

Full Length Research Paper

Effect of types of curing on strength of geopolymer concrete

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In order to address environmental effects associated with Portland cement, there is need to develop alternative binders to make concrete. An effort in this regard is the development of geopolymer concrete, synthesized from the materials of geological origin or by product materials such as fly ash, which are rich in silicon and aluminum. This paper presents results of an experimental study on the density and compressive strength of geopolymer concrete. The experiments were conducted on fly ash based geopolymer concrete by varying the types of curing namely ambient curing and hot curing. The ratio of alkaline liquid to fly ash was fixed as 0.4. For all the samples the rest period was kept as 5 days. For hot curing, the temperature was maintained at 60°C for 24 h in hot air oven. The compressive strength test was conducted for each sample and the results showed that there is an increase in compressive strength with the increase in age for ambient cured specimens. For hot cured samples the increase in compressive strength with age was very less as compared to that of specimens subjected to ambient curing. The density of geopolymer concrete was around 2400 kg/m³ which is equivalent to that of conventional concrete.

Key words: Fly ash, geopolymer concrete, alkaline liquid, density, compressive strength.

INTRODUCTION

Demand for concrete as construction material is on the increase and so is the production of cement. The production of cement is increasing about 3% annually (McCaffrey, 2002).

The production of one ton of cement liberates about one ton of CO₂ to atmosphere (Roy, 1999). Among the green house gases, CO₂ contributes about 65% of global warming. Furthermore, it has been reported that the durability of ordinary Portland cement concrete is under examination, as many concrete structures especially those built in corrosive environments start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life.

Although the use of Portland cement is unavoidable in the foreseeable future, many efforts are being made to reduce the use of Portland cement in concrete. On the

other hand, the abundant availability of fly ash worldwide creates opportunity to utilize this by-product of burning coal, as a substitute for OPC to manufacture concrete. When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass (Malhotra, 2002; Malhotra and Mehta, 2002), is a significant development. Davidovits (1999) proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as fly ash and rice husk ash. He termed these binders as geopolymers. Palomo et al. (1999) suggested that pozzolans such as blast furnace slag might be activated using alkaline liquids to form a binder and hence totally replace the use of OPC in concrete. In this scheme, the main contents to be activated are silicon and calcium in the blast furnace slag.

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The main binder produced is a C-S-H gel, as the result of the hydration process.

The term geopolymer describes a family of mineral binders with chemical composition same as zeolites. Hardened geopolymer concrete has an amorphous microstructure which is quite similar to that of ancient structures such as Egyptian pyramids and Roman amphitheaters. Geopolymer pioneered by Joseph Davidovits is an inorganic aluminosilicate polymer synthesized from predominantly silicon (Si) and aluminium (Al) materials of geological origin or byproduct materials like fly ash, metakaolin, Granulated Blast furnace slag etc. The polymerisation process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. The chemical reaction comprises the following steps:

1. Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
2. Orientation or condensation of precursor ions into monomers.
3. Setting or polycondensation or polymerization of monomers into polymeric structures.

Compared with ordinary Portland cement concrete, geopolymers show many advantages. Low-calcium fly ash-based geopolymer concrete has excellent compressive strength, suffers very little drying shrinkage and low creep, excellent resistance to sulfate attack, and good acid resistance. It can be used in many infrastructure applications. One ton of low-calcium fly ash can be utilized to produce about 2.5 cubic meter of high quality geopolymer concrete, and the bulk cost of chemicals needed to manufacture this concrete is cheaper than the bulk cost of one ton of Portland cement. Given the fact that fly ash is considered as a waste material, the low calcium fly ash-based geopolymer concrete is, therefore, cheaper than the Portland cement concrete. The superior properties of geopolymer concrete can further enhance the economic benefits. Moreover, reduction of one ton of carbon dioxide yields one carbon credit and this carbon credit significantly adds to the economy offered by the geopolymer concrete. In terms of reducing global warming, geopolymer technology could reduce approximately 80% of CO₂ emission to the atmosphere caused by cement and aggregate industry.

In 2001, when this research began, several publications were available describing geopolymer pastes and geopolymer coating materials (Davidovits, 1991; Davidovits, 1994; Davidovits et al., 1994; Balaguru et al., 1997; van Jaarsveld et al., 1997; Balaguru, 1998; van Jaarsveld et al., 1998; Davidovits, 1999; Kurtz et al., 1999; Palomo et al., 1999; Barbosa et al., 2000). However, very little was available in the published literature regarding the use of geopolymer technology to make low calcium (ASTM Class F) fly ash-based

geopolymer concrete.

In this paper an attempt has been made to study the properties of geopolymer concrete such as density and compressive strength for two different types of curing.

EXPERIMENTAL PROGRAM

Materials

Low calcium fly ash (ASTM class F) collected from Mettur Thermal Power Station was used for casting the specimens. Fine Aggregate (sand) used is clean dry river sand. The sand is sieved using 4.75 mm sieve to remove all the pebbles. Fine aggregate, having a specific gravity of 2.62, bulk density of 1701.84 kg/m³ and fineness modulus of 2.42, was used. Coarse aggregates of 20 mm maximum size having a fineness modulus of 6.94, bulk density of 1679.7 kg/m³ and specific gravity of 2.87 were used. Water conforming to the requirements of water for concreting and curing was used through out. Alkaline liquids are used in geopolymerisation. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

In the present investigation, a combination of Sodium hydroxide solution and sodium silicate solution was used as alkaline solution. Sodium hydroxide is available commercially in flakes or pellets form. For the present study, sodium hydroxide flakes with 98% purity were used for the preparation of alkaline solution. Sodium silicate is available commercially in solution form and hence it can be used as such. The chemical composition of sodium silicate is: Na₂O-14.7%, SiO₂-29.4% and Water -55.9% by mass

Mix design of geopolymer concrete

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 77% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. From the past literatures it is clear that the average density of fly ash-based geopolymer concrete is similar to that of OPC concrete (2400 kg/m³). Knowing the density of concrete, the combined mass of alkaline liquid and fly ash can be arrived at. By assuming the ratios of alkaline liquid to fly ash as 0.4, mass of fly ash and mass of alkaline liquid was found out. To obtain mass of sodium hydroxide and sodium silicate solutions, the ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5. For the present investigation, concentration of NaOH solution is taken as 8 M. Extra water (other than the water used for the preparation of alkaline solutions) and dosage of super plasticizer was added to the mix according to the workability desired. Using the above procedure the mix was designed and the mix proportions are given in Table 1.

Preparation of geopolymer concrete

To prepare sodium hydroxide solution of 8 molarity (8 M), 320 g (8 x 40 that is, molarity x molecular weight) of sodium hydroxide flakes was dissolved in one litre of water. The mass of NaOH solids in a solution will vary depending on the concentration of the solution expressed in terms of molar, M. The mass of NaOH solids was measured as 248 g per kg of NaOH solution of 8 M concentration. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before making the geopolymer concrete to get the desired alkaline solution. The solids constituents of the fly

Table 1. Details of mix proportions.

Alkaline liquid to fly ash ratio	Fly ash (Kg/m ³)	Fine aggregate (Kg/m ³)	Coarse aggregate (Kg/m ³)	NaOH solution (Kg/m ³)	Na ₂ SiO ₃ solution (Kg/m ³)	Total water (Kg/m ³)	Total geopolymer solids (Kg/m ³)	Water to geopolymer solid ratio
0.4	394.3	554.4	1293.4	45.1	112.6	136.3	455.2	0.3

**Figure 1.** Specimens under ambient curing.**Figure 2.** Hot curing of specimens.

ash-based geopolymer concrete, that is the aggregates and the fly ash, were dry mixed in the pan mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and

wet mixing was done for 4 min. Twelve cubes of size 150 mm x 150 mm x 150 mm were cast and compaction was done by mechanical vibration using a table vibrator.

Curing of geopolymer concrete

After casting the specimens, they were kept in rest period for five days and then they were demoulded. The term 'Rest Period' was coined to indicate the time taken from the completion of casting of test specimens to the start of curing at an elevated temperature. This may be important in certain practical applications. For instance, when fly ash-based geopolymer concrete is used in precast concrete industry, there must be sufficient time available between casting of products and sending them to the curing chamber. At the end of the Rest Period, six test specimens were kept under ambient conditions for curing at room temperature as shown in Figure 1. Remaining six specimens were kept at 60°C in hot oven for 24 h as shown in Figure 2.

RESULTS AND DISCUSSION

Density of geopolymer concrete

Variation of density of geopolymer concrete after 7 and 28 days of curing is presented in Figure 3. Density values range from 2251 to 2400 kg/m³. The density of geopolymer concrete was found approximately equivalent to that of conventional concrete. As the age of concrete increases, there is a slight increase in density as shown

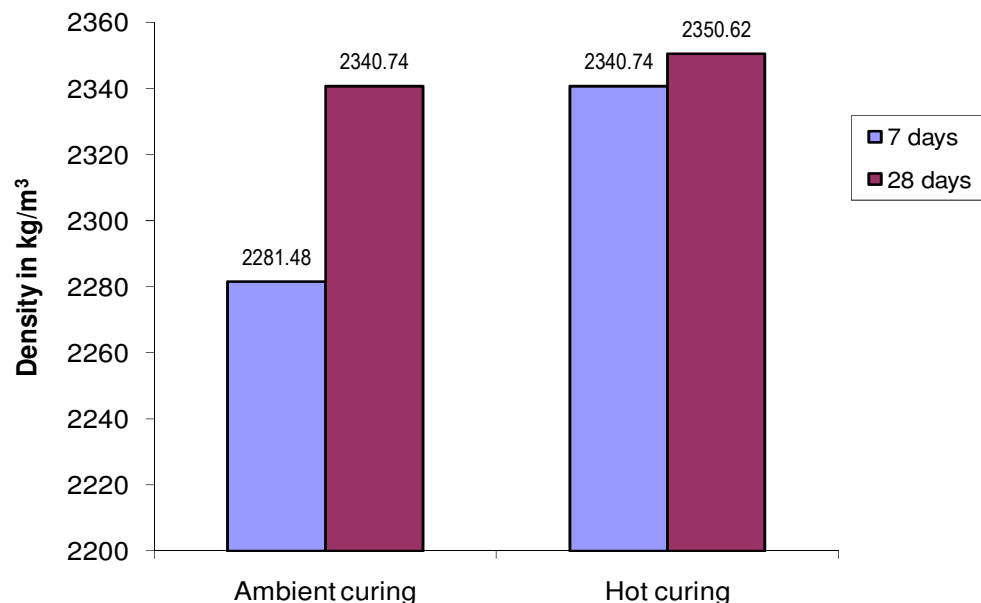
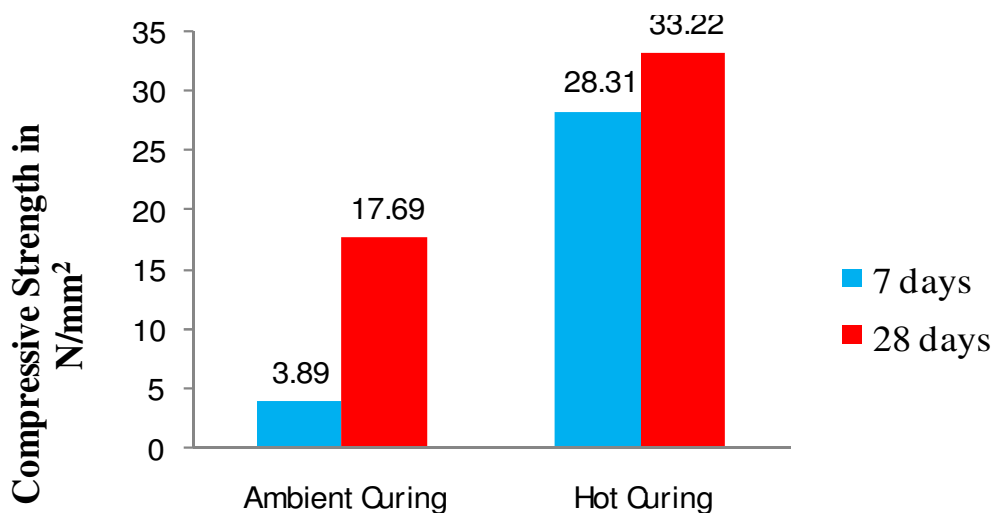


Figure 3. Variation of density with age of geopolymer concrete.



For Alkaline liquid to fly ash ratio 0.4

Figure 4. Variation of compressive strength with age of geopolymer concrete.

in Figure 3. Variation of density is not much significant with respect to age of concrete and type of curing.

Compressive strength

The compressive strength after 7 and 28 days of curing is presented in Figure 4 which shows a graphical representation of variation of compressive strength for

7 days and 28 days of curing. Compressive strength of hot cured specimens is more than that of ambient cured specimens both for 7 and 28 days. 28 days compressive strength of hot cured specimens was about 2 times more than that of ambient cured specimens. 7 days compressive strength of hot cured specimens was around 7 times more than that of ambient cured specimens. In ambient curing the 28 days compressive strength is about 4.5 times the 7 days compressive strength. In hot

curing the 28 days compressive strength is about 1.2 times the 7 days compressive strength.

Conclusion

The compressive strength of hot cured concrete is much higher than that of ambient cured concrete. In ambient curing, the compressive strength increases as the age of concrete increases from 7 days to 28 days. The compressive strength of hot cured fly ash based geopolymer concrete does not increase substantially after 7 days. The average density of fly ash based geopolymer concrete is similar to that of OPC concrete. Geopolymer concrete is more environmental friendly and has the potential to replace ordinary Portland cement concrete in many applications such as precast units.

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