UTILISATION OF GEOPOLYMER CONCRETE FOR INDUSTRIAL DEVELOPMENT

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Abstract

The aim of this experiment is to utilise the locally available industrial waste products to produce binder for concrete production in order to minimise Portland cement consumption. This is achieved by using alkali- activated binder known as geopolymer which is embodiment of mineral polymers obtained from geochemistry. Four geopolymer concrete mixtures were designed using Fly ash and kaolin as source materials designated as MXX, MX1, MX2 and MX3 while sodium hydroxide and sodium silicate were used as alkali activators. Portland cement concrete with the same grade was also prepared to serve as control. Geopolymer concrete specimens were cured in oven at temperatures of 30^{o}C, 50^{o}C, 70^{o}C,100^{o}C and 120^{o}C respectively. Compressive strength of geopolymer concrete was determined and compared with that of OPC concrete. The results show that the compressive strengths of geopolymer concrete was much higher than that of OPC concrete. It was also discovered that the strength increased with increasing temperature and curing time.

Keywords: Geopolymer, Cement, Concrete, temperature, Fly ash, Compressive strength

Introduction

Research interest in the geopolymer technology has increased tremendously for the past decade due to environmental effect of production of OPC which has generated a lot of concern on the future of construction industry[1]. Portland cement is the only binder used in concrete production, hence its consumption is similar to that of water[2].With the increased urbanization, the demand for cement increased tremendously with its attendant consequences on the environment. The production of one ton of Portland cement emits approximately one ton of Co2 in the atmosphere which results in global warming and ozone layer depletion[3-5]. A lot of effort has been made to reduce CO2 emission and energy consumption in concrete. This is made possible by partial replacement of Portland cement with supplementary cementitious materials(SMCs) such as fly ash, silica fume, rice husk ash, bone ash etc which produce more environmentally concrete[6-7]. Regrettably, these attempts to reduce CO2 through blended cement has not yielded positive result as much greenhouse gases are still emitted into the atmosphere as well as low early strength recorded. However, a breakthrough have been made to have environmentally friendly concrete, which can lower CO_2 emission. This is achieved by 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[8-10]. 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[11-16]. In this study, fly ash was used as base material to manufacture of geopolymer concrete and the mechanical properties of geopolymer concretes was investigated as regards its compressive strength which showed a good performance over OPC concrete.

Experimental

Materials

Low calcium Fly ash conforming to the requirements of ASTM C618, Class F was used in this investigation which was obtained from National Power Station, Dadri, Uttar Pradesh, India. Ordinary Portland cement was obtained from construction site at Sharda university. The chemical compositions of OPC and Fly ash are given in Table 1.

Table 1. Chemical composition of binders

Chemical composition (%)	OPC	Fly ash	Kaolin
Loss on ignition	2.48	3.79	13.97
Silicon dioxide (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_30_5)	0.08	-	-
Sodium Oxide (Na_2O)	0.09	0.84	0.27

Potassium Oxide (K_2O)	1.17	2.40	0.44
Manganese Oxide (MnO)	0.19	-	-
Aluminium Oxide (Al_2O_3)	4.68	28.80	38.38
Iron Oxide (Fe_2O_3)	3.20	8.80	0.30

Coarse aggregates of sizes 20 mm and 10 mm were used while river sand was used as fine aggregate. Sieve analyses were performed to determine the particle size distribution as per BS 812, Part1, 1975 and given in Table 2.

Table 2. Sieve analysis of aggregates

BS Sieve Size(mm)	Percentage passing		
	20mm	10mm	Fine aggregates
25	100	100	-
20	95.6	94.8	-
2.5	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			

Distilled water was used in all the experiments. Naphthalene sulfonate based superplasticizer was used as chemical admixtures. The alkali activators used were solutions of sodium hydroxide and sodium silicate.

Preparation of alkali

Solution of sodium hydroxide with 14M concentration was prepared and left for 24 hours before mixing with sodium silicate. The mixtures of sodium hydroxide and sodium silicate solution was left for one day to allow for geopolymerisation process.

Mix proportion of geopolymer concrete

The preparation of geopolymer concrete is similar to conventional method of OPC concrete. Since the density of geopolymer concrete is approximately equal to that of OPC concrete

(2400Kg/m^3). Aggregates also occupy 75-80% by mass in geopolymer concretes[17] . In the present mix, 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. To improve the workability of fresh geopolymer mix, Naphthalene sulfonate based superplasticizer was used in all the mixes. Fine and coarse aggregates, superplasticizers and alkali were kept constant. Three geopolymer concrete mix designs MX1, MX2 and MX3 were prepared by replacing fly ash with kaolin in the ratios of 10%, 20% and 30% respectively while MXX was prepared with 100% fly ash. Portland cement concrete with the same grade was also designed as control mix. The detailed mix design of geopolymer concrete is given in Table 3 .

Table 3.Mix proportion of geopolymer concrete

MIX NO	Quantity of ingredients(Kg/m^3)									
	Coarse Aggregate		OPC	Fly ash	Kaolin	SS	NaOH (14M)	S P	ALK/ FA	W/S
	20mm	10mm								
MXX	820	400	0	380	0	113	45	4.0	0.4	0.2.
MX1	820	400	0	342	38	113	45	4.0	0.4	0.2
MX2	820	400	0	304	76	113	45	4.0	0.4	0.2
MX3	820	400	0	266	114	113	45	4.0	0.4	0.2
OPC	820	400	380	0	0	-	-	4.0	-	0.3

Casting of geopolymer concrete mixes

The conventional techniques used in OPC concrete were adopted. A saturated surface dry (SSD) fine and coarse aggregates were mixed together in 600 mm x 900 mm mixing pan for about 3 minutes. The alkali solution was mixed with superplasticizer and then added to the dry materials and mixing continued for 2 minutes. The whole mixture was then transferred into a tilting type drum concrete mixer and mixing continued for 3 to 5 minutes. The fresh geopolymer concrete formed pellets when homogeneously mixed in a drum concrete mixer and were very stiff in consistency as far as workability is concerned; however, adequate compaction was achieved. The mixture was casted in a 100 mm x100 mm x100mm steel mould 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 hours.

Curing of geopolymer concrete

After demoulding, all the geopolymer samples were transferred in the oven for heat curing at 100^{o}C for 72 hours. The samples were then left at room temperature after curing until the day of testing. The cubes for compressive strengths were tested in 3, 7, 14, 21, and 28 days respectively. Moreover, in order to determine the effect of temperature on compressive strength of geopolymer concrete, samples MX3 was subjected to heat curing at different temperatures of 30^{o}C, 50^{o}C, 100^{o}C and 120^{o}C respectively.

Results and discussions

3.1. Effect of temperature on compressive strength

The effect of temperature on compressive strength of geopolymer concrete is shown in Fig.1.

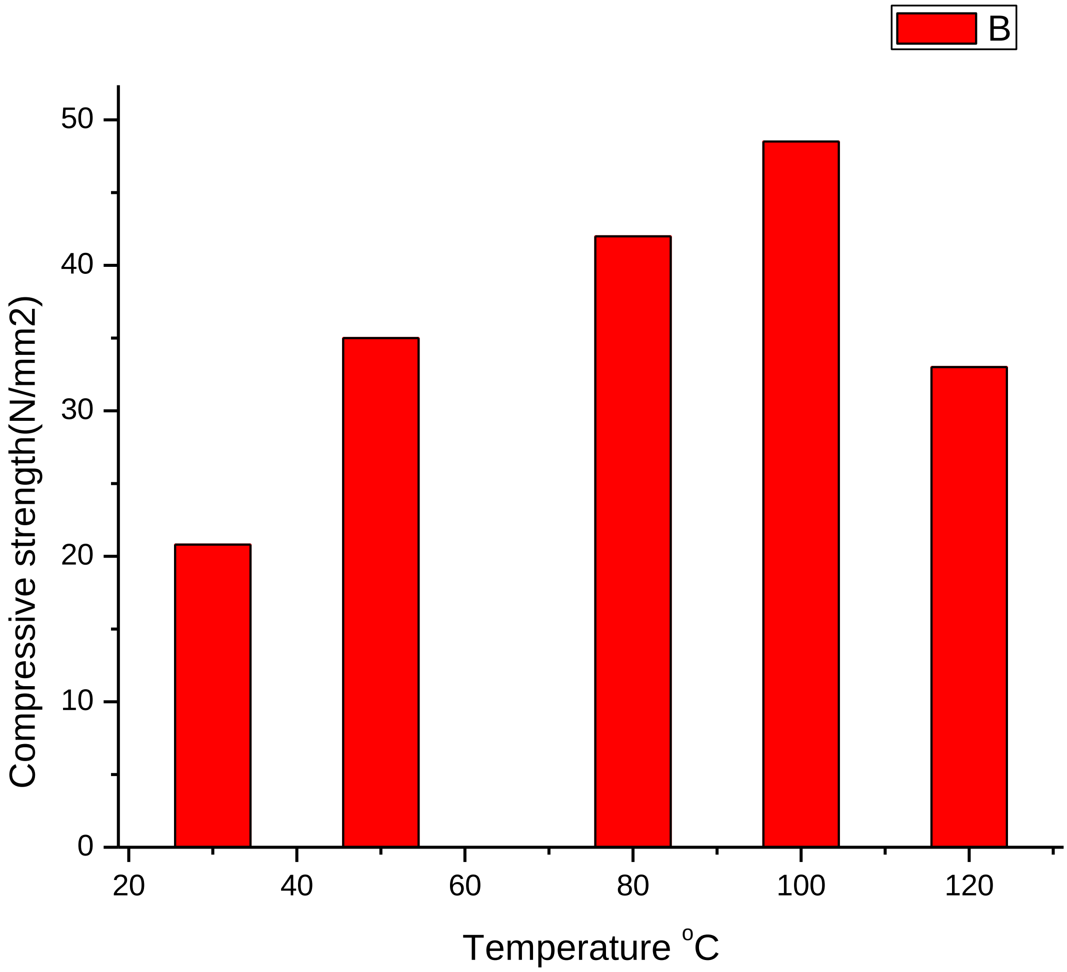

Fig1. Effect of temperatures on the compressive strength of Mix3

The results show that the compressive strength increased with temperature up to 100°C and decreased at 120°C. This graph shows the optimum limit to which geopolymer concrete can be cured for maximum result. It is observed that higher temperature causes excessive loss of moisture and subsequent cracks in the specimen, which produce void thereby resulting in the loss of strength[18].

3.2. Compressive strengths of blended geopolymer concrete

The variations of compressive strength of fly ash and fly ash/kaolin based-geopolymer concretes and that of OPC based concrete are shown in Fig.2.

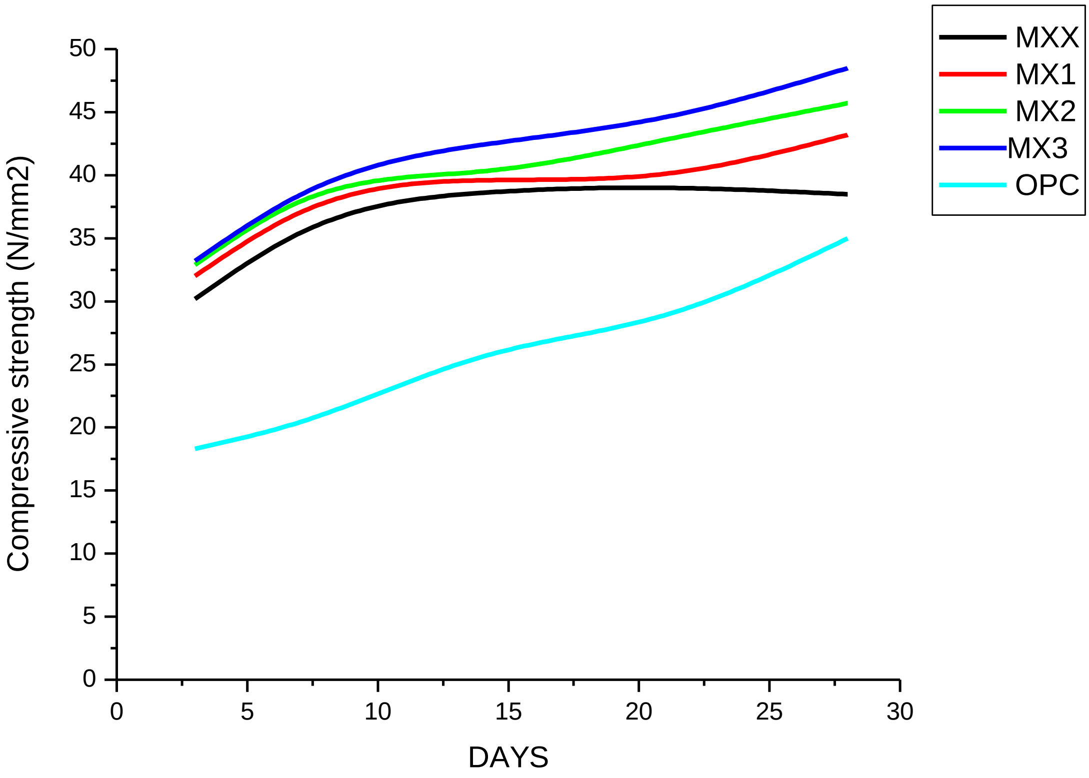

Fig.2. Compressive strength of geopolymer concrete in relation to control

It is observed that OPC has the lowest value of compressive strength at all the times. The variations of compressive strength followed the sequence.

$$\text{Com.Str.}_{\text{OPC concr.}} < \text{Com.Str.}_{\text{Fly ash based Geopolymer concr}} . < \text{Com.Str.}_{\text{Kaolin based Geopolymer concr}} .$$

The high values of compressive strengths of geopolymer concretes may be attributed pozzolanic nature of source materials with high content of amorphous aluminium oxide silicon dioxide with very fine spherical particles and has great potential of enhancing the mechanical properties of concrete. The result of partial replacement of fly ash with kaolin in geopolymer concrete on compressive strength show that as the percentage replacement increased, the strength also increased. At 30% replacement, the strength was much higher than the control and also higher than all the geopolymer mixtures. The results also show that the compressive strengths of geopolymer concrete are much higher than that of OPC concrete. The differences in compressive strengths may be due to differences in the composition, structure, particle size and dissolution rates of Kaolin and Fly ash[19]

Conclusion

Results showed that supplementary cementitious materials(SCMs) of geological origin which are rich in aluminium silicate are good materials for geopolymer concrete especially when blended with fly ash. Replacement of Fly ash with 30 % Kaolin showed much higher compressive strength as compared to the concrete made from OPC. On the other hand when fly ash was replaced by 10% Kaolin, the compressive strength was found to be higher than that of concrete made from OPC. The compressive strength of geopolymer concrete increased with age. Moreover, the strength of geopolymer concrete increased with increased temperature. At temperature of 120^{o}C, the strength decreased.

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