

Fly Ash-Based Geo Polymer Concrete

Khalid Bashir¹

¹(Civil Department, Bharath University, India)

ABSTRACT : *To reduce greenhouse gas emissions, efforts are needed to develop environmentally friendly construction materials. This paper presents the development of fly ash-based geopolymer concrete. In geopolymer concrete, a by-product material rich in silicon and aluminum, such as (ASTM C 618 Class F) fly ash, is chemically activated by a high-alkaline solution to form a paste that binds the loose coarse and fine aggregates, and other unreacted materials in the mixture. The test results presented in this paper show the effects of various parameters on the properties of geopolymer concrete. The applications of geopolymer concrete and future research needs are also identified. Fly ash, considered to be a waste material rich in silica and alumina and hence can be used as a source material for manufacture of Geopolymers. These binder shave been reported to achieve high early strength and better durability as compared to Ordinary Portland cement based counterparts.*

Keywords: *Compressive strength, Fly Ash, GeoPolymer, Ordinary Portland, Weight loss.*

I. INTRODUCTION

Fly ash based Geopolymers are one branch in the Geopolymer family and these have attracted more attention since the 1990s. As a novel binder, the performance of fly ash based Geopolymers is promising, especially in some aggressive situations where Portland cement concretes are vulnerable. Geopolymer binders might be a suitable alternative in the development of acid resistant concrete. In the past few decades, Geopolymer binders have emerged as one of the possible alternative to OPC binders. Fly ash, one of the source materials for geopolymer binders, is available abundantly worldwide, and yet its use to date is limited. From the 1998 estimation, the global coal ash production was more than 390 million tons annually, but its use was less than 15%. In the future, fly ash production will increase, especially in countries such as China and India. From these two countries alone, it is estimated that by the year 2010 the amount of the fly ash produced will be 780 million tons annually. Accordingly, efforts to use this by product material in concrete manufacture are important to make concrete more environmentally friendly. This paper presents the technology of making geopolymer concrete (Class F) dry fly ash as its source material and presents the results of laboratory tests conducted on this material [1].

1.1 Geopolymer Concrete

Geopolymer is used as the binder, instead of cement paste, to produce concrete. The geopolymer paste binds the loose coarse aggregates, fine aggregates and other unreacted materials together to form the geopolymer concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the portland cement concrete, the aggregates occupy the largest volume, that is, approximately 75 to 80% by mass, in geopolymer concrete. The silicon and the aluminum in the fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the geopolymer paste that binds the aggregates and other unreacted materials.

II. EXPERIMENTAL WORK

In the present experimental work, low-calcium (Class F) dry fly ash obtained from the silos at a local power station(Neyveli) was used as the base material. The chemical composition of the fly ash, as determined by x-ray fluorescence (XRF) analysis, is given in TABLE 1. Analytical grade sodium hydroxide in flake form (NaOH with 98% purity) and sodium silicate solutions (Na₂O = 14.7%, SiO₂ = 29.4% and water = 55.9% by mass), were used as the alkaline activators. To avoid the effect of unknown contaminants in the mixing water, the sodium hydroxide flakes were dissolved in distilled water. The activator solution was prepared at least one day prior to its use. To improve the workability of fresh concrete, a commercially available naphthalene-based high-range water-reducing admixture was used. Four types of locally available aggregates, that is, 20,14, and 7 mm aggregate, and fine sand, in saturated surface dry condition, were mixed together. The grading of this combined

aggregate had a fineness modulus of 5.0

TABLE 1—Composition of Fly Ash as determined by XRF (mass %)

Silica	Alumina	Iron	Calcium	Sodium	Ti	Magnesium	LOI*
39.58	8.17	23.03	18.62	0.97	0	4.23	5.12

*Loss on ignition

TABLE 2—Experimental investigation of flyash

PROPERTIES OF FLYASH USED	
PROPERTIES	VALUES
Sample Collection	Nayveli Lignite Corporation(TN)
Fineness	61%
Normal Consistency	38%
Initial Setting Time	36 min
Specific Gravity	2.63

2.1 Procedure

2.1.1 The aggregates and the fly ash were mixed dry in a pan mixer for 3 min.

2.1.2 The alkaline solutions and the high-range Water-reducing admixture were mixed together, then added to the solid particles and mixed for another 3 to 5 min.

2.1.3 The fresh concrete had a stiff consistency and was glossy in appearance. The mixture was cast in 100 x 200 mm cylinder steel molds in three layers.

2.1.4 Each layer received 60 manual strokes and vibrated for 10 s on a vibrating table. Five cylinders were prepared for each test variable.

2.1.5 Immediately after casting, the samples were covered by a film to avoid the loss of water due to evaporation during curing at an elevated temperature.

2.1.6 After being left in room temperature for 30 to 60 min, specimens were cured in an oven at a specified temperature for a period of time in accordance with the test variables selected.

2.1.7 At the end of the curing period, the 100 x 200 mm test cylinders were removed from the molds and kept in the plastic bag for 6 h to avoid a drastic change of the environmental conditions.

2.1.8 The specimens were then left to air dry at room temperature until loaded in compression at the specified age in a universal test machine.

2.1.9 Numerous trial mixtures of GeoPolymer concrete were made and tested in the laboratory

III. EFFECT OF PARAMETERS

In this section, we present the influence of various parameters on the compressive strength of geopolymer concrete as observed in the laboratory tests.

3.1 Concentration of sodium hydroxide.

In TABLE 3, the only difference between the Mixtures A-1 and A-3 is the concentration of sodium hydroxide as measured by Molarity (second column). Mixture A-3 with higher concentration of NaOH yielded higher compressive strength than Mixture A-1. A similar trend is also observed for the Mixtures A-2 and A-4.

TABLE 3—Effect of parameters on Compressive Strength

Mixture	Concentration of NaOH liquid in molarity (M)	Sodium silicate/NaOH liquids ratio by mass	7-day compressive strength after curing at 60 °C for 24
A-1	8M	0.4	17.3
A-2	8M	2.5	56.8
A-3	14M	0.4	47.9
A-4	14M	2.5	67.6

3.2 Sodium silicate-to-sodium hydroxide liquid ratio.

The effect of sodium silicate-to-NaOH ratio in liquid form on compressive strength can be seen by comparing the compressive strengths of Mixtures A-1 and A-2 as well as A-3 and A-4 in TABLE 3. For Mixtures A-1 and A-2, although the concentration of NaOH liquid (in terms of molarity) is the same, in Mixture A-2 the sodium silicate/NaOH ratio is higher than that of Mixture A-1. This produced a higher compressive strength in Mixture A-2 than Mixture A-1. A similar trend is also observed in the results of Mixtures A-3 and A-4. The results given in TABLE 3 reveal that the interrelation of various oxides contained in the mixture composition affects the compressive strength.

3.3 Curing temperature.

Fig 1 shows the effect of curing temperature on the compressive strength for Mixtures A-2 and A-4. All other test variables were held constant. Higher curing temperature resulted in larger compressive strength, even though an increase in the curing temperature beyond 60 °C did not increase the compressive strength substantially.

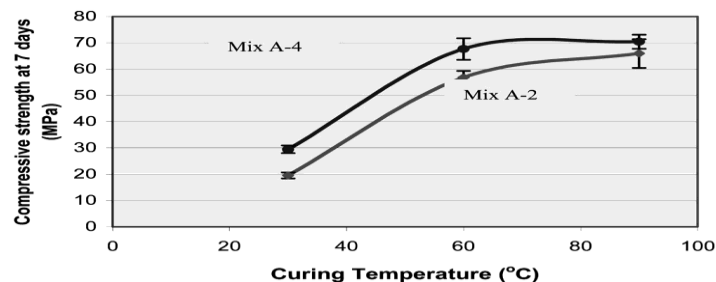


Figure 1 Effect of curing temperature on compressive strength.

3.4 Curing time.

Fig 2 shows the influence of curing time on the compressive strength for Mixture A-2. Longer curing time improved the polymerization process resulting in higher compressive strength. The results indicate that a longer curing time at 60 °C does not produce weaker material. However, the increase in strength for curing periods beyond 48 h is not significant. [2]

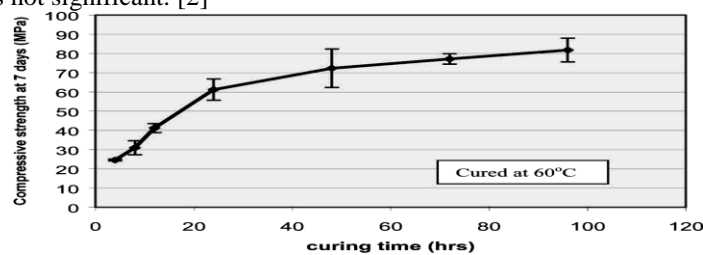


Fig. 2 Influence of curing time on compressive strength for mixture A-2.

3.5 Age of concrete.

Fig 3 shows the effect of age of concrete on the compressive strength. The concrete specimens for this purpose were prepared without adding any high-range water-reducing admixture, and there was no delay time and rest period. Because the chemical reaction of the geopolymer paste is a fast polymerization process, the compressive strength does not vary with the age of concrete, when cured for 24 h. This observation is in contrast to the well-known behavior of OPC concrete, which undergoes a hydration process and hence gains strength over time.

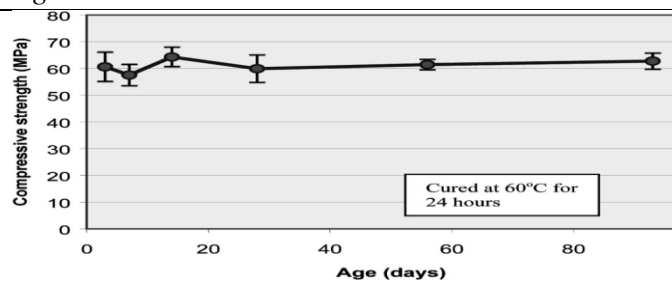


Figure. 3 Compressive strength at different ages for mixture A-2

3.6 Unit weight.

The unit weight of concrete primarily depends on the unit weights of aggregates used in the mixture. Because the type of aggregates in all mixtures did not vary, the unit weight of the concrete varied only marginally between 2330 to 2430 kg/m³

IV. APPLICATIONS OF GEOPOLYMER CONCRETE

The authors have used conventional methods, similar to those used in the case of portland cement concrete, for mixing and placing of geopolymer concrete. For a specified compressive strength, the required workability of the concrete, in terms of slump, can be obtained by adjusting the water content and the concentration (in terms of molar) of sodium hydroxide in the mixture. For instance, the authors have successfully manufactured many mixtures with a compressive strength in the range of 30 to 80 MPa and the slump of concrete varying from 100 to 250 mm depending on the molar of sodium hydroxide and the mass of extra water added to the mixture. A series of 175 x 175 x 1500 mm reinforced geopolymer concrete columns were also manufactured and tested in the laboratory. The compressive strength of the concrete in these structural columns ranged between 42 to 66 MPa, and the slump was approximately 240 mm. The details of this research will be presented in forthcoming papers. With the current state of knowledge, the authors believe that geopolymer concrete is ideally suitable for the manufacture of precast concrete (both reinforced and prestressed) elements and other products needed for infrastructures. Based on their laboratory experience, the authors found that the cost of geopolymer concrete per cubic meter is approximately the same as that of portland-cement concrete. If one considers the impact of the possible carbon dioxide tax on the price of cement and the environmental advantage of utilization of fly ash, the geopolymer concrete may prove to be economically advantageous.

V. CONCLUSION

Based on the experimental work reported in this paper, the following conclusions are drawn:

- 5.1. Higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength of geopolymer concrete (TABLE 3)
- 5.2. Higher the ratio of sodium silicate-to-sodium hydroxide liquid ratio by mass, higher is the compressive strength of geopolymer concrete (TABLE 3);
- 5.3. As the curing temperature in the range of 30 to 90 °C increases, the compressive strength of geopolymer concrete also increases (Fig. 1).
- 5.4. Longer curing time, in the range of 6 to 96 h (4 days), produces larger compressive strength of geopolymer concrete. However, the increase in strength beyond 48 h is not significant;
- 5.5. The compressive strength of geopolymer concrete cured for 24 h at 60 °C does not depend on the age

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