Mechanical and Durability Properties of Fly Ash-Based Geopolymer Concrete

Arani Dutta and Narayan Chandra Moharana

Abstract Portland cement plays a very important part in construction, but the manufacturing process emits almost 5–7% of the CO_2 in the world and it is one of the main causes of global warming. This paper discusses about the alternative material to Portland cement and compares between their strength and durability. The main material in this study is fly ash which is an industrial waste and easily available. In India, every year almost 120 million tons of fly ash is produced in the power plants and fly ash is very rich in silicon and aluminium; that is why it is a very good replacement for cement and this way we can recycle the waste also. Geopolymer is a mixture of fly ash with sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). In this paper, geopolymer is made using the combination of M25-grade concrete. The ratio between NaOH and Na_2SiO_3 is kept constant which is 1:2 and the morality of NaOH varied from 10 M to 16 M. In geopolymer concrete, cement is 100% replaced by fly ash. The compressive strength and durability parameter is compared between geopolymer concrete cubes (which is kept at different curing conditions) and concrete cubes in which Portland cement is replaced by 25% of fly ash.

Keywords Global warming · Fly ash · Portland cement · Sodium hydroxide · Sodium silicate

1 Introduction

Portland cement is the principal material used in construction but the manufacturing process is very harmful for environment as it releases 1 tonne of CO_2 per 1 tonne of cement [1]. It is one of the green house gases responsible for global warming and is a great threat to mankind. Nowadays, it is an important issue to develop environmentally friendly and sustainable construction material [2]. The only way to reduce the effect alternative material to Portland cement are blended cement and geopolymers [3]. Geopolymer proves to be the best which completely replaces the Portland cement by aluminosilicate materials like fly ash, blast furnace slag, metakoline, silica

A. Dutta · N. C. Moharana (✉)
Kalinga Institute of Industrial Technology (Deemed to Be University), Patia, Bhubaneswar, India
e-mail: nmoharanafce@kiit.ac.in

B. B. Das et al. (eds.), *Recent Developments in Sustainable Infrastructure*, Lecture Notes in Civil Engineering 75, https://doi.org/10.1007/978-981-15-4577-1_61

fume, etc., which are rich in alumina (Al) and silica (Si) with alkali activators like NaOH, Na2SiO3 KOH, K2SiO3, etc. [4]. On curing at higher temperature, polymerization takes place and products are calcium aluminates silicate hydrate(C–A–S–H) and sodium aluminate silicate hydrate(N–A–S–H) which bind the inert materials to form geopolymer concrete [4–7]. One of the drawback is the heat curing which is not suitable for sight conditions. Normal curing provides lower strength. On other hand, the alkali activator NaOH of higher molar value provides higher strength.

1.1 Effect of Curing on Strength

It was observed that high-temperature cured GPC with rest period about 3 days after casting gains higher strength than GPC cured immediately after casting with low temperature and OPC concrete at 28 days. GPC samples displayed little gain of strength after steam curing was over up to 28 days [8]. As curing temperature increases the strength of the GP mortar increases and optimum temperature is found to be 75 °C. Also the duration of heat curing enhances the strength and optimum heat curing duration is predicted as 2 days. Microstructure of the mortar get weakened at elevated curing temperature and therefore strength get reduced [9]. Compressive strength increases up to 100 °C curing temperature and at 120 °C started decreasing. This loss of strength attributed to the formation of crack due to the loss of moisture at high temperature. Compressive strength of the OPC found to be more than GPC. This is due to heterogeneous microstructure which is due to the disruption of packing of binder at the presence of air void [10]. In comparison to KOH, NaOH activator provides better compressive strength because higher amount of silicate and aluminates monomers are found in case of NaOH. It is attributed that the sodium cations of NaOH provide better geopolymerization due to smaller in size as compared to potassium cation and can easily migrate through the network of moist gel [10] reported that the naphalene-based superplasticizer provides better strength than melamine formaldehyde and polycarboxilate ether-based superplasticizer. Noushini and Castel [11] reported that compressive strength of geoplymer concrete cured at 75 °C for 18 h is found to be about 20 and 15% more than that of heat-cured and normal curing OPC concrete, respectively. Curing at 75 °C for 18 h may be considered as the optimum temperature and duration of curing. Normal curing of GPC at an ambient temperature produces much lower strength and are not suitable for practical purpose. Gunasekara et al. [12] reported that the Geopolymerization continues beyond 90 days up to 365 days and the compressive strength is at per with cement concrete. Compressive strength of GPC and OPC concrete increases with curing period and strength of GPC is higher than that of OPC concrete. Also compressive strength for both the cases are higher for high-temperature curing because the increase in temperature accelerates the geopolymerization in GPC and hydration in OPC concrete [×6]. AdbElaty et al. [2] reported that at higher alkali solution/binder (AS/B) ratio, there is noticeable amount of compressive strength, split tensile strength and modulus of elasticity enhancement and best result is found for 30–40% of NaOH.

Also found (AS/B) plays a rule as that of W/C ratio on OPC concrete. Increase in liquid to binder ratio (L/B) in alkali solution reduces the mechanical properties and vice versa [2]. Chemical activator of multi-compound Na_2SiO_3/NaOH) are found to be most effective for the enhancement of compressive strength [7]. Compressive strength of geopolymer mix is effected by chemical reactivity between the amorphous AlO_3, CaO and Na_2O present in fly ash and alkali activators and this chemical reactivity depends on the median particle size and contents of amorphous SiO_2. Finer is the fly ash particles better is the blending in geopolymer mix due to smaller friction between its components and also increase in exposure area of amorphous SiO_2 to alkali activators. Thus, as a result, there is better geopolymerization [13]. Hadi et al. [13] also reported that fly ash with finer particles has greater coverage of aggregates and forms a dense intertransition zone on aggregate surface which results in higher binding strength. Thus, the optimum value of alkaline to fly ash ratio (AL/F) to achieve optimum vale of compressive strength are different for different fly ash sources depending on particle size and contents of amorphous SiO_2, CaO and Na_2O. Geopolymerization is controlled by chemical equilibrium achieved between amorphous Al_2O_3 and SiO2. Thus, the optimum value of Na_2SiO/NaOH ratio is dominated by characteristic of fly ash. High amount of Si^{4+} Na^+ is liberated from Na_2SiO_3 may congested and inhibits the geopolymerization [13]. Fly ash having higher contents of SiO_2 necessitates higher amount of NaOH to release SiO_2 and other oxides from fly ash to initiate geopolymerization. Larger sized particles in fly ash reduces the surface area exposure of amorphous SiO_2 and Al_2O_3 to alkali activator. On the other hand, unreacted particles exhibits week in geopolymerization and results in strength degradation [13]. It is observed that increase in temperature in hydrothermal curing, enhances the compressive strength. It is attributed to the acceleration of geopolymerization reaction due to the increase in liberation of more reactive alkali at higher temperature [14]. On normal curing at 95% humidity, compressive strength increases with time due to the increase in reactive alkali which accelerates the geopolymerization [14].

1.2 Workability

Particle size and shape have dominant influence on the workability of GP mortar. Finer is the fly ash higher is the flow value. On the other hand, if fly ash particles of are spherical and smooth higher is the flow value [9]. Workability of geopolymer concrete increases due to lubricating effect of Na_2SiO_3 on spherical fly ash particles [12]. But high (Na_2SiO_3/NaOH) ratio reduces the workability due to high viscosity of Na_2SiO_3. On the other hand, high-liquid alkaline/fly ash ratio increases the workability. High concentration of NaOH increases the setting time [7]. N-based superplasticizer is most effective in geopolymer matrix activated by NaOH only but PC-based superplasticizer is most effective if the activator is the mixture of Na_2SiO_3 and NaOH. Flow value was tested with slump test and found that the OPC concrete exhibits more slump value than GPC and it is attributed to the viscosity of Na_2SiO_3

GPC increases the cohesiveness. [15]. Polycarboxylate (PC)-based sperplasticizer is found to be more effective to class C fly ash than class F fly ash. It is because negatively charged particles of PC-based superplasticizer get strongly bonded with Ca^+ ion liberated from Class C fly ash providing negative ion which repulse each other and increases the dispersion capacity. Thus, flow value increases [16]. On the contrary, napthalene-based superplasticizer is more effective for class F fly ash. It is attributed to better chemical stability of the naphalene-based superplasticizer in alkaline environment science the pH value of this superplasticizer ranges from 6 to 9 [16].

1.3 Porosity and Microstructure

Porosity of fly ash-based GPC is found to be more than that of OPC counterpart. It is because Na_2–AlO_3–SiO_2–H_2O gel is less denser than C–S–H gel in OPC concrete. Both heat as well as ambient cured GPC exhibit lower water absorption value than that of OPC concrete. But inappropriate curing condition increases the voids and thus water absorption increases. [11]. In case of fly ash geopolymer concrete, uneven material distribution due to more quantity of coarse particles leads high microporosity [12]. X-Ray tomography test reveals that the voids in Portland pozzolana cement concrete (PPCC) are less than that of GPC but size of the voids in GPC are smaller [15]. Fly ash-based GPC is more porous because the principal reaction product the sodium alumino silicate gel (N–A–S–H) is three-dimensional network product attributes higher porosity. On he other hand, presence of un-reacted fly ash particles also causes high porosity [15, 17]. Sorpitivity coefficient decreases for fly ash-based GPC cured at 75 °C and curing duration 24 h. It is attributed to the formation of denser geopolymer net work which reduces the void and increases the tortuosity. However, increase in heat curing temperature and duration increases the serpitivity coefficient. It is attributed to the elevated temperature which extends the capillary pore net work and thus effects the tortuosity characteristic [11]. GPC specimen displays the high sorptivity value due to large pore structure [17].

1.4 Durability

Geopolymerization continues and corresponding increase in alumino silicate gel fills the cracks and voids. Thus, the durability properties improve with time [12]. Geopolymer concrete exhibits better resistance to aggressive environment laden with acid and sulphate [7]. In some environments, carbonation depth is found to be more in GPC than that in OPC counterpart. In case of fly ash-based GPC, $NaCO_3$ is formed as a primary carbonation product and it would dissolve in water when exposed to weather. Thus, leaching out of carbonation product causes GPC more porous and allow more

CO_2 diffusion through the concrete surface [17]. Chloride penetration and free chloride contents in GPC are found to be more compared to OPC counterpart because of high porosity and thus the GPC concrete are more prone to reinforcement corrosion. In case of OPC concrete, the presence of C_3AF and C–S–H gel binds the chloride contents to form Fidel's salt and thus the rate of chloride penetration diminishes. Also amount of free chloride is found to be less than GPC. High porosity of GPC results in high chloride penetration [17]. Objective of present study to compare the flow value and compressive strength of fly ash-based geopolymer concrete cured at normal temperature and at high temperature in oven, with normal OPC concrete and fly ash concrete with 25% of fly ash replacement. Also comparison of durability parameters such as acid resistance, chloride resistance and sorptivity. Therefore, in this research work, class F fly ash is used as aminosilicate material and mixture of NaOH and Na_2SiO_3 is used as alkaline solution. The ratio between NaOH and Na_2SiO_3 is kept fixed which is 1:2 throughout the experiment but four types of molarities of NaOH is taken 10, 12, 14 and 16 M molar, respectively, to study the effect of molarity on strength and flow value. The change in molarity shows a difference in adhesiveness, flow, strength prominently. Durability and mechanical properties of geopolymer concrete specimen cured in two different curing conditions are compared with that of the OPC concrete and fly ash concrete counterparts. Different curing conditions show a significant difference in strength in geopolymer concrete.

2 Experimental Programme

To fulfil the research objective, experimental programme under taken are discussed in this part. Details about the material properties, mixing, preparation, curing and testing for strength and durability requirements are discussed.

3 Materials

Fly ash used in this study is class F fly ash obtained from NALCO, Angul power plant, Orissa. The physical properties are given as: Specific gravity = 2.9, Water absorption = 15%, Colour—Tan to dark grey. Chemical compositions are given in Table 1 and Fig. 1 for fly ash.

NaOH or caustic soda of make Adity Birla were used in the experiment is procured from Shivam Chemicals, Bhubaneswar. The properties specified by the manufacture

Table 1 Chemical constituents of fly ash

Major constituents	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O
%	59.3	25.86	5.81	1.71	1.07	0.68	1.89	0.07

Fig. 1 Fly ash

Fig. 2 NaOH flakes

are given as chemical formula = NaOH, Melting point = 318 °C, Appearance—White, waxy, opaque crystals, Odour—odourless and Density = 2.13 g/cm^3. Figure 2 shows the flakes of NaOH.

Industrial-grade Na_2SiO_3 was procured from Surendra chemicals, Kolkata. The properties provided by the manufacture are as follows: Chemical formula = Na_2SiO_3, Appearance—White to greenish opaque crystals or liquid, Density = 2.61 g/cm^3 and Melting point = 1,088 °C. Figure 3 shows the liquid Na_2SiO_3.

OPC 53 grade cement from RAMCO Cement Limited was used and physical properties obtained from laboratory test are given as follows: Consistency = 28%, Initial and final setting times = 100 min and 230 min, respectively, Compressive strength after 3, 7 and 28 days are 35.5 Mpa, 47 Mpa and 55.5 Mpa, respectively,

Fig. 3 Liquid Na_2SiO_3

Specific gravity = 3.15. All physical properties satisfy the requirements of IS 12269-1987 [18].

Crushed granite sized 10 mm and 20 mm are used as coarse aggregate. The physical properties are given as Specific Gravity = 2.7, Fineness Modulus = 6.2, Water Absorption = 0.4%. All above physical properties and gradations confirms to the specifications of IS: 383-1970 [19].

Fine aggregates obtained from River Mahanadi conforms to zone III. The physical properties are given as Specific Gravity = 2.65, Fineness Modulus = 2.47, Water Absorption = 0.85% and are conforming to the specification of IS: 383-1970 [19].

Clean potable tap water obtained from the Laboratory of Civil Engineering Department of KIIT, Deemed-to-be-University was used for mixing and curing of concrete.

3.1 Preparation of Concrete Specimens and Details

Three types of cube specimens of size 150 mm × 150 mm × 150 mm [20] were used in the study. Those are (1) normal OPC concrete specimen, (2) fly ash concrete(cement replaced by 25% fly ash and (3) geopolymer concrete specimens (GPC) and detailed in Table 2.

Table 2 Specimen details

Specimen name	Details	Curing conditions
MOP	OPC concrete	Normal water curing
MOF	25% fly ash replacement+OPC	Normal water curing
G10MC	Geopolymer 10 molar	Normal water curing
G10MA	Geopolymer 10 molar	Oven curing
G12MC	Geopolymer 12 molar	Normal water curing
G12MA	Geopolymer 12 molar	Oven curing
G14MC	Geopolymer 14 molar	Normal water curing
G14MA	Geopolymer 14 molar	Oven curing
G16MC	Geopolymer 16 molar	Normal water curing
G16MA	Geopolymer 16 molar	Oven curing

Table 3 Mix proportion for M25 normal OPC concrete cube

Specimen	Cement kg/m^3	Fly ash kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Water kg/m^3	W/B
MOP	492.5	–	617.23	1105	197	0.4
MOF	369.3	123.2	617.2	1105	197	0.4

Table 4 Ingredients of geopolymer concrete

Specimen	Fly ash kg/m^3	NaOH kg/m^3	Na_2SiO_3 kg/m^3	$NaOH:Na_2SiO_3$	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Alkali/binder ratio	W/B
G10M & G10MA	492.5	74	148	1:2	702	1256	0.45	0.4
G12M & G12MA	492.5	74	148	1:2	702	1256	0.45	0.4
G14M & G14MA	492.5	74	148	1:2	702	1256	0.45	0.4
G16M & G16MA	492.5	74	148	1:2	702	1256	0.45	0.4

3.2 Mix Proportions

Mix proportion by weight = 1:1.25:2.24 was selected as found from mix design for M 25 using OPC 53 grade cement as per IS:10262-2008. Ingredients for normal concrete and fly ash concrete are given in Table 3, numbers of cube samples were casted 12 for each categories of concrete.

For geopolymer concrete, same the mix proportion as above was used (1:1.25:2.24) by replacing cement by fly ash by 100%. Binder/alkaline ratio was taken 0.45. The ratio of NaOH to Na_2SiO_3 was taken 1:2 which remains constant for all samples. Constituents of different samples are tabulated in Table 4. Numbers of cube samples were casted 27 for each categories of geopolymer concrete.

3.3 Mixing Procedure

For normal concrete and fly ash concrete, normal mixing procedure was followed. Cube specimens were casted by placing fresh concrete in three layers and tamping with 25 blows with tamping bar and compaction with vibrating table for 30 s and finally finished with trawling (Figs. 4, 5 and 6).

For geopolymer concrete, samples of alkali solution to total alkali ratio as 1:2 were used. The blending of Na_2SiO_3 and NaOH exerts some amount of heat. To take it down to the surrounding temperature, the arrangement was kept for 24 h before they were blended with fly ash and aggregates. In concrete mixture machine, the

Fig. 4 Preparation of NaOH solution

Fig. 5 Geopolymer concrete cube

Fig. 6 Cubes compaction by vibrating table

Table 5 Workability in term of slump value

Sample	MOP	MOF	G10	G12	G14	G16
Slump in mm	120	125	90	85	70	50

aggregates and fly ash were mixed dry for around 5 min. Then mixing was done with alkali blend and requisite amount of water for 5 min. Cube specimens were casted by placing fresh concrete in three layers and tamping with 25 blows with tamping bar and compaction with vibrating table for 30 s and finally finished with trawling.

3.4 Casting of Cube Specimens

The steel moulds were covered with oil on their inside surface and concrete mix was poured into the moulds in three layers. Each layer was consistently compacted by a tamping bar with 25 numbers of blows and by vibrating table for 1 min. Finally, the top surface was finished utilizing a trowel.

3.5 Curing Process

The ordinary concrete cubes and the fly ash concrete cubes were kept in curing tank up to 7, 28 and 56 days after de-moulding. Half of the geopolymer concrete cubes were placed in the curing tank after de-moulding and another half were kept in the oven for 24 h at 75 °C and after that those were kept in ambient temperature.

4 Testing

4.1 Workability of Fresh Concrete

See Table 5.

4.2 Testing of Hardened Concrete for Compressive Strength

Testing of CTM machine of 2000 KN from AIMIL LTD is available in the Department of Civil Engineering Laboratory of KIIT, Deemed-to-be-University, is shown in Fig. 7. For compressive strength, the specimens were tested for 7, 28 and 56 days

Fig. 7 Cube testing in CTM

and following the test procedure in accordance to IS:516-1959. [21]. Test results in average are summarized in Table 6.

Table 6 Compressive strength of different specimen

Specimen	7 days (N/mm^2)	28 days (N/mm^2)	56 days (N/mm^2)
MOP-Normal OPC	38.157	47.87	53.88
MOF-OPC+25% fly ash replacement	33.87	55.1	59.91
G10MC–G PC10 molar (curing tank)	18.23	20.54	21.52
G10MA–GPC 10 molar(oven curing)	25.29	29.31	35
G12MC–GPC 12 molar(curing tank)	22.2	23.14	24.75
G12MA–GPC 12 molar(oven curing)	45.85	51.2	54.59
G14MC–GPC 14 molar(curing tank)	24.85	26.22	27.98
G14MA–GPC 14 molar(oven curing)	48.4	55.72	56.42
G16MC–GPC 16 molar (curing tank)	30.2	31.29	33.55
G16MA–GPC16 molar(oven curing)	55.62	60.25	62.22

Table 7 Acid attack results

Specimen	Wt. before test	Wt. after test	Wt. Loss in %	Compressive strength after acid attack in N/mm^2	Compressive strength of reference sample N/mm^2	Strength loss (%)
MOF	8.52	8.035	5.69	33.56	64.91	48.0
G10MA	8.358	8.223	1.615	30.617	35.00	12.0
G12MA	8.406	8.376	0.356	48.143	54.59	11.8
G14MA	8.48	8.45	0.354	52.46	58.42	10.2
G16MA	8.473	8.41	0.320	56.85	62.22	08.0

4.3 Test for Durability Parameters

In durability parameters, acid resistance, chloride resistance and sorptivity were tested on the specimens after 28 days of curing drying to constant weight oven at 100 °C.

4.3.1 Acid Attack on Concrete

To study the results of acid resistance and its effect on all categories of specimen, those were immersed in 1% solution on sulphuric acid (H_2SO_4) as described above for 28 days. Cube specimens were taken out one day before test and dried completely up to constant weight by oven at 100 °C. And then the weight was taken and tested for compressive strength including the reference samples which were kept for comparison purpose. Details of test results on weight difference and strength changes are given in Table 7.

4.3.2 Chloride Attack on Concrete

To study the results of chloride attack and its effect on geopolymer concrete specimen and MOF specimen 1% solution on sodium chloride (NaCl) is used. After 28 days of curing and the weight was taken both geopolymer concrete and MOF specimens were immersed entirely into the acid solution and kept for more 28 days. Cube specimens were taken out one day before test and dried completely. And then the weight was taken and tested. Some reference sample was kept for comparison purpose. The weight difference and strength changes are given in Table 8.

Table 8 Chloride attack result

Specimen	Wt. before test	Wt. after test	Wt. Loss/gain %	Compressive strength of reference samples N/mm^2	Compressive strength after chloride attack in N/mm^2	Strength loss (%)
MOF	8.61	8.590	0.232 loss	64.91	63.93	1.00
G10MA	8.39	8.576	2.217 gain	35.00	33.073	5.50
G12MA	8.367	8.566	2.378 gain	54.59	51.52	3.70
G14MA	8.176	8.303	1.553 gain	58.42	56.263	3.69
G16MA	8.337	8.53	1.315 gain	62.22	60.347	3.00

4.3.3 Sorptivity

Geopolymer cubes (16 molar) were cured for 28 days and after that dried in oven at 100 °C. After that the cubes were taken out and three side of the cubes were coated with colour and epoxy to restrict the flow to one side only. The specimens were then immersed in water not more than 5 mm depth. The water absorption were measured for a span of 30 min in an interval provided in the Table 9. Each time the specimen were taken out and excess water was wiped off with the help of a damped cloth. Those were weighted in weight machine.

$I = S.t^{1/2}$, therefore $S = I/t^{1/2}$; Where S = sorptivity in mm, t = elapsed time in mint. I (cumulative infiltration) = $\Delta w/Ad$ Δw = change in weight = W2–W1, where W1 = Oven dry weight of cube in grams, W2 = Weight of cube after 30 min capillary suction of water in grams, A = surface area of the specimen through which water penetrated and d = density of water.

Table 9 Sorptivity results

Time (minute)	Initial weight (kg) (W1)	Final weight (kg) (W2)	Δw = cumulative weight gain (kg)	Density of water (kg/m^3)	Surface area (m^2)	$I = \Delta w/Ad$ (mm)	S
0	8.520	8.520	0.000	997	0.0225	0	0
1	8.520	8.523	0.0035	997	0.0225	0.1778	0.1778
4	8.523	8.526	0.006	997	0.0225	0.2674	0.1337
9	8.526	8.528	0.008	997	0.0225	0.3566	0.11887
16	8.528	8.530	0.010	997	0.0225	0.4457	0.1114
25	8.530	8.531	0.011	997	0.0225	0.4903	0.0895
30	8.531	8.531	0.011	997	0.0225	0.4903	0.0895
Sorptivity = $I/(t)^{0.5}$ = 0.089 $mm/t^{.05}$							

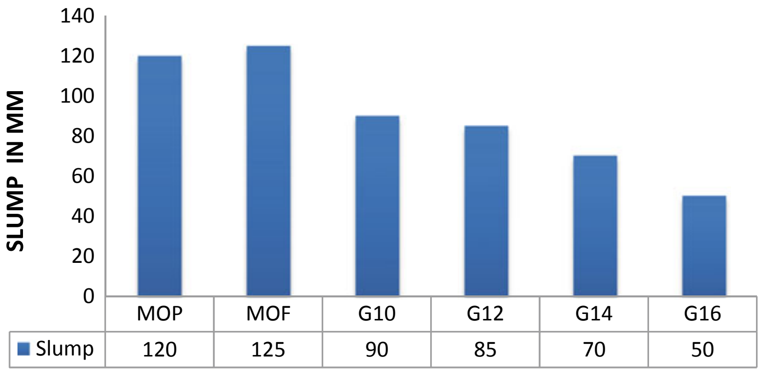


Fig. 8 Variation in workability

5 Result and Discussion

The previous chapter was about the test done and the results. This chapter discuss about the comparison result and the reason.

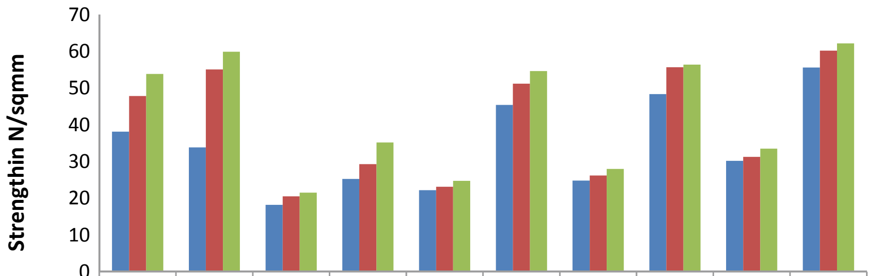
5.1 Workability

Change of workability in term of slump values are represented in the Fig. 8. Slump value of OPC concrete is 120 mm, whereas fly ash concrete displays 125 mm slump. It is due to the spherical particle size of fly ash. On the contrary, the slump value of G10 samples reduces to 90 mm and decreases as molarities of Na_2SiO_3 in GPC increases. It is attributed to the increase in viscosity of Na_2SiO_3 increases the cohesiveness of the GPC mix [15].

5.2 Compressive Strength Results

The compressive strength of all mixes at the age of 7, 28 and 56 days are provided in Table 5 and represented in Fig. 9.

OPC concrete and fly ash concrete are found to achieve much better strength up to 56 days. Seven days strength of fly ash concrete is lower than that of OPC concrete due to replacement of 25% fly ash which are not involved in pozzolanic action in early ages. Strength enhancement between 7 days to 56 days in OPC concrete is found to be 41% which is lower than that for fly ash concrete (76%). Fly ash concrete presents higher strength than OPC concrete both at the age of 28 and 56 days and it is due to the additional C–S–H gel produced from pozzolinic reaction [1]. Compressive strength



	MOP	MOF	G10MC	G10MA	G12MC	G12MA	G14MC	G14MA	G16MC	G16MA
Series1	38.16	33.87	18.23	25.29	22.2	45.45	24.85	48.4	30.2	55.62
Series2	47.87	55.1	20.54	29.31	23.14	51.2	26.22	55.72	31.29	60.25
Series3	53.88	59.91	21.52	35.2	24.75	54.65	27.98	56.42	33.55	62.22

Fig. 9 Compressive strength comparison

of GPC samples increases with the increase in molarities of NaOH for both the curing conditions. It is observed that the compressive strength of 16 M oven-cured GPC cubes were highest. High-temperature cured GPC specimens show comparatively much more strength as compared to the counterparts which were cured in normal curing tank. Strength enhancement in all GPC sample of both curing conditions between 7 and 56 days are small and about 12%. Strength of temperature-cured GPC with 16 M NaOH is observed to be as per the OPC and fly ash concrete both at the age of 28 and 56 days. Normally cured 16 M GPC samples gains strength up to 30 N/mm^2 which satisfy the requirement of M20 concrete.

The change in compressive strength with the change in molarities of NaOH for both the curing conditions is represented in Fig. 10. The reason for the enhancement

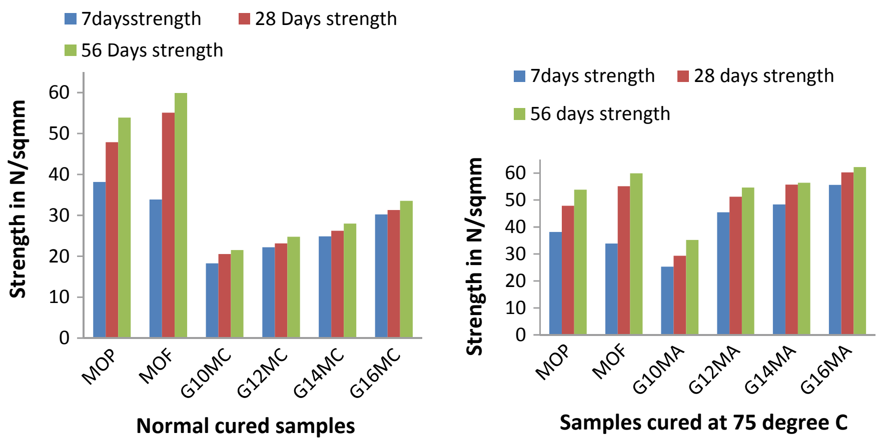
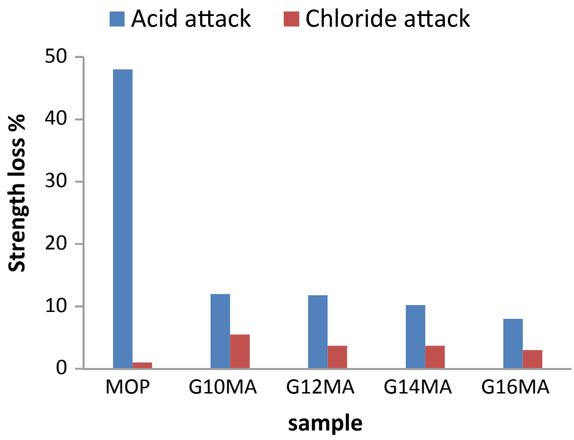


Fig. 10 Variation of compressive strength with change of molarity

Fig. 11 Strength loss in acid and salt attack



of strength in both the oven-cured and normal cured specimen with increase in the molarity of NaOH on GPC may be attributed to the availability of more alkalis for geopolymerization. Higher strength in temperature-cured GPC sample than the normal cured counterparts may be attributed to the availability of more reactive alkalis at higher temperature.

5.3 Acid Attack Results

The test result of acid resistance was given in previous Table 7. The test results shows that the 25% fly ash replacement specimen (MOF) had a drastic fall in strength, at about 48%, whereas the strength loss for 10 M, 12 M, 14 M and 16 M specimen are 12%,11.5% 10.2% and 8%, respectively.

Figure 11 shows the change in strength after acid attack and from the graph it is clearly visible that the G16MA shows greater acid resistivity as compared to the other specimens. In Fig. 12, we can see the weight change of the specimen due to the leaching effect of acid. Weight loss in OPC is 5.0%. The graph clearly shows that the weight loss in geopolymer specimens were very less about 0.35% as compared to the MOF specimen. So it may be concluded that geopolymer concrete poses very good resistance against H_2SO_4 attack.

5.4 Chloride Attack Results

Table 7 shows the test results of chloride attack on different specimen. The test result shows that MOF specimen lost only 1% of its strength where as strength loss of geopolymer concrete cube of 10 M, 12 M, 14 M and 16 M was 5.5%, 3.7%,

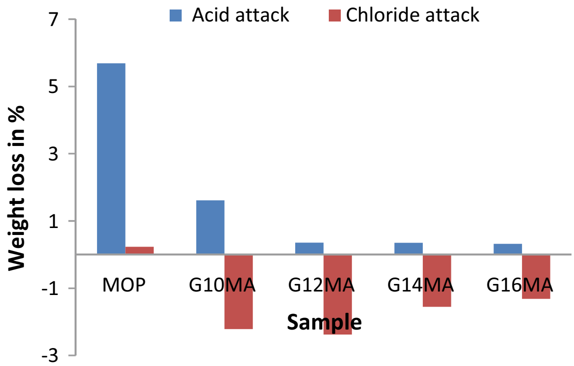


Fig. 12 Change in weight in acid and salt attack

3.69% and 3%, respectively. Figure 12 represents nominal changes in strength in both geopolymer specimens as well as MOF specimen.

Figure 11 presents that there is a loss of weight in MPF sample, whereas there is an increase of weight after the immersion into the NaCl solution. It is due to some amount of salt get deposited into pore spaces the specimens. Percentage gain of weight of GPC samples decreases with an increase in the molarity of NaOH due to pore refinement.

5.5 Sorptivity Results

The test results are provided in Table 8 and Fig. 13 represents the variation of soptivity (s)with respect to an increase in time. Sorptivity increases in a rapid manner up to 5 min. It may be due to initial dryness of the specimen and surface porosity. Then the values decreases in irregular manner. It may be attributed to increase in capillary distance towards interior and tortiocity of capillary path.

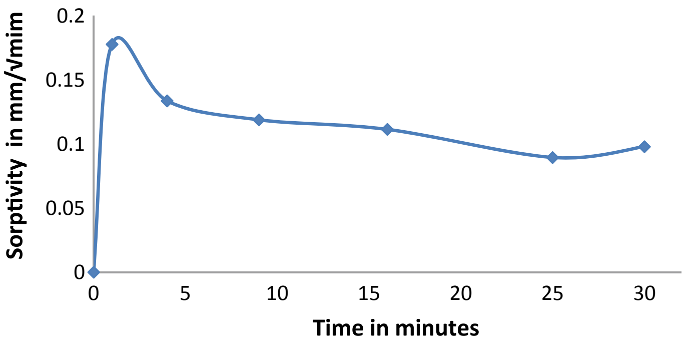


Fig. 13 Variation of sorptivity (s) with respect to time

6 Conclusion

Normal cured GPC displays lower strength in comparison to high-temperature cured GPC and normal cured OPC counterpart and strength increase with the increase in molarities of NaOH. Therefore, it may be recommended for the situations where there is requirement of low strength. Geopolymer concrete shows a very good compressive strength with compare to normal OPC concrete with 25% fly ash replacement. Increase in molarities of NaOH in geopolymer concrete enhances the compressive strength. GPC displays better resistance against acid attack but weak in chloride attack in comparison to OPC counterpart. Increase in molarities of NaOH in geopolymer concrete also enhances the resistance against in acid attack and chloride attack in term of weight and strength loss.

References

1. Nevelle AM (2012) Properties of concrete, text book on concrete tecnology, 4th Edn. Pearsion Education, p 63
2. AdbElaty MAA, Ghazy MF, El Hameed MFA (2017) Optimization of geopolymer concrete by principal component analysis. ACI Mater J Techn Pap 253–264
3. Aslani F (2016) Thermal performance modeling of geopolymer concrete. J Mater Civil Eng 28(1):04015062(1–12)
4. Mehta A et al. (2017) Influence of various parameters on strength and absorption properties of fly ash based geopolymer concrete designed by Taguchi method. Constr Build Mater 150:817–824
5. Albitar M, Mohamed MS, Vasintin P, Drechsler M (2017) Durability evaluation of geopolymer and conventional concretes. Constr Build Mater 136:174–185
6. Singh B, Ishwarya G, Gupta M, Bhattacharyya SK (2015) Geopolymer concrete: a review of some recent developments. Constr Build Mater 85:78–90
7. Ken PW, Ramli M, Ban CC (2015) An overview on the influence of various factors on the properties of geopolymer concrete derived from industrial by products. Constr Build Mater 77:370–395
8. Sarkar PK, Kelly S, Yao Z (2014) Effect of fire exposure on cracking, spalling and residual strength of fly ash geopolymer concrete. Mater Des 63(2014):584–592
9. Chindaprasirt P, Chareerat T, Hatanaka S, Cao T (2011) High strength geopolymer using Fine High calcium Fly ash. J Mater Civ Eng 23(3):264–270
10. Okoye FN, durgaprasad J, Singh NB (2015) Mechanical properties of alkali activated fly ash/Kaolin based geopolymer Concrete. Constr Build Mater 98:685–691
11. Noushini A, Castel A (2016) Effect of heat curing on transport properties of low-calcium fly ash based geo-polymer concrete. Constr Build Mater 112:464–477
12. Gunasekara.C, Law DW, Setunge S (2016) Long term permeation properties of different fly ash geo polymer concretes. Constr Build Mater 124:352–362
13. Hadi MNS, Al-Azzawi M, Yu T Effect of fly ash characteristic and alkaline activator components on compressive strength of fly ash based geo-polymer mortar
14. Allahverdi A, Vafaei M, Maghsoodloorad H (2017) Quality control and assessment of geopolymer cements based on reacted and free alkali. Constr Build Mater 153:274–283
15. Pilehvar S, Cao VD, Szczotok AM, Valentini L, Salvioni D,Magistri M, Pamies R, Kjoniksen AL (2017) Mechanical properties and micro scale changes of geopolymer concrete and Portland cement concrete containing micro-encapsulated phase change. Cement Concrete Res 100:341–349

16. Xie J, Kayali O (2016) Effector super plasticizer on workability enhancement of Class F and Class C fly ash based geopolymers. Constr Build Mater 122:36–46
17. Pasupati K,Berndt M,Sanjayan J, Rajeev P (2017) Durability of low-calcium fly ash based geopolymer concrete culvert in a saline environment. Cement Concrete Res 100:297–310
18. IS 12269-1987, Specification for 53 grade ordinary Portland cement. BIS, New Delhi
19. IS: 383-1970, Specificationfor coarse and fine aggregates from natural sources for concrete, reaff 1993. BIS, New Delhi
20. IS:456-2000 Plain and reinforced concrete code of practice. BIS, New Delhi
21. IS:516-1959 Methods of testing strength of concrete Reaff 1999. BIS, New Delhi