

## FACTORS INFLUENCING THE COMPRESSIVE STRENGTH OF FLY ASH BASED GEOPOLYMER CONCRETE

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**ABSTRACT:** The global cement industry contributes around 1.35 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-made greenhouse gas emissions to the earth's atmosphere. This paper deals with the reduction of these emissions by the use of fly ash based Geopolymer concrete. It is a great deal towards conserving the environment as the main raw material- the geopolymer concrete is obtained from the potentially harmful and toxic fly ash, which is also a generated waste from several combustion processes. This paper also gives an insight about the physical properties of the polymer and its effects with regard to the curing time, water content and super plasticizer, along with the manufacturing techniques of the fly ash based geopolymer concrete.

**Keywords** -greenhouse gas emissions,toxic fly ash,super plasticizer

### I. INTRODUCTION

The global cement industry contributes around 1.35 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-made greenhouse gas emissions to the earth's atmosphere [1,2]. Hence, the development of geopolymer concrete became an important step towards the production of environmentally friendly concretes. Geopolymer is an inorganic alumino-silicate compound, synthesized from materials of geological origin or from by-product materials such as fly ash, rice husk ash, etc., that are rich in silicon and aluminium [3]. Therefore, the use of geopolymer technology not only substantially reduces the CO<sub>2</sub> emissions by the cement industries,[4] but also utilizes the waste materials such as fly ash.

### II. EXPERIMENTAL WORK

Table 1- Chemical composition of fly ash

#### 2.1. Materials

S.No	Components	%
1	SiO <sub>2</sub>	53.36
2	Al <sub>2</sub> O <sub>3</sub>	26.49
3	Fe <sub>2</sub> O <sub>3</sub>	10.86
4	CaO	1.34
5	Na <sub>2</sub> O	0.37
6	K <sub>2</sub> O	0.8
7	TiO <sub>2</sub>	1.47
8	MgO	0.77
9	P <sub>2</sub> O <sub>5</sub>	1.43
10	SO <sub>3</sub>	1.7
11	LOI	1.39

In the experimental work, class F-fly ash was used as the base material. **Table** shows the chemical composition of the fly ash, as determined by X-Ray Fluorescence (XRF) analysis[4,5].

#### 2.2. Loss on ignition

Analytical grade sodium hydroxide in flake form (NaOH with 98% purity), and sodium silicate solution (Na<sub>2</sub>O = 14.7%, SiO<sub>2</sub> = 29.4% and water = 55.9% by mass), were used as the alkaline activators. In order to avoid the effect of unknown contaminants in the mixing water[5], the sodium hydroxide flake was dissolved in distilled water and the activator liquid was prepared at least one day prior to its use. To improve the workability of fresh concrete, a commercially available naphthalene-based super plasticizer was used. Four types of locally available aggregates, i.e. 20 mm aggregate, 14 mm aggregate, 7 mm aggregate and fine sand, in saturated surface

dry condition were mixed together[6]. The grading of this combined aggregate had a fineness modulus (FM) of 5.0.

#### 2.3. Manufacture and Test of Specimens

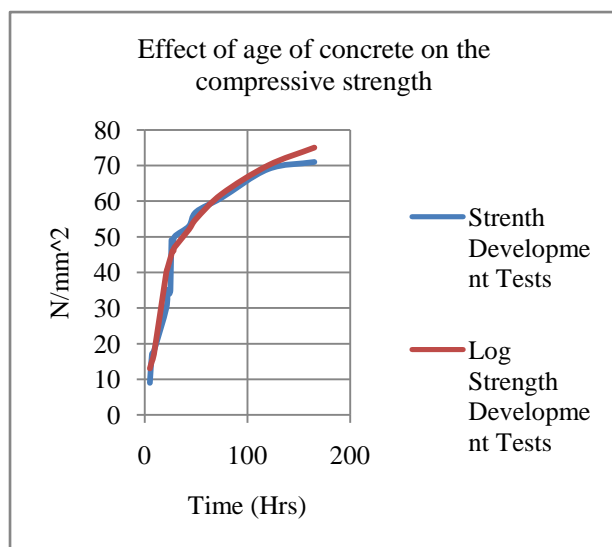
The aggregates and the fly ash were mixed dry in a pan mixer for 3 minutes. The alkaline solutions and the super plasticizer were mixed together, then added to the solid particles in the mixer, and mixed for another 3 to 5 minutes. The fresh concrete had a stiff consistency and was glossy in appearance. The mixture was cast in

100x200 mm cylinder steel moulds in three layers. Each layer received 60 manual strokes and vibrated for 10 seconds on a vibrating table. Five cylinders were prepared for each test variable. Immediately after casting, the samples were covered by a film, and left in room temperature for 30-60 minutes [7,8]. The specimens were then cured in an oven at a specified temperature for a period of time in accordance with the test variables selected. At the end of the curing period, the 100x200 mm test cylinders were removed from the oven, and kept in the moulds for six hours in order to avoid drastic change of the environment [8]. The specimens were then removed from the moulds, left to air dry at room temperature until loaded in compression at the specified age in a universal test machine.

### III. TEST RESULTS

#### 3.1. Detail of Solutions and Curing of Specimens

The solution contains 8M concentration of NaOH solution and Sodium Silicate/NaOH solution by 2.5 mass [9]. This solution is cured for 24 hours at a temperature of 60 °C. The test data points plotted in various graphs correspond to the mean value of the compressive strengths of five test cylinders in a series [9]. The standard deviations were plotted on the test data points as the error bar. The activator liquids-to-fly ash ratio by mass was kept constant approximately at 0.35. The coarse and fine aggregates constituted about 77 percent by mass in the mixes.

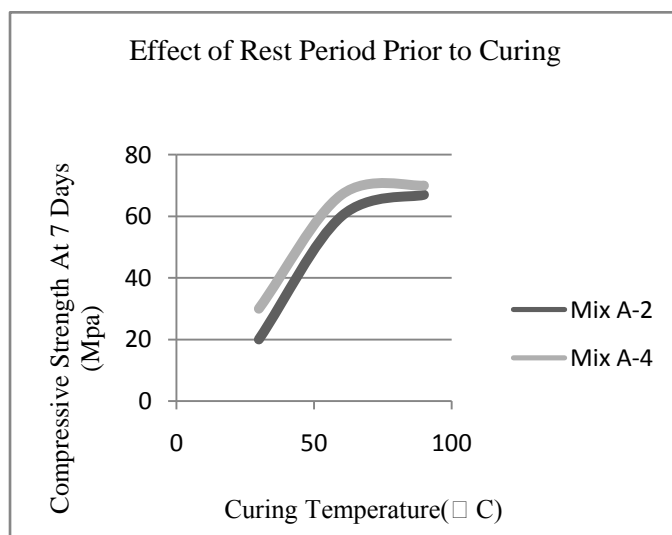


#### 3.2. Compressive Strength at Different Ages

Because the chemical reaction of the geopolymer gel is due to substantially fast polymerization process, the compressive strength does not vary with the age of concrete [10]. This observation is in contrast to the well-known behavior of OPC concrete, which undergoes hydration process and hence gains strength over the time.

#### 3.3. Effect of Curing Time

Longer curing time improves the polymerization process resulting in higher compressive strength. The results shown in Figure 2 indicate that longer curing time does not produce weaker material as claimed by Jaarsveld et al [11]. However, the increase in strength Fig 1 Compressive Strength at Different Ages van after curing for 48 hours is not significant.



#### 3.4. Effect of Super plasticizer

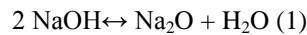
In this study, the mix composition, curing period, curing time etc. were kept constant. The super plasticizer was added in proportion to the fly ash in the mix by mass. The cylinders were tested in compression on the 7th-day after casting. In the fresh state, the concrete has a stiff consistency [10]. Although adequate compaction was achievable, an improvement in the workability was considered as desirable. Tests were therefore performed to study the effect of adding commercially available naphthalene-based super plasticizer [8]. The addition of super plasticizer improved the Figure 2-% of Superplasticiser (by mass of fly ash) workability of the fresh concrete but had very

Compressive Strength at 7 days (MPa) little effect on the compressive strength up to about two percent of this admixture to the mass of fly ash. Beyond this value, there is some degradation of the compressive strength. In the other set, there was no rest period and the test cylinders were placed in the oven immediately after casting [6]. The results plotted that there is very little difference between the strengths of the two sets of specimens. This is an important outcome in practical applications of concrete [3].

### 3.5. Effect of Water Content in the Mix

In order to study the effect of water content on the compressive strength of geo polymer concrete, several tests were performed. The basic mix included 14M concentrated NaOH solution and 2.5 mass of Sodium silicate/NaOH solution [11]. The other details of the mixes were the same as those used in the earlier part of this paper. The percentage of the super plasticizer to the mass of fly ash was 1.5%, the delay time was 30 minutes, and there was no rest period. In order to quantify the water content in the geo polymer concrete mix, the ratio of water (H<sub>2</sub>O)-to-sodium oxide (Na<sub>2</sub>O) was calculated in terms of molar ratio of the oxides. Note that both H<sub>2</sub>O and Na<sub>2</sub>O are identified in both the activator liquids used in this study [10]. For the basic mixture, the molar ratio of H<sub>2</sub>O-to- Na<sub>2</sub>O was calculated as 10.0.

That is, the sodium silicate is composed of H<sub>2</sub>O and Na<sub>2</sub>O. Also, the sodium hydroxide flake (NaOH), which was dissolved in water, can be expressed as;



### 3.6. Effect of the molar H<sub>2</sub>O-to-Na<sub>2</sub>O ratio on Compressive Strength

In order to vary the H<sub>2</sub>O-to-Na<sub>2</sub>O molar ratio, water was added to the basic mixture to yield two other values of molar ratio of H<sub>2</sub>O-to- Na<sub>2</sub>O. By adding extra water of 10.6 kg/m<sup>3</sup>, the molar ratio of H<sub>2</sub>O-to-Na<sub>2</sub>O became 11.25, and by adding extra water of 21.2 kg/m<sup>3</sup>, this ratio was 12.50. The 7-day compressive strengths of concrete cylinders produced from the basic mixture and the two other mixtures as described above, are plotted for different curing temperatures [7,9].

As to be expected, the addition of water improved the workability of the mixtures. The results shown in Figure 2 clearly demonstrate the effect of the molar ratio of H<sub>2</sub>O-to-Na<sub>2</sub>O on the compressive strength of geopolymer concrete. The trends of these test results are similar to those observed by Barbosa et al [12] for their tests on geopolymer pastes. The results shown in Figure 2 also confirm that an increase in the curing temperature increases the concrete compressive strength. However, increasing the curing temperature from 75°C to 90°C did not 90°C 75°C 45°C 30°C.

### 3.7. Effect of the Water-to-Geopolymer Solids ratio on Compressive Strength

For a given geopolymer concrete, the total mass of water in the mixture is taken as the sum of the mass of water in the sodium silicate solution, the mass of water in the sodium hydroxide solution, and the mass of extra water, if any added to the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide flake, and the mass of sodium silicate solids (the mass of Na<sub>2</sub>O and SiO<sub>2</sub> in sodium silicate solution). The test data demonstrate that the compressive strength of geopolymer concrete decreases as the ratio of water-to geopolymer solids by mass increases. The test trends are somewhat analogous to the well-known effect of water-to-cement ratio on the compressive strength of OPC concrete, although the chemical processes involved in the formation of the binders of both these types of concretes are entirely different.

## IV. CONCLUSIONS

Several series of tests on geopolymer concrete were performed. Based on the experimental results reported in the paper, the following conclusions are drawn:

1. The compressive strength of geopolymer concrete does not vary with the age of concrete (Figure 1).
2. Longer curing time improves the polymerisation process resulting in higher compressive strength (Figure 2).
3. Commercially available Naphthalene-based super plasticizer can be utilised to improve the workability of the fresh geopolymer concrete without resulting in any segregation and degradation in the compressive strength up to 2% of this admixture by mass of fly ash.
4. Water content plays an important role in determining the compressive strength of geopolymer concrete as well as the workability of the fresh concrete.

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