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An Experimental Study on the Behaviour of Geopolymer Concrete Compared to Conventional Concrete

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***Abstract*- Conventional concrete uses cement which pollutes the environment by emitting carbon dioxide during its production .To overcome this issue, low calcium fly ash based geopolymer is used as a binder instead of cement paste to produce concrete. Geo polymer are members of the family of inorganic polymers. The waste materials have been introduced into the construction industry to replace cement. Fly ash is a source of Si and Al that react with alkaline solutions, sodium hydroxide and sodium silicate which forms a polymeric binder. Fly ash used in this paper was low-calcium dry fly ash (ASTM Class F). The properties of fly ash based geopolymer concrete and conventional concrete are studied through various tests** .

***Keywords*- Alkali activated fly-ash based geo-polymer, construction material for green building, geo-polymer concrete, eco-friendly construction material, low calcium based geo-polymer concrete, GGBS(Ground Granulated Blast Furnace Slag).**

I. INTRODUCTION

Concrete usage around the world is second only to water and Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are too many. The cement industry is held responsible for some of the CO2 emissions. The amount of the carbon dioxide released during the manufacturing of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced.

The demand for Portland cement is increasing day by day and hence, efforts are being made in the construction industry to address this by utilising supplementary materials and developing alternative binders in concrete; the application of geo-polymer technology is one such alternative. The abundant availability of fly ash worldwide creates opportunity to utilise this by-product of burning coal, as a substitute for OPC to manufacture concrete. When used as a full replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel.

In 1978, Davidovits (1999) proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as fly ash and rice husk ash. He termed these binders as geo-polymers.

Palomo et al (1999) suggested that pozzolans such as blast furnace slag might be activated using alkaline liquids to form a binder and hence totally replace the use of OPC in concrete

Hence, in this paper an effort is made to identify and study the effect of salient parameters that affects the properties of low-calcium fly ash-based geo-polymer concrete and the properties of concrete at varied concentrations of alkali solutions and how the change in temperature affects the strength characteristics.

II. GEOPOLYMER

Geo-polymer is a term covering a class of synthetic alumino-silicate materials with potential use in a number of areas, essentially as a replacement for Portland cement and for advanced high-tech composites, ceramic applications or as a form of cast stone. The name Geo-polymer was first applied to these material by Joseph Davidovits in the 1970s, although similar materials had been developed in the former Soviet Union since the 1950s, originally under the name "soil cements". However, this name never found widespread usage in the English language, as it is more often applied to the description of soils which are consolidated with a small amount of Portland cement to enhance strength and stability. Geo-polymer cements are an example of the broader class of alkali-activated binders, which also includes alkali- activated metallurgical slags and other related materials.

A. *Constituents of geo-polymer concrete*

There are two main constituents of geo-polymers, namely the source materials and the alkaline liquids. The source materials for geo-polymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product

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materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. could be used as source materials. The choice of the source materials for making geo-polymers depends on factors such as availability, cost, type of application and specific demand of the end

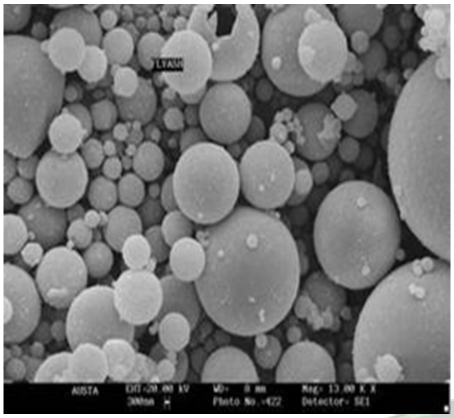

Figure 1 Ungraded fly-ash

B. Fly Ash

According to the American Concrete Institute (ACI) Committee 116R, fly ash is defined as "the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses from the combustion zone to the particle removal system" (ACI Committee 232 2004). Fly ash is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. Fly ash particles are typically spherical, finer than Portland cement and lime, ranging in diameter from less than 1 µm to no more than 150 µm.

The chemical composition is mainly composed of the oxides of silicon (SiO_2), aluminium (Al_2O_3), iron oxide(Fe_2O_3), and calcium oxide (CaO), whereas magnesium, potassium, sodium, titanium, and sulphur are also present in a lesser amount.

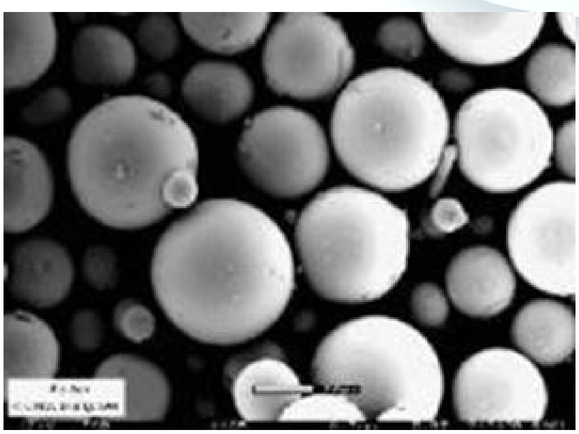

Figure 2 Graded fly-ash

The characteristics of fly ash that generally considered are loss on ignition (LOI), fineness and uniformity. LOI is a measurement of un-burnt carbon remaining in the ash. Fineness of fly ash mostly depends on the operating conditions of coal crushers and the grinding process of the coal itself. Finer gradation generally results in a more reactive ash and contains less carbon.

C. Use of Fly Ash in Concrete

Fly ash plays the role of an artificial pozzolana, where its silicon dioxide content reacts with the calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (C-S-H) gel. The spherical shape of fly ash often helps to improve the workability of the fresh concrete, while its small particle size also plays as filler of voids in the concrete, hence to produce dense and durable concrete.

An important achievement in the use of fly ash in concrete is the development of high volume fly ash (HVFA) concrete that successfully replaces the use of OPC in concrete up to 60% and yet possesses excellent mechanical properties with enhanced durability performance.

D. Alkaline Liquids

The most common alkaline liquid used in geo-polymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate (Davidovits 1999; Palomo et al. 1999; Barbosa et al. 2000; Xu and van Deventer 2000; Swanepoel and Strydom 2002; Xu and van Deventer 2002). The use of a single alkaline activator has been reported (Palomo et al. 1999; Teixeira- Pinto et al. 2002), Palomo et al (1999) concluded that the type of alkaline liquid plays an important role in the polymerisation process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. Xu and van Deventer (2000) confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid enhanced the reaction between the source material and the solution. Furthermore, after a study of the geo-polymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution.

E. GGBS:

The production of GGBS requires little additional energy compared with the energy required for the production of Portland cement. The replacement of Portland cement with GGBS will led to a significant reduction of carbondioxide gas emission.

GGBS is therefore an environmentally friendly construction material.

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F. Polymerisation Process

Geo-polymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si- Al minerals, which results in a three-dimensional polymeric chain and ring structure consisting of Si-O- Al-O bonds

$$M_n [-(SiO_2)_z - AlO_2]_n \cdot wH_2O$$

Where: M = the alkaline element or cation such as potassium, sodium or calcium;

The symbol – indicates the presence of a bond,
n is the degree of poly-condensation or polymerisation;
z is 1, 2,3, or higher, up to 32.

The schematic formation of geopolymer material can be shown as described by

The chemical reaction may comprise the following steps

- Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- Transportation or orientation or condensation of precursor ions into monomers.
- Setting or poly-condensation/polymerisation of monomers into polymeric structures.

However, these three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately (Palomo et al. 1999).

The last term in Equation reveals that water is released during the chemical reaction that occurs in the formation of geo-polymers. This water, expelled from the geo-polymer matrix during the curing and further drying periods, leaves behind discontinuous Nano-pores in the matrix, which provide benefits to the performance of geo-polymers. The water in a geo-polymer mixture, therefore, plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement mixture during the hydration process. [4] discussed about amplifier power relation, impedance , T π and microstripline matching networks.

The geo-polymerization process (alkaline activation of fly ash in the aqueous environment at pH>12) accompanied by the hardening of the material is different from the hydration processes of inorganic binders (e.g. Portland cement). This process obviously takes place predominantly “via solution” when, first, the fly ash particles are dissolved and a new

G. Chemical composition of the geo-polymers

Differences due to various conditions of the alkaline activation can be found .

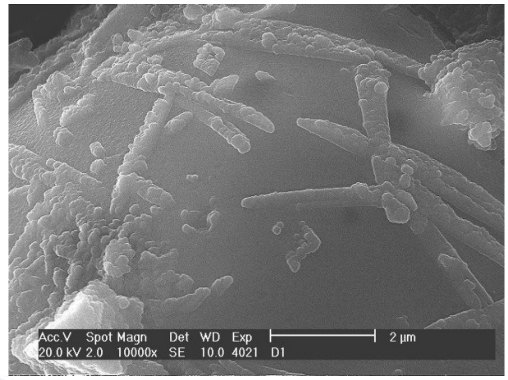

Figure 3 Beginning of the geo-polymers phase development on the surface of the fly ash particle

The band corresponding to Si-O and Al-O vibrations can be observed in the original fly ash at 1,080-1,090 cm^{-1} but this band is displaced towards lower values in the geo-polymers.

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III. EXPERIMENTAL DEDUCTIONS

A. Mixture Proportions:

The mixture proportion of concrete contains coarse aggregate, fine aggregate, fly ash, GGBS, Sodium silicate solution and NaOH solution. Three different mixtures with 8M, 10M and12M were prepared and compressive strengths of these sample cubes were measured.

The sodium hydroxide (NaOH) solids were dissolved in water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M.

For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. Similarly, the mass of NaOH solids per kg of the solution for 10M and 12M concentration was measured.

The sodium silicate solution and the sodium hydroxide Solution were mixed together at least one day prior to use to prepare the alkaline liquid. On the day of casting of the specimens, the alkaline liquid was mixed together and the extra water (if any) to prepare the liquid component of the mixture.

B.Mix Design:

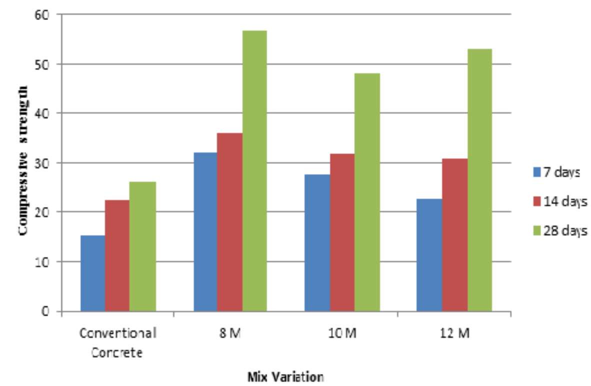
The concrete mix is designed as per IS10262-1982 and IS 456-2000 for the conventional concrete and finally 90% of fly ash and 10% of GGBS can be replaced for cement. The mix proportions of M20 concrete are 1:1.88:2.83.

C. Test specimens:

The concrete cubes of size 100mm x 100 mm, cylinders of size 150mm x 300 mm, prism of size 100mm x 500mm were used as test specimens to determine the compressive strength, split tensile strength, flexural strength and durability of concrete for both cases i.e. normal concrete and modified concrete. The ingredients of concrete were thoroughly mixed till uniform consistency was achieved.

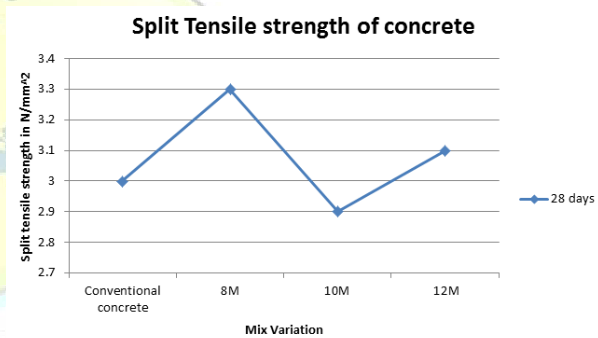
D. Results and Discussions:

Experiments were conducted on normal concrete and modified concrete by replacing cement with fly ash.



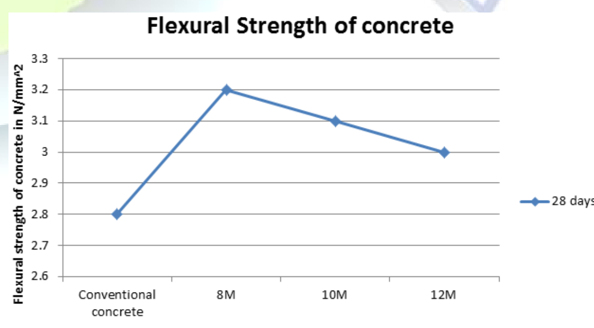
Graph 1: Compressive strength of concrete

From this graph, it is concluded that 8M has greater compressive strength when compared to conventional concrete.



Graph 2: Split tensile strength of concrete

From this graph, it is concluded that 8M has greater tensile strength at 28 days is achieved.



Graph 3:Flexural strength of concrete

From this graph, it is concluded that 8M has greater flexural strength of concrete.

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IV. EFFECT OF SALIENT PARAMETERS

A. Ratio of Alkaline Liquid-to-Fly Ash

The ratio of alkaline liquid-to-fly ash, by mass, was not varied. This ratio was taken as 0.4

B. Concentration of Sodium Hydroxide (NaOH) Solution

Mixtures were made to study the effect of concentration of sodium hydroxide solution on the compressive strength of concrete. The test cubes were left at ambient conditions for about 30 minutes prior to start of dry curing . The curing time was 24 hours at various temperatures. The measured 7th day compressive strengths of test cubes are given in table.

C. Effect of Molarity of Alkaline Solutions

Mixture	Concentration of NaOH solution (In molars)	Ratio of Sodium Silicate to NaOH solution	Compressive strength at 7^{th} day in Mpa
1	8 M	2.5	32
2	10 M	2.5	27.76
3	12 M	2.5	26.76

D. Addition of GGBS

In fresh state, the geo-polymer concrete has a stiff consistency. Although adequate compaction was achievable, an improvement in the workability was considered as desirable. For ambient curing, GGBS has been added to achieve strength.

E. Density

The density of concrete primarily depends on the unit mass of aggregates used in the mixture. Because the type of aggregates in all the mixtures does not vary, the density of low calcium fly ash based geo-polymer concrete varied only from marginally between 2330 to 2430 kg/m^3.

F. Water Content of Mixture

In OPC Concrete water in the mixture chemically reacts with the cement to produce a paste that binds the aggregates. In contrast, the water in a low-calcium fly ash-based geo-polymer concrete mixture does not cause a chemical reaction. In fact, the chemical reaction that occurs in geo-polymers produces water that is eventually expelled from the binder.

VI. DISCUSSION

The main objective of this study was to find the effect of varied concentrations of alkaline solutions on the strength characteristics of the concrete. We expect that the combined use of KOH and NaOH would help in achieving a more rigid structure and hence improve the strength characteristics.

Based on the general finding, the following conclusions were drawn:

Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly-ash based geo-polymer concrete and higher the ratio of sodium silicate-to-sodium hydroxide ratio by mass, higher is the compressive strength of fly ash based geo-polymer concrete,produces higher compressive strength of fly ash-based geo-polymer concrete.

- In the process of conducting the test fly ash were procured from two different vendors which also led to contrasting variation in the results.
  Thus, highlighting the importance of choice of fly ash.

- A general increase in the compressive strength with increase in the molarity was seen.

- Importance of curing temperature also was clearly seen in the tests conducted.

- Another important observation was that curing under normal sunlight yielded strength of 16 N/mm^2. This test was done in the month of February 2012 in Sardar Vallabhbhai National Institute of Technology, Surat(Gujarat) in India, where the ambient temperature was around 25 ^{0}C, hence, similar test when conducted in hotter months can yield still better results. Thus, making insitu use of fly ash concrete a future possibility.

- In the rate analysis , the available resources fly ash based concrete is not expensive than cement concrete and hence economical. However in the broader picture considering carbon credit, waste disposal and limited availability of non-renewable resources, geo-polymer concrete is sure to play major role in construction industry.

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