# Development of Fly Ash based Geopolymer Concrete

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Abstract: Cement and concrete are widely used in building and construction practices throughout the world. The use of Ordinary Portland Cement (OPC) requires use of additional energy and poses environmental damage. The objective of this project is to provide a green alternative construction material to OPC by geopolymerization of industrial wastes. This study made an effort to develop a low-cost working recipe that utilizes a combination of fly ash (FA) and red mud (RM) with different additives to create a geopolymer with comparable or better performance to OPC. The effectiveness of the methodology was tested by evaluating the synthesis factors and testing the unconfined compressive strength.

#### 1. Introduction

Concrete is the second most widely used construction material next to water globally, owing to its better controllable structural properties, which significantly increased its demand in construction industry. Cement industry is manufacturing cement on a gigantic scale to fulfill this demand since it is the main constituent of concrete. The global production of cement is estimated at over 2.8 billion tones according to recent industry data, the concept of geopolymer concrete was forwarded by a French scientist Joseph Davidovits who proposed alkaline liquid as an activator to be used to react with some source material rich in silicon and aluminum, such as industry and agro waste products like fly ash or rice husk ash to produce geopolymer mortar which act as binder.

India produced 163.56 MT of fly ash in 2013-2014 which is an environment threat to the public, so need of the hour is to dispose of it properly, which encourages the use of fly ash as an alternative to OPC based concrete. The production of Portland cement, a main component of making concrete, contributes significant amount of greenhouse gas, because the production of one ton of Portland cement also releases about one ton of carbon dioxide gas into the atmosphere. Therefore, the introduction of a novel binder called 'geopolymer' by Davidovits, promises a good prospect for application in the concrete industry as an alternative binder to Portland cement. In terms of reducing global warming, the geopolymer technology could reduce the CO2 emission to the atmosphere caused by cement and aggregates industries by 80%, an attempt has been made to develop an alternative concrete binder by applying the geopolymer technology and utilizing fly ash as the source material to produce the Fly Ash-Based Geopolymer Concrete.

Approximately half of the electricity consumed in the world is generated by burning coal. The majority of the waste left behind during the coal burning process is called fly ash, consisting of fine spherical particles composed mainly by silica and alumina. Fly ash disposal costs are expected to increase due to government regulations aimed at regulating fly ash disposal. Storage lagoons, commonly used as longterm storage facilities, also are potential environmental hazards. Inorganic polymer concrete (geopolymer) is an emerging cementitious material, synthesized from materials

of byproducts such as fly ash (FA). Geopolymer concrete, unlike the normal cement concrete does not contain Ordinary Portland Cement (OPC). This inorganic aluminasilicate polymer is created via a chemical reaction under highly alkaline conditions between fly ash and an activator solution of sodium hydroxide and sodium silicate. The development of engineered geopolymer concrete could contribute to a widespread recycling of fly ash into geopolymer concrete, greatly reducing the amount of fly ash placed in long-term storage facilities, while at the same time producing valuable carbon off-set credits to the coal-fired power generation industry. This investigation is aimed at gaining a better understanding of manufacture of geopolymer concrete and study of the structural behavior of geopolymer concrete elements. This extensive investigation has led the investigators of this research project to fabricate India's first biggest steam curing chamber among the technical institutions of our country. Also they have studied the durability of geopolymer concrete using corrosion analyser equipment. The outcome of the project focuses the geopolymer concrete (GPC) as acid and sulfate resistant, corrosion resistant and confirms that it possesses the high compressive and tensile strengths, rapid strength gain rate.

## 2. Background

Concrete made with Portland cement is the most widely used material on earth. The concrete industry is the largest user of natural resources in the world. Globally, over 14 billion tons of concrete is placed per year and accounts for the annual 2.8 billion tons of Portland cement produced. Significant increases in cement production have been observed and are anticipated to increase due to the massive Increase in infrastructure and industrialization in India, China and in neighboring countries. It is generally agreed that the production of Portland cement clinker is expensive and ecologically harmful. The emissions generated by Portland cement productions are principal contributors to the greenhouse gas (GHG) effect. For instance, the production of Portland cement for concrete accounts for an estimated 5 percent of global anthropogenic carbon dioxide. Recent estimates of the emissions from cement production reveals that 377 million metric tons of carbon was generated in 2013, this indicates that emissions have more than doubled since the mid-1970s from fossil-fuel burning and cement production. While necessary measures may be undertaken to

reduce the generation of carbon dioxide from cement kilns, carbon dioxide emission is still in the order of 600 kg of carbon dioxide per ton of cement of which 400 kg per ton is the result of the calcination of limestone. The United Nations Intergovernmental Panel on Climate Change (IPCC) has identified the unmindful pumping of CO2 into the atmosphere is the main culprit for the climate change and highlighted that the 'largest mitigation potentials are in the steel, cement and pulp and paper industries. Carbon emission data is alarming; the 2016 carbon emission estimate was an all-time high and the highest average growth rates in industrial-sector CO2 emissions are projected for developing countries. As one such rising economy, India has an international obligation of reducing CO2 emissions.

In view of the serious impact of carbon dioxide on the environment and the continued anticipated growth of industrialization and urbanization, there is a need to redirect the building industry away from its overwhelming reliance on Portland cement by developing alternative binder systems.

The second alternative, geopolymer binders, is an emerging area of technology. Davidovits first proposed that an alkaline liquid could be used to react with the silicon (Si) and aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce cementitious binders. Because the chemical reactions that takes place in this case is a polymerization process and the source materials are of geological origin, he coined the term "geopolymer" to represent these binders. Geopolymers are members of the family of inorganic polymers. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

Research is currently moving from the chemistry domain that includes binder (mortar) composition and properties to engineering, in which mechanical and structural behavior of geopolymer concretes are studied researched. It has been found that geopolymer concrete has good engineering properties including compressive strength, enhanced tensile strength, bond strength, sulphate and acid resistance and the potential for enhanced durability.

## **3.** Geopolymer Technology

Geopolymer materials represent an innovative technology that is generating considerable interest in the construction industry, particularly in light of the ongoing emphasis on sustainability, although geopolymer technology is considered new,the technology has ancient roots and has been postulated as the building material used in the construction of the Pyramids at Giza as well as in other ancient construction (Davidovits 1984; Barsoum and Ganguly 2006; Davidovits 2008).

#### 3.1 Geopolymers

Geopolymers are the synthetic analogues of natural zeolite materials, which substantially differ from OPC, because Geopolymers use a totally different reaction pathway in order to attain structural integrity.Geopolymers consist of a polymeric silicon-oxygen-aluminum framework with alternating silicon and aluminum tetrahedral joined together in three directions by sharing all the oxygen atoms. The fact that four coordinated aluminum with respect to oxygen creates a negative charge imbalance, and therefore, the presence of cations is essential to maintain electric neutrality in the matrix. Positive ions such as K+ or Na+ that are present in framework cavities, balance the negative charge. For the chemical designation of Geopolymers based on silico-aluminates, the term poly (sialate) that is an abbreviation for silicon-Oxo-aluminate has been proposed. Poly (sialates) are chain and ring polymers with Si4+ and Al3 in 4-fold coordination with oxygen and their general formula is Mn[(SiO2)z- AlO2]n•wH2O, where z is 1, 2 or 3, M is a monovalent cation such as K+ or Na+, n is the degree of polycondensation and z is 1, 2 or>>3. Chains and rings are formed and cross-linked together always through a sialate Si-O-Al bridge.

#### **3.2 Geopolymer Concrete**

The development of Geopolymer concrete is attributed to Prof. Davidovits who, in 1978, first proposed that a Geopolymer matrix could replace cement as a binder in concrete. Davidovits' theory was that an alkaline solution could be added to an aluminium-silicon rich source material to produce cement-like binder and termed this as 'Geopolymer' binder. Fly ash, a by-product from coal industry, is the most widely used source material for Geopolymer concrete because of its availability, suitable composition and low calcium content with low loss of ignition. However, other materials that are rich in silicon and aluminum can be used including rice husk ash, blast furnace slag, metkaolin and natural Al-Si minerals. Geopolymer concrete is a concrete which does not utilize any Portland cement in its production. The primary difference between Geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminium oxides in the low-calcium fly ash reacts with the alkaline liquid to form the Geopolymer paste that binds the loose coarse aggregates and fine aggregates together to form the Geopolymer concrete. As in the case of Portland cement concrete, the coarse and fine aggregates occupy about 75% to 80% of the mass of Geopolymer concrete. The influence of aggregates such as grading, angularity and strength are considered to be the same as in the case of Portland cement concrete (Lloyd and Rangan, 2009). Therefore, this component of Geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete.

## 3.3 Constituents of Geopolymer Concrete

The main constituent of Geopolymer concrete is low calcium ASTM class F fly ash, alkaline liquid, coarse and fine aggregates. Unlike ordinary cement concrete in which cement is mixed in the range of 350 kg/m3 to 450 kg/m3 depending upon the grade of concrete, an equivalent quantity of fly ash is taken and mixed to obtain Geopolymer concrete. In this research, Class F fly ash obtained from Thermal Power Station is used to manufacture Geopolymer concrete.

#### 3.4 Source of Geopolymerization

The source materials may be natural minerals such as kaolinite, Calcined kaolinite (metakaolin) and clays (Davidovits 1991; Barbosa 2000; Xu and van Deventer 2002). Alternatively, industry waste products such as fly ash, slag, red mud, rice-husk ash and silica fume may be used as feedstock for the synthesis of Geopolymers. It has been proved that calcined materials such as slag, fly ash and metakaolin which are mostly amorphous undergo high reaction during Geopolymerisation than non-calcined materials. For fly ash-based Geopolymers, mechanical strength increases due to the formation of an Al-rich alumino-silicate gel during the first stage of alkaline activation of fly ash particles and may further increase as a result of the Si enrichment of the material. It has also been found that Geopolymers derived from metakaolin may require too much of water due to increase in porosity and therefore become too soft for construction application although metakaolin remains important in the production of Geopolymers for applications such as adhesives, coatings and hydroceramics. Also, the microstructure and properties of Geopolymers depend strongly on the nature of the initial source materials. As a result, it is important to understand the reactivity and chemistry of raw materials in order to optimize both cost and technical performance for certain applications. The cement industry seems to have realized the potential of fly ash as a resource and it could be seen from the increased share of fly ash in the blended cement production in recent years. The recent statistics of Cement Manufacturers' Association indicate that the share of Portland pozzolana cement (PPC) has dramatically jumped from 26.17% to 44.36% between 2010 and 2012, an increase of almost 70 percent within a span of just four years. The responsibility of large- scale utilization of fly ash in concrete construction in India falls on the shoulders of the cement industry. In India, major initiatives are needed to use this resource in large volumes in construction sector especially housing and infrastructure projects and to pursue technologies mentioned in this report to make it a value added product for export and use in India. It is also estimated that only 14 million tons of the total 100 million tone of fly ash get utilized. The reactivity of fly ashes is dependent on their glass content and other mineral phases present in it. Indian fly ashes are more crystalline than those obtained in other countries with the glass content ranging from 47.0% to 60.9%.

#### 3.5 Alkaline Liquid

Locally available silicates and hydroxides of sodium are used to prepare alkaline liquid. Though silicates and hydroxides of potassium could be used to prepare alkaline liquid, sodium based silicates and hydroxides are used in this research considering the high cost of potassium based chemicals. Sodium silicate is the common name for a compound sodium metasilicate, Na2SiO3, also known as water glass or liquid glass. It is available in aqueous solution and in solid form and is used in cements, passive fire protection, refractories, textile and lumber processing, and automobiles. Sodium carbonate and sili con dioxide react when molten to form sodium silicate and carbon dioxide and the chemical equation read as Na2CO3 + SiO2  $\rightarrow$ Na2SiO3

+ CO2. Sodium hydroxide (NaOH), also known as caustic soda, is a caustic metallic base. It is used in many industries, mostly as a strong chemical base, in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents and as a drain cleaner. Worldwide production of NaOH was approximately 60 milli on tons in 2004, while the demand was 51 million tons. Pure sodium hydroxide is a white solid available in the form of pellets, flakes and granules. It is hygroscopic and readily absorbs carbon dioxide from the air and therefore it should be stored in an airtight container. It is very soluble in water and is highly exothermic when it is dissolved in water. Sodium hydroxide solution will leave a yellow stain on fabric and paper. Care should be taken while handling the sodium hydroxide pellets or flakes. Gloves and masks should be worn while weighing the sodium hydroxide and while dissolving it in water. Sodium silicate and sodium hydroxide are mixed in suitable proportions to obtain the alkaline liquid. In this research, the molarities of sodium hydroxide used were 8M, 12M and 14M.

#### 3.6 Curing of Geopolymer Concrete

The most important operation in the manufacture of Geopolymer concrete is curing. Unlike OPC concrete which needs water for curing, Geopolymer concrete requires heat or temperature to activate the chemical reaction that takes place in Geopolymer matrix. Steam curing, dry curing and curing at ambient temperature are the types of curing that could be employed to cure the Geopolymer concrete. The steam curing and dry curing are collectively called Heatcuring. In India, the possibility of curing at ambient temperature is high. But, in India only in summer temperature is between 26°C and 40°C. The main drawbacks in adopting ambient temperature curing are found to be the longer time it consumes to cure the concrete to get required compressive strength and the non-availability of required temperature in winter. On the other hand, the advantage of heat-curing is attainment of required compressive strength within several hours and even during all seasons. The requirement of boiler and fire wood to generate steam or electrical energy to produce heat makes it a little expensive.

Throughout this research, dry-curing is adopted to cure the Geopolymer concrete elements between 60°C and 90°C in a heat curing chamber exclusively designed for this experimental work. The heat curing enhances the compressive strength of Geopolymer concrete by 15% than steam curing and also attains its full strength in 24 hours.

#### 3.7 Research Significance

This topic is one among the fields of high profil e research and commercial interests over the past decade. Geopolymer Technology paved way for conversion of waste by product materials into valuable material. Some reports outside India stated that Geopolymer concrete has good strength and durability aspects. However, till date, no published results could be found using Indian Fly ash based Geopolymer concrete. The results of this extensive work will provide data and information about mixture optimization and application into structural elements for the needy successors. This research may significantly be accepted and applied in real construction practices as an alternative to OPC concrete.

#### 3.8 Research Objective

The aim of this research is to study the factors ruling the compressive strength of fly ash based Geopolymer concrete and behaviour of both short and slender columns. The main aims of this research program are:

- To experimentally examine the development and application of "Geopolymer Technology" with Indian fly ash and materials.
- To examine the crack pattern, deflection and load carrying capacity of both short and slender reinforced concrete columns manufactured using dry heat curing process.
- To investigate the thermal behaviour and bond strength of fly ash based Geopolymer concrete.
- To evaluate the cost effectiveness of low calcium fly ash based Geopolymer concrete over OPC concrete.

#### 3.9 Scope of Work

The scope of the research work is stated below: To produce Geopolymer concrete mixtures with target compressive strength for the manufacture of all the columns.

- To identify and study the effect of salient parameters that affects the properties of low-calcium fly ash based Geopolymer concrete.
- To ascertain various strength aspects of Geopolymer concrete such as tensile strength, flexural strength, bond strength and thermal stability.
- To manufacture and test reinforced fly ash-based Geopolymer concrete short columns and slender columns under monotonically increasing load with concrete compressive strength as test variable.
- To perform calculation on load carrying capacity of both short columns and slender columns using current code provisions available for portland cement concrete members.

## 4. Literature Review

#### 4.1 Introduction

This chapter presents a brief review of the terminology and the chemistry of geopolymers and the past studies on geopolymer concrete.

#### 4.2 Environmental Issues

The production of Portland cement requires a large input of energy and at the same time produces a large quantity of CO2 as a result of the calcination reaction during the manufacturing process. According to Lawrence (2003) the calcination of CaCO2 to produce 1 ton of Portland cement releases 0.53 tons of CO2 into the atmosphere and, if the energy used in the production of Portland cement is carbon fuel, then an additional 0.45 tons of CO2 is produced. Therefore, the production of 1 ton of Portland cement releases approximately 1 ton of CO2 into atmosphere. There are 80% to 90% less greenhouse gas emissions released in the production of fly ash. Therefore a 100% replacement of OPC with GGBS or fly ash would have a significant impact on the environment. The climate change is attributed not only to the global warming, but also to the global dimming due to the pollution present in the atmosphere. Global dimming is related to the reduction of the amount of sunlight reaching the earth due to pollution particles in the air blocking the sunlight. With the effort to reduce the air pollution that has been taken into implementation, the effect of global dimming may be reduced; however, it will increase the effect of global warming. From this view, the global warming phenomenon should be considered more seriously and action to reduce the effect should be given more attention and effort.

#### 4.3 Fly Ash

Fly ash is a by-product of the combustion of finely ground coal used as fuel in the generation of electric power. A dust collection system removes the fly ash as a fine particulate residue from combustion gases before they are discharged into the atmosphere. The ash content of coal used by thermal power plants in India varies between 25% and 45%. Coal with an ash content of around 40% is mostly used in India for thermal power generation. As a consequence, a large amount of fly ash is generated in thermal power plants causing several disposal-related problems. In spite of initiatives taken by the government, several nongovernmental organizations and research and development organizations, the total utilization of fly ash is only about 50%. India produces 130 million tons of fly ash annually This is expected to reach 185 million tons by 2017. Disposal of fly ash is a growing problem as only 15% of fly ash is currently used for applications like concrete, the remaining being used for land filling. Globally less than 25% of the total annual fly ash produced in the world is utilized. Fly ash has been successfully used as a mineral admixture component of Portland pozzolana blended cement for nearly 60 years.

Various technologies have been developed for the gainful utilization and safe management of fly ash due to the concerted efforts of Fly Ash Mission of the Government of India since 2007. As a result, the utilization of fly ash has increased to 78 million tons in 2013-14. Fly ash was moved from "hazardous industrial waste" to "waste material" category during the year 2004 and during November 2009, it became a saleable commodity.

Fly ash utilization has started gaining acceptance. The present generation of fly ash from coal based thermal power plants in India is 131 MT/year and it is expected to increase to 300-400 MT/year by 2016-17 (Second international summit on fly ash utilization, 2013). Fly ash used in this study was low-calcium (ASTM Class F) dry fly ash from thermal power station. The anthracite and bituminous coals produce low calcium fly ash which possesses truly pozzolanic properties due to the high content of silica, while the lignite or sub-bituminous coals produce high calcium fly ash which is both a cementitious and pozzolanic material (it has lower silica and alumina but higher CaO content. As per ASTM 618-08 there are two types of fly ash; class F which is low in calcium oxide (CaO) with a content of less than 10% and is derived from bituminous coals. Class C is high in CaO with greater than 10% content and is produced from sub-bituminous and lignite coals.

ASTM C989 specifies typical class F fly-ash having 4.3% CaO and typical class C fly-ash having 27.4% CaO. Fly ash in concrete makes efficient use of the products of hydration of cement such as calcium hydroxide, which are otherwise a source of weakness in normal cement concretes and convert them into denser, stronger C-S-H compounds by pozzolanic reaction. The heat generated during hydration initiates the pozzolanic reaction of fly ash (ACI 1995). When concrete containing fly ash is properly cured, fly ash reaction products fill in the spaces between hydrating cement particles, thus lowering the concrete permeability to water and aggressive chemicals. Properly proportioned fly ash concrete mixes impart properties to concrete that may not be achievable through the use of Portland cement alone. These mixes are more durable, economical, strong and also ecofriendly as it utilizes an ecologically hazardous material. The colour of fly ash can be dark grey, depending upon the chemical and mineral constituents. Fly ash particles are typically spherical, finer than Portland cement and lime. The detail of fly ash production as worldwide is given in Table2.1.

| <b>Table 2.1:</b> | Worldwide | Production | of Fly ash |
|-------------------|-----------|------------|------------|
|-------------------|-----------|------------|------------|

| Name of Country | Production     | Utilization    |
|-----------------|----------------|----------------|
|                 | (Million Tons) | (Million Tons) |
| Australia       | 59             | <25            |
| China           | >150           | 52             |
| Germany         | 78             | 40             |
| India           | >132           | 48             |
| Japan           | 55             | 29             |
| Russia          | 102            | 32             |
| South Africa    | 78             | 57.9           |
| Spain           | 58             | 26             |
| UK              | 60             | 34             |

#### 4.4 Uses of Fly Ash in Concrete

Fly ash in the mix replaces Portland cement, producing big savings in concrete material cost. As a cement replacement, 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 (CS-H) gel. The unique spherical shape and particle size distribution of fly ash make it good mineral filler in Hot Mix Asphalt (HMA) applications and improve the fluidity of flowable fill and grout. The consistency and abundance of fly ash in many areas present unique opportunities for use in structural fills and other highway applications. For example, the construction of roads in India is implemented with 50% OPC replacement by the fly ash. The use of High Volume Fly Ash (HVFA) in the place of ordinary Portland cement in concrete shows excellent mechanical property and durability performance.

Phair and Van Deventer have carried out an experimental study on 'Fly Ash-Based Geopolymeric Binders Activated with Sodium Aluminate' and discovered that an aluminate activated geopolymer is mechanically superior to typical hydroxide and silicate activated geopolymers. The major conclusion of this is that an aluminate activator also reduced energy costs. Hou (2007) have suggested that the use of sodium hydroxide alone to activate the geopolymer results in a weak bond between the paste and aggregate. Results indicate that sodium hydroxide in combination with sodium silicate (liquid glass) is essential to ensure a stable bond between the paste and aggregate. Wong (1999) have investigated the effect of fly ash on strength and fracture properties of the interfaces between the cement mortar and aggregates.

During 1970s, the Structural Engineering Research Centre, Chennai has utilised fly ash in concrete as partial replacement for cement. Based on the research and development work at the centre, a two storied building measuring 300 square meters was constructed as early as in 1975 in Structural Engineering Research Center, Chennai. Fly ash was used as a partial replacement of cement in precast reinforced and pre stressed concrete structural elements and in cement mortar for plastering and masonry in the construction of the building. This experimental building was constructed to demonstrate the use of fly ash in concrete construction with a view to effect savings in the use of cement and to study the long term performance of the building.

#### 4.5 Geopolymer

Geopolymers are inorganic polymeric binding materials developed Joseph Davido vits bv in 1970s. Geopolymerisation involves a chemical reaction between solid aluminosilicate oxides and alkali metal silicate solutions under highly alkaline conditions yielding amorphous to semi-crystalline three- dimensional polymeric structures, which consist of Si-O-Al bonds (Palomo et al, 1999). 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 shown in equation (2.1) which consists of Si-O-Al-O bonds.

$$M_n$$
 [-(SiO<sub>2</sub>) z–AlO<sub>2</sub>]<sub>n</sub>.wH<sub>2</sub>O .... (2.1)

Where "z" is 1, 2 or 3 or higher up to 32; M is a monovalent cation such as potassium or sodium, and "n" is a degree of polycondensation (Davidovits has also distinguished 3 types of polysialates, namely the Poly (sialate) type (-Si-O-Al-O), the Poly (sialate-siloxo) type (-Si-O-Al-O-Si-O) and the Poly (sialate- disiloxo) type (-Si-O-Al-O-Si-O).

The schematic formation of geopolymer material is given in Equations (2.2).

These formations indicate that all materials containing mostly Silicon (Si) and Aluminum (Al) can be used to make the geopolymer material.

 $(Si_2O_5, Al_2O_2)n + nSiO_2 + nH_2O \xrightarrow{NaOH, KOH} n(OH)_3 - Si-O-Al-O-Si-(OH)_3$ (OH)<sub>2</sub>

$$n(OH)_{3} -Si-O-Al-O-Si-(OH)_{3} \xrightarrow{NaOH, KOH} (Na,K)^{(+)} -(-Si-O-Al-O-Si-O-) + nH_{2}O$$

$$(OH)_{2} \qquad O \qquad O$$

$$(OH)_{2} \qquad (2-2)$$

Hue studied that the aluminum available for geopolymer reaction during synthesis appears to have a dominant effect in controlling setting time. Similarly increasing the SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio leads to longer setting times.

#### 4.6 Source Material and Alkaline Liquid

The main constituents of geopolymer concrete are source material and alkaline liquid. The material that contains Silicon (Si) and Aluminum (Al) in amorphous form is a possible source material for the manufacture of geopolymer. By-product materials such as fly ash, silica fume, slag, ricehusk ash, red mud, etc. could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost and type of application.

Low calcium (ASTM Class F) fly ash is preferred as a source material than high calcium (ASTM Class C) fly ash. The presence of calcium in big quantities may interfere with the polymerisation process and alter the microstructure (Gurley, Van Jaarsveld (1999) have identified the potential use of waste materials such as fly ash, contaminated soil, mine tailings and building waste to immobilize toxic metals.

Calcined source materials such as fly ash, slag, calcined kaolin show a higher final compressive strength when compared to non-calcined materials such as instance kaolin clay, mine tailings, and naturally occurring mineral Fly ash is considered to be advantageous due to its high reactivity that comes from its finer particle size than slag. The suitability of various types of fly ash to be geopolymer source material has been studied by Fernandez-Jimenez and Palomo.

The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. Palomo et al (1999) have reported the study of fly ash-based geopolymers. A combination of sodium hydroxide with sodium silicate was used in the study and the results showed that alkaline liquid is a main factor affecting the mechanical strength and the combination of sodium hydroxide with sodium silicate produced high compressive strength. Experimental study that involves the observation of structural behavior of fresh fly ash-based geo-polymer concrete. The main objective of this study was to find the effect of varied concentrations of alkaline solutions on the strength characteristics of the concrete. The test conducted, yielded certain important findings such as increase in the compressive strength with increase in the molarity. Curing under normal sunlight yielded strength of 16N/mm<sup>2</sup> and curing when done by wrapping with plastic bag showed better compressive strength as it preserves the moisture. In the rate analysis carried, waste disposal and limited availability of non-renewable resources, geopolymer concrete is sure to play major role in construction industry.

#### 4.7 Durability of Geopolymer Concrete

Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. Durability is not always an absolute property since different forms of concrete require different degrees of durability depending upon its use. The durability of concrete has been evaluated in this study through parameters related to the permeability and chemical attack. Djwantoro Hardijito(2004) have described the effects of several factors on the properties of fly ash based geopolymer concrete especially the compressive strength. The test variables included were: the age of concrete, curing time, curing temperature, quantity of super plasticizer, the rest period prior to curing and the water content of the mix. It has been found that, after being exposed to sulphuric acid solution, fly ash based geopolymer concrete was structurally inert except development of some fine cracks on the surface whereas OPC concrete shows sign of severe damage.

Olivia (2008) have investigated on the water permeability of low calcium fly ash geopolymer concrete. The conclusion drawn is that fly ash geopolymer concrete exhibits low water absorption. Low water/binder ratio and a better grading are recommended in order to reduce the capillary porosity and the overall porosity of geopolymer concrete. It has been reported that compressive strength increases with increase in concentration of NaOH from 8M to 16M. Increase in compressive strength was observed with increase in curing time and also tensile strength increased with increase in concentration of NaOH except for 72 hours curing time.

Ranganath (2010) have conducted an experimental investigation on effect of fly ash, water content, ratio of sodium silicate to sodium hydroxide solution by the mass and the duration of elevated temperature curing on the properties of fly ash based geopolymer concrete (GPC). It was found that as the water content increases the optimum fly ash content also increases to obtain maximum strength.

In addition the given fly ash content increase in the alkaline solution content does not contribute additional strength. It has been found that long curing at elevated temperature increases the strength of geopolymer concrete; however elevated temperature curing beyond 20 hours does not contribute significant strength.

Andy Adam (2009) has carried out an experimental investigation on the strength and durability properties of Alkali Activated Slag (AAS) and fly ash based geopolymer concrete in terms of chemical attack. Concrete has been tested for workability, compressive strength, depth of carbonation, rapid chloride permeability and chloride ponding. Microstructure studies were conducted using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDAX). The study concludes that AAS and fly ash based geopolymer concretes can exhibit comparable strength to OPC and slag- blended OPC concretes.

Experimental investigation on the properties of geopolymer concrete. Test experiments have proved that fly ash based Geopolymer concrete has excellent compressive strength, suffers very low drying shrinkage, low creep, excellent resistant to sulphate attack and good acid resistance. The workability of the concrete in terms of slump and compacting factor are observed to be excellent. The geopolymer concrete in fresh state has been observed to be highly viscous and good in workability.

The project aims at making and studying the different properties of geopolymer concrete using this fly ash and the other ingredients locally available in Gujarat. Potassium Hydroxide and sodium Hydroxide solution were used as alkali activators in different mix proportions. The effects of various salient parameters on the compressive strength of low-calcium fly ash-based geopolymer concrete are discussed by considering the ratio of alkaline solution to fly ash (by mass) 0.35 constant. The specimens were cured at two different temperature  $25^{\circ}$ C and  $60^{\circ}$ C for 24 hours in the oven.

The main parameters studied were the compressive strength, curing temperature, effectof wet-mixing time, influence of handling time on compressive strength, effect of super plasticizer on compressive strength, effect of super plasticizer on slump of concrete, effect of water-togeopolymer solids ratio by mass on compressive strength, stress-strain relation of geopolymer concrete in compression. Experimental results indicate that the compressive strength of GPC increased over controlled concrete by 1.5 times and split tensile strength of GPC increased over controlled concrete by 1.45 times. The flexural strength of GPC increased over controlled concrete by 1.5 times. In pull out test GPC increases over controlled concrete by 1.5 times.

Reddy (2011) have conducted an experimental study to evaluate the durability characteristics of low calcium fly ashbased geopolymer concretes subjected to the marine environment, compared to ordinary Portland cement concrete with similar exposure by means of accelerated corrosion testing of the reinforcing steel. In order to achieve this goal 8 molar geopolymer, 14 molar geopolymer and Ordinary Portland Cement Concrete (OPC) mix were prepared and tested for exposure in seawater. The test results indicate that the GPC shows excellent resistance to chloride attack with a longer time to corrosion cracking compared to ordinary Portland cement concrete. Results conclude that the electrical resistivity and permeability of the low calcium fly ash-based GPC were not significantly affected by the severe marine environment in view of reduced cracking.

#### 4.8 Acid Resistance

Douglas (1992) has reported the changes in dynamic modulus of elasticity, pulse velocity, weight and length of sodium silicate-activated slagcement concrete after 120 days of immersion in 5% sodium sulphate solutions. The changes were smaller than those in the controlled specimens immersed in lime-saturated water.

Bakharev (2003) has investigated the durability of Alkali Activated Slag (AAS) concrete exposed to sulphate attack. AAS concrete was immersed in a solution containing 5% sodium, 5% magnesium and 5% sodium and magnesium sulphate solution. The main parameters studied were the compressive strength, products of degradation and micro structural changes. It was found that in AAS concrete the material prepared using sodium hydroxide had the best performance due to its stable cross-linked alumino silicate polymer structure.

Experimental results indicate that use of geopolymer cement as partial replacement for Ordinary Portland Cement (OPC) effectively improves both the compressive strength and resistance to sulphuric acid. Replacement of 50% OPC by geopolymer cement increased the 28-day compressive strength by 50% and reduced the mass loss of concrete specimens subjected to eight weeks of immersion in sulphuric acid solutions with pH of 0.3 and 0.6 by 42% and 30%, respectively. A direct relationship between the ability of geopolymer modified concrete specimens to resist sulphuric acid and their normal 28-day compressive strength was found, but varied with the binderused.

Brock William Tomkins (2011) has evaluated the chemical resistance of Fly Ash based Geopolymer Concrete (FAGC) and Red Mud based Geopolymer Concrete (RMGC). The chemical resistance tests involve sodium hydroxide and sulphuric acid at  $20^{\circ}$ C and  $90^{\circ}$ C. Results indicated OPC experienced some strength deterioration in both acid environment(-24.9 to -25.6%) and alkaline environment (-2.2 to -13.3%). FAGC was found to have better acid resistance (+3.8 to -17.6%). RMGC exhibited a strength increase of 52.4% in sulphuric acid while also displaying strength enhancement of +50.5% in sodium hydroxide. This performance suggests that FAGC and RMGC are both suitablere placements.

#### 4.9 Water Permeability

Olivia have carried out an experimental study on water penetrability properties, namely, water absorption, volume of permeable voids, permeability and sorptivity of low calcium fly ash geopolymer concrete. Seven mixes were cast in 100 x 200 mm cylinders and cured for 24 hours at  $60^{\circ}$ C in the steam curing chamber. It is found that mix with aggregate grading(7, 10, 20 mm) shows low water permeability and void content. Results indicate that the low water/binder ratio and a well-graded aggregate have large influences on geopolymer concrete permeability.

Monita Olivia and Hamid Nikraz (2011) have conducted a study on the strength development, water absorption and water permeability of low calcium fly ash geopolymer concrete. Geopolymer mixtures with variations of water/binder ratio, aggregate/binder ratio, aggregate grading and alkaline/fly ash ratio were investigated. The result shows that the average water absorption of fly ash geopolymer was less than 5%, which can be classified as "low". The overall percentage of Apparent Volume of Permeable Voids (AVPV) was less than 12% and was classified as "good".To improve the quality of geopolymer mortar durability tests such as water absorption test and acid resistance test (HCl and H2SO4) were also conducted. The main focus of the investigation is on the optimum utility of the available fly ash and minimizing the water absorption and attaining high compressive strength. The results suggest that increase in curing temperature results in an increase in the compressive strength of the geopolymer mortar. Steam curing increases the compressive strength and the strength of stream cured bricks is more when compared to air curing. The percentage weight loss of geopolymer bricks when immersed in different concentration of H2SO4 and HCl is found to be very much lower when compared to other types of bricks. Further, the percentage weight loss increases with the increase in acid concentration. The increase in percentage of weight due to water absorption of geopolymer bricks is very small fraction when compared to that of other types of bricks.

#### 4.10 Geopolymer Concrete Brick Prism

Abrams (1992) has investigated on the strength and durability of unreinforced masonry elements. Experimental results showed that unreinforced masonry can possess considerable capacity for inelastic deformation and need not be limited in strength by force which induced initial lateral flexure or diagonal tensile crack. It has been reported that the structural behavior and strength of reinforced geopolymer concrete beams and columns were similar to those made of Portland cement concrete. The in-situ deformation characteristics of mortar and brick joint have been determined. The result shows that the strength and deformation characteristic of masonry constituents are more representative of the actual composite behavior of masonry. The property of brick and mortar joint was also found to be more appropriate.

Mauren brecher (1980) has described the effects of various factors on prism strength. The Canadian masonry design standard for buildings allow two methods of determining compressive strength of masonry, (i) tabular values based on unit strength and mortar type (ii) axially loaded prisms such as two-course block-workstacks.the properties of brick masonry using table moulded bricks and wire-cut bricks from India with various types of mortars. The table moulded brick masonry using lean mortar failed due to loss of bond between brick and mortar. The wire-cut brick masonry exhibited a better correlation between mortar strength and masonry strength.

Freeda Christy (2013) has conducted a study on the compressive strength of brick masonry subjected to axial loading. The study focuses on the effect of the masonry components with different types of bonding on compressive strength. Short prisms have been tested under axial compressive load using clay brick and fly ash brick. The results shows that elastic modulus of the brick masonry can be determined with the prism strength and the equivalent homogenized elastic property of the masonry was derived with the elastic properties of brick, mortar and the reinforcement.

#### 4.11 Inference from Literature Study

Review of literature indicates a big importance for geopolymer in the near future, in the construction sector. The use of fly ash in geo-polymer concrete is particularly important, as the disposal of this waste is a worldwide problem. Low calcium (ASTM Class F) fly ash was used with ratio of sodium silicate solution-to-sodium hydroxide solution by mass of 2.5. Molarity of sodium hydroxide (NaOH) solution was chosen in the range of 8M to14M. Ratio of activator solution-to-fly ash by mass was fixed to be 0.40. Curing at elevated temperatures was done in two different ways, i.e. curing at room temperature and in the laboratory oven at 60°C.

#### 4.12 Scope of the Research

Accumulation of unmanaged waste especially in the developing countries has resulted in increased environmental concern. Recycling of such wastes as building material appears to be a viable solution not only for problems like pollution but also to the problem of economical design of buildings. This research has utilized low-calcium (ASTM Class F) fly ash as the base material for making geopolymer concrete which was obtained from thermal power plants, across India. The property studied includes the physical, mechanical and the chemical properties of geopolymer concrete block. Consequently, the scope of this research is to conduct a study on the properties of geopolymer hollow block. The potential for improving the performance of new concrete mixture has to be ascertained through experimental investigation.

## 5. Methodology

#### 5.1 Introduction

The performance of geopolymer concrete mixture was experimentally studied and the experimental testing procedures used for the evaluation of different concrete properties are presented in this chapter. The tests have been performed as per Indian Standards. The various test specimens used for the present studies are also discussed in the following sections.

The testing of concrete plays an important role in controlling and confirming the quality of cement concrete works (Shetty, 2007). Systematic testing of raw materials and fresh concrete are inseparable parts of any control programme for

concrete. The main task is that when different materials are used in the concrete, careful steps are to be taken at every stage of work for different tests. The tests also have a deterring effect on those responsible for construction work. Tests are made by casting cubes or cylinder from the respective concrete. It is to be noted that the standard compression test specimens give a measure of the potential strength of the concrete, not of the strength of the concrete in structure. In this study total experimentation consists of the following tests:

- 1) Compressive strength test
- 2) Split tensile strength test
- 3) Flexural strength test
- 4) Water permeability test

- 5) Resistance of GPC blocks in 3% sulphuric acid.
  - a) Change in weight
  - b) Residual compressive strength
  - c) Residual tensile strength
  - d) pH value of solution 6. Behavior of unreinforced geopolymer brick masonry prism.

A detailed study was carried out on concrete as per the specifications prescribed IS (Indian Standards): 516-1959 to ascertain the above properties and the test procedure adopted are described here. Flow chart of experimental processes is shown in Figure 3.1.



Figure 3.1: Flow Chart for Experimental Processes

#### 5.1.1 Compressive Strength Test

Compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is implied primarily to resist compressive stress. In this experimental investigation, both geopolymer concrete cubes and hollow blocks were used for testing compressive strength. The load at which the specimen ultimately fails is noted. Compressive strength is calculated by dividing load by area of specimen as shown in equation3.1.

Where,  $fc = P/a \dots 3.1$ 

 $F_c$  = Cube compressive strength in N/mm<sup>2</sup>

- P = Cube compressive load causing failure in N.
- a = Cross sectional area of cube in mm<sup>2</sup>

It was determined by using Compression Testing Machine (CTM) of 1000 KN capacity. Cube specimens of 150 x 150 x 150 mm and hollow block of 100 x 100 x 250 mm with one hollow of size 45 x 75 x 125 mm dimension were cast. The specimens were tested as per IS 516:1959. The cubes were tested for compression testing at the age of 7, 14 and 28 days. A total of 12 number geopolymer concrete cubes and hollow blocks were casted for a particular mix. For each mix at particular ages four specimens were tested for compression testing and the average value have been recorded and shown in the tables. The photographic view of

the experimental facility used to test the compressive strength is shown in Figure 3.2.



Figure 3.2: Compressive Strength Testing

#### **5.1.2 Split Tensile Strength Test**

The tensile strength is one of the basic and important properties of concrete. Concrete is not usually expected to resist direct tension due to its low tensile strength and brittle nature. The methods of determining the tensile strength of concrete can be broadly classified as (a) direct method, and (b) indirect method.

The direct method suffers from a number of difficulties relating to holding the specimen properly in the testing machine without introducing stress concentration, and to the application of uniaxial tensile load which is free from eccentricity to the specimen. As concrete is weak in tension, even a small eccentricity of load can induce combined bending and axial force condition and the concrete fails at the apparent tensile stress other than the tensile strength.

The splitting tests are well known indirect tests used for determining the tensile strength of concrete sometimes referred to as split tensile strength of concrete. In these tests a compressive force is generally applied to a Concrete specimen in such a way that the specimen fails due to tensile stresses developed in the specimen. The tensile stress at which the failure occurs is termed the tensile strength of concrete. Due to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an elastic analysis. The magnitude of the tensile stress  $f_{ct}$  (acting in a direction perpendicular to the line of action of applied loading) is given by the formula shown in equation (3.2).

Where,

- P = Maximum load applied in Newton
- d = Cross sectional dimension of the specimen in mm.
- l = Length of the specimen in mm.

The ratio of the split tensile strength to cylinder strength not only varies with the grade of the concrete but is also dependent on its age. Split tensile strength was determined using Universal Testing Machine (UTM) of capacity 1000 kN. The split tensile strength of concrete was tested using 100 150 mm cylinder specimens. Four test specimens were cast and used to measure the split tensile strength for each test conditions and average value was considered. The photographic view of the experimental facility used to test the split tensile strength is shown in Figure 3.3.



Figure 3.3: Split Tensile Test for Cylinder

#### **5.1.3 Flexural Strength Test**

Flexural strength is a measurement that indicates the resistance of a material to deformation when placed under load. The beam specimens were  $100 \times 100 \times 500$  mm in cross-section. Two legged vertical stirrups of 8 mm diameter at a spacing of 100 mm centre to centre were provided as shear reinforcement. The clear cover of the beam was 20 mm. The geometry of the beam specimen is shown in Figure



Figure 3.4: Geometry of Beam Specimen (All Dimensions are in mm)

The test specimen was mounted in a universal testing machine of 1000 KN capacity. The load was applied on two points from centre of the beam towards the support. The flexural strength of the specimen shall be expressed as the modulus of rupture  $f_b$  The photographic view of the experimental facility used to test the flexural strength is shown in Figure 3.5.

Equation (3.3) and (3.4) represents the formula for calculating flexural strength When a < 13.3, then

$$\mathbf{f}_{b} = \frac{(3p \times a)}{(bxd)^{2}} \qquad \cdots \qquad (3.3)$$

Where a> 13.3, then

$$f_b = \frac{(Px1)}{(b \times d)^2} \dots (3.4)$$

 $f_b$  = Flexural Strength of Specimen in KN/mm<sup>2</sup>

a = Distance between crack point and nearest support point in mm.

b = Measured width of the beam in mm.

d = Measured depth of the beam in mm.

l = Length of the beam in mm.

P = Load applied in KN.



Figure 3.5: Experimental Setup for Flexural Test

#### 5.2 Water Absorption Studies on Geopolymer Concrete

The durability of concrete has been evaluated in this study through parameters related to permeability. The absorption study was done to know the permeability characteristics of geopolymer concrete and was performed in **accordance to ASTM C 642-82 at 7,14 and 28 days.** 

The specimens used for this test were  $150 \times 150 \times 150$  mm cubes with different concentration of NaOH ranging from 8M to 14M. Both specimens that are cured at room temperature and at  $60^{\circ}$ C are tested for water absorption criteria. The percentage absorption was calculated using the equation (3.5). The absorption values for all the specimens were compared with recommendations given by Concrete Society Board (CEB, 1989) and this comparison is presented in Table 3.1

Absorption % = 
$$\left(\frac{w_2 - w_1}{w_1}\right) \times 100 \dots (3.5)$$

Where, W1 = Weight of specimen after complete drying at 105oC (kg).

W2 = Final weight of surface dry sample after immersion in water (kg).

|   | Absorption (%) | Absorption Rating | Concrete Quality |
|---|----------------|-------------------|------------------|
| ſ | <3.0           | Low               | Good             |
| ſ | 3.0 to 5.0     | Average           | Average          |
|   | >5.0           | High              | Poor             |

## 5.3 Resistance of Fly Ash Based Geopolymer Concrete Block to Sulphuric Acid

The sulphuric acid resistance of fly ash based geopolymer concrete blended with an additional calcium source. Ordinary Portland Cement (OPC) was added as additional calcium in geopolymer system as fly ash replacement (10, 20 and30%).The specimens were exposed to 2% sulphuric acid solution up to the age of 365 days, and the deterioration was identified in terms of mass loss and compressive strength retained. Micro structural analysis; SEM, XRD and EDS was also carried out

#### 5.3.1 Change in Weight

To perform the acid attack studies in the present investigation immersion techniques was adopted. After 28 days of casting cube specimens were immersed in a 3% H2SO4 solution. The solution was kept at room temperature and the solution was stirred regularly at least twice a day to maintain uniformity. The solution was replaced at regular intervals to maintain concentration of solution throughout the test period. The evaluations were conducted after 7, 14 and 28 days from the date of immersion. After removing the specimens from the solution, the surfaces were cleaned with a soft nylon wire brush using portable water to remove weak products and loose material from the surface. Then, the specimens were allowed to surface dry and the measurements were taken. From the initial measurement and measurements at particular intervals the losses of weight were studied for both sample cured at room temperature and at  $60^{\circ}$ C.

## 5.3.2 Residual Compressive Strength and Split Tensile Strength

The details of compressive strength and split tensile strength for various grades of concrete with different molarity exposed for a period of 7, 14, and 28 days to sulphuric acid for both specimen cured at room temperature and at 60oC were studied. Residual compressive strength and tensile strength and percentage weight loss of geopolymer after acid immersion have been studied and compared Residual compressive strength and tensile strength was calculated based on the following formula.

Residual compressive strength and split tensile strength (%)

$$= \left[\frac{D}{C}\right] \times 100$$

Where, C = Initial compressive and tensile strength at the age of 28 days.

D = Compressive strength or tensile strength after exposure.

#### 5.3.3 pH Value of Solution

The variation of pH of geopolymer specimens was studied. The initial value of pH for 3% sulphuric acid solution prior to immersion of specimens was 1. The variation of pH was evaluated for duration of 0, 3, 6, 9, 12 and 15 days. The geopolymer mix GP1, GP2, GP3 and GP4 were immersed in sulphuric acid solution and the change in pH value was observed.

#### 5.4 Behaviour of Unreinforced Geopolymer Brick Prism

Masonry is a material built from units and mortar that induce an anisotropic behavior for the composite. Lack of knowledge on the properties of the composite material imposes low assessments of the strength capacity of the masonry wall. Masonry is extensively used in India as infill walls in reinforced concrete buildings. Analysis and design of buildings with masonry require material properties of masonry; for example, modulus of elasticity of masonry is required in the case of linear static analysis. Stress-strain curves of masonry are required in the case of a more detailed nonlinear analysis. Atkinson and Noland (1983), Mc Nary and Abrams (1985) state that the prediction of compressive strength and deformation of full scale masonry based on compressive tests of stack-bond masonry prism and the interpretation of the results of prism tests have a significant influence on the allowable stress and stiffness used in masonry design. When structural masonry is subjected to vertical and horizontal loading, one of the most important parameters for design is the stress-strain relationship. In particular, elasticity modulus is a mechanical property influenced by different factors, such as: the large scatter of experimental tests, compressive strength of unit and shape of unit (hollow or solid). In engineered masonry, the compressive strength and the modulus of elasticity of the material are the two main components of the element. Compressive strength is important because it determines the bearing capacity of the element, the modulus of elasticity is important because it provides the estimate of deformation of the element under loading. Axial compression tests of brick masonry prisms are used to determine the specified axial strength of the brick masonry. The Bureau of Indian Standards IS: 1905 (1987) suggest to use brick masonry prisms having the dimensions of minimum 40 cm height with aspect ratios (h/t) between 2 to 5 in order to determine the axial strength of the brick masonry.

In the present research work 35 specimens of brick masonry prism were tested to obtain stress–strain curves for typical masonry used in the Indian construction industry. Burnt clay solid bricks and geopolymer brick were used in constructing masonry prisms. The geopolymer bricks for two different mix proportion using 10M and 12M NaOH concentration were produced in an industry which is presently producing fly ash bricks.

The behaviour of unreinforced geopolymer masonry prism is compared with ordinary clay brick masonry prism. English bond unreinforced clay brick prism (CBP) and Geopolymer brick prism (GBP (M1) and GBP (M2)) of brick size 225 x 105 x 70 mm were casted using 10M and 12M NaOH concentration with prism dimension of 609 x 220 x 609 mm (h/t = 2.77) and 609 x 220 x 914 mm (h/t = 4.3). Figure 3.6 and 3.7 shows the photographic view of the specimens built for experimental work.



Figure 3.6: Brick Masonry Prism



Figure 3.7: Geopolymer Brick Prism

#### 5.5 Preparation of Test Specimens

The test specimens such as cube, cylinder, prism and hollow block were cast for studying the mechanical and chemical property. Geopolymer concrete bricks were used to study the behaviour of prism for various heights. Sample specimens of cube, cylinder and hollow block are shown in Figures 3.8 to 3.11.



Figure 3.8: Sample Specimens of Cylinder



Figure 3.9: Sample Specimens of Cube



Figure 3.10: Sample Specimens of Hollow block



Figure 3.11: Sample Specimens of Geopolymer brick

Curing was performed in an oven for 24 hours at  $60^{\circ}$ C and also specimens were kept for air curing. The dimensions of different specimens used for the present study are listed in Table 3.2 and 3.3 and also illustrated in Figure 3.12 and 3.13.

Specimens were prepared based on the following test conditions:

- 1. Mixes: GP1, GP2, GP3, GP4.
- 2. Curing days: 7, 14 and 28 days.
- 3. Concentration of NaOH: 8M, 10M, 12M and 14M.
- 4. Curing: Room Temperature and Elevated temperature.
- 5. Ratio of activator solution-to-fly ash, by mass: 0.4.
- 6. Mix Ratio: The trail ratio was chosen as 1:1.1:2.6.
- 7. Ratio of sodium silicate -to-sodium hydroxide solution:

2.5.

8. Ratio of fly ash to binder: 1:0.5:4.

Table 3.2: Details of Specimen

|                        |          | 1                             |
|------------------------|----------|-------------------------------|
| Material               | Shape    | Dimensions of the             |
| Properties             |          | Specimens (mm)                |
| Compressive Strength   | Cube     | 150x150x150                   |
| Flexural Strength      | Prism    | 100x100x500                   |
| Split Tensile Strength | Cylinder | 100x150 x500                  |
| Hollow block           | Cube     | 100 x100 x250 with one hollow |
|                        |          | of size 45 x 75 x 125         |

| Table 3.3 Specimen Details of Brick Maso |
|--|
|--|

| S. | Designation  | Type of    | Size of         | Molarity of |
|----|--------------|------------|-----------------|-------------|
| No | of the Prism | Brick      | Prism (mm)      | NaOH        |
| 1  | CBP          | Burnt clay | 609 x 220 x 609 | -           |
|    |              | brick      |                 |             |
| 2  | CBP          | Burnt clay | 609 x 220 x 914 | -           |
|    |              | brick      |                 |             |
| 3  | GBP (M1)     | Geopolymer | 609 x 220 x 609 | 10M and 12M |
|    |              | brick      | and             |             |
|    |              |            | 609 x 220 x 914 |             |
| 4  | GBP (M2)     | Geopolymer | 609 x 220 x 609 | 10M and 12M |
|    |              | brick      | and             |             |
|    |              |            | 609 x 220 x 914 |             |

#### 5.6 Summary

Detailed study was carried out on concrete as per the specifications prescribed IS (Indian Standards): 516-1959 to ascertain the above properties and the test procedure adopted are described in this chapter. Tests pertaining to durability, chemical resistance and behaviour of geopolymer concrete are discussed in detail

## 6. Mix Design

#### 6.1 Introduction

To produce concrete of desired strength, various mix proportioning methods are used on the basis of type of work, types, availability and properties of material, field conditions and workability and durability requirements. As geopolymer concrete is a new material in which cement is totally replaced by fly ash and activated by alkaline solutions. Chemical composition, fineness and density of fly ashes are different from cement. Similarly, in cement concrete, water Plays main role during hydration process while water cement out during polymerization process a sin case of geopolymer concrete. Therefore it is necessary to develop a new mix design procedure for geopolymer concrete to achieve desired strength at required workability. So, in the present investigation, geopolymer concrete mix design procedure is proposed on the basis of quantity and fineness of fly ash to achieve desired strength quantity of water to achieve required degree of workability grading of fine aggregate and fineness-to-total aggregate ratio by maintaining solution-to-fly ash ratio by mass of 0.35, waterto- geopolymer binder ratio of 0.40, sodium silicate-tosodium hydroxide ratio by mass of 2.0 and tested after oven heating at a temperature 60 °C for duration of 24 h and tested after test period of 7 days 14 days 28 days.

#### **6.2 Experimental Work**

In order to improve the durability of fly ash concrete, a series of experimental work is carried out, where durability improving admixture is used to reduce drying shrinkage and improve freezing-thawing resistance, air content, waterbinder ratio, and fly ash replacement ratio on the performance of fly ash concrete. The results show that by using durability improving admixture in non air–entraining fly ash concrete can be improved by 10%-20% and the drying shrinkage is reduced by 60%.

#### 6.2.1 Materials

In the proposed mix proportioning method, low calcium processed fly ash of thermal power plant was used as source material. The laboratory grade sodium hydroxide in flake form (97.8 % purity) and sodium silicate (50.72 % solids) solutions are used as alkaline activators. Locally available river sand is used as fine aggregate and locally available 20 and 12.5 mm sizes crushed basalt stones are used as coarse aggregates.

#### 6.2.2 Flyash

Quantity and fineness of fly ash plays an important role in the activation process of geopolymer. It was already pointed out that the strength of geopolymer concrete increases with increase in quantity and fineness of fly ash,. Similarly higher fineness shows higher workability and strength with early duration of heating. So, the main emphasis is given on quantity and fineness of fly ash in the development of mix proportioning procedure of geopolymer concrete. So, in the proposed mix design procedure, quantity of fly ash is selected on the basis of fineness of fly ash and target strength.

#### 6.2.3 Alkaline Activators

In the present investigation, sodium based alkaline activators are used. Single activator either sodium hydroxide or sodium silicate alone is not much effective as clearly seen. So, the combination of sodium hydroxide and sodium silicate solutions are used for the activation of flyash based geopolymer concrete. It is observed that the compressive strength of geopolymer concrete increases with increase in concentration of sodium hydroxide solution and or sodium silicate solution with increased viscosity of fresh mix. Due to increase in concentration of sodium hydroxide solution in terms of molarity (M) makes the concrete more brittle with increased compressive strength. Secondly, the cost of sodium hydroxide solid is high and preparation is very caustic. Similarly to achieve desired degree of workability, extra water is required which ultimately reduce the concentration of sodium hydroxide solution. So, the concentration of sodium hydroxide was maintained at 13 M while concentration of sodium silicate solution contains Na2O of 16.37 %, SiO2 of 34.35 % and H2O of 49.72 % is used as alkaline solutions. Similarly, sodium silicate-tosodium hydroxide ratio by mass was maintained at 2 which set cubes within 24 h after casting and gives fairly good results of compressive strength.

#### 6.2.4 Water

From the chemical reaction, it was observe that the water comes out from the mix during the polymerization process.

The role of water in the geopolymer mix is to make workable concrete in plastic state and do not contribute towards the strength in hardened state. Similarly the demand of water increases with increase in fineness of source material for same degree of workability. So, the minimum quantity of water required to achieve desired workability is selected on the basis of degree of workability, fineness of fly ash and grading of fine aggregate.

#### 6.2.5 Aggregate

Aggregates are inert mineral material used as filler in concrete which occupies 70–85 % volume. So, in the preparation of geopolymer concrete, fine and coarse aggregates are mixed in such a way that it gives least voids in the concrete mass. This was done by grading of fine aggregate and selecting suitable fine-to-total aggregate ratio. Workability of geopolymer concrete is also affected by grading of fine aggregate similar to cement concrete. So, on the basis of grading of fine aggregate, fine-to-total aggregate ratio is selected in the proposed mix proportionating method.

#### 6.3 Degree of Heating

For the development of geopolymer concrete, temperature and duration of heating plays an important role in the activation process. In the present investigation, cubes were de molded after 24 h of casting and then place in an oven for heating at 60 °C for a period of 24 h. After specified degree of heating, oven is switched off and cubes are allowed to cool down to room temperature in an oven itself. Then compression test is carried out on geopolymer concrete cubes after a test period of 7 days. Test period is the period considered in between testing cubes for compressive strength and placing it in normal room temperature after heating. It is observed that the compressive strength of geopolymer concrete increases with increase in duration and test period. From the design point of view, 24 h of oven curing at 60 °C and tested after a period of 7 days was fixed as per past research.

#### 6.4 Water to Geopolymer Binder Ratio

Water-to-geopolymer binder ratio, the ratio of total water ( i.e. water present in solution and extra water if required) to material involve in polymerization process (i.e. fly ash and sodium silicate and sodium hydroxide solutions) plays an important role in the activation. process. Rangan suggested the water-to-geopolymer solid ratio in which only solid content in solution and fly ash is considered. But the calculation is tedious and water present in solution indicates the concentration of solution itself. So, in the present water-to-geopolymer investigation. binder ratio is considered. From the investigation, it is observed that the compressive strength reduces with increase in water-togeopolymer binder ratio similar to water-to-cement ratio in cement concrete. At water-to-geopolymer binder ratio of 0.35, the mix was very stiff and at 0.40, the mix was segregated. Similarly water come out during polymerization process and does not contribute anything to the strength. So, water-to-geopolymer binder ratio is maintained at 0.40 which gives better results of workability and compressive strength.

#### 6.5 Solution to Fly Ash Ratio

As solution (i.e. sodium silicate + sodium hydroxide) to fly ash ratio increases, strength is also increases. But the rate of gain of strength is not much significant beyond solution to fly ash ratio of 0.35. Similarly the mix was more and more viscous with higher ratios and unit cost is also increases. So, in the present mix design method, solution-to-fly ash ratio was maintained at 0.35.

#### 6.6 Preparation of Geopolymer Concrete Mixes

Preparation of geopolymer concrete is similar to that of cement concrete. Two types of coarse aggregates, sand and fly ash were mixed in dry state. Then add prepared mixture solution of sodium hydroxide and sodium silicate along with extra water based on water-to-geopolymer binder ratio and mix thoroughly for 3-4 min so as to give homogeneous mix. It was found that the fresh fly ash based geopolymer concrete was viscous, cohesive and dark in color. After making the homogeneous mix, workability of fresh geopolymer concrete was measured by flow table apparatus as per IS 5512-1983 and IS 1727-1967. Concrete cubes of side 150 mm are casted in three layers. Each layer is well compacted by tamping rod of diameter 16 mm. All cubes were place on table vibrator and vibrated for 2 min for proper compaction of concrete. After compaction of concrete, the top surface was leveled by using trowel.

After 24 h of casting, all cubes were de molded and then placed in an oven for thermal curing (heating). To avoid the sudden variation in temperature, the concrete cubes were allowed to cool down up to room temperature in an oven. Three cubes were cast and tested for compressive strength for each curing period.

## 6.7 Method Proposed for Mix Proportioning (For M20 Grade Of Concrete)

While carrying out concrete mix design, there are chances that we do not consider some technical points results the production of poor quality concrete.

#### 6.7.1 Data Required for Mix Design

- a) Characteristic compressive strength of Geopolymer Concrete (fck).
- b) Fineness of fly ash in terms of specific surface inm2/kg.
- c) Workability in terms of flow.
- d) Oven curing (heating) 60 °C for 24 h and tested after 7days.
- e) Fineness modulus of fine aggregate.
- f) Water absorption and water content in fine and coarse aggregate.

#### 6.8 Design Steps Requirements

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be large as possible with the limits as per BIS.

- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

#### 6.8.1 Selection of Quantity of Fly-Ash (F)

Quantity of fly ash selected based on target mean strength and fineness of fly ash at solution-to-fly ash ratio of 0.35.

#### 6.8.2 Calculation of the Quantity of Alkaline Activators

Based on the quantity of fly ash (F) determined in the previous step, the amount of total solution is obtained using solution-to-fly ash ratio of 0.35 by mass. After that, quantity of sodium silicate and sodium hydroxide is decided using sodium silicate-to-sodium hydroxide ratio of 1 by mass.

## 6.8.3 Calculation of the Solid Content in Alkaline Solution

Calculation of Total Solid Content in Alkaline Solution Calculate solid content in sodium silicate and sodium hydroxide solution on the basis of percentage solid present in each solution.

#### 6.8.4 Selection of Quantity of water

Selection of Quantity of Water Workability of geopolymer concrete is depending on total quantity of water including water present in both alkaline solutions and the degree of workability. Select the total quantity of water required to achieve desired workability based on fineness of flyash.

#### 6.9 Correction in Water Content

In concrete, volume occupied by fine and coarse aggregate is about 70–85% of total volume. Similarly, finer particles have large surface area as compared to coarser one and hence required more water to produce workable mix IS10262 suggested some correction in water content for the mix proportioning of cement concrete on the basis of grading of fine aggregate. In geopolymer concrete role of water is to make workable concrete. So, it is recommended to apply same correction to geo- polymer concrete in the proposed mix design on the basis of grading zones of fine aggregate. On the basis of grading zones of fine aggregate.

#### 6.10 Calculation Of Additional Quantity of water

In geopolymer concrete, alkaline solutions are used which contains certain quantity of water on the basis of their concentration. But to meet workability requirements, additional water may be added in the mix externally which is calculated as:

Additional quantity of water; if required = Total quantity of water - Water present in alkaline solutions.

#### 6.11 Calculation of Fine and Coarse Aggregate Content

Aggregate Contents is obtained using following relations: Total quantity of aggregate = Wet Density of Geopolymer concrete – (Quantity of Geopolymer Binder + Additional water; if any)

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Sand content = (Fine-to-total aggregate content in %] X (Total quantity of aggregate) Coarse aggregate content =(Total quantity of aggregate) – (Sand content).

## 6.12 Actual Quantity of Material Required on the Basis of Field condition

The above mix proportion has been arrived on the assumption that aggregates are saturated and surface dry. For any deviation from this condition i.e. when aggregates are moist or air dry or bone dry, correction has to be applied on quantity of mixing water as well to the aggregates.



Figure 4.1: Relation between fineness of fly ash and density of geopolymer concrete

#### 6.13 Result and Discussion

It was found that the fresh fly ash-based geopolymer concrete was viscous, cohesive and dark in color and glassy appearance. After making the homogeneous mix, workability of fresh geopolymer concrete was measured by flow table apparatus as per IS 5512-1983 and IS 1727-1967. Freshly mixed geopolymer concrete is viscous in nature and water comes out during polymerization process, methods like slump cone test is not suitable to measure workability as concrete subside for long time while in compaction factor test, concrete cannot flow freely. So, flow table test is recommended for workability measurement of geopolymer concrete.

After measuring workability, concrete cubes of side 150 mm were cast in three layers and each is properly compacted similar to cement concrete. Then after 24 h of casting, all cubes were demoulded and weight was taken for the calculation of mass density. Average weight of three cubes was considered for calculation of mass density. It is observed that the average mass density obtained by proposed method is 2,601.48 kg/m3 which is 3.33 % higher than that considered in design method.

Then cubes were placed in an oven for thermal curing at 60°C for 24 h. To avoid sudden variation in temperature, the concrete cubes were allowed to cool down up to room temperature in an oven itself. Three cubes were cast and tested for compressive strength after 7 days of test period. Here, test period is the period considered after removing the cubes from oven till the time of testing for compressive strength. It is observed that the compressive strength of M20 grade geo- polymer concrete is 27.22 MPa tested after 7 days of test period which is 2.69 % less than the target strength (28.25 MPa) considered in proposed mix design

method which is within the limit of +/-15 % as per IS 456-2000. These method provides, comparatively, economical mix than other method.

## 7. Experimental Laboratory Work

#### 7.1 Testing of the Geopolymer Concrete Specimens

Thirty three cubes of size 150X150mm and cylinder of size 150mm diameter 300mm high were cast and out of which three cubes each were used to determine the compressive strength and three cylinders each were used to determine the split tensile strength at 24 hours for different grades of Geopolymer Concrete. A total of 300 numbers of specimens were tested in this study to find out the grades of Geopolymer Concrete incorporating M-sand. All Geopolymer concrete mixes designed using mix design procedure outlined in Indian standards IS 10262-1982. It is recommended to have necessary precautionary measures on workers because heat generation of alkaline liquid will be more. The aggregates were prepared in saturated-surface-dry (SSD) condition. Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. The concrete ingredients are collected and mixed in the pan mixture for about 5 minutes. Alkaline liquid was then added to the mixture and the mixing is done for another 5 minutes. After the mixing, the flow value of fresh Geopolymer concrete was determined in accordance with Slump Test IS 516-1959. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength. Flow Test (workability) was carried out by Slump Cone Test as described for cement concrete shown in Figure 5.1. After the flow test, fresh concrete was placed in the respective moulds as described in the IS 516-1959 and as shown in Figure 5.2.and Figure

5.3.Thefresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete. The specimens were left standing for one hour and then cured at 57° to 60°C in the heat curing chamber for about 24 hours as shown if Figure 5.4. Demoulding was done at 24 hours at the time of heat curing age. After the curing period, the specimens were left at the room temperature for

about an hour and ready for testing. Thus, the compressive strengths and tensile strength of concrete were determined on the same day in accordance with IS 516- 1959. The Details of Geopolymer Concrete Mixtures are shown in Table 5.1 to 5.3. Fly ash coarse sodium si silicates silicate aggregate sodium sodium sand hydroxide sand



Figure 5.1: The ingredients of geopolymer concrete



Figure 5.2: Paste of fresh geopolymer concrete



Figure 5.3: Slump Measurement of Fresh Concrete



Figure 5.4: The heat Curing of Geopolymer Concrete

| Table 5.1: Detai                 | <b>Table 5.1:</b> Details of Geopolymer Concrete Mixtures M1 TO M10 (kg/m <sup>3</sup> ) |       |       |        |       |       |       |       |       |       |  |
|----------------------------------|--|-------|-------|--------|-------|-------|-------|-------|-------|-------|--|
| Content                          | M 1  | M 2   | M 3   | M 4    | M 5   | M 6   | M 7   | M 8   | M 9   | M10   |  |
| Fly ash                          | 455  | 480.7 | 480.2 | 554.7  | 543.7 | 585.6 | 554.7 | 585.6 | 552.6 | 555.  |  |
| Sand                             | 635.4  | 585.4 | 620.5 | 560.4  | 535.4 | 535.4 | 450   | 576   | 567.8 | 550.8 |  |
| Coarse aggregate                 | 1249.5   | 1118  | 1108  | 1002.2 | 987.5 | 832.8 | 929.1 | 1018  | 987.5 | 957.9 |  |
| Water                            | 36.5   | 44.2  | 44.2  | 14.2   | 28.3  | 28.3  | 14.2  | 12.7  | 44.2  | 44.2  |  |
| NaOH solution                    | 58.8   | 63.5  | 63.5  | 68.8   | 72.2  | 72.2  | 74.8  | 78    | 78    | 68.5  |  |
| Na <sub>2</sub> SiO <sub>3</sub> | 145  | 163.1 | 163.1 | 170    | 180.5 | 180.5 | 184.6 | 200.5 | 190.5 | 171.1 |  |
| M-Sand                           | 613  | 608.1 | 610   | 589.9  | 615.6 | 572.2 | 613   | 670.8 | 589.9 | 572.2 |  |

**Table5.2:** Details of Geopolymer Concrete Mixtures M11 TO M20 (kg/m<sup>3</sup>)

| Content                          | M11   | M12   | M13   | M14   | M15   | M 16  | M 17  | M 18  | M 19  | M20   |
|----------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Fly ash                          | 638.2 | 510.7 | 585.6 | 483.7 | 554.7 | 583.7 | 564.7 | 585.6 | 584.7 | 585.6 |
| Sand                             |       | 567.1 | 586   | 585.4 | 535.4 | 567.1 | 535.4 | 543.2 | 515.2 | 535   |
| Coarse aggregate                 | 929.1 | 882.2 | 907.5 | 1018  | 832.8 | 882.2 | 832.8 | 902   | 798.2 | 883   |
| Water                            | 44.2  | 28.3  | 28.3  | 28.3  | 14.2  | 14.2  | 14.2  | 14.2  | 28.3  | 12.7  |
| NaOH solution                    | 68.5  | 68.5  | 79.8  | 70.2  | 73    | 73    | 73.8  | 73.8  | 80.8  | 80.8  |
| Na <sub>2</sub> SiO <sub>3</sub> | 171.1 | 171.1 | 204.6 | 175.5 | 180.3 | 180.3 | 185.6 | 185.6 | 204.6 | 204.6 |
| M-Sand                           | 615.6 | 652.1 | 670.8 | 572.2 | 613   | 652.1 | 615.6 | 589.9 | 572.2 | 670.8 |

Table 5.3: Details of Geopolymer Concrete Mixtures M21 TO M30 (kg/m<sup>3</sup>)

| tuble etc. Details of Geoporymer Coherete Minitares Mi21 10 Mi30 (Mg m ) |       |       |       |       |       |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Content  | M 21  | M 22  | M 23  | M 24  | M 25  | M 26  | M 27  | M 28  | M 29  | M 30  |
| Fly ash  | 570.8 | 547   | 585.6 | 564.7 | 519.7 | 585   | 585   | 585   | 638.2 | 485.6 |
| Sand   | 535   | 567.1 | 535.4 | 535.4 | 613   | 550.8 | 585.4 | 567.1 | 545   | 613   |
| Coarse aggregate   | 883   | 957.9 | 832.8 | 832.8 | 964   | 907.5 | 1018  | 957.9 | 882.2 | 1218  |
| Water  | 28.3  | 44.2  | 12.7  | 28.3  | 44.2  | 14.2  | 28.3  | 14.2  | 12.7  | 14.2  |
| NaOH Solution  | 78.24 | 68.5  | 82    | 82.2  | 68.5  | 82.8  | 82.8  | 83    | 68.5  | 65    |
| Na2SiO3  | 195.6 | 171.1 | 210.5 | 205.5 | 171.1 | 210.6 | 210.6 | 207.3 | 171.1 | 167.3 |
| M-Sand   | 572.2 | 608.1 | 615.6 | 615.6 | 625.7 | 572.2 | 550.1 | 572.2 | 613   | 713   |

As per section 3.3.3 mix proportions were arrived based on the variables given. The aim of the work to arrive the mix ratios for M20-M35 as per the Indian standard. The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The modulus of elasticity of concrete is relatively constant at low stress levels but starts' decreasing at higher stress levels as matrix cracking develops. The existing cracks in the transition zone and the existing void spaces make the transition zone weak. This causes the Elastic modulus of Elasticity to drop gradually with increasing loads. While using M- sand in Concrete the voids will be increased because of its texture and shape hence the Modulus of Elasticity is reduced. Concrete with high compressive strength and low modulus of elasticity have shown the loss in stiffness. Hence we have to use more sand compare to natural sand.

#### 7.2 Compressive Strength of Concrete

The Test was carried out on 150mm x 150mm x 150mm size cube to determine the Compressive strength of Geopolymer Concrete as per IS 516-1959. A 2000kN capacity standard Compression Testing Machine was used to conduct the test shown in Figure 5.5. The test result of the specimens shown in Table 4.4 and 4. is the average of the strength of three specimens. Comparison of Compressive strength for mix ratio using sand and M-sand is shown in Figure 5.6. and 5.7.



Figure 5.5: Test Set up for measuring the Cube Compressive Strength

| Table5.4: | Compressive  | Strength of | Geopolymer | Concrete  | using River sand |
|-----------|--------------|-------------|------------|-----------|------------------|
|           | 001101000110 | Strongen or | 000001,    | 001101000 | asing it of same |

| 1                           |      |      |      |      |      |      |      | 0    |      |      |
|-----------------------------|------|------|------|------|------|------|------|------|------|------|
| Mix                         | M 1  | M 2  | M 3  | M 4  | M 5  | M 6  | M 7  | M 8  | M 9  | M 10 |
| Compressive strength in MPa | 16   | 21   | 21   | 21   | 23   | 20   | 23   | 25   | 22   | 23   |
| Mix                         | M11  | M12  | M13  | M14  | M15  | M 16 | M 17 | M 18 | M 19 | M 2  |
| Compressive strength in MPa | 23   | 24   | 24   | 23   | 23   | 33   | 30   | 33   | 30   | 35   |
| Mix                         | M 21 | M 22 | M 23 | M 24 | M 25 | M 26 | M 27 | M 28 | M 29 | M 30 |
| Compressive strength in MPa | 33   | 33   | 35   | 35   | 36   | 37   | 37   | 38   | 38   | 17   |

| Table 5.5: Compressive Strength of Geopolymer Concrete using M-Sand |      |      |      |      |      |      |      |      |      |      |
|---|------|------|------|------|------|------|------|------|------|------|
| Mix   | M 1  | M 2  | M 3  | M 4  | M 5  | M 6  | M 7  | M 8  | M 9  | M 10 |
| Compressive strength inMPa  | 18   | 3    | 23   | 22   | 21   | 20   | 22   | 25   | 25   | 29   |
| Mix   | M11  | M12  | M13  | M14  | M15  | M 16 | M 17 | M 18 | M 19 | M 20 |
| Compressive strength in MPa   | 29   | 25   | 25   | 26   | 26   | 30   | 31   | 32   | 30   | 32   |
| Mix   | M 21 | M 22 | M 23 | M 24 | M 25 | M 26 | M 27 | M 28 | M 29 | M 30 |
| Compressive strength inMPa  | 26   | 26   | 38   | 36   | 37   | 36   | 39   | 37   | 38   | 18   |



Figure 5.6: Comparison of Compressive strength of GPC mixes cast with Sa



Figure 5.7: Comparison of Compressive strength of GPC mixes cast with M-Sand

#### 7.3 Split Tensile Strength

The test was carried out on 100 x 200 mm size cylinder to determine Split Tensile Strength of GPC as per IS: 516-1959. The Tensile failure of Concrete using Sand and M Sand is shown in Figure 5.8. A 2000kN capacity standard compression testing machine was used to conduct the test as

shown in Figure 5.8. The test result of the specimens shown in Table 4.6 and 5.7 is the average of the strength of three specimens. Comparison of Split Tensile strength for mix ratio using sand and M-sand is shown in Figure 4.9 and 4.10. Tensile failure of Concrete using Sand and M sand is shown in figure 5.1



Figure 5.8: Test Set up for measuring the Split Tensile Strength of Cylinder

| Mix                          | M 1  | M 2  | M 3  | M 4  | M 5  | M 6  | M 7  | M 8  | M 9  | M 10 |
|------------------------------|------|------|------|------|------|------|------|------|------|------|
| Split Tensile strength (MPa) | 2.8  | 3.21 | 3.36 | 3.21 | 3.36 | 3.13 | 3.36 | 3.36 | 3.28 | 3.36 |
| Mix                          | M11  | M12  | M13  | M14  | M15  | M 16 | M 17 | M18  | M 19 | M 20 |
| Split Tensile strength (MPa) | 3.36 | 3.43 | 3.43 | 3.36 | 3.36 | 4.02 | 3.83 | 4.02 | 3.83 | 4.14 |
| Mix                          | M 21 | M 22 | M23  | M 24 | M 25 | M 26 | M 27 | M28  | M 29 | M 30 |
| Split Tensile strength (MPa) | 4.02 | 4.02 | 4.14 | 4.14 | 4.20 | 4.26 | 4.26 | 4.32 | 4.32 | 2.89 |

| Table 5.6: S | Split Tensile | Strength of | GPC using | River Sand |
|--------------|---------------|-------------|-----------|------------|

| <b>Tabel 5.7:</b> Split Tensile strength of GPC using M-Sand |      |      |      |      |      |      |      |      |      |      |
|--|------|------|------|------|------|------|------|------|------|------|
| Mix  | M 1  | M 2  | M 3  | M 4  | M 5  | M 6  | M 7  | M 8  | M 9  | M 10 |
| Split Tensile strength (MPa)                                 | 2.97 | 3.36 | 3.43 | 3.43 | 3.36 | 3.36 | 3.28 | 3.28 | 3.50 | 3.77 |
| Mix  | M 11 | M 12 | M 13 | M 14 | M 15 | M 16 | M 17 | M 18 | M 19 | M 20 |
| Split Tensile strength (MPa)                                 | 3.77 | 3.50 | 3.57 | 3.57 | 3.50 | 3.83 | 3.90 | 3.96 | 3.83 | 3.96 |
| Mix  | M 21 | M 22 | M 23 | M 24 | M 25 | M 26 | M 27 | M 28 | M 29 | M 30 |
| Split Tensile strength (MPa)                                 | 3.57 | 3.57 | 4.32 | 4.20 | 4.26 | 4.20 | 4.37 | 4.26 | 4.32 | 2.97 |



Figure 5.9: Comparison of Split Tensile strength of GPC mixes cast with Sand







Figure 5.11: Tensile failure of Concrete using Sand and M Sand

#### 8. Environmental Benefits of the Technology

The use of fly ash as a source material has environmental advantages in addition to those presented by the replacement of Portland cement. The use of the industrial byproducts such as fly ash in a high value product like concrete imparts better value-addition to these materials rather than low end usage as landfills and pavement sub-bases. It significantly decreases the use of natural resources and energy, for example, every million tons of fly ash that replaces Portland cement helps to conserve one million tons of lime stone, 0.25 million tons of coal and over 80 million units of power. The cement industry is the main culprit for the atmospheric pollution and mainly responsible for the emission of Green House Gases like CO2. Production of one ton of cement approximately releases one ton of CO2 into the atmosphere. Hence every million ton of fly ash used for geopolymer concrete helps the abatement of 1.0 million tons of CO2 to atmosphere. It also obviates the problem of their safe storage and/or disposal. Presently, most fly ash is being handled in wet form and disposed off in ash ponds which are harmful for the environment and occupy a vast area. The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 square kilometres or one square metre of land per person. Hence, use of geopolymer concrete helps us to increase the land available for agricultural and other purposes. Further, non toxic chemicals are used for the production of geopolymer concrete. These chemicals can be handled by land without any additional protection. Hence, geopolymer concrete developed using fly ash is an environment friendly green material.

## 9. Economic Benefits of the Technology

In preparing the geopolymer concrete, the Ordinary Portland Cement is replaced 100 percent by fly ash and hence geopolymer concrete is termed as cement less concrete. The price of fly ash based geopolymer concrete is estimated about 10 to 30 percent cheaper than Portland cement concrete. Heat-cured low-calcium fly ash-based geopolymer concrete offers several economic benefits over Portland cement concrete. One ton low-calcium fly ash can be utilized to manufacture approximately three cubic meters of high quality fly ash-based geopolymer concrete, and hence earn monetary benefits through carbon-credit trade. The heat-cured low-calcium fly ash-based geopolymer concrete may yield additional economic benefits when it is utilized in infrastructure applications.

In the case of infrastructure applications, space available for keeping precast elements is very much restricted. Precast elements made out of normal concrete require 28 days for gaining full strength. But at the same time, heat cured geopolymer concrete attains full strength in one day. This results in savings in cost of expensive moulds and at the same time less space is required to keep the geopolymer concrete precast elements as they can be moved out of casting yard quickly.

Further, expensive steam curing chamber is not required at site. Cost effective steam curing arrangement made out of tarpaulins would be sufficient at site.

#### **10.** Conclusions

From the experimental investigation the following conclusions are made:

- Geopolymer concrete can be manufactured with low calcium fly ash with different molarities of NaOH. The steam cured geopolymer concrete beams with 8 Molarity NaOH solutions attain higher strength.
- 2) Adequate curing temperature  $(60^{\circ}C 75^{\circ}C)$  and adequate curing time (minimum 24 hrs) can give better results.
- 3) The geopolymer concrete with steam curing at  $75^{\circ}$ C increases the strength by 35-50 percent when compared to geopolymer concrete without steam curing.
- 4) Workability which influences the properties of the fresh concrete and cube compressive strength, flexural strength which influences the properties of the hardened concrete have been identified. Low-calcium fly ashbased geopolymer concrete has an excellent compressive strength and is suitable for structural applications.
- 5) The reason for the improvement in compressive strength of geopolymer concrete is the chemical reaction due to the speedy polymerization process and aging of the alkaline liquid.
- 6) While testing the geopolymer concrete specimen, the one cast with 8 Molarity NaOH solution showed higher strength compared with other molarity specimens because when H<sub>2</sub>O-to-Na<sub>2</sub>O molar ratio increases the strength of geopolymer concrete decreases.
- 7) Geopolymer binders have emerged as one of the possible alternative to OPC binders due to their reported high early strength and resistance against acid and sulfate attack apart from its environmental friendliness
- As geopolymer has better corrosion resistance, evidenced from corrosion tests, it can be used for making precast products like under ground pipes, box culverts etc.
- 9) Since it is possible to produce geopolymer concrete of strength higher than 50 MPa it could be used for prestressed Concrete works.
- 10) Geopolymer bricks show very high compressive strength when compared to ordinary bricks
- 11) The strength of geopolymer bricks can be brought to the level of ordinary bricks by using lower molar solutions of NaOH.

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