



Mechanical properties of alkali activated flyash/Kaolin based geopolymer concrete



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HIGHLIGHTS

- Geopolymer concretes reduce green house gas emissions.
- Geopolymer concretes were made by fly ash, kaolin, alkalies and sodium silicate.
- NaOH gave higher compressive strength as compared to KOH.
- Combination of 50% FA and 50% Kaolin gave maximum strength.

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ABSTRACT

Five geopolymer concrete mixes were casted using Fly ash, Kaolin, sodium hydroxide, potassium hydroxide, sodium silicate and aggregates. Portland cement concrete (M30) was used as a reference sample. The effect of temperature, sodium and potassium hydroxides and different superplasticizers on the compressive strength was studied. Portland cement concrete with the same mixture proportion was also casted as control. A total of 245 cubes of 100 mm × 100 mm were crushed including the trial experiments. The cubes were cured in oven at different temperatures (40 °C, 60 °C, 80 °C, 100 °C and 120 °C). The results have shown that the compressive strengths increased with increasing temperature, curing time and type of alkali activators. Naphthalene sulfonate based superplasticizer performed better than other superplasticizers. The compressive strength in the presence of 1.0% Naphthalene sulfonate superplasticizer was found 23.3% and 30.9% higher than in the presence of Melamine–formaldehyde and Polycarboxylate ester respectively. Mechanism of strength development has been discussed.

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1. Introduction

Portland cement is one of the most important components of concrete. With the increase of population, the demand for Ordinary Portland cements (OPC) increases. In general 1 tone of cement production generates 1 tone CO₂ gas. The cement industry is second only to power generation in the production of CO₂ and accounts for 7–8% of the planet's human-produced CO₂ emissions [1–3]. Attempts are being made to reduce CO₂ emissions and lower the energy consumption. One of the alternatives to produce more environmentally friendly concrete is to replace the amount of OPC in concrete with by-product materials such as Fly ash in the form of blended cement [4,5]. However, the major drawbacks of blended cements are low early strength. Another way to have

environmentally friendly concrete, which can lower CO₂ emission, is the development of inorganic alumino-silicate polymer, called geopolymer, synthesized from materials of geological origin or by-product materials such as Fly ash that is rich in silicon and aluminum [6–8]. There is a growing volume of scientific literature exploring the properties of geopolymeric materials on the laboratory scale and number of research papers on geopolymer cements using Fly ash has been published [9–14]. However, in the present paper Fly ash is replaced with different amounts of Kaolin and the mechanical properties of geopolymer concretes have been studied in detail.

2. Experimental

2.1. Materials

Low calcium Fly ash conforming to the requirements of ASTM C618 (Class F) and Kaolin were used in this investigation. Commercially available Kaolin and the Fly ash obtained from National Power Station, Dadri, Uttar Pradesh, India, were

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used during the experiments. OPC was used for making OPC concrete for comparing the compressive strengths of geopolymer concretes. The chemical compositions of OPC, Fly ash and Kaolin are given in Table 1. Coarse aggregates of sizes 20 mm and 10 mm and river sand as fine aggregate were used. Sieve analyses were performed to determine the particle size distribution as per BS 812, Part1, 1975 and given in Table 2. Physical properties of gravels and sand are given in Table 3. Distilled water was used in all the experiments. Naphthalene sulfonate (N.S), Malamine–formaldehyde (GN-51) and Polycarboxylate ester (Chryso-730) based superplasticizers were used as admixtures. The alkali activators used were solutions of sodium hydroxide, potassium hydroxide and sodium silicate.

2.2. Preparation of alkalis

Solutions of sodium and potassium hydroxides (14 M each) were prepared separately. The solutions prepared were left for 24 h before mixing with sodium silicate. The mixtures of sodium hydroxide/potassium hydroxide and sodium silicate solutions were left for 1 day and then used for geopolymerization process.

2.3. Mix proportion of geopolymer concrete

The geopolymer concrete was prepared by conventional method as OPC concrete. Since the density of geopolymer concrete is almost equal to that of OPC concrete (2400 kg/m³), aggregates also occupy 75–80% by mass in geopolymer concretes [15]. In the present mix design of geopolymer concrete, coarse and fine aggregates were taken as 77% by mass of the entire mixture. Fine aggregates were 30% by mass of the total aggregates. The ratio of sodium silicate to sodium hydroxide solution was kept 2.5. 14 M NaOH solution was used. To improve the workability of fresh geopolymer mix, Naphthalene sulfonate based superplasticizer was used in all the mixes. In order to compare the effectiveness of different superplasticizers on compressive strength of geopolymer concrete, different doses of superplasticizers (Naphthalene sulfonate, Malamine–formaldehyde and Polycarboxylate ester based superplasticizers) were added separately to Mix4 and compressive strengths were measured. Six mixes were made. Amounts of fine and coarse aggregates, superplasticizers and alkali were kept constant while Fly ash was partly replaced by Kaolin as given in Table 4. Four mixes Mix1, Mix2, Mix3 and Mix4 of geopolymer concretes using NaOH were prepared and their compositions are given in Table 4. Fifth Mix designated as Mix5 was also prepared by using KOH (14 M) instead of NaOH. A control mix with Portland cement (M30) was prepared in order to compare with those of geopolymer concretes. The detailed mix design of geopolymer concrete mixes is given in Table 4.

Table 1
Chemical composition of OPC, Fly ash and Kaolin.

Constituents	Composition (%)		
	OPC	Fly ash	Kaolin
Loss on ignition	2.48	3.79	13.97
Silicon oxide (SiO ₂)	19.01	50.7	45.3
Calcium oxide (CaO)	66.89	2.38	0.05
Magnesium oxide (MgO)	0.81	1.39	0.25
Phosphate (P ₂ O ₅)	0.08	–	–
Sodium oxide (Na ₂ O)	0.09	0.84	0.27
Potassium oxide (K ₂ O)	1.17	2.40	0.44
Manganese oxide (MnO)	0.19	–	–
Aluminum oxide (Al ₂ O ₃)	4.68	28.80	38.38
Iron oxide (Fe ₂ O ₃)	3.20	8.80	0.30

Table 2
Sieve analysis of aggregates.

BS sieve size (mm)	Percentage passing of aggregates of different size		
	20 mm (aggregate)	10 mm (aggregate)	Fine aggregates (aggregate)
25	100	100	–
20	95.6	94.8	–
12.5	26.4	19.1	–
10	6.2	4.4	–
4.75	0.5	0	100
2.36	–	–	98.95
1.18	–	–	84.65
0.60	–	–	59.5
0.30	–	–	34.1
0.15	–	–	2.5
Pan	–	–	–

Table 3
Physical properties of gravels and sand.

Sample	Sp. Gravity	Water absorption (%)	Fineness modulus
20 mm aggregate	2.5	0.17	2.7
10 mm aggregate	2.4	0.87	2.8
Sand	2.6	–	2.1

2.4. Casting of geopolymer concrete mixes

The conventional techniques used in OPC concrete were adopted. First fine and coarse aggregates were saturated surface dry (SSD) and then mixed together in 600 mm × 900 mm mixing pan for about 3 min. The alkali solution was mixed with superplasticizer and then added to the dry materials and mixing continued for 2 min. The whole mixture was then transferred into a tilting type drum concrete mixer and mixing continued for 3–5 min. The fresh geopolymer concrete formed pellets when homogeneously mixed in a drum concrete mixer and were very stiff in consistency as far as workability was concerned; however, adequate compaction was achieved. The mixture was casted in a 100 mm × 100 mm steel mold in three layers, and each layer given 60 strokes with 20 mm compacting rod. Eight cubes were casted for each mix beside the trial mixes. The casted samples were left in the laboratory at room temperature for 48 h (Fig. 1).

2.5. Curing of geopolymer concrete

The process of polymerization requires high temperature and in order to know the optimum curing temperature Mix4 after demolding was heated at different temperatures for 72 h. After demolding, all the samples (Mix1, Mix2, Mix3, Mix4 and Mix5) were transferred in the oven for heat curing at 100 °C for 72 h. The samples were then left at room temperature after curing until the day of testing.

2.6. Effect of KOH on compressive strength

Mix5 given in Table 4 was prepared by using 14 M KOH in place of 14 M NaOH and the compressive strengths were determined at different intervals of time as in the presence of NaOH.

2.7. Fourier transform infrared (FTIR) spectral studies

FTIR spectra were recorded in KBr phase in the frequency range 400–4000 cm⁻¹.

2.8. TG/DTG/DTA studies

TG/DTG/DTA of geopolymer cements were recorded from room temperature to 800 °C in N₂ atmosphere at a heating rate of 10 °C/min.

2.9. SEM studies

SEM pictures of Mix1 were recorded with Quanta FEG 250 ESEM instrument.

3. Results and discussion

3.1. FTIR studies

In order to confirm the formation of geopolymer, FTIR spectra were recorded (Fig. 2). A strong peak at ~1000 cm⁻¹ in all the three samples is associated with Al–O and Si–O asymmetric stretching vibrations, characteristic of geopolymerization [16] and the presence of a zeolitic precursor (amorphous aluminosilicate network structure) [17]. A broad band in the region 3400–3600 may be due to stretching vibrations of OH groups from the water molecules. The amorphous nature of the geopolymer is affected by the type of alkali cation [17,18]. It is well known that variation in the ratio SiO₂/Na₂O significantly modifies the degree of polymerization of the dissolved species in an alkaline silicate solution [18,19]. This plays a significant role in determining the structure and properties of geopolymer gels.

3.2. Thermal studies

In order to know the thermal stability of geopolymers, TG/DTG/DTA studies were made (Fig. 3). The weight loss starts at around

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