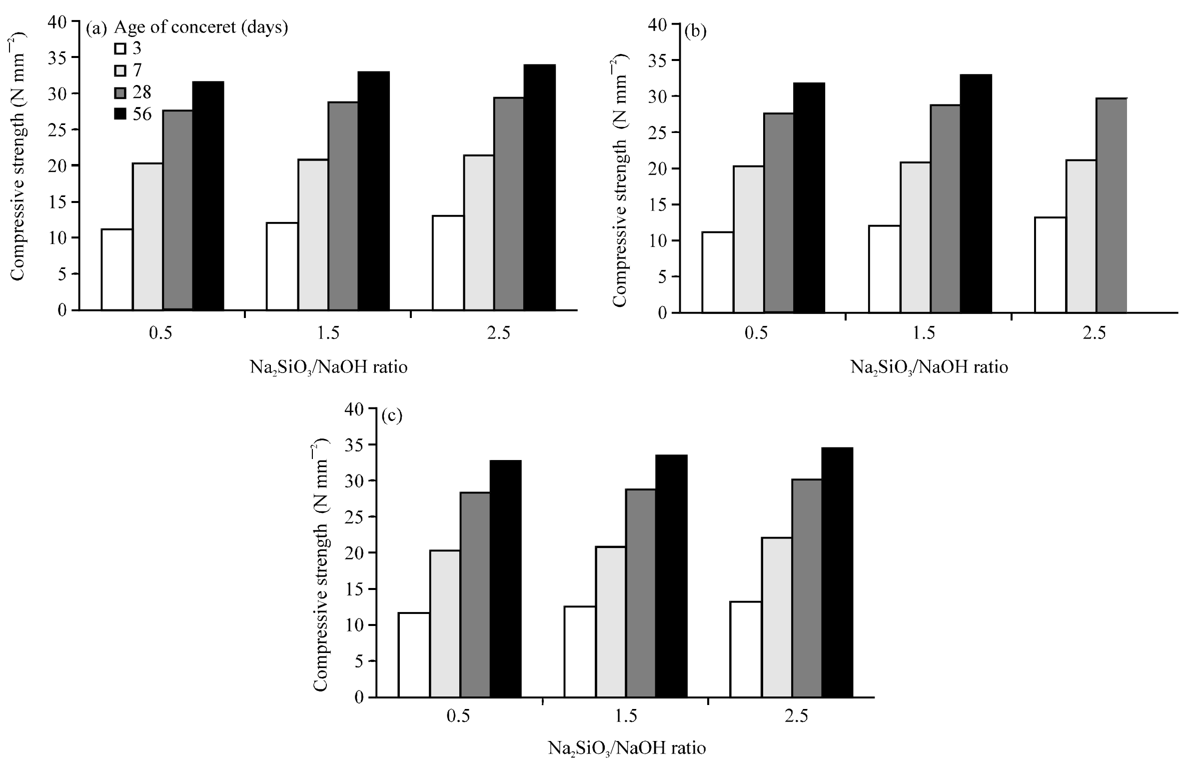

Fig. 3(a-c): Effect of age on compressive strength for AL/SF ratio (a) 0.25, (b) 0.30 and (c) 0.35

specimens the strength increases at early age. The rate of increase in compressive strength for the age 3 days to 7 days was around 43 to 84%, for the age of 7 days to 28 days was around 35 to 40% and for the age of 28 days to 56 days it was found to be 14 to 16% for all the AL/SF ratio 0.25, 0.30, 0.35 for all the Na_2SiO_3/NaOH ratio 0.5, 1.5 and 2.5, respectively. Even though gain in compressive strength observed in early ages but optimum percentage of gain in strength is observed for AL/SF = 0.25 and Na_2SiO_3/NaOH = 0.5 for all the ages of specimens.

CONCLUSION

The study reveals the possibility of using silica fume based geopolymer concrete to find out its compressive strength by considering the parameters such as effect of Na_2SiO_3/NaOH ratio, effect of AL/SF ratio and effect of age of concrete. From the experimental investigation it was found that out of three different ratios of Na_2SiO_3/NaOH, three different ratios of AL/SF ratios and four different ages of silica fume based geopolymer concrete AL/SF = 0.25 and Na_2SiO_3/NaOH = 0.5 yielded better gain in compressive strength. By considering the AL/SF ratio = 0.25 there is an increase in strength of 73% for 3 to 7, 38% for 7 to 28 and 15% for 28 to 56 days for all the ratios of Na_2SiO_3/NaOH ratios. Similarly by considering the Na_2SiO_3/NaOH ratio = 0.5, there is an increase in strength of 84% for 3 to 7, 38% for 7 to 28 and 15% for 28 to 56 days for all ratios of AL/SF ratios. Hence the use of silica fume as a geopolymer concrete is recommended for the construction industry.

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REFERENCES

Bakharev, T., 2005. Resistance of geopolymer materials to acid attack. Cem. Concr. Res., 35: 658-670.

Brough, A.R., A. Katz, G.K. Sun, L.J. Struble and R.J. Kirkpatrick, 2001. Adiabatically cured, alkali-activated cement-based wasteforms containing high levels of fly ash. Cem. Concr. Res., 31: 1437-1447.

Chindaprasirt, P., T. Chareerat and V. Sirivivatnanon, 2007. Workability and strength of coarse high calcium fly ash geopolymer. Cem. Concr. Composites, 29: 224-229.

Cioffi, R., L. Maffucci and L. Santoro, 2003. Optimization of geopolymer synthesis by calcination and polycondensation of a kaolinitic residue. Res. Conserve Recycl., 40: 27-38.

Davidovits, J., 1999. Chemistry of geopolymeric systems, terminology. Proceedings of the 99th International Conference on Geopolymer. June 30-July 2, 1999, Saint, Quentin, France.

Guo, X., H. Shi and W.A. Dick, 2010. Compressive strength and microstructural characteristics of class C fly ash geopolymer. Cem. Concr. Compos., 32: 142-142.

Kovalchuk, G., A. Fernandez-Jimenez and A. Palomo, 2008. Alkali-activated fly ash. Relationship between mechanical strength gains and initial ash chemistry. Mat. Construc., 58: 35-52.

Palomo, A., M.W. Grutzeckb and M.T. Blanco, 1999. Alkali-activated fly ashes: A cement for the future. Cem. Concr. Res., 29: 1323-1329.

Phair, J.W. and J.S.J. van Deventer, 2002. Characterization of fly-ash-based geopolymeric binders activated with sodium aluminate Ind. Eng. Chem. Res., 41: 4242-4251.

Provis, J.L., G.C. Lukey and J.S.J. van Deventer, 2005. Do geopolymers actually contain nanocrystalline zeolites? A reexamination of existing results. Chem. Mater., 17: 3075-3085.

Puertas, F., S. Martinez-Ramirez, A. Alonso and T. Vasquez, 2000. Alkali-activated fly ash/slag cements: Strength behaviour and hydration products. Cem. Concr. Res., 30: 1625-1632.

Raijiwala, D.B. and H.S. Patil, 2011. Geopolymer concrete: A concrete of next decade. J. Eng. Res. Stud., 2: 19-25.

Rattanasak, U. and P. Chindaprasirt, 2009. Influence of NaOH solution on the synthesis of fly ash geopolymer. Min. Eng., 22: 1073-1078.

Yunsheng, Z., S. Wei and L. Zongjin, 2010. Composition design and microstructural characterization of calcined kaolin-based geopolymer cement. Applied Clay Sci., 47: 271-275.