

Experimental Investigations on Geo Polymer Concrete based on Class C Fly Ash

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Abstract

Background/Objectives: To address the environmental constraints due to cement production, strength properties of high-calcium fly ash based Geo Polymer Concrete (GPC) has been explored in this paper. **Methods/Statistical Analysis:** High-calcium (class C) fly ash from Neyveli Thermal Power Plant has been used for the production of GPC. Combination of sodium silicate and sodium hydroxide solution was used as alkaline solution. Alkaline solution to fly ash ratio was varied as 0.35 and 0.45. Concentration of sodium hydroxide solution was maintained as 8M and 12M. Three types of curing such as ambient curing, oven curing and External exposure curing were adopted. **Findings:** The compressive strength of Geo Polymer Concrete was tested at 7, 14, 28 and 60 days. Flexural strength was determined at 28 days. From the test results it was found that 1) Alkaline solution to fly ash ratio of 0.35 and 12M concentration of NaOH solution produced high strength in Geo Polymer Concrete, 2) Compressive strength of external exposure concrete was more than that of oven and ambient cured concrete. **Application/Improvements:** Class C fly ash can be used for the production of Geo Polymer Concrete with acceptable strength.

Keywords: Class C Fly Ash, Compressive Strength, External Exposure Curing, Flexural Strength Geo Polymer Concrete

1. Introduction

Utilisation of concrete as a major construction material is a worldwide phenomenon and the concrete industry is the largest user of natural resources in the world. Massive use of concrete is driving the massive global production of cement, estimated as about 2.8 billion tonnes. Associated with this is the inevitable carbon-dioxide emission of about 7% of total global production. Geo Polymer Concrete is one of the green alternatives to Portland cement concrete. Geo polymers are a relatively new group of materials which were developed by Joseph Davidovits in 1970's. Fly ash based geo polymer are one of the branch in the geo polymer family and these have attracted more attention since 1990's¹⁻².

The physical and chemical characteristics of fly ash mainly depend on coal source and method of production³⁻⁵. Fly ash mainly contains the high percentage of silica and

alumina. The main difference between class F Fly Ash (FFA) and class C Fly Ash (CFA) is the calcium content. Particle size, calcium content, alkali metal content, amorphous content, morphology and origin of fly ash may affect the properties of geo polymers. Calcium content in fly ash in significant quantities could interfere with polymerisation process and may alter the microstructure^{6,7}. Significant amount of research work has been reported on FFA based Geo Polymer Concrete⁸⁻¹¹. CFA based Geo Polymer Concrete has been subjected to limited amount of analysis^{6,7,12,13}.

2. Experimental Program

In this research work, it was aimed to study the effect of alkaline solution concentration and curing conditions on compressive strength of Geo Polymer Concrete based on class C Fly Ash. Flexural strength of Geo Polymer Concrete was also determined at 28 days.

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2.1 Materials and Mix Proportions

Class C Fly Ash obtained from Neyveli Thermal Power Plant was used as source material. The properties of CFA were determined in accordance with IS: 1727-1967 and presented in Table 1. Locally available river sand with fineness modulus of 2.62 and crushed granite stone aggregate of 20-mm (maximum) size was used as fine aggregate and coarse aggregate respectively. The specific gravity of both coarse and fine aggregate was 2.69 and 2.60 respectively and the water absorption was 0.40% and 0.50% respectively. Sodium silicate solution, A53 with SiO_2 to Na_2O ratio by mass approx 2.0 ($\text{Na}_2\text{O} = 14.7\%$, $\text{SiO}_2 = 29.4\%$ and water = 55.9%) and the sodium hydroxide with 97-98% purity, in pellet form was used. Mix proportions adopted were shown in Table 2. Alkaline solution to fly ash ratio

Table 1. Properties of class C Fly Ash

S. No	Properties	Test Results
Physical properties		
1	Specific gravity	2.53
2	Fineness, percentage passing on 75 μm sieve	84%
3	Colour of fly ash	Grey
Chemical properties		
4	SiO_2	32.62
5	Al_2O_3	31.23
6	Fe_2O_3	8.48
7	TiO_2	1.65
8	CaO	17.12
9	MgO	3.49
10	Na_2O	0.91
11	K_2O	0.10
12	Loss on ignition	0.93

Table 2. Mixture proportion per m^3 of Geo Polymer Concrete

Materials	Mass in Kg/m^3	
Alkaline sol /fly ash (by mass)	0.35	0.45
Coarse aggregate	1260	1260
Fine aggregate	540	540
Fly ash	444	414
Sodium hydroxide solution	45	53
Sodium silicate solution	111	133
Super plasticizer	5.80	5.80
Extra water added (liter/ m^3)	36	14

was varied as 0.35 and 0.45. The concentration of sodium hydroxide solution was varied as 8M and 12M.

2.2 Casting and Curing

In the laboratory, aggregates (SSD) and fly ash were first mixed together in the pan mixer thoroughly. The alkaline solution was then added to the dry materials and the mixing continued till homogenous mixture was obtained. The fresh concrete was transferred immediately into cubical moulds of size $100 \times 100 \text{ mm}$ and compacted with the help of table vibrator. After casting, Geo Polymer Concrete specimens were cured immediately. Three types of curing such as ambient, oven and external exposure curing were adopted in this study. In ambient curing, specimens were kept under ambient laboratory conditions for curing. In oven curing, the specimens were cured in oven at 60°C for 24 hours followed by ambient curing till the age of testing. In external exposure curing, the specimens were covered with gunny bags and exposed to heat of sunlight.

2.3 Compressive Strength

Compressive strength of GPC specimens was determined at 7, 14, 28 and 60 days. The test result reveals that the compressive strength of Geo Polymer Concrete ranged from a minimum of 6.75 MPa to a maximum of 38 MPa. The results show that the strength development is related to variables such as alkaline to fly ash ratio, concentration of sodium hydroxide solution and curing conditions in this experimental study. The compressive strength of Geo Polymer Concrete was increased with increase in the concentration of NaOH solution at alkaline solution to fly ash ratio of 0.35 (Figure 1). Compressive strength at 12M concentration of sodium hydroxide solution was about two times higher than 8M concentration for all curing conditions at alkaline solution to fly ash ratio of 0.35. In geo polymerization process, strong alkalis are required to activate the silicon and aluminum present in the fly ash to allow the glassy structure to partially or totally dissolve and then transform into a very compacted composite. The solubility of alumino-silicate increases with increasing NaOH concentration¹¹.

When alkaline solution to fly ash ratio increases to 0.45, the influence of sodium hydroxide concentration on compressive strength development was reduced and the above trend was reversed. At early ages up to 14 days, concentration of sodium hydroxide solution has marginal influence on compressive strength development. At later

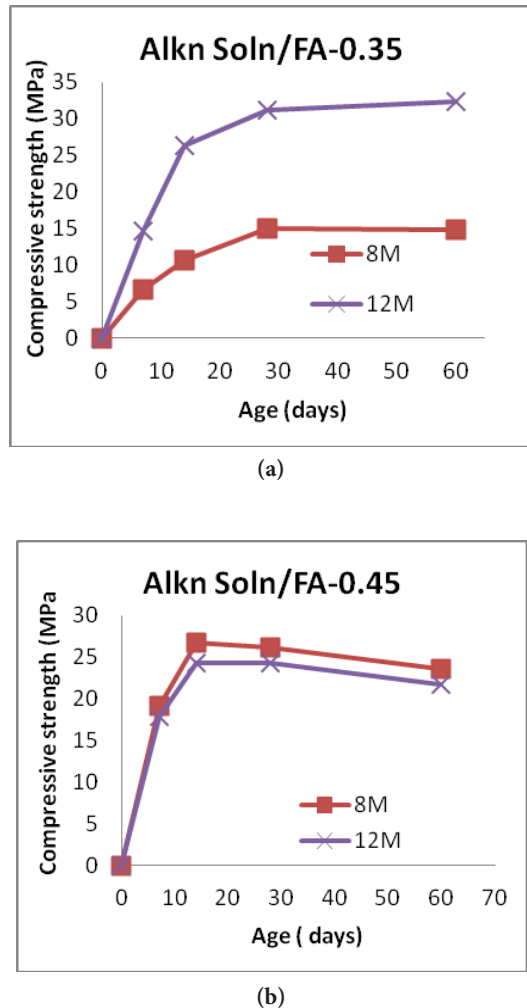


Figure 1. Compressive strength of Geo Polymer Concrete at ambient curing for alkaline solution to fly ash ratio of (a) 0.35 and (b) 0.45.

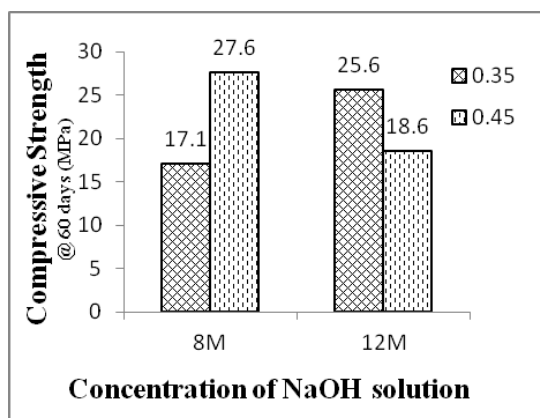


Figure 2. Compressive strength of external exposure cured concrete with respect to alkaline solution to fly ash ratios and concentration of sodium hydroxide solution.

ages, compressive strength at 8M concentration was about 30% higher than 12M concentration. At large concentrations of OH ions, alumino-silicate gel formed during the reaction may be got deposited on fly ash particles and this in turn will reduce the further reaction rate. This is in good agreement with Bakharev, 2005¹¹. Effect of alkaline solution to fly ash ratio on compressive strength of Geo Polymer Concrete specimens was shown in Figures 1 and 2. The alkaline solution to fly ash ratio has considerable effect on the compressive strength of Geo Polymer Concrete. When alkaline solution to fly ash ratio was increased from 0.35 to 0.45, compressive strength of Geo Polymer Concrete was increased by about 60% for lower concentration of NaOH solution. At higher concentration of NaOH solution, the above trend is reversed. Compressive strength of Geo Polymer Concrete was decreased by about 30% when alkaline solution to fly ash ratio increased from 0.35 to 0.45. Maximum compressive strength of Geo Polymer Concrete was obtained when alkaline solution to fly ash ratio was 0.35 and concentration of NaOH solution was 12M.

Effect of curing conditions on the compressive strength of Geo Polymer Concrete was depicted in Figure 3. Compressive strength development in ambient curing is low when compared to other curing conditions. The reason is that sufficient heat to cause proper dissolution of Si and Al present in source material is not developed at ambient conditions. Compressive strength attained at 7 and 14 days in ambient curing was about 70% and 100% when compared to 28 days. Compressive strength development at oven curing was higher when compared to ambient curing. Maximum compressive strength of about 20 MPa was attained in almost 7 days. Gain in strength after 7 days was almost less/marginal. This may be due to the insufficient development of three

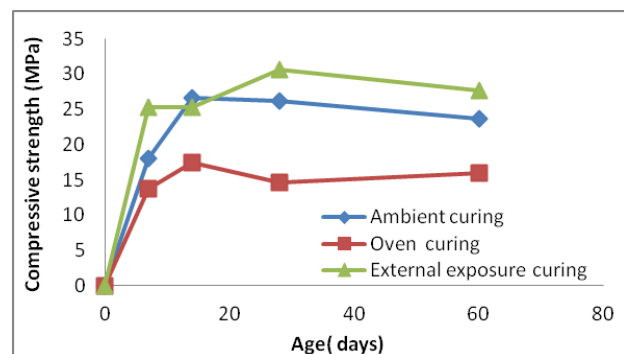
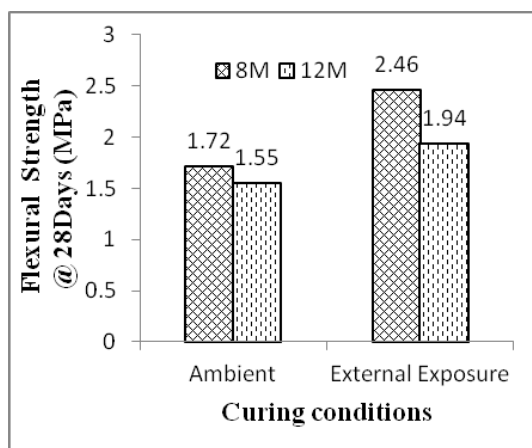


Figure 3. Compressive strength of Geo Polymer Concrete with respect to curing conditions for alkaline solution to fly ash of 0.45.

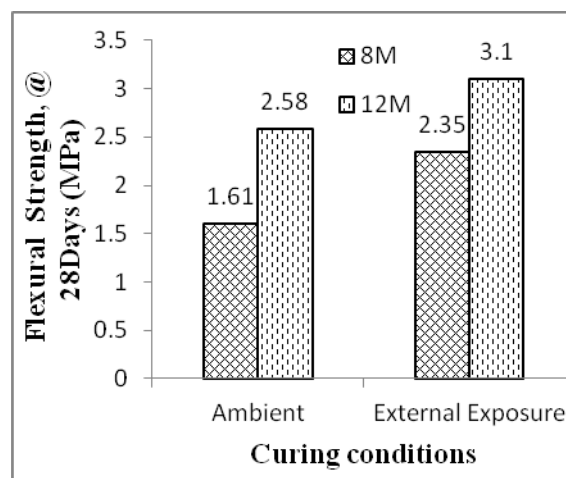
dimensional geo polymeric alumino-silicate network caused by the presence of calcium in alumino-silicate network¹¹. In external exposure curing conditions, compressive strength was increased with age up to 28 days. Maximum compressive strength of about 38 MPa was attained at external exposure curing. External exposure curing conditions resulted in higher compressive strength when compared to ambient and oven curing conditions, because of higher amount of heat energy obtained in external exposure curing. However compressive strength begins to decrease after curing at 28 days at external exposure curing. This may be due to break down the granular structure of Geo Polymer matrix due to dehydration and excessive shrinkage. External exposure curing method generated about 23% and 96% higher strength than ambient and oven curing conditions respectively.

2.4 Flexural Strength

Flexural strength test on hardened Geo Polymer Concrete was performed on beam specimens of size 500 mm x 100 mm x 100 mm beam specimens were test at 28 days. The flexural strength corresponding to failure of the specimen is calculated based on mode of failure. Flexural strength of external exposure cured Geo Polymer Concrete was more than that of ambient curing (Figure 4). In external exposure curing, flexural strength increases by about 46% when compared to ambient curing. Flexural strength was increased as the alkaline solution to fly ash ratio was increased from 0.35 to 0.45. Maximum flexural strength of about 3.1 MPa was noticed; when alkaline solution to fly ash ratio was 0.45 and concentration of NaOH solution was 12M.



(a)



(b)

Figure 4. Flexural strength of Geo Polymer Concrete for alkaline solution to fly ash of (a) 0.35 and (b) 0.45 respectively

3. Conclusions

Based on the test results, the following conclusions are drawn:

- Alkaline solution to fly ash ratio, concentration of sodium hydroxide solution and curing conditions significantly influences on compressive strength development of Geo Polymer Concrete.
- When alkaline solution to fly ash ratio was 0.35, 12M concentration of NaOH develops higher compressive strength, where as 8M concentration of NaOH develops more compressive strength at alkaline solution to fly ash ratio of 0.45.
- In ambient and external exposure curing, compressive strength increases with the age of concrete. The compressive strength of oven cured concrete does not increase substantially after 14 days. Compressive strength development at oven curing was higher when compared to ambient curing. Compressive strength of external exposure cured concrete was about 23% and 96% higher than ambient cured and oven cured concrete respectively.
- Maximum compressive strength of about 39 MPa was achieved when alkaline solution to fly ash ratio was 0.35 and concentration of NaOH solution was 12M at external exposure curing conditions. External exposure curing up to 28 days can be recommended for getting desired compressive strength in Geo Polymer Concrete.

- Increased use of class C Fly Ash in Geo Polymer materials indirectly reduces the emission of green house gas CO₂ released from cement industry.

4. Acknowledgements

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