ACID RESISTANCE OF FLY ASH BASED GEOPOLYMER CONCRETE

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ABSTRACT. This research report presents the study on the development of strength for various grades of geopolymer concrete. Trial mix was chosen for low calcium fly ash based Geopolymer concrete of strength 30 N/mm^2.The concentration of the sodium hydroxide solution was varied as 8 Molar, 10 Molar, 12 Molar, 14 Molar and 16 Molar. The effect of change in concentration on mechanical property such as compressive strength, tensile strength, flexural strength for GPC solid block is studied. An experimental study was conducted to assess the acid resistance of fly ash based geopolymer concrete blocks. Durability of specimens was assessed by immersing the GPC specimen in 5% sulphuric acid for a period of 15, 30, 45 and 60 days. Evaluation of chemical resistance in terms of change in weight, residual compressive strength, residual tensile strength and residual flexural strength is carried out. The results obtained are produced and discussed.

Keywords: Geopolymer Concrete (GPC), Silica, Aluminosilicate, Residual compressive strength, Residual tensile strength, Residual flexural strength, Molar, Durability.

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INTRODUCTION

The contribution of green house gas emission due to ordinary Portland cement production worldwide is approximately 7%. For each ton of Portland cement manufactures, it is estimated that one ton of CO_2 is released into the environment. Compared to Portland cement, flyash based Geopolymer concrete can reduce carbon emissions by 80% which has the potential to reduce global emissions by approximately 2.1billion tons a year [1]. Geopolymer Concrete (GPC) is the name given to concrete where the binder is entirely replaced by an inorganic polymer formed between a strong alkaline solution and an alumina silicate source. The source material such as flyash that are rich in silicon (Si) and aluminium (Al) are activated by alkaline liquid to produce the binder.

Concrete industry depends largely on the ordinary Portland cement as their primary binding material. It is widely used as a binding material because of its high compressive strength, durability and availability. One of the most effective ways to produce more environment friendly concrete and to reduce global carbon footprint is by using supplementary cementitious materials as partial cement replacement materials to produce a new cementless binder such as fly ash which is called geopolymers [2]. Fly ash is produced as a by-product from a coal burning power plant industry which is widely available worldwide and its disposal is a major problem due to scarcity of land, environmental problems and other issue[3]. In recent years many research has shown that use of fly ash with alkali content such as, salts of silica and non silicate salts of weak acids can be used as binder content in mortar and concrete by replacing 100 percent of ordinary Portland cement [4]. In Geopolymer concrete made by using fly ash as an alumina silicate material, the silica and alumina present in the fly ash is basically induced and activated by alkaline activators to form a gel known as alumina silicate. This alumina silicate gel is responsible for the binding of coarse and fine aggregates present in the matrix to form the geopolymer concrete [5, 6]. This inorganic alumina silicate polymer is called geopolymer. This reaction between alkaline liquid and alumina silicate material is known as geopolymerization. There are various types of material and industrial by products which can be used as alumino silicate material such as fly ash, blast furnace slag, clay mineral (kaolinite, Feldspar), solid industrial waste residue and many other material which are rich in alumina and silicate content [7].

This research work basically aims at the durability characteristics of fly ash based geopolymer concrete cube in which there is 100 percent replacement of cement with fly ash which is used as an alternative binder material. The research puts a light on the method of manufacturing of low calcium fly ash based geopolymer concrete cubes , beams and cylinder for determining the various properties such as compressive strength, split tensile strength and flexural strength. Geopolymer concrete cubes, beams and cylinders are also tested for chemical resistance.

AIM AND OBJECTIVE OF RESEARCH

The main objective of this research is to study the durability characteristics of geopolymer concrete and the effect of aggressive environment exposure on the physical properties and mechanical strength of geopolymer concrete and how its durability and properties are deliberately exhausted with the time. The results coming out from the research work arecompared with the normal OPC behavior to perform the comparative study between the two.

MATERIALS AND THEIR TEST RESULTS

Following are the materials used in this research work:

- **Cement:** For the research 43 grade OPC is used for the entire experimental study. Its properties are shown in Table-1.

Table 1 Properties of OPC Cement

Properties of OPC Cement	Values Obtained
Normal consistency	33%
Initial Setting time	45 min.
Final Setting time	250 min.
Specific Gravity	3.15
Fineness	3.5%

- **Fly ash:** In this experimental study geopolymer concrete is made by using low calcium fly ash (ASTM Class F) which is activated by using sodium hydroxide (NaOH) of varying molarity concentration and sodium silicate. The fly ash is obtained from Singaji thermal power plant, Khandwa. The properties and its chemical composition are given in Table 2 below.

Table 2 Properties of fly ash

Constituents	Values in %
Silica (SiO2)	47
Alumina (Al2O3)	30
Sodium (Na2O)	0.2
Calcium Oxide (CaO)	1.66
Ferric Oxide (Fe2O3)	13
Loss On Ignition	1.5

- **Alkaline activating solution:** For fly ash based geopolymer concrete, mixture of sodium silicate and sodium hydroxide was used as an activating solution. Sodium hydroxide (NaOH) was bought from a local market in the form of pallets of size 3mm with specific gravity of 2.13 and having purity of about 95%. The flakes of sodium hydroxide is dissolved in water and stirred for about 2 minutes to form a solution. The reaction of sodium hydroxide with water is an exothermic reaction and can produce a temperature of about 80^{o}C. This NaOH solution is kept in an open condition for about 24 hours prior to mixing so that it comes to the normal temperature. The sodium hydroxide is then mixed with sodium silicate solution in the required proportion based on the strength requirement. The mass of NaOH solids in the solution depends on the concentration of the solution which is expressed in terms of Molar concentration. For eg. The 8 molar concentration of sodium hydroxide is prepared by adding 8 x 40 = 320 grams of NaOH solids per litre of solution either in flakes or pellet form, where 40 represent the molecular weight of sodium hydroxide. Now for determining the content of sodium silicate content in the alkali activator solution the sodium silicate to sodium hydroxide ratio is required which depends on the strength requirement. For this research work the ratio was taken as 2.5 based on the mix design. The detailed review on the mix design is mentioned in the appendix below. Constituents of sodium silicate in mentioned in Table-3.

Table 3 Sodium Silicate constituents

Constituent	Values in %
Sodium content (Na_2O)	15
Silicate content (SiO_2)	30
Water content (H_2O)	55

- **Aggregate**: Sand is used as a fine aggregate in the mix which is purchased from the local traders. Various properties of sand and its sieve analysis results are discussed below in a table-4. The grading of sand is conforming to zone 3 as per IS: 383-1970.Two sizes of coarse aggregates were used namely 10mm and 20mm nominal size. The coarse aggregates were made from crushed black granite stone conforming to IS: 383-1970. The properties of the aggregate are presented below in Table-5.

Table 4 Physical properties of Fine Aggregate

Properties	Values
Specific gravity	2.7
Bulk Density (Loose state)	1510 kg/m^3
Bulk Density (Compacted State)	1650 kg/m^3

Table 5 Properties of Coarse Aggregate

Properties of aggregate	Obtained values
Specific gravity	2.83
Bulk Density (Loose state)	1500 kg/m3
Bulk density (compacted state)	1650 kg/m3

METHODOLOGY ADOPTED

- Preparation of trial mix of OPC and GPC of grade M30 to get suitable mix proportion as per IS: 10262-2009.
- Measurement of workability of GPC and OPC before casting
- Casting of GPC and OPC beam, cube and cylinder specimens.
- GPC specimens after casting were kept in hot air oven for 24 hours at 600^{0}C whereas OPC specimens were kept in curing tank for 28 days.
- GPC specimens after 24 hrs of hot curing were kept in open atmosphere for 28 days.
- After 28 days some of these specimens were tested in a set of 3 to get the initial compressive strength, flexural strength and split tensile strength.
- Now the remaining cube specimens were weighted to get the initial weight and then all the specimens were immersed in 5% concentrated sulfuric acid solution.
- Now these immersed specimen are taken out after 15, 30, 45 and 60 days in a set of 3 each, for cube, beam and cylinder and these specimens are dried for 24 hrs in an open atmosphere and tested to determine the loss in weight, compressive strength, split

tensile strength and flexural strength for both OPC and GPC and results are compared for both.

Details of Test Specimens

- **OPC concrete specimen**: In total there are 45 numbers of concrete specimens of grade M30 are casted out of which 15 nos. are cube of size 150x150x150mm, 15 nos. are beams of size 100x100x500mm and 15 nos. are cylinder of dia. 150mm and height 300mm. 3 specimens of each type are first tested for compressive strength, flexural strength and split tensile strength after 28 days of curing and rest of the specimens are tested in a set of 3 after immersing the specimens in 5% concentrated sulphuric acid solution at a period of 15, 30, 45 and 60 days.

- **Geopolymer concrete specimen:** In total there are 225 number of geopolymer concrete specimens are casted. Out of which 75 cubes are casted of varying molarity. Similarly 75 beams and 75 cylinders are casted of varying molarity of alkali activating solution. This each set of 75 cube, beam and cylinder comprises of sub set of 15 numbers each of 8M, 10M, 12M, 14M, 16M concentration.

MIX PROPORTION FOR OPC AND GPC SPECIMENS

In this experimental work IS method of mix design is adopted according to the procedures covered in IS 10262-1982. The mix proportion for M30 OPC mix is shown in Table-6.

Table 6 Mix proportion of M30 OPC Mix

Ingredients	Water (Kg/m^3)	Cement (Kg/m^3)	F.A. (Kg/m^3)	C.A. (Kg/m^3)
Content	164	410	546	1363.5
Ratio	0.4	1	1.33	3.32

In this experimental work there are 5 types of mixes are designed for geopolymer concrete with varying molarities of alkali activating solution. The molarities of sodium hydroxide used for making geopolymer concrete mix are 8M, 10M, 12M, 14M and 16M, and the performance of geopolymer concrete is evaluated. The value adopted for the ratio of sodium silicate to sodium hydroxide is 2.

Table 7 Mix proportion of M30 Geopolymer concrete mix per cubic meter

Designation	Aggregate		Fly Ash (kg)	NaOH Solution		Sodium Silicate (Kg)
	C.A (Kg)	F.A (Kg)		Mass (Kg)	Molarity (M)	
G1	1270	545	440	60	8	120
G2	1270	545	440	60	10	120
G3	1270	545	440	60	12	120
G4	1270	545	440	60	14	120
G5	1270	545	440	60	16	120

The geopolymer concrete mix specimens were designated as G1, G2, G3, G4, and G5. The mix proportion for M30 GPC mix is shown in Table-7. The method adopted for mixing casting and curing is discussed in journals in detail [8].

RESULTS & DISCUSSION

Workability of Concrete Mix

In this experimental program the workability of geopolymer concrete mix as well as OPC concrete mix is determined by using slump cone test. It has been observed that as the concentration of alkali activator increases the workability of the concrete mix decreases this is because the percentage of solid content in the activator solution increases and the water content decreases. Because of this decrease in the water content the mix becomes stiffer and the workability decrease. Slump value variation for different grade of mix is shown in Table-8 and Fig-1.

Table 8 Slump values for different grade of Mix

Mix Designation	Slump (mm)
G1	75
G2	72
G3	63
G4	60
G5	57
B1 (OPC)	55

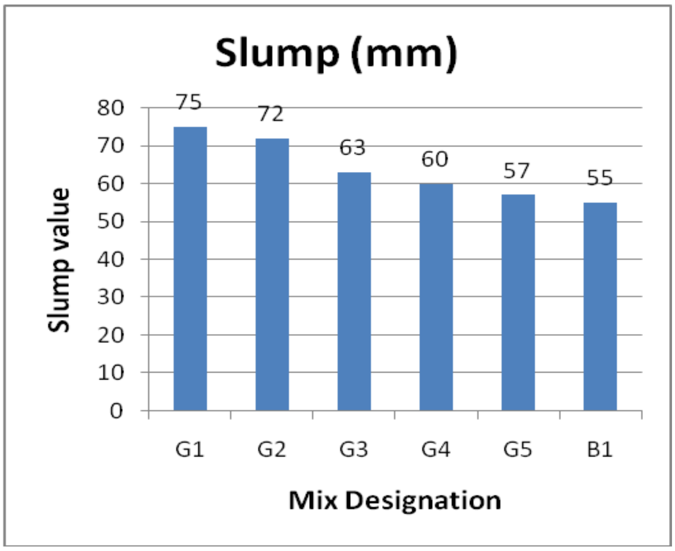

Figure 1 Slump value variation for different grade of mix

Compressive Strength and Residual Compressive Strength

The compressive strength of the specimen varies from 32.2 N/mm^2 to 37.62N/mm^2 for GPC after 28 days of air curing whereas for OPC the value obtained is 38.73 N/mm2 as shown in table-9. Variation in compressive strength and the residual compressive strength of GPC and OPC after immersing in 5% sulfuric acid for 15, 30, 45 and 60 days are shown in Table-9 and Table-10 respectively. Results are graphically shown in Figure 2.

Table 9   Compressive strength of OPC and GPC after 28 days of curing

Mix Designation	NaOH Molarity	Compressive strength (MPa)
G1	8M	32.20
G2	10M	33.26
G3	12M	36.93
G4	14M	37.62
G5	16M	33.15
B1 (OPC)	NIL	38.73

Table 10   Residual compressive strength of GPC and OPC specimens

Mix Designation	Compressive strength of cube after acid immersion (days) (N/mm^2)			
	15	30	45	60
G1	29.9	28.13	25.38	24.91
G2	31.1	29.23	26.27	25.92
G3	34.92	32.57	29.47	29
G4	35.71	33.36	30.24	30
G5	31	29.15	26.2	25.91
B1 (OPC)	37.18	34.85	31.33	31.21

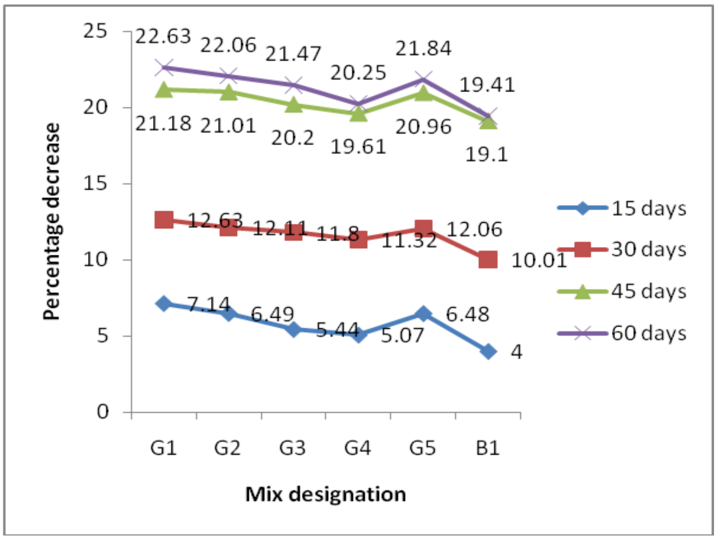

Figure 2   Percentage decrease in compressive strength of GPC and OPC specimens

Flexural Strength and Residual Flexural Strength

For Geopolymer concrete the flexural strength varies from 2.24 N/mm2 to 3.54N/mm2 as shown in table- 11 whereas in OPC specimen the flexural strength obtained is about 3.89 N/mm2 after 28 days of curing. Variation in flexural strength and the residual flexural strength of GPC and OPC after immersing in 5% sulphuric acid for 15, 30, 45 and 60 days are shown in Table 11 and Table 12 respectively. Results are graphically shown in Figure 3.

Table 11 Flexural strength of OPC and GPC after 28 days of curing

Mix Designation	NaOH Molarity	Flexural strength (N/mm^2)
G1	8M	2.74
G2	10M	2.83
G3	12M	3.61
G4	14M	3.83
G5	16M	2.81
B1 (OPC)	NIL	3.92

Table 12 Residual flexural strength of GPC and OPC specimens

Mix Designation	Flexural strength of cube after acid immersion (days) (N/mm^2)			
	15	30	45	60
G1	2.65	2.5	2.35	2.23
G2	2.74	2.62	2.5	2.41
G3	3.51	3.41	3.29	3.19
G4	3.73	3.63	3.52	3.41
G5	2.72	2.61	2.54	2.44
B1 (OPC)	3.83	3.72	3.61	3.51

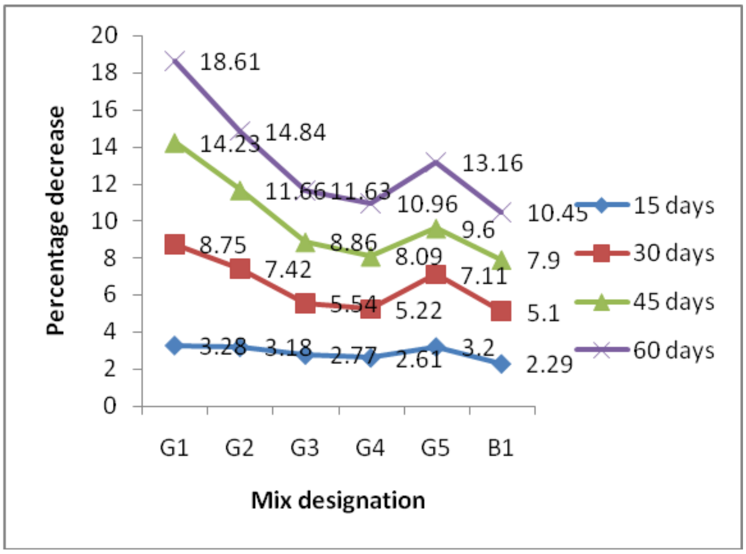

Figure 3 Percentage decrease in flexural strength of GPC and OPC specimens

Split tensile strength and Residual split tensile Strength

For Geopolymer concrete the split tensile strength varies from 2.82 N/mm2 to 4.18N/mm2 as shown in table- 13 whereas in OPC specimen the split tensile strength obtained is about 4.26 N/mm2 after 28 days of curing. Variation in split tensile strength and the residual split tensile strength of GPC and OPC after immersing in 5% sulfuric acid for 15, 30, 45 and 60 days are shown in Table 13 and Table 14 respectively. Results are graphically shown in Figure 4.

Table 13 Split tensile strength of OPC and GPC after 28 days of curing

Mix Designation	NaOH Molarity	Split tensile strength (N/mm^2)
G1	8M	2.82
G2	10M	3.22
G3	12M	4.04
G4	14M	4.18
G5	16M	2.93
B1 (OPC)	NIL	4.26

Table 14 Residual split tensile strength of GPC and OPC specimens

Mix Designation	Split tensile strength of cube after acid immersion (days) (N/mm^2)			
	15	30	45	60
G1	2.72	2.57	2.42	2.3
G2	3.11	2.97	2.84	2.74
G3	3.93	3.82	3.68	3.57
G4	4.08	3.96	3.84	3.72
G5	2.83	2.73	2.65	2.54
B1 (OPC)	4.16	4.04	3.92	3.8

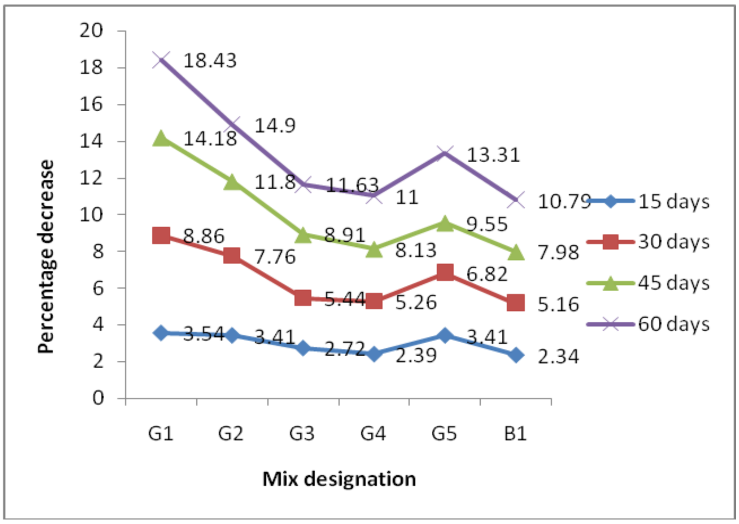

Figure 4 Percentage decrease in split tensile strength of GPC and OPC specimens

Change in weight after immersing the cube specimens in acid

In order to analyze the effect of severe environmental exposure on the specimen the specimens were immersed in 5% concentrated sulfuric acid and the specimens were tested after a regular intervals of 15 day, 30 days, 45 days and 60 days of exposure. The loss in weight is determined for GPC and OPC specimen at these intervals to get a comparative idea about the performance of both. The percentage loss in weight varies from 0.44 to 1.52 for GPC specimen and 0.41 to 0.95 for OPC specimen. The values of the change in weight after interval of 15 days are mentioned in the Table-15. In this study Geopolymer concrete shows a minor change in the weights of the specimen and results obtained are not better but comparable to concrete. These results give preliminary idea that the GPC shows good resistance to acid attack. Results are graphically shown in Figure 5.

Table 15 Weight change of GPC and OPC specimens

Mix Designation	Initial weight (Kg)	Weight of cube after acid immersion (Days) (Kg)			
		15	30	45	60
G1	8.128	8.075	8.048	8.010	8.004
G2	8.268	8.221	8.198	8.165	8.150
G3	8.317	8.277	8.259	8.235	8.227
G4	8.336	8.299	8.280	8.257	8.254
G5	8.319	8.274	8.251	8.235	8.214
B1 (OPC)	8.348	8.313	8.295	8.273	8.268

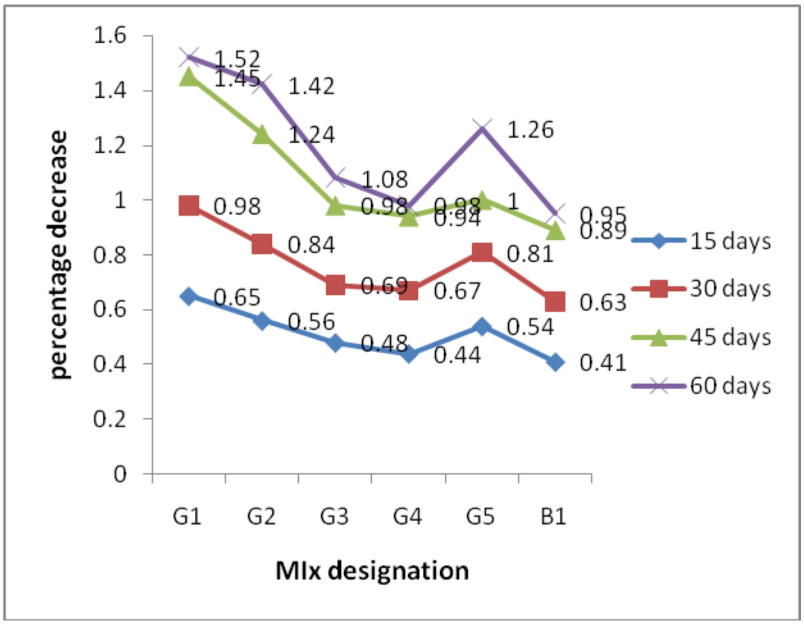

Figure 5 Percentage decrease in weight of GPC and OPC specimen

CONCLUSIONS

Based on the present experimental work, the following conclusions are drawn:

- Compressive strength, split tensile strength and flexural strength increases with the increase in concentration of alkali activator till 14M.
- At 16M concentration of alkali activator the strength of the specimen decreases rapidly, this is because of the alkali aggregate reaction due to high concentration of alkali activator and reactivity of aggregates with alkali. At 16M concentration the efflorescence was also observed on the specimens.
- The maximum value of compressive strength, Split tensile strength and Flexural strength of the GPC specimen obtained was 37.62N/mm2, 4.18 N/mm2, 3.83N/mm2 at 14M concentration of alkali activator.
- The percentage loss in weight for GPC specimen varies from 0.44% to 0.98% for 14M concentration whereas for OPC it varies from 0.41% to 0.95%.
- The optimum range of concentration of alkali activator that can be used in the production of GPC member lies between 12M to 14M for using in harsh environmental condition.
- The performance of GPC specimens was not superior then OPC specimens but the results obtained were also not inferior, they were comparable to OPC specimens.

FUTURE SCOPE OF GEOPOLYMER CONCRETE

- More practical recommendations for encouraging the use of geopolymer concrete in construction technology and practical applications such as precast concrete members and waste management need to be developed in Indian scenario.
- Various researchers in their study shown that the addition of fiber material in the concrete can improve the mechanical characteristic of concrete by providing crack arresting mechanism. Future study can be focused on the addition of fiber on the post-crack mechanism of the geopolymer concrete. Further study on the bonding between the steel and fiber with geopolymer concrete need to be studied.
- The behavior of geopolymer concrete at an elevated temperature of about 800-9000C need to be studied for having an idea about its potential as heat resisting construction material.

REFERENCES

1. Anjan Chatterjee, K. "Indian Fly Ashes: Their Characteristics and Potential for Mechanochemical Activation for Enhanced Usability", Journal of Materials in Civil Engineering, Vol. 23, No. 6, pp.783-788, 2011.
2. Davidovits, J. "Geopolymer chemistry and application", Geopolymers Institute, ISBN 2-651-4820-1-9, 2008.
3. Davidovits, J. "Global Warming Impact on the Cement and Aggregates Industries", World Resource Review, Vol. 6, No. 2, pp. 263-278, 1994.
4. Hardjito, D. and Rangan, B.V. "Development and properties of Low-Calcium Fly Ash-based, Geopolymer Concrete", Research Report GC-I, Faculty of Engineering, Curtin University of Technology, 2005.

5. Chindaprasirt, J. “High- Alkali Cements for 21st century concretes”, Concrete Technology past, present and future, ACI Special Publication, Vol. SP144, pp. 383-398, 1994.

6. Buchwald, A. and Schulz, M. “Alkali-activated binders by use of industrial byproducts”, Cement Concrete Research, Vol. 35, pp. 968-973, 2005.

7. Bakharev, T. “Geopolymeric materials prepared using Class F fly ash and elevated temperature curing”, Cement and Concrete Research, Vol.35, pp.1224-1232, 2006.

8. Anuradha, R., Sreevidya, V., Venkatasubramani, R. and Rangan, B.V: Modified guidelines for geopolymer concrete mix design using Indian standard”, Asian Journal of Civil Engineering Vol. 13, No. 3, pp. 353-364, 2012.