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Strength and workability of low lime fly-ash based geopolymer concrete

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Abstract

Geopolymer concrete prepared from low lime based fly-ash and a mixed alkali activator of sodium hydroxide and sodium silicate solution are investigated. An increase in compressive strength of these concrete samples is observed with increased molarity of NaOH solution. The workability of concrete decreases when the molarity of NaOH solution is increased for the samples cured at 60°C.

Keywords: Concrete, fly-ash, geopolymer, compressive strength.

Introduction

Manufacturing of Portland cement is a resource exhausting, energy intensive process that releases large amount of the green house gas (CO_2) into the atmosphere. Production of one ton of Portland cement requires about 2.8 tons of raw materials, including fuel and other materials. As a result of de-carbonation of lime, manufacturing of one ton of cement generates about one ton green house gas (Davidovits, 1993). At present, efforts have been made to promote the use of pozzolans to practically replace Portland cement. Recently, another class of cementitious materials, produced from an alumino-silicate activated in a high alkali solution, has been developed. This cementitious material is termed as geoploymer. The mortar and concrete made from geopolymers possess similar mechanical performance and appearance properties to those from Portland cement. It is well known that geopolymers have excellent performance with respect to fire resistance, acid resistance and stabilization/solidification of heavy metal waste (Duxson *et al.,* 2007).

Geopolymer concrete

It is an inorganic polymer similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline. The polymerization 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, as follows:

$$Mn\,[-(SiO_2)\,z\text{-}AlO_2]\,n.\,wH_2O$$

Where,

M = the alkaline element, -indicates the presence of a bond, n is the degree of polycondensation or polymerization, z is1,2,3 or higher up to 32.The strength of geopolymer depends on the nature of source materials. Geopolymers made from calcined source materials, such as metakaolin (calcined kaolin), fly-ash, slag etc., yield higher compressive strength when compared to those synthesized from non-calcined materials, such as kaolin clay. A combination of sodium or potassium silicate and sodium or potassium hydroxide has been widely used as the alkaline activator. Because heat is a reaction accelerator, curing of a fresh geopolymer is carried out mostly at an elevated temperature.

Experimental analysis of components

Materials

Fly-ash: Low-calcium (ASTM Class F) fly-ash is preferred as a source material than high calcium (ASTM Class C) fly-ash. The presence of calcium in high amount may interfere with the polymerization process and alter the microstructure (Gourley, 2003). In the present investigation, the fly-ash used was obtained from Ramagundam thermal power station (RTPS) in Andhra Pradesh. Chemical analysis of fly-ash (Table 1) reveals that the fly-ash confirm to the various specifications of IS: 3812-1987.

Table 1. Chemical composition of fly-ash used.

Chemical composition of fly-ash	Quantity present in the fly-ash used (%/mass)
$SiO_2 + Al_2O_3 + Fe_2O_3$	92.65
SiO_2	61.18
Cao	1.34
MgO	-
Total sulphur as SO_3	-
Available alkali as Na_2O	0.051
Loss-on-ignition	1.63

Table 2. Physical properties of aggregates used in the mix.

Properties	Fine aggregate	Coarse aggregate
Fineness modulus	2.27	7.06
Specific gravity	2.43	2.64
Bulk density in loose state	1646 kg/m^3	1564 kg/m^3

Aggregates: (i). Natural sand obtained from the local market is used as fine aggregate. The physical properties of fine aggregate (Table 2) like specific gravity, bulk density, gradation and fineness modulus were tested in accordance with IS: 2386. (ii). The crushed coarse aggregates of 20mm and 6mm maximum size obtained from the local crushing plants are used in the present investigation. The physical properties of coarse aggregate such as specific gravity, gradation and fineness modulus are tested in concurrence with IS: 2386.

Alkaline solution: The sodium hydroxide used in this study was in flake form and of 98% purity. The sodium silicate solution (Na_2SiO_3) used is available locally. The composition of the solution is Na_2O=12.65%, SiO_2=29.93%, H_2O=56.42% by mass.

Super plasticizer: To improve the workability of the fresh geopolymer, concrete super plasticizer (CONPLAST SP-430) is used in the mix and the dosage of the super plasticizer is fixed to 1.5% of the mass of fly-ash (ASTM, 2001).

Table 3. Trial mix proportions for 1 m^3 of concrete for 10 M NaOH solution.

Weight of fly-ash	400 kg
Alkaline liquid solution/fly-ash ratio	0.6
Na_2SiO_3/NaOH ratio	2.5
Mass of NaOH (10 M)	68.57 kg
Mass of Na_2SiO_3	171.42 kg
Mass of aggregates	1760 kg
Sand: coarse aggregate (6mm): coarse aggregate (20 mm)	0.4: 0.3: 0.3
Mass of sand	704 kg
Mass of coarse aggregate 20 mm & 6 mm	528 kg, 528 kg
Mass of super plasticizer	6

Na_2SiO_3: NaOH: fly-ash: sand: C.A (20 mm): C. A (6 mm) = 0.453:0.146:1:1.76:1.32:1.32.

Mix design (Table 3)

Three types of locally available aggregates *viz*. 20 mm, 6 mm coarse aggregates and fine sand in saturated surface dry condition were mixed together in the ratio 0.3:0.3:0.4, respectively.

To start with, the trial mix proportion parameters were fixed, based on estimations and results of previous experiments submitted in the research report (Hardjito & Rangan, 2005).

Table 4. Workability of geoploymer concrete.

Conc. of NaOH	Slump (mm)	Vee-Bee time (sec.)
10 M	160	11.00
12 M	140	12.91
14 M	135	13.20
16 M	110	14.00

Casting and curing

The mixture is casted in 100×100×100 mm size cubes by using hand held vibrator. Immediately after casting, the samples are covered to avoid the loss of water due to evaporation while they were left in room temperature for 60 min. specimens were cured in an oven at a specified temperature of 60°C for a period of 24 h (ASTM, 2001). At the end of curing period the 100×100×100 mm cubes are removed from the moulds. The specimens are then left to air-dry at room temperature, until they are loaded in compression testing machine at the specified age.

Results and discussion

The workability results of slump and Vee-Bee time are presented in Table 4 and the results shows that as the molarity of NaOH solution increases the workability of concrete decreases. The compressive strength results are presented in Table 5 for the concrete mix. Each presented value is the average of 6 readings. The compressive strength of concrete increases with the age for a particular molarity of NaOH solution and the 28 d compressive strength of concrete increases as the molarity of the NaOH solution is increased.

Table 5. Compressive strength of geopolymer concrete cured at 60°C.

Conc. of NaOH	Compressive strength N/mm^2			
	7 d	14 d	21 d	28 d
10 M	25.22	25.63	26.19	27.02
12 M	27.38	28.11	28.90	29.33
14 M	28.18	28.86	28.97	31.00
16 M	29.80	29.82	30.70	32.20

Conclusion

The workability of geopolymer concrete is reduced with higher concentrations of sodium hydroxide (in the range of 10 M to16 M) solution which results in a higher compressive strength. There is a slight increase in the compressive strength with age of the concrete for a defined concentration of NaOH solution. The addition of high-range water reducing admixture with 1.5% of fly-ash (by mass) resulted no much impact on the compressive strength of the hardened concrete, but improved workability of fresh geopolymer concrete.

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