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Preparation of Geopolymer Concrete and Determination of its Strength

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Abstract:- *World's most consumed construction material is concrete made up of cement, aggregates, water and additives as it is found to be more versatile, durable and reliable. Concrete is the second most consumed material after water, which required large quantities of Portland cement. The manufacturing process of Ordinary Portland Cement (OPC) results in destruction of the environment due to the emission of CO2 as well mining also results in unrecoverable loss to nature. The amount of carbon emissions is increasing on an alarming scale and hence, it is required to find an alternative material to the existing expensive cement-concrete. Geopolymer concrete is an alternative construction material which is produced by the chemical action of inorganic molecules. Fly Ash, a by- product of coal obtained from the thermal power plant is abundantly available worldwide. Fly ash which is rich with silica and alumina activated with alkaline activators form aluminosilicate gel that act as the binding material for the concrete. It is an excellent alternative construction material to normal concrete without using any amount of ordinary Portland cement. Geopolymer concrete shows a greener substitute for ordinary Portland cement concrete in some applications. This paper reviews the structural properties of Geopolymer concrete and its applications.*

Keywords *-geopolymer concrete, fly ash, GGBFS, alkaline solutions.*

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I. Introduction

The contribution of ordinary portland cement (OPC) production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually or approximately 7% of the total greenhouse gas emissions to the earth's atmosphere. Also, it has been reported that 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.

The concrete industry has recognized these issues. For example, the U.S. Concrete Industry has developed plans to address these issues in "Vision 2030: A Vision for the U.S. Concrete Industry." In this document, strategies to retain concrete as a construction material of choice for infrastructure development, and at the same time to make it an environmentally friendly material for the future, have been outlined.

To produce environmentally friendly concrete, Mehtasuggested the use of fewer natural resources, less energy, and to minimize carbon dioxide emissions. He categorized these short-term efforts as industrial ecology. The long-term goal of reducing the impact of unwanted by-products of industry can be attained by lowering the rate of material consumption.In line with the above view, one of the efforts to produce more environmentally friendly concrete is to partially replace the amount of OPC in concrete with by-product materials such as fly ash. An important achievement in this regard is the development of high-volume fly ash (HVFA) concrete that uses only approximately 40% of OPC, and yet possesses excellent mechanical properties with enhanced durability performance. The test results show that HVFA concrete is more durable than OPC concrete.

This paper presents the technology of making geopolymer concrete using low-calcium (Class F) dry fly ash as its source material and presents the results of laboratory tests conducted on this material

II. Overview On Geopolymer Concrete

Several studies have been made to address the fore said environmental concerns. The alternate pozzolan materials include fly ash, silica fume, ground granulated blast furnace slag (GGBFS), rice husk ash. French Professor Davidovits first introduced the word "Geopolymer". Geopolymer concrete is an alternative to conventional concrete which does not utilize cement as a binder but the binding properties is facilitated by using source materials which are rich in silica and alumina. The binding property is achieved by the reaction of alkaline solutions with the pozzolan source material [3]. The reaction between the source material and alkaline solution forms a gel known as aluminosilicate. The gel so formed binds the aggregates and other materials in concrete to form geopolymer concrete.

III. Past Research On Geopolymer Concrete

The chemical compositions of geopolymer materials are similar to zeolite, but they reveal an amorphous microstructure. High-alkaline solutions are used to induce the silicon and aluminum atoms in the source materials to dissolve and form the geopolymer paste. The polymerization process may be assisted by applied heat, followed by drying. The chemical reaction period is fast, and the required curing period may be within 24 to 48 h. Davidovits reported that this material possesses excellent mechanical properties, does not dissolve in acidic solutions, and does not generate any deleterious alkali-aggregate reaction even in the presence of high alkalinity.

Very limited research data are available in the literature. Most of the past research on the behavior of geopolymeric material was based on the binder paste or mortar using small size samples. In addition, some of the conclusions are contradictory. Based on the laboratory tests on fly ash-based geopolymer binder, Palomo, Grutzeck, and Blanco have shown that the curing temperature, the curing time, and the type of activator affected the compressive strength, while the solution-to-fly ash ratio was not a relevant parameter. Increase in the curing temperature increased the compressive strength. The type of alkaline activator that contained soluble silicates resulted in a higher reaction rate than when hydroxides were used as the only activator.

IV. Materials And Their Source

- Class F Fly ash, low calcium content taken from Bhoopalapally Thermal power station, Telangana.
- Fine Aggregate, Un-sieved taken from the nearest building material store.
- Coarse Aggregate, 20mm-30mm taken from the nearest building material store.
- Chemicals(NaOH and $Na_2SiO_3.5H_2O$) taken from Unique traders, Hyderabad.

V. Literature Review

Abdullah et. al. (2017)focused on the topic” A review on fly-ash based geopolymer concrete without Portland cement”. The study included various parameters such as curing process, compressive strength, workability, resistance against aggressive environment and behavior of geopolymer at elevated temperature. The study concluded that fly ash based geopolymer concrete is better than normal concrete in many aspects such as workability, exposure to aggressive environment, exposure to elevated temperature and compressive strength.

Raut et. al. (2019)focused the topic “Geopolymer concrete: A review of some decent developments”. The study included various parameters such as effect of bulk density and porosity, effects of water transport properties, C-S-H phase effect, effect of admixtures, curing conditions, effect on compressive, flexural strength and durability. The study concluded that geopolymer concrete has considerable potential to be used as a construction material in several applications.

Wallah et. al. (2004)focused the topic “Geopolymer concrete: A review”. The study included various parameters scompressive strength, durability, economic benefits of geopolymer concrete, necessity of geopolymer concrete and application of geopolymer concrete. The study concluded that geopolymer concrete is resistant to corrosion and fire and has high compressive and tensile strength.

Elchalakani et. al. (2018) focused the topic “Geopolymer concrete: A review”. The study included various parameters such as necessity of geopolymer concrete, constituents and properties of geopolymer concrete, Applications and limitations of Geopolymer concrete. The study concluded that due to high early strength, Geopolymer concrete shall be effectively used in the precast industries, so that huge production is possible in short duration and the breakage during transportation shall also be minimized.

Olivia et. al. (2011) focused the topic “Review on strength and Durability studies on Geopolymer concrete”. The study included various parameters such as constituent materials to produce geopolymer concrete, mixing proportions and properties of geopolymer concrete, Factors affecting strength of geopolymer, Workability of fresh geopolymer, Casting and curing of geopolymer specimen, and Major hardened properties of geopolymer concrete. The study concluded that geopolymer concrete has significant potential as a good engineering material for the future research, as the GPC is not only environmental friendly but also possesses excellent mechanical properties.

VI. Methodology

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. Three types of locally available aggregates, that is, 20, 25, and aggregate, and fine sand, in saturated surfacedry condition, were mixed together. The grading of this combined aggregate had a fineness modulus of 5.0.

The aggregates and the fly ash were mixed dry in a pan mixer for 3 min. 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. The fresh concrete had a stiff consistency and was glossy in appearance. The mixture was cast in 150 x 150 x 150 mm cubical steel molds in three layers and also in the cylindrical molds of 260mm dia. Each layer received 30 manual strokes. Three cubes and Three cylinders were prepared for each test specimen.

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. After being left in room temperature for 60 to 120 min, specimens were cured in an oven at a specified temperature(**45**° C) for a period of time in accordance with the test variables selected.

At the end of the curing period, the 150 x 150 x 150 mm test cubes and 260mm dia. cylinders were removed from the molds and kept in the plastic bag for 6 h to avoid a drastic change of the environmental conditions. The specimens were then left to air dry at room temperature until loaded in compression at the specified age in a compressive strength test machine. The loading rate and other test procedures used were in accordance with the details specified in the relevant Indian Standard for testing OPC concrete.

The Numerous trial mixtures of geopolymer concrete were made and tested in the laboratory. The data collected from these studies indicated that the salient parameters affecting the compressive strength of geopolymer concrete are as listed below:

- Silicon oxide (SiO2)-to-aluminum oxide (Al2O3) ratio by mass of the source material (fly ash); this ratio should preferably be in the range of 2.0 to 3.5 to make good concrete;
- Activator liquids-to-source material (fly ash) ratio by mass;
- Concentration of sodium hydroxide (NaOH) liquid measured in terms of Molarity (M), in the range of 8 to 16 M;
- Sodium silicate-to-sodium hydroxide liquid ratio by mass; the effect of this parameter depends on the composition of the sodium silicate solution;
- Curing temperature in the range of 30 to 90 °C;
- Curing time in the range of 6 to 96 h; and
- Water content in the mixture.

It must be noted that only the binder (which usually occupy approximately 20 to 25% of the total mass) is different in geopolymer concrete when compared to OPC concrete. Therefore, the effects of properties and grading of aggregates were not investigated in this study.

VII. Table-1: MIX DESIGN (Ratio in kgs)

MIX TYPE	FLY ASH	FINE AGGREGATE	COARSE AGG.
M-1	**1.0**	**2.0**	**2.5**
M-2	**1.0**	**2.5**	**3.0**
M-3	**1.0**	**3.0**	**4.0**

VIII. 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. Each of the test data points plotted.

In the experimental work, the activator liquids-to-fly ash ratio by mass was kept constant at approximately 0.35. The coarse and fine aggregates constituted approximately 70% by mass in all mixtures.

Table 2 gives the composition of four different mixtures and the 7-day compressive strengths of 150 x 150 x 150 mm test cubes cured at 45 °C for 24 h. In Table 2, the second column gives the concentration of NaOH liquid in terms of molarity (M). The third column is the ratio of sodium silicate/NaOH by mass in liquid form. The last column gives the mean 7-day compressive strengths of test cylinders.

8.1 Concentration of sodium hydroxide

In Table 2, the only difference between the Mixtures C-1 and C-2 is the concentration of sodium hydroxide as measured by Molarity (second column).

8.2 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 C-1 and C-2(Table 2). The ratio of the sodium silicate to sodium hydroxide liquid ratio is 2/1.

The results given in Table 2 reveal that the interrelation of various oxides contained in the mixture composition affects the compressive strength.

8.3 Table-2: 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 40 °C, MPa	14-day compressive strength after curing at 45 °C, MPa	28-day compressive strength after curing at 45 °C, MPa
C-1	12M	0.3	14.18	18.20	20.68
C-2	14M	0.4	23.11	30.22	36.48

8.4 Curing temperature

Figure 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

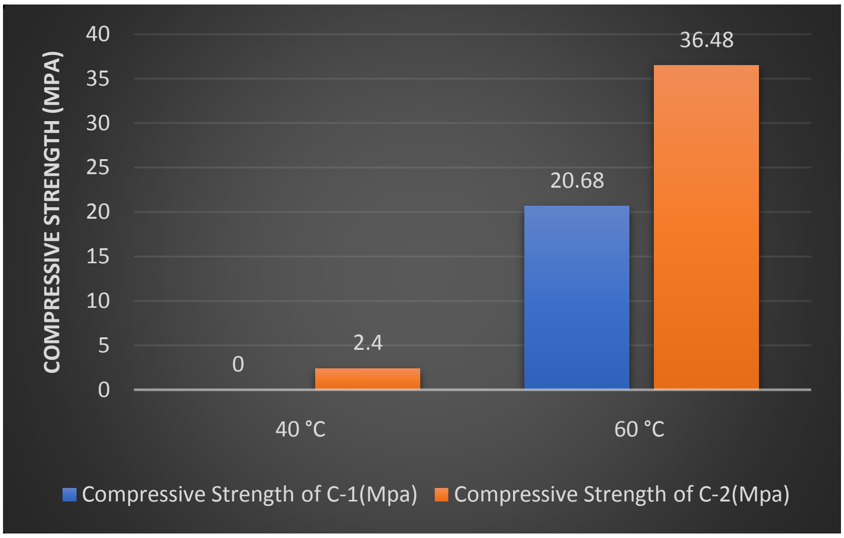


Fig. 1—*Effect of curing temperature on compressive strength.*

8.5 Curing time

Figure 2 shows the influence of curing time on the compressive strength for Mixture C-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 as claimed by van Jaarsveld, van Deventer, and Lukey.[10] However, the increase in strength for curing periods beyond 48 h is not significant.

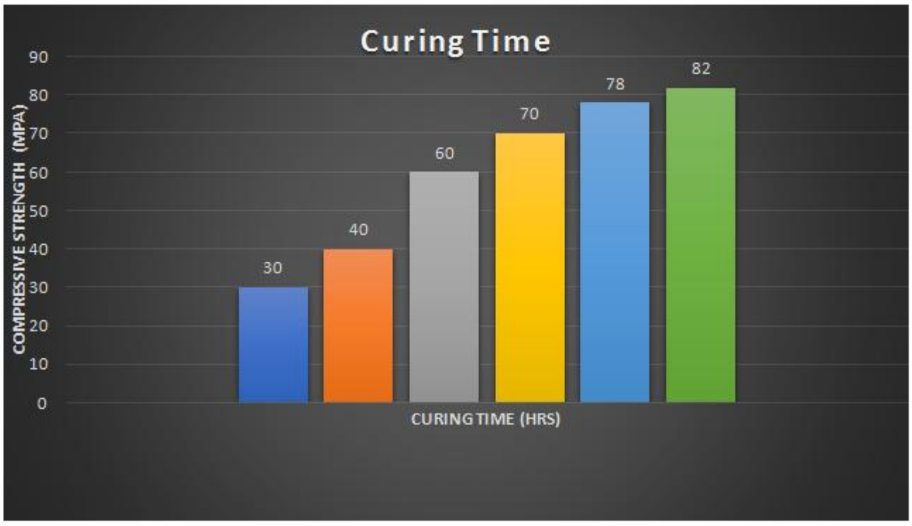


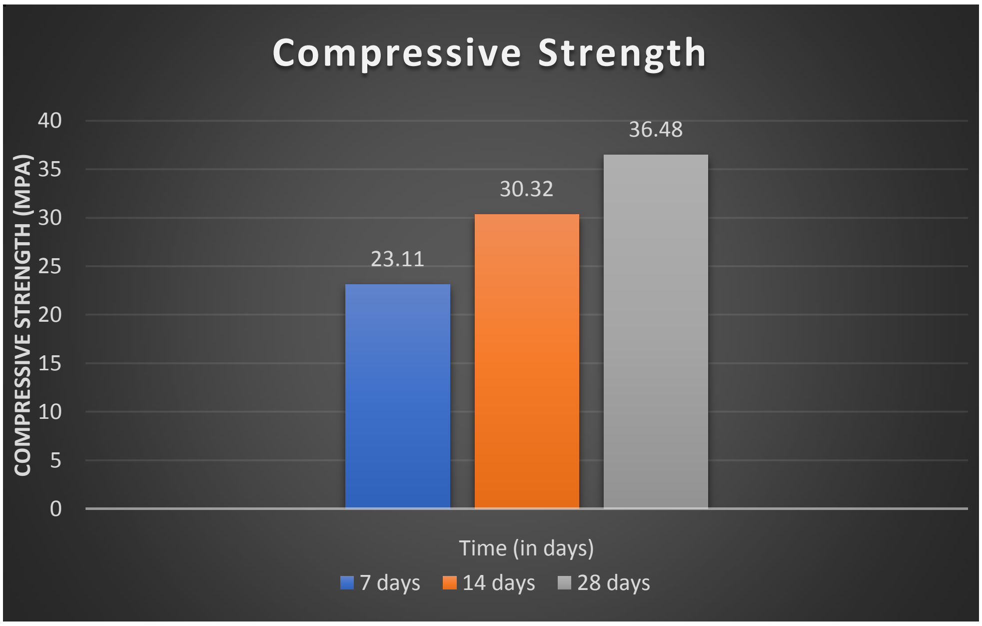
Fig. 2—*Influence of curing time on compressive strength for Mixture C-2.*

8.6 Table-3: Effect of parameters on Tensile strength

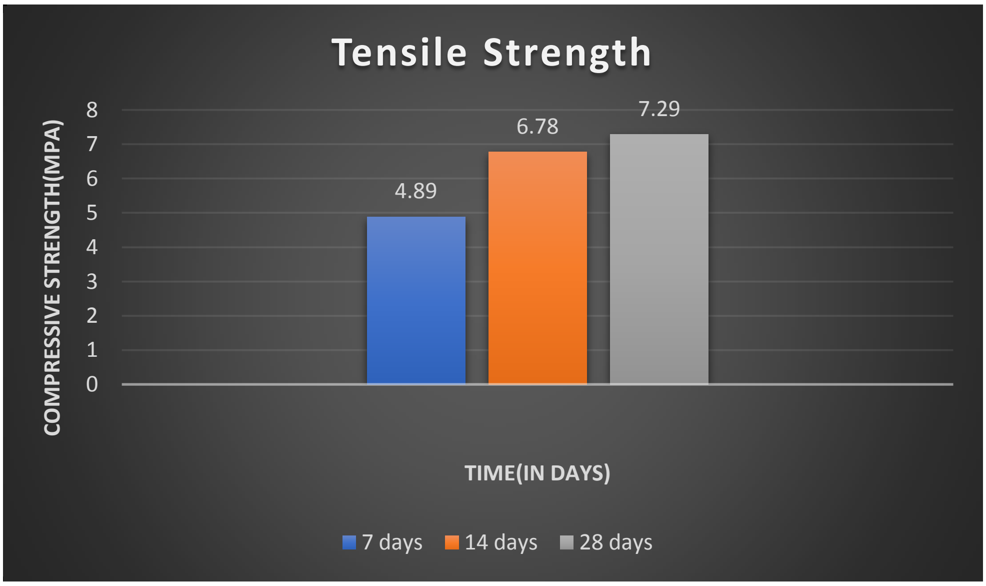
Mixture	Concentration of NaOH liquid in molarity (M)	Sodium silicate/NaOH liquids ratio by mass	7-day Tensile strength after curing at 40 °C, MPa	14-day Tensile strength after curing at 45 °C, MPa	28-day Tensile strength after curing at 45 °C, MPa
C-1	12M	0.3	3.26	4.18	4.96
C-2	14M	0.4	4.89	6.78	7.29

IX. Graphical Representationof Strengths

Graph-1 represents the Compressive strengths of the Concrete cubes (150 x 150 x 150 mm) at 7,14, and 28 days.



Graph-2 represents the Tensile strengths of Concrete Cylinders 0.26mϕ



X. Conclusion

This paper presented the development of geopolymer concrete. The binder in this concrete, the geopolymer paste, is formed by activating by-product materials, such as low-calcium (Class F) fly ash, that are rich in silicon and aluminum.

In the experimental work, the fly ash from a local power generation plant was used as the source material. A combination of sodium silicate solution and sodium hydroxide solution was used as the activator. The geopolymer paste binds the loose coarse and fine aggregates and any unreacted materials to form the geopolymer concrete. Based on the experimental work reported in this paper, the following conclusions are drawn:

1. Higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength of geopolymer concrete (Table 1);
2. Higher the ratio of sodium silicate-to-sodium hydroxide liquid ratio by mass, higher is the compressive strength of geopolymer concrete (Table 1);
3. As the curing temperature in the range of 30 to 90 °C increases, the compressive strength of geopolymer concrete also increases (Fig. 1);
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. The addition of high-range water-reducing admixture, up to approximately 2% of fly ash by mass, improved the workability of fresh geopolymer concrete with very little effect on the compressive strength of hardened concrete;
6. The rest period between casting of specimens and the commencement of curing up to 60 min has no effect on the compressive strength of geopolymer concrete;
7. The fresh geopolymer concrete is easily handled up to 120 min without any sign of setting and without any degradation in the compressive strength;
8. As the ratio of water-to-geopolymer solids by mass increases, the compressive strength of the concrete decreases;
9. The compressive strength of geopolymer concrete cured for 24 h at 60 °C does not depend on the age; and
10. The geopolymer concrete undergoes very little drying shrinkage and low creep.The resistance of geopolymer concrete against sodium sulfate is excellent.

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