# FACTORS AFFECTING COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

## A Thesis

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***By***


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**JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY**

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# CERTIFICATE

This is to certify that the work which is being presented in the thesis titled **“FACTORS AFFECTING COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE”** in partial fulfilment of the requirements for the award of the degree of Masters of Technology in Civil Engineering with specialization in “**Construction Management**” and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Tarun Sarthak Sood (162658)** during a period from August 2017 to May 2018 under the supervision of **Mr. Anirban Dhulia**, Assistant Professor and **Dr. Veeresh Gali**, Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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# CONTENTS

## List of Figures

# List of Tables

## List of Graphs

# ABSTRACT

Geopolymer Concrete is an eco-friendly material that uses source material which is rich in silica and alumina such as Fly Ash, Ground Granulated Ballast Furnace Slag, and Silica Fume, Rice Husk etc. in combination with alkaline liquids such as Sodium Hydroxide /Potassium Hydroxide and Sodium Silicate solution. Since the reaction that takes place here is polymerisation, therefore, the term Geopolymer Concrete was coined. Today one of the major problems that the world is facing is environmental pollution and global warming. While talking about construction industry mainly the production of Ordinary Portland cement (OPC) causes the emission of pollutants in very large amount which results in environmental pollution. The emission of carbon dioxide in huge amount during the production of Ordinary Portland cement is a severe issue because for the production of one ton of OPC approximately one ton of carbon dioxide is emitted into the atmosphere. The Geopolymer Concrete Technology seems to be a promising alternative to conventional OPC concrete. This report will review the factors that affect compressive strength of Geopolymer Concrete along with the basic procedure of casting of Geopolymer moulds. Sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$) are the alkaline liquids that will be used in this study. Cube specimens of size 150 x 150 x 150 mm were casted and tested for their compressive strength. Dry Heat Curing was adopted wherever elevated temperature curing is required, rest of the specimens will be cured at ambient temperature. It was found that compressive strength of Geopolymer concrete increased with decrease in content of fly ash and increase in content of GGBS. Further it was also noticed that the compressive strength of Geopolymer concrete increases even after 28 days unlike Portland cement concrete. The method of dry heat curing and rest period are of great significance in Geopolymer concrete which are discussed in detail in later part of the report. For all the specimens the ratio of $Na_2SiO_3$: NaOH = 1.8 was kept constant. The super-plasticizer dosage was kept to be 1.5% of FA+GGBS. Extra water, 10% of FA+GGBS was added to improve the workability. Water absorption of aggregates was considered separately. The purpose of the project is to set up optimum values to prepare Geopolymer concrete as per the material readily available in Indian market.

**Keywords:** *Geopolymer Concrete, Fly Ash, GGBS, Sodium Hydroxide, Sodium Silicate, Super-plasticizer, Compressive Strength.*

# CHAPTER 1

# INTRODUCTION

## 1.1 General Introduction

One of the major challenges in today's life is global warming caused by emission of greenhouse gases. Key contributor to this problem is cement industry which is one of the major harm to our environment. When alternate binders are compared to binders manufactured using Portland cement alone it is found that they have ability to grow and hold significant economic and environmental advantages. For example there cost is less as compared to Portland cement and also they are less polluting. The interest is growing in sustainable materials as well as in structures which has led to significant efforts of R&D in the development of viable substitute to simple Portland cement concretes. Geopolymer Concrete (GPC) together with Geopolymer can be highly non-polluting and conservationist when used as a binder since GPCs are made from by-products of factories and its carbon residue is very less as compared with conventional Portland cement based concretes.

Even though, a new technology is introduced named as Geopolymer, having medieval roots and has been demanded as better building material which has also been used for the purpose of construction of the pyramids at Giza as well as in other former constructions. There are no wide spread applications of GPC till date; however the technology is quickly progressing in various countries like Europe and Australia. Because of the respective effort in lifting sensitive goods like high- alkali activating solution and the inevitability for controlling increase in temperature. Geopolymer systems are being developed by significant research which addresses many impediments. Moreover, present research is focusing on growth of more user-friendly Geoploymers which do not require the use of high alkaline activating solutions. So far, none of the possible application has approached beyond the development period but the long lasting credits of Geopolymer make them tempting for use in high-cost, intense- environment applications such as bridges.

To bring out appearing trends in Geopolymer in India as well as in abroad many workshops are planned to provide better exposure to current research activities.

Series of lectures have been included in the programme which is designed by CSIR – SERC scientists and many other renowned personalities in Geopolymer research field. Different technologies involved in these researches have also been included.

## 1.2 Material Required

### 1.2.1 Fly Ash:

Fly ash is by-product of thermal power plants. (Fig. 1.1) It is residue of coal that is burnt at very high temperatures to generate electricity in thermal power plants. Fly ash consists of very fine particles which are driven out of boiler along with other gases. Heavy ash that deposits at the bottom of boiler is called bottom ash. In today's modern boilers, there is an equipment installed called electrostatic precipitator which was made compulsory to be installed in industries by the Indian government. This electrostatic precipitator entraps all the ash that otherwise blows out of the boiler with other gases due to its very minute and lightweight particles. Since this ash flies away with the flue gases and is collected at the top of the boiler hence it got its name as Fly Ash. If we combine the bottom ash and fly ash together then it is known as coal ash. The content of fly ash depends upon the type of coal being burned but the major constituents of any fly ash are aluminium oxide, silicon dioxide and calcium oxide represented by the symbol $Al_2O_3$, $SiO_2$ and CaO respectively.

Fig 1.1 Sample of Fly Ash

### 1.2.2 Ground-Granulated Blast-Furnace Slag:

Ground-granulated blast-furnace slag (GGBS or GGBFS) is a by-product of steel industry. Molten iron slag which is a by-product of iron and steel industry is taken out of the blast-furnace and is extinguished in water or steam. This in term produces a product that is glassy and granular which is then dried and grounded into a fine powder. (Fig1.2) GGBS is found to be advantageous for the concrete industry as it has very low cost and is easy to obtain , it also has other good properties such as it has good resistant to chemical attack and good thermal properties. Again the major components are $Al_2O_3$, $SiO_2$ and CaO.

Fig. 1.2 Sample of GGBFS

### 1.2.3 Sodium Hydroxide (NaOH)

The most common alkali activator used in Geopolymer concrete is NaOH. (Fig 1.3) As an activator NaOH is not as active as KOH ions. But the ions of NaOH are smaller in size and therefore they can penetrate inside the network with an easy effort. Also NaOH ions possess density of very high charge which offers additional zeolitic formation energy.

Fig. 1.3 Sample of Sodium Hydroxide Pellets

The properties of resultant paste of Geopolymer concrete are subject to concentration of NaOH solution. While forming binder high conc. of NaOH may help in chemical dissolution but it resists formation of ettringite and CH (carbon-hydrogen) bond.

It has also been studied by the researchers that the high concentration of NaOH may give higher strength at early ages but for the aged specimens it was found that the concrete had poor morphology and non-uniformity due to excessive OH ions. One of the advantage of using NaOH as an activator is that the resultant Geopolymer concrete is more crystalline and therefore has greater stability in harsh environments such as resistant to sulphates and acids.

### 1.2.4 Sodium Silicate ($Na_2SiO_3$)

When at high temperatures of about 1100°C and above, sand is fused with sodium carbonate then the Sodium silicates are formed. The product of above reaction is dissolved with high pressure steam and a semis-viscous liquid is formed which is known as water glass. Sodium Silicate in its physical state can be seen in Fig 1.4 below.

Sodium silicate or water glass alone cannot be used as activator to initiate pozzolanic reaction because it lacks enough activation potential. Therefore it is always used in addition to sodium hydroxide to improve alkalinity and improve the strength of specimens. Therefore, NaOH and $Na_2SiO_3$ are most common alkali activators used in Geopolymer concrete production.

Fig 1.4 Sample of Sodium Silicate

Commercially, sodium silicate can be found in different grades and states such as powdered form or liquid form, but liquid form has more tendencies to initiate reaction. It was found from the survey that $Na_2SiO_3$ having $SiO_2$ to $Na_2O$ mass ratio of 2.0 mixed with NaOH activator 24 hours prior to use offers better results.

### 1.2.5 Aggregates

As in Portland cement concrete, Aggregates in Geopolymer concrete have the same role to play. Around 80% of Geopolymer concrete like conventional concrete consists of aggregates only which are major factor that decide strength of specimen. The only point to be taken care of in case of aggregates is that it should not hinder formation of alumina-silicate gel in any possible way. If aggregates consist of cryptocrystalline silica, microcrystalline quartz or milk-glass (opaline), onyx and agate then it may be harmful for the reaction that occurs in Geopolymer concrete.

### 1.2.6 Super-plasticizer

Super-plasticizer is a chemical that can be used to improve the workability of the required mix by keeping the amount of water in the mix as low as possible. In case of Geopolymer concrete it also helps in maintaining the water to Geopolymer solids ratio which is discussed later in this report. Further in this study naphthalene based super-plasticizer from Fosroc chemicals (Fig 1.5) was used which is commercially available under the Marketing name as Fosroc Conplast SP 430.

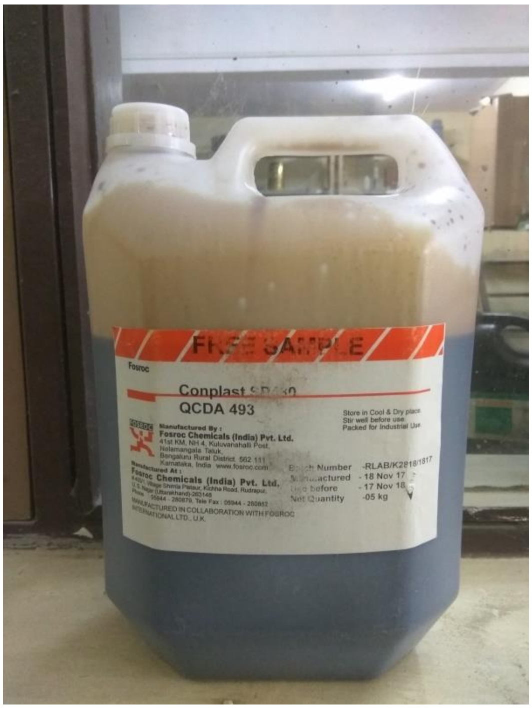



Fig 1.5 Naphthalene based Super-plasticizer

## 1.3 Problem Statement

Today one of the major problems that the world is facing is global warming and adverse change in climate. One of the major reasons for global warming is emission of greenhouse gases where carbon dioxide, oxides of nitrogen and sulphur stand on the top of the list. The total release of carbon dioxide all around the world is around 23 billion tonne per year. The figure is massive and scary in itself. Of the total carbon dioxide, the Portland cement industry constitutes 7% of it

The Portland cement industry uses 2 tonne of total raw material which in term produces 1 tonne of cement and approximately 0.87 tonne of carbon dioxide, around 3kg oxides of nitrogen, ground level smog, 0.4 kg of particulate matter having size as less as 10µ is emitted straight into the atmosphere. This particulate matter along with other minute particles is also harmful to respiratory system of humans and cause many health related issues. Now a days, cement industry has been working on improving the amount of carbon dioxide emissions by improving overall process technology and also by improving the efficiency of whole process. But no further improvement can be made in this area as the base process of production of Portland cement is calcination of limestone. Mining of limestone not only has adverse impact on pattern of land use but it also affects local water regimes and quality of air is also compromised. As the cement industry handle millions of tonnes of dry material therefore even 0.1% of this dry material when emitted into the atmosphere becomes very dangerous for humans and also for the environment. Hence dust emission is one of the massive issue that the cement industry is facing.

Talking about sustainability, cement industry cannot be categorised as sustainable industry as its raw material comes by mining which in turn affects the pattern of land use and product produced by this industry cannot be recycled. By keeping concept of waste management in mind, the by-product of thermal power plant such as fly ash and by product of steel industry such as slag can be used as a binder in place of cement and the energy utilised in production of cement can be reduced significantly. The energy along with raw material can be saved and also the greenhouse gases emitted into the atmosphere can be reduced up to the certain limit. In this manner we can turn the waste by-product into useful and valuable product such as Geopolymer concrete.

## 1.4 OBJECTIVES

1. To study change in compressive strength of Geopolymer Concrete by varying percentage of Fly Ash and GGBFS content.

2. To study 3, 7, 28, 56 days strength of resultant concrete.

3. To study strength characteristics with varying curing temperature.

4. To study the significance of Rest Period in Geopolymer concrete.

5. To utilise waste material and totally replace use of cement hence develop an eco-friendly concrete.

## 1.5 Scope of the Project Work

As production of Ordinary Portland cement releases a lot of carbon dioxide into the atmosphere and is one of the major reasons for global warming therefore there is need of some alternative eco-friendly material to save our environment. Geopolymer concrete can be an alternative to use of Ordinary Portland Cement, moreover GPC makes use of materials such as Fly Ash, Ground Granulate Blast Furnace Slag which are waste product released in huge amount by thermal power plants and steel industries. Use of Geopolymer Concrete will not only solve the problem of disposal of these industrial wastes but also restrict release of huge amount of carbon dioxide into the atmosphere. Moreover as these binding materials are waste products of Industries therefore they can be obtained in much lower cost as compared to cement, contributing to economy in Geopolymer concrete.

# CHAPTER 2

# LITERATURE REVIEW

In 1988 Joseph Davidovits who is a French material scientist introduced the term 'Geopolymer' to define the family of mineral binders which had same chemical composition as that of zeolites. The microstructure of the binder was found to be amorphous. Geopolymers are different from Portland cements as there is no hydration process in their case and there is no formation of calcium silicate hydrates in the matrix. The Geopolymer gains its structural strength by process of poly-condensation which is carried out between silica and alumina. The chief ingredients of Geopolymer concrete are the source material and the alkaline liquid. The selection of source material depends upon the content of silicon and aluminium present. The source material should be rich in both of the above minerals. Whereas alkaline liquids used are NaOH/KOH in addition to $Na_2SiO_3$. Other alumina-silicate materials such as zeolites, alumina-silicate gels etc. are different than Geopolymers. For e.g. alumina-silicate gel have less concentration of solids when compared with Geopolymerisation.

## Škvára František, Doležal Josef, Svoboda Pavel, Kopecký Lubomír, Pawlasová Simona, Lucuk Martin, Dvořáček Kamil, Beksa Martin, Myšková Lenka, Šulc Rostislav[2]

"*Concrete Based on Fly Ash Geopolymers*"

The authors of the above paper developed fly ash based Geopolymer concrete. The fly ash was collected locally from the Czech power plant. The Geopolymer concrete was tested for its different properties such as rheological properties, strength evolution, chemical composition, porosity and the interference caused by aggregates. It was found that there was no damage to specimens subjected to NaCl for even upto 720 days i.e. no corrosion was found. The maximum compressive strength that was observed in the research was found to be 70MPa when tested after 28 days. [2]

## Rangan B. V. [4]

*"Fly ash-based geopolymer concrete"*

The above research included wide range of study conducted on Geopolymer concrete. In this study specimens of reinforced Geopolymer concrete were casted and tested for different long term and short term properties. From the results it was found that the compressive strength of specimens for 7 days at elevated temperature was 58 MPa whereas for dry cured sample it was 45 MPa. The compressive strength for the steam cured specimen was found to be 56 MPa. [4]

## McDonald M., Thompson J. L. [6]

"*Sodium Silicate: A Binder for the 21st Century*"

In this study silicate chemistry and formulation were studied. They described the method for preparing sodium silicate binder. They stated that when discussing about sodium silicate as a binder, the most important property is weight ratio of $SiO_2$ to $Na_2O$. The most common ratio is found to be 3.2 which is adopted all around the world and helps in polymerisation process. They concluded that there are many varieties and grades of sodium silicate solution available in the market commercially and it is difficult to select appropriate type for particular research therefore the above paper can help a researcher in selecting suitable type of activator. [6]

## Pacheco-Torgal, F., Castro-Gomes, J., & Jalali, S. [3]

"*Alkali-Activated Binders: A Review*"

The above paper is a review paper on past work on Geopolymer concrete and alkali activated binders. The paper focuses on historical background, terminology and products of hydration. They said that the Portland cement has many disadvantages like it is susceptible to acid resistance, the low durability and high $CO_2$ emission into the atmosphere. Therefore there is need of alternate material such as Geopolymer concrete. It was said that the exact reaction that takes place in alkali activated binders is yet not known but it depends on the source material that is used and the type of alkali activators used to initiate the reaction. The product of reaction is zeolites as in case of polymers. They studied the step by step processes that take place in the reaction and stated that there are three main stages in this reaction, namely, dissolution, orientation which consists of oligomerisation and polymerisation and hardening which consists of gelisation and transformation into zeolite. [3]

## Fernández-Jiménez, A., Palomo, A., Pastor, J. Y., & Martin, A[7]

"*New Cementitious Materials Based on Alkali-Activated Fly Ash: Performance at High Temperatures*"

In this paper the authors studied the behaviour of alkali activated cement in terms of mechanical properties at elevated temperatures containing no OPC. In this study they conducted two types of mechanical tests to study properties of Geopolymer concrete at different temperatures. The results of this study showed that the Geopolymer concrete performed better than conventional concrete in all aspects. Very minute cracks were observed in new binder concrete. Therefore, it was concluded that alkali activated Geopolymer concrete has better thermal advantages when compared to Portland cement concrete.[7]

## Sofi Y. and Gull I. [5]

"*Experimental Investigation on Durability Properties of Fly Ash Based Geo Polymer Concrete"*

They found out different mix ratios for different grades of Geopolymer concrete and studied the compressive strength and parameters affecting compressive strength of GPC. They also studied the durability properties of GPC such as permability and resistance to acid attack. They concluded that the Geopolymer Concrete possess good compressive strength and good durability properties and also that M20 grade GPC can be formed by adopting nominal mix of 1:1.5:3. They concluded that high temperature of about 60°C is necessary for GPC to gain strength. They also concluded that the Geopolymer concrete has good future in precast industry. [5]

## Jamdade P. K., Kawade U. R. [13]

"*Evaluate Strength of Geopolymer concrete by using oven curing"*.

In this study the researchers developed Geopolymer concrete using alkaline liquids and studied the behaviour and strength characteristics of Geopolymer concrete at different curing temperatures such as 60°C, 90°C, 120°C. They found that the compressive strength of Geopolymer concrete increased with increase on temperature of curing. Polymerization process was improved by longer curing time as a result Geopolymer concrete of higher compressive strength was achieved.[13]

## Aravind A., M.P. Mathews [18]

"*Mechanical properties of Geopolymer concrete reinforced with steel fiber".*

Their main area of study was compressive strength and split tensile strength of Geopolymer Concrete. They performed several experiments by using the Box–Behnken experimental design which is a type of response surface methodology. Response surface methodology can be defined as empirical optimization technique which can be used to evaluate the relationship between the experimental outputs and factors called X1, X2, and X3. In order to obtain the results for this approach, variance has been analysed and calculated in order to analyse the accessibility of the model. They concluded that the strength of GPC increased with the increase in molarity of NaOH and longer curing time with temperature ranging between 60°C to 90°C also increased the compressive strength of GPC. Their main conclusion was that the split tensile strength of GPC increased with increase in amount of steel fiber. They also concluded that Box Behnken design can successfully be adopted. [18]

## Shah K. C., Parikh A.R., Parmar K.J. [14]

"*Strength parameters and durability of fly ash based Geopolymer concrete*."

In this research work Mr. Kamlesh first fixed different parameters such as AL to FA ratio, NaOH to $Na_2SiO_3$ ratio, molarity of solution and curing temperature. At the end of 28 days the compressive strength of GPC mix was found to be 52 MPa whereas compressive strength for OPC mix was found to be 46MPa. Therefore, difference of 6 MPa was noticed between GPC and conventional concrete under same duration of curing. Two mixes were prepared among which the first mix consisted of GPC whereas the second mix was OPC. Both the mixes had equal amount of cementatious material. They concluded that the compressive strength, split tensile strength and pull out strength of GPC mix were higher than that of OPC mix. They also concluded that the oven cured GPC had higher resistant to salt attack, acid attack and sulphate attack. Also minor increase in concrete mass was observed in case of GPC due to absorption of salt and sulphate acids. The test results also showed that the seven days strength of oven cured concrete is way higher than the specimen of concrete cured under ambient conditions. [14]

## Jaydeep S., Chakravarthy B. J.

"*Optimum mix for Geopolymer concrete using admixtures"*

The researchers tried to obtain optimum mix for Geopolymer concrete. They casted GPC cubes of size 150x150x150 (mm) and tested them at the end of 7days and 28 days. They adopted two type of curing for Geopolymer concrete that is direct sunlight curing and heat curing at higher temperature. They concluded that the compressive strength of Geopolymer concrete when cured in oven at higher temperature was significantly higher than that cured under direct sunlight. They also found that the strength increases as the molarity of alkaline solution increases.

## Sanni S.H., Khadiranaikar R. B.

"*Performance Of Alkaline Solutions On Grades Of Geopolymer Concrete"*.

They prepared four different mixes for different strength ranging between 30 MPa to 60 MPa. In whole research the molarity of NaOH was kept constant to 8 molar. The alkaline solutions used were NaOH and $Na_2SiO_3$. Different ratios were set for these alkaline solutions such as 2, 2.5, 3.0 and 3.5. Later the effect of ratio of alkaline solution on compressive strength was studied. Like all other investigations, the test specimens used here were of standard 150x150x150 (mm) size in addition with cylinders of size 100x200 (mm) were casted. They concluded that the workability of GPC increased with increase in amount of alkaline solution which is very obvious. They also found that as the ration of alkaline liquid increases so does the workability. They obtained GPC having compressive strength as high as 60 MPa and split tensile strength as 4.9 MPa. In their investigation they also said that the optimum ratio of alkaline liquid can be taken as 2.5.

## Joseph B., Mathew G.

"*Influence of aggregate content on the engineering properties of Geopolymer concrete"*

They studied the effect of aggregate content on engineering properties of Geopolymer concrete. They concluded that compressive strength increases with temperature upto 100°C. They also found that early strength of GPC can be achieved by heat curing for 24 hours at suitable temperature. It was found that about 96% of the 28 day strength under normal curing was achieved in 7 days when specimens were heat cured. They also found that the Modulus of Elasticity and Poissions Ratio of GPC can be brought near to or even higher than in case of ordinary concrete.

## Laskar A.I., Bhattacharjee R.

"*Effect of Plasticizer and Super-plasticizer on Workability of Fly Ash Based Geopolymer Concrete"*

In this study they used two type of super-plasticizer among which the first one was Lignin based and the second one was polycarboxylic ether based super-plasticizer. They concluded that when the molarity of alkaline solution was below 4M, the water reducer helped in increasing the slump of GPC which was measured using slump cone. However, at higher molarity of Alkaline solution i.e. above 4M the dosage of super-plasticizer had adverse effect on GPC. In both the cases the Lignin based super-plasticizer was found to be more effective. But it was found that at dosage of above 1.5% segregation of concrete was observed.

Davidovits [1988] recommended that a basic fluid could be utilized to respond with the silicon (Si) and the aluminium (Al) in a source material of topographical root or in industries waste material, for example, fly ash, slag and rice husk fiery remains to create folios. Since the reaction that happens for this situation is a polymerization procedure, he instituted the term "Geopolymer". Geopolymer concrete will be concrete which does not use any OPC Cement in its creation. Geopolymer concrete is being examined widely and demonstrates guarantee as a substitute to Portland cement concrete. Now the time has come when the research, from its chemical origin, has shifted to its practical implications and commercial adaption. [1]

While talking about Geopolymer concrete, it has two main constituents, namely the source material and the alkaline liquid. The silicon (Si) and the aluminium (Al) should be the main contents of the source material. The source material could be kaolinite, clays, etc. which occurs naturally or alternatively, one can also use industrial by-product materials such as silica fume, slag, fly ash, rice-husk ash, red mud, etc as source materials. There are different factors on which choice of selecting source material depends such as material should be readily and easily available, cost, specific demand as required by the end user and type of application. Sodium or potassium based soluble alkali metals are used as the alkaline liquids.

The most common alkaline liquid used in Geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.[1]

Mostly low-calcium fly ash is favoured over high calcium fly ash as a source material in Geopolymer concrete. High amount of calcium is present in fly ash can alter the micro structure of Geopolymer concrete and can also obstruct the polymerization process. [10]

## Mixture Proportions of Geopolymer Concrete

The binder acts as the major difference between Geopolymer concrete and conventional concrete. The contents of low calcium fly ash such as silicon and aluminium oxides along with alkaline liquid react with each other and as a result form a mortar known as Geopolymer paste that acts as a binder and holds together all constituents of concrete. The percentage mass ratio for coarse and fine aggregate in Geopolymer concrete is same as that of Portland cement concrete. All other properties and requirements for preparing Geopolymer concrete are same as required for conventional concrete such as strength, grading and angularity of required aggregates. Thus the methods those are already available for designing conventional concrete can be readily used for designing Geopolymer concrete mix.

The past studies on Geopolymer concrete show that the workability and compressive strength of GPC are prejudiced by the properties of material that form part of Geopolymer paste and their respective proportions. Some of the research results have shown the following considerations:

- High compressive strength was observed with higher molarity of sodium hydroxide solution used in Geopolymer concrete.
- High compressive strength was observed with higher ratio of sodium silicate solution - to - sodium hydroxide solution used in Geopolymer concrete.
- As the amount of the water in the mixture increases the slump for the Geopolymer concrete also increases, However for the lower slump values super plasticizer may be added.
- The strength of Geopolymer concrete decreases with increase in molar ratio of H2O - to - Na2O.

## Geopolymer Concrete Properties

It was observed that the strength and the behaviour of reinforced structural members made up of Geopolymer concrete were similar to that of conventional concrete. Same was observed for elastic properties of GPC structural members. [Sofi et al, 2007; Chang, 2009].

It was also observed that heat cured specimens of Geopolymer concrete had excellent engineering properties such as greater resistance to sulphate attack, minimal drying shrinkage and better acid resistance. [Wallah and Rangan, 2006].

It was found that in case of Geopolymer concrete the failure mode and behaviour pattern for concrete columns and beams is same as that in case of conventional concrete. Test results revealed that the practices used in calculation of conventional concrete can also be used for reinforced Geopolymer concrete columns. Elastic bending theory along with the serviceability design provision as mentioned in the standards were used to calculate the mid-span deflection at service load for reinforced beams made up of Geopolymer concrete. Good interrelationship between test and deflections was found.

It was found that the Geopolymer concrete had stronger bond with the reinforcement bar as compared to conventional concrete. The design steps available in building codes and standards can be used to calculate the shear and bond strength of reinforcement provided in Geopolymer concrete.

Therefore, the current standards and codes as used for conventional OPC concrete can be used to design structural members made up of reinforced Geopolymer concrete. Geopolymer concrete not only has good strength characteristics but it also offers good durability and good fire resistant properties therefore it can be used in structural applications as well. Since Geopolymer concrete requires high temperature curing to gain high strength therefore other than in-situ applications it can be good alternative for precast industries.

## Durability of Geopolymer Concrete

Durability can be termed as the ability of concrete to resist chemical attack, weathering action, and abrasion. In whole of the action, the engineering properties of the concrete shall remain same. Since, different type of concrete has different applications therefore the durability of concrete is not an absolute property and depends on concrete use. The durability of concrete has been evaluated in this study through parameters related to the permeability and chemical attack.

**Hardjito D., Wallah S. E., Sumajouw D. M., Rangan B. V.**

*"Factors influencing the compressive strength of fly ash-based geopolymer concrete"*

The authors 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.

**Song, X. J., Marosszeky, M., Brungs, M., & Munn, R.**

*"Durability of fly ash based geopolymer concrete against sulphuric acid attack"*

In this experimental study has exposed several facts about resistance to chloride attack and sulphate attack in Geopolymer concrete. In observations it was noticed that with exposure to sulphuric acid, the Geopolymer concrete showed no damage other than development of some minute cracks on its surface where on the other hand conventional concrete suffered from severe damage.

**Olivia M., Nikraz H.**

"*Water penetrability of low calcium fly ash geopolymer concrete"*

The authors have explored on the properties of water penetrability of ASTM CLASS F fly ash based Geopolymer concrete. In their results they concluded that the fly ash based Geopolymer concrete had 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. Anurag Mishra et al (2008) have carried out an experimental study on the effect of concentration of alkaline liquid and curing time on strength and water absorption of Geopolymer concrete. They also found that as the molarity of alkaline solution i.e. NaOH increases from 8 molar to 16 molar the compressive strength also increases. Same was observed for tensile strength of Geopolymer concrete. They also concluded that as the curing time for the Geopolymer concrete increases the compressive strength also increases.

**Ranganath R. V., Saleh M.**

*"Some optimal values in geopolymer concrete incorporating fly ash"*

The authors 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). In their study they stated that if we increase the amount of water in the mix the proportion of fly ash is also mandatory to be increased in order to achieve higher compressive strength. Also they stated in their study that for given content of fly ash in the mix the increases in proportion of alkaline solution will not contribute to any additional compressive strength. Lastly they stated that the prolonged curing time for Geopolymer concrete will add extra strength to it but curing time longer than 20 hours will not add any significant strength to the Geopolymer concrete specimens.

## Adam A.

*"Strength and durability properties of alkali activated slag and fly ash-based geopolymer concrete"*

In this study the strength and durability of Fly ash based and Alkali activated Slag based Geopolymer Concrete in response to chemical attack was found out. In this study they exposed the specimens to chemicals by different methods such as chloride ponding. They also found out the rapid chloride permeability and depth of carbonation in their survey. They used SEM i.e. Scanning Electron Microscopy and EDAX i.e. Energy Dispersive X-ray Spectroscopy to conduct the microstructure studies. In their result they concluded that the Fly Ash based and Alkali Activated Slag based Geopolymer concrete has similar properties to that of OPC based and Slag based conventional concrete.

## Deevasan K. K., Ranganath R. V

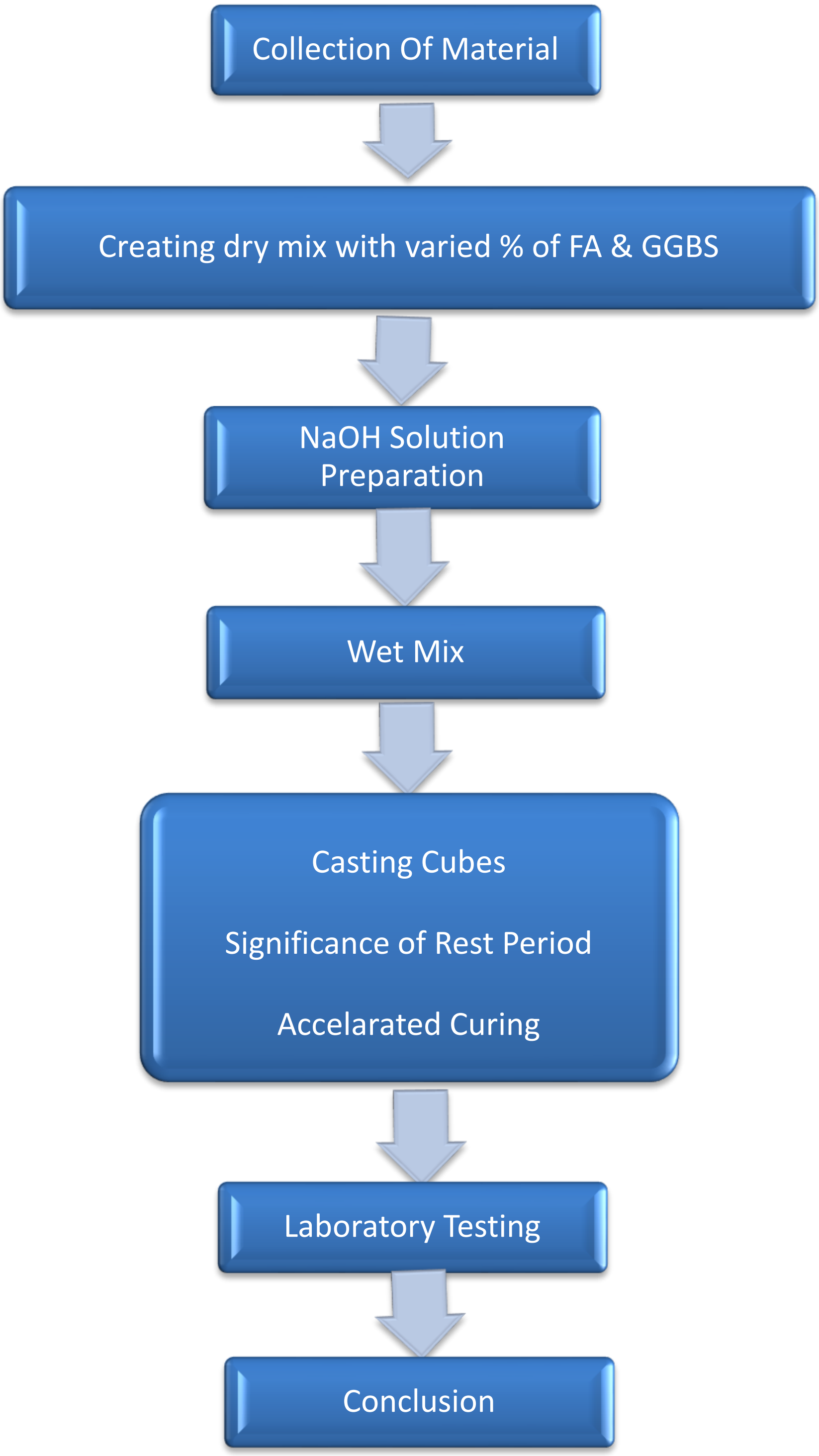
"Geopolymer concrete using industrial by-products"

In his study his main focus was on use of industrial waste in order to develop eco-friendly material. Relatively large quantities of alkali effluents are being produced from paper and other poly-fibre industries worldwide. In his study he replaced alkali solution in Geopolymer concrete, partially with the by-product of fibre industry. The test results of this study showed that use of such industrial effluents can be made successfully by strengthening them with alkali solutions such as sodium hydroxide and sodium silicate solution. Eventually Geopolymer concrete having compressive strength of 50MPa can be achieved.

# CHAPTER 3

# METHODOLOGY

Material was collected from suitable location and was sent to laboratory to know the chemical composition of different materials. After the results were obtained, materials were finalised to use in GPC for e.g. Fly Ash was tested to know whether the fly ash is Class C fly ash or Class F fly ash. Similarly, properties of GGBS, Sodium Silicate were also found out.



# CHAPTER 4

# PLANNING SCHEDULE

Collection of material

1. Collection of Fly Ash and GGBFS.
2. Collection of Sodium Hydroxide (NaOH) in pallet form.
3. Collection of Sodium Silicate and Super-plasticizer.

Creating Dry Mix with varied percentage of Fly Ash and GGBFS

Commercially available Fly Ash and GGBS will be collected and suitable percentages of both the material will be fixed. For e.g. $F_{60}G_{40,}$ $F_{70}G_{30}$, $F_{80}G_{20}$ The material will be mixed to obtain homogeneous dry mix.

NaOH Solution Preparation

The solution will be having 8M molarity. For this suitable amount of NaOH in pellet form will be dissolved in distilled water.

Wet Mix

NaOH along with Sodium Silicate, Super Plasticizer and distilled water will be mixed separately in a different container to obtain a wet mix.

Then both the wet mix and dry mix will be mixed together to obtain a homogeneous Geopolymer concrete.

Casting of Cubes and Rest Period

Five sets of three cubes will be casted having different mix proportion. After Final setting time is achieved, one set of cubes will be given rest period of three days to learn the significance of Rest Period before curing in Geopolymer Concrete.

Accelerated Curing

Remaining set of cubes will be kept for accelerated curing at suitable elevated temperature in dry oven.

Laboratory Testing

1. All set of cubes will be checked for their compressive strength under CTM.
2. Graphs will be computed out of different proportion of material and compressive strengths obtained

Conclusion

After computing all the results obtained and information from different graphs certain conclusion will be made which will give us the idea about behaviour of compressive strength with varied percentage of FA and GGBS content and also the behaviour of GC with respect to rest period and curing temperature.

# CHAPTER 5

# MATERIAL USED AND THEIR PROPERTIES

## 5.1 Fly Ash

Fly Ash was obtained from NTPC Thermal Power Plant, Dadri located in Gautam Budh Nagar district of Uttar Pradesh about 25 km from Ghaziabad and about 9 km from Dadri. The coal for the power plant is sourced from Piparwar Mines, Jharkhand.

The sample of Fly Ash was submitted to MCB Testing Laboratory, Bahadurgarh, Haryana to know its Physical and Chemical Properties. The table below illustrates the properties of Fly Ash:-

**Table 5.1:** Properties and composition of Fly Ash used in mix

| Sr. No. | Parameters | Test Results | Requirements as in IS:3812 (P-1):2013 (SPFA) | Method of test w.r.t. IS. |
|---|---|---|---|---|
| **A.** | **Physical Properties :-** | | | |
| 1. | Specific Gravity | 2.21 | ----- | 1727:1967 |
| 2. | Fineness ($m^2$/kg) | 360 | 320 Min | 1727:1967 |
| 3. | Particles Retained in 45µ sieve | 20.8 | 34 Max | 1727:1967 |
| 4. | Lime Reactivity, N/$mm^2$ | 5.1 | 4.5 Min | 1727:1967 |
| 5. | Compressive Strength at 28 days, % by PCM | 89.6 | 80% of the corresponding PCM cubes, Min | 1727:1967 |
| 6. | Soundness by Autoclave test expansion, % | 0.052 | 0.8 Max | 1727:1967 |
| **B.** | **Chemical Properties:-** | | | |
| 1. | $SiO_2$+$Al_2O_3$+$Fe_2O_3$ % by mass | 90.6 | 70.0 Min | 1727:1967 |
| 2. | $SiO_2$% by mass | 48.2 | 35.0 Min | 1727:1967 |
| 3. | Reactive Silica % by mass | 27.8 | 20.0 Min | 3812 (P-1):2003 |
| 4. | MgO % by mass | 2.5 | 5.0 Max | 1727:1967 |

| | | | | |
|---|---|---|---|---|
| 5. | Total Sulphur as $SO_3$, % by mass | 1.2 | 3.0 Max | 1727:1967 |
| 6. | Total Chlorides, % by mass | 0.017 | 0.05 Max | 4032:1985 |
| 7. | Loss on Ignition, % by mass | 1.1 | 5.0 Max | 1727:1967 |

The above test parameters, sample complies with requirements of IS: 3812(P-1):2013(SPFA). Also the above fly ash complies with ASTM C618 Low calcium Fly Ash and can be called as Class F Fly Ash.

## 5.2 GGBS:-

Commercially available GGBS of JSW brand was obtained having following chemical properties:-

**Table 5.2:** Chemical Composition of Ground Granulated Blast Furnace Slag used in mix

| **PARAMETER** | **JSW GGBS** | **As Per IS: 12089 – 1987 (Reaffirmed 2008)** |
|---|---|---|
| Cao | 37.34% | --- |
| $Al_2O_3$ | 14.42% | --- |
| $FE_2O_3$ | 1.11% | --- |
| $SiO_2$ | 37.73% | ---` |
| Magnesium Oxide (Mgo) | 8.71% | Max. 17.0%` |
| Manganese Oxide (MnO) | 0.02% | Max. 5.5% |
| Sulphide Sulphur | 0.39% | Max. 2.0% |
| Loss On Ignition | 1.41% | --- |

The results showed that the presence of $SiO_2$ and $Al_2O_3$ in considerable amount confirmed that JSW GGBS can be used to partially replace Fly Ash. However, high amount of CaO may cause hindrance in polymerization of GPC.

## 5.3 Sodium Silicate Solution :-

Commercially available *Loba Sodium Silicate Solution Extra Pure* was obtained having following physical and chemical properties :-

**Table 5.3 :** Properties and composition of Sodium Silicate

| | | | | | |
|---|---|---|---|---|---|
| 1. | Physical state at $20^0$C | Liquid | 7. | Colour | Opaque Viscous |
| 2. | PH value | 11.2 | 8. | Melting point/Frezing point [$^0$C] | 0.6 $^0$C |
| 3. | Boiling point [$^0$C] | $100^0$C | 9. | Evaporation rate | >1 |
| 4. | Vapour Pressure [$20^0$C] | 14mm Hg (@$20^0$C) | 10. | Vapour Pressure mm/Hg | 14mm Hg (@$20^0$C) |
| 5. | Vapour density | 0.7 | 11. | Density [g/cm$^3$] | 1.39 |
| 6. | Solubility in water [% weight] | Soluble in water | | | |

Specification :-

**Table 5.4 :** Specification of Loba Sodium Silicate

| | |
|---|---|
| Appearance | Clear colorless solution |
| Assay (as $Na_2O$) | 7.5-8.5% |
| Assay (as $SiO_2$) | 25-28% |
| Free alkali | Passes test |

Clearly, from the above table, $Na_2O$ : $SiO_2$ ratio can be seen to have anywhere between 2.9 to 3.73 which is considered to be an important parameter and affects ultimate strength of GPC.

## 5.4 Sodium Hydroxide and Preparation of Solution of Desired Molarity :-

Sodium Hydroxide is a common chemical and can be obtained easily in any chemical shop. In this study, Sodium Hydroxide obtained was in pallet form. To prepare solution of desired molarity, the calculation is shown below taking example to prepare 16M solution :-

Different type of units are used to express concentration of a solution. The most common unit of expressing concentration of a solution is molarity. *Molarity (M)* is the concentration of a solution expressed as the number of moles of solute per litre of solution:

$$\text{Molarity} = \frac{(\text{Number of moles of solute})}{\text{Volume of solution in litre}}$$

For example, if we prepare 1M solution of NaOH then in every 1 litre of solution it will consist of 1 mole of sodium hydroxide. Therefore, wherever M is written it denotes mol/L.

## To prepare 1 litre of 16 molar solution

Molarity to be achieved = 8 mol/litre

Required Volume of solution = 1 litre

8 mol/l = number of moles of solute / 1 litre

Number of moles of solute = 8 mol/l * 1 l

Therefore, Number of moles = 8 mole

To prepare one litre of one molar solution of sodium hydroxide we need one mole of sodium hydroxide.

1 mol of Sodium hydroxide = 40 g of NaOH

Therefore amount of NaOH to be dissolved in 1 litre of water to get one litre of 8 molar solution.

= 40g * 8 = 320g of NaOH

## 5.5 Super-plasticizer:-

The type of plasticizers used in study was obtained from Fosroc Chemicals Gujrat, India, having brand name as Conplast SP 430. This super-plasticizer is Napthalene based rather than new generation super-plasticizer which is polycarboxylate based super-plasticizer used in concrete industry. It was found from the literature review that for development of Geopolymer Concrete, Napthalene based super-plasticizer is more suitable hence same was used in this study.

### 5.5.1 Description:

**Conplast SP 430**

Description

Conplast SP430 G8 is made up of Sulphonated Napthalene Polymers. Conplast SP430 G8 is commercially supplied as a brown liquid. This super-plasticizer is instantly dispersible in water.

Conplast SP430 G8 has been specially formulated to give high water reductions upto 25% without loss of workability or to produce high quality concrete of reduced permeability.

### 5.5.2 Uses

1. To produce pumpable concrete
2. To produce high strength, high grade concrete M30 & above by substantial reduction in water resulting in low permeability and high early strength.
3. To produce high workability concrete requiring little or no vibration during placing.

### 5.5.3 Advantages

1. Improved workability - Easier, quicker placing and compaction.
2. Increased strength - Provides high early strength for precast concrete with the advantage of higher water reduction ability.
3. Improved quality - Denser, close textured concrete with reduced porosity and hence more durable.
4. Higher cohesion - Risk of segregation and bleeding minimised; thus aids pumping of concrete
5. Chloride free - Safe in prestressed concrete and with sulphate resisting cements and marine aggregates.

### 5.5.4 Properties:-

**Table 4.5:** Properties of Super-plasticizer

| | |
|---|---|
| Specific gravity | 1.24 to 1.26 * |
| Chloride content | Nil to IS:456 * |
| Air entrainment | Approx. 1% additional air is entrained |

### 5.5.5 Application instructions

**Dosage**

The optimum dosage is best determined by site trials with the concrete mix which enables the effects of workability, strength gain or cement reduction to be measured. Site trials with Conplast SP430 G8 should always be compared with mix containing no admixture. As a guide, the rate of addition is generally in the range of 0.5 - 2.0 litres /100 kg cement.

**Over dosing**

An over dose of double the recommended amount of Conplast SP430 G8 will result in very high workability and some retardation of setting time will occur. However, the ultimate compressive strength will not be impaired.

# CHAPTER 6

# LABORATORY EXPERIMENTS

## 6.1 Determination of water absorption and specific gravity for coarse aggregates:-

**6.1.1 Aim:** To find the water absorption capacity and specific gravity of coarse aggregates to be used in this project.

**6.1.2 Apparatus Required:**

1. A wired basket having mesh of size not more than 6.3mm with suitable hooks or hangers to suspend the basket from the weigh balance.
2. Heat Oven required to maintain temperature above 100°C, preferably 110°C.
3. A bucket or a container filled with water in which wired basket is to be immersed. The depth of this bucket should be such that wired basket should completely immerse in water when filled with coarse aggregates.
4. An airtight container having capacity similar to the basket described in (1).
5. A spring balance or digital balance is required which can measure weight between 0.5g to 5kg. It should be of such type that when wired basket is completely immersed in water it should be able to weigh the basket weight in immersed condition.
6. Dry clothes to bring the aggregates in surface dry condition and a tray to weigh the aggregates on balance.

**6.1.3 Procedure:**

The aggregate to be tested is washed properly so that any dust on the surface is removed and then any excess water is drained and around 2 kg of aggregate is placed inside the wired basket and the basket is immersed in the bucket filled with water. The wired basket should be immersed in such a way that it has a cover of at least 50mm of water at the top. The temperature of the water should be maintained anywhere between 20° to 30°C. The entrapped air between the aggregates is removed by lifting the basket up and down several times and after the entrapped air is removed the basket along with the aggregates is kept immersed in water filled bucket for period of 24 hours.

After 24 hours, by the time when aggregate has absorbed water, the basket along with aggregates is weighed while immersed in water by suspending it with digital weigh balance. The weight is noted down and marked as W1 g.

Fig 6.1: Weight of aggregate along with wired basket immersed in water filled bucket

After this the basket and aggregates are removed from the water and the excess surface water is allowed to be drained. Then the aggregate is transferred onto a dry cloth and aggregates are rubbed with the cloth to bring them into the surface dry condition. The wired basket is again returned into the water filled bucket and air bubbles are removed by shaking the basket in water and then the weight of empty basket in immersed condition is noted down and marked as W2 g.

By the time the aggregate transferred onto the absorbent cloth have come onto saturated surface dry condition i.e. no further water/moisture can be removed with help of cloth. At this point, the surface dried aggregate is weighed on a weigh balance by transferring it onto a tray. The tray should be tarred first or the weight of tray should be subtracted separately from the total weight to get the weight of SSD aggregates. This weight of SSD aggregates is marked as W3 g. Then the Aggregate along with the tray is kept into the oven where the temperature is set to 110°C for 24 hours. Next day, the tray is removed, cooled down and it is then weighed and marked as W4 g.

Similarly, at least 2 observations are to be carried out.

### 6.1.4 Calculation:

Weight of wired basket + saturated aggregate immersed in water = W1 g

Weight of wired basket immersed in water = W2 g

Therefore, Weight of saturated aggregate in water = W1 – W2 = Ws g.

Weight of saturated surface dry aggregate = W3 g.

Weight of water equal to the volume of the aggregate = W3 – Ws

Weight of oven dried aggregate = W4 g.

**Observation:**

| | 7mm | 14mm | 20mm |
|---|---|---|---|
| W1 | 1665 | 4080 | 2370 |
| W2 | 535 | 535 | 535 |
| Ws | 1130 | 3545 | 1835 |
| W3 | 1803 | 3377 | 2996 |
| W3-Ws | 673 | 168 | 1161 |
| W4 | 1785 | 3316 | 1785 |

**1.** Water Absorption $= \frac{[(W3-W4)*100]}{W4}$

For 7 mm aggregate, Water absorption = 1.0084%

For 12 mm aggregate, Water absorption = 1.83%

For 20 mm aggregate, Water absorption = 0.9774%

**2.** Specific Gravity $= \frac{(\text{Dry weight of aggregate})}{Weight\ of\ equal\ volume\ of\ water\ as\ that\ of\ aggregates}$

$$= \frac{W4}{W4-Ws} \quad = \frac{W4}{W3-(W1-W2)}$$

For 7 mm aggregate, Specific Gravity = 2.6523

For 12 mm aggregate, Specific Gravity = 2.67

For 20 mm aggregate, Specific Gravity = 2.555

**Limits**: The specific gravity of aggregate ranges should be between 2.5 to 3.0. The water absorption of aggregates should be between 0.1 to 2.0%

## 6.2 Determination of water absorption and specific gravity for coarse aggregates:-

**6.2.1 Aim:** To find the water absorption capacity and specific gravity of coarse aggregates to be used in this project.

**6.2.2 Apparatus Required:**

1. Pycnometer having capacity of about 1 litre having a conical top made up of metal. The top at its apex should have a hole of 6mm diameter. The top should be water tight such that water inside pycnometer should not leak out.

Fig 6.2: Pycnometer

2. A weigh balance having ability to measure weight between 0.5g to 3.0 kg. The weigh balance should be of such a type that it should be able to weigh the pycnometer filled with water and sand.
3. A heat oven to maintain temperature of above 100°C. Preferably 110°C.
4. A tray to weigh and keep the sand inside oven.
5. Agitating rod, funnel and a set of filter paper.

**6.2.3 Procedure:**

1 kg sample of sand to be tested for the above listed properties shall be collected in a tray and should be filled with distilled water. It should be kept in mind that the sand to be tested must pass from IS 4.75mm sieve and the w=temperature of distilled water shall be anywhere between 20°C to 30°C. After the sand has been immersed the sand

should be shaken gently with help of agitating rod. This is done in order to escape out the air bubbles entrapped with in the sand. Leave the sample in immersed condition for 24 hours.

Next day, the water from the tray should be drained very carefully by passing it through a filter paper. Any sand particles that are entrapped in the filter paper shall be returned back into the tray. After this the saturated sand should be stirred with agitating rod for time till the sand achieves surface dry condition and no extra water is seen on the sample. This can be made out from observing the free movement of each sand particle without actually sticking with each other due to excess water. Then the saturated surface dry sand shall be weighed and marked as A.

Then this sample shall be introduced into a pycnometer filled with distilled water. This will emit out any air entrapped in the sand. The pycnometer shall also be rotated around its axis to take care of any extra air bubbles and make sure that they are emitted out. Then the pycnometer shall be completely filled with distilled water up to its apex. Any water droplets sticking to the pycnometer on outer surface shall be wiped off and whole assembly shall be weighed and marked as B.

Then all of the sand along with water shall be transferred from pycnometer to the tray. Care shall be taken that whole sand particles are transferred. Then the pycnometer should be filled with distilled water again up to its apex like before and weighed and marked as C.

Then water contained in the tray having sample shall be drained off by allowing it to pass through filter paper and again any particles of aggregate entrapped in filter paper shall be returned into the tray. The sample along with the tray shall be then placed inside an oven where temperature of 110°C shall be maintained. Then the sand shall be weighed and marked as D.

At least 2 observations shall be made.

**6.2.4 Calculations**:

1. Water Absorption = $\frac{A-D}{D}$ x100

= $\frac{500-496}{496}$ x 100 = 0.80%

Therefore water absorption of fine aggregate is 0.80%

**2.** Specific Gravity $= \frac{D}{A-(B-C)}$

$= \frac{496}{500-(1826-1514)}$ = 2.64

Therefore the specific gravity of fine aggregate is 2.64.

# CHAPTER 7

# MIX DESIGN AND IMPORTANT FACTORS

## 7.1 Factors affecting strength of Geopolymer Concrete

The properties of GPC are influenced by number of factors and parameters that interrelate with each other in unknown manner. Unlike OPC based conventional concrete, the strength of Geopolymer concrete does not solely depends on water to cement ratio. From the above literature it was found that the there are four different and major factors which affect the development of strength in Geopolymer concrete. All those factors are mentioned and described further as follows.

### 7.1.1. Water to Geopolymer Solids Ratio (W: GPS)

Since there is no strong literature available on design of Geopolymer concrete therefore a parameter called water to Geopolymer solids ratio was introduced.[15] This parameter is used by many researchers having interest in Geopolymer concrete.

In this parameter the W stands for the total water that is contributed into the mix by both the alkaline solutions (i.e. NaOH Solution and Sodium Silicate Solution) and also any extra water added into the mix to improve the workability. On other side, GPS in the parameter stands for Geopolymer Solids that are from base material such as fly ash and GGBS, sodium hydroxide solids and sodium silicate solids.

The results have shown that as the W: GPS decreases the compressive strength for GPC increases. However the workability of the GPC mixes decreases [16, 15,]. Later in this project the statement was found to be true.

### 7.1.2. Alkaline Liquid to Fly Ash Ratio (AL: FA)

The second important parameter in GPC is the ratio of alkaline liquids to Fly Ash. From the literature survey it was found that as this ratio increases the compressive strength of Geopolymer concrete also increases. [11] Both the above mentioned ratios are also inter-related with each other.

### 7.1.3. Ratio of Sodium Silicate to Sodium Hydroxide Solution ($Na_2SiO_3$: NaOH)

The alkaline liquid is one of the most important constituent in Geopolymer concrete since the fly ash or GGBS do not possess self-binding properties. Therefore it is alkaline solution only that will activate the silica and alumina in order to initiate polymerization process. The authors in the above literature survey have agreed that as this ratio increases the strength of Geopolymer concrete also increases. [17, 16, 11]. Since the Sodium Hydroxide is costlier than Sodium Silicate therefore the research on this very column is limited and has not been carried out on ratios above 2.5.

### 7.1.4. Molar Concentration of Sodium Hydroxide

The fourth important parameter that largely affects the strength development in Geopolymer concrete is the molarity of sodium hydroxide. This parameter is considered in all of the researches and the molarity of sodium hydroxide solution is selected according to the strength to be achieved and budget of the research since Sodium Hydroxide is one of the most costly constituent of Geopolymer concrete. The results in the above studies have shown that the compressive strength of Geopolymer Concrete increases with the increase in molarity of Sodium Hydroxide solution. [17, 15]. Again due to the high cost of Sodium Hydroxide pellets the behaviour of Geopolymer Concrete is not investigated on molarity above 16M.

## 7.2 Mix Design Procedure:-

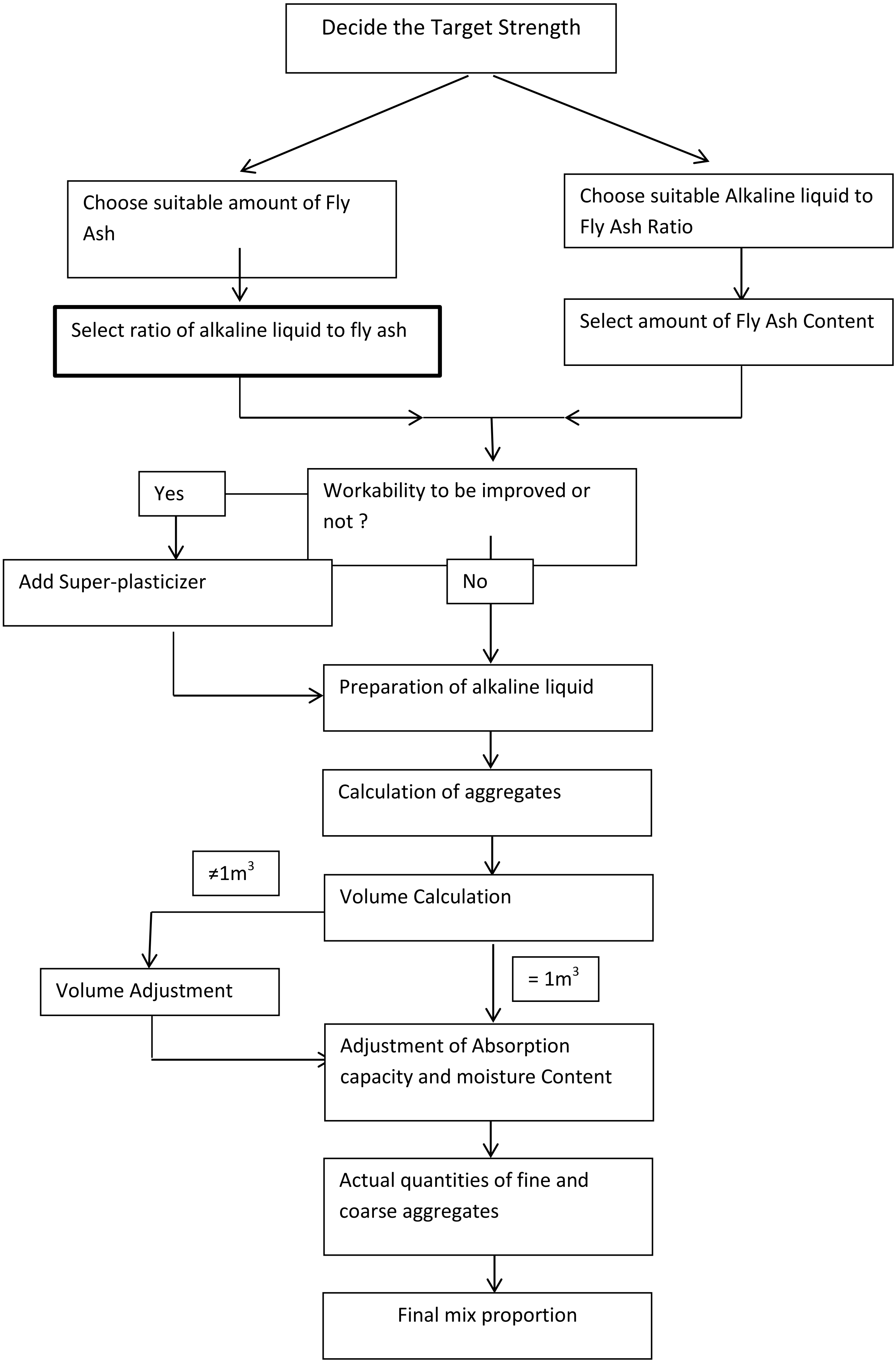



Fig. 7.1: Flow chart showing mix design procedure

## 7.3 Mix Design Calculation:

1. Let the unit weight of concrete = 2400 $Kg/m^3$

2. Mass of aggregate = 0.77 x 2400

= 1848 $Kg/m^3$

Out of which,

15% 20mm Aggregate = 0.15 x 1848

= 277.2 $Kg/m^3$

20% 14mm Aggregate = 0.20x1848

=369.6 $Kg/m^3$

35% 7 mm Aggregate = 0.35 x 1848

=646.8 $Kg/m^3$

30% Fine Sand = 0.30 x 1848

= 554.4 $Kg/m^3$

3. Mass of Fly Ash and Alkaline Liquid

= 2400 – 1848

=552$Kg/m^3$

Take AL to FA ratio = 0.35

AL / FA = 0.35

(AL + FA) / FA = (0.35 + 1) / 1

552 / FA = 1.35 / 1

FA = 552 / 1.35

= 408.88 i.e. 408 $kg/m^3$

∴ AL = 552-408.88

=143.11 i.e. 144 kg/$m^3$

Take $Na_2SiO_3$: NaOH = 2.5: 1

Therefore NaOH = 41.14 kg/$m^3$ and, $Na_2SiO_3$ = 103 kg/$m^3$

4. Sodium Silicate Solution having water as 66.5%

Therefore, water per cubic meter from $Na_2SiO_3$ = (66.5 / 100) x 103

= 68.495 Kg

Geopolymer Solids in mix = 103-68.496 =34.505

5. Also, Water per cubic meter from sodium hydroxide solution

26 % Solids and 74% water, therefore,

Solids = (26/100) x 41.14 =10.6964 kg/$m^3$

Water = (74/100) x 41.44 =30.7436 kg/$m^3$

Total mass of water = 68.495 + 30.7436 = 99.2386 kg/$m^3$

It should be kept in mind that while mixing the concrete water in surface dry condition shall be used therefore water absorbed by aggregate should also be considered while taking out total mass of water in Geopolymer Concrete Mix.

Total mass of solids = ( FA + $Na_2SiO_3$ + NaOH ) Solids

=408 + 34.505 + 10.6964

= 453.20

Therefore the water to Geopolymer solids ratio comes out to be

= 99.2386 / 453.20 = 0.218

Super-plasticizer can be used as 3% to 5% of mass of fly ash.

The above mix design was used to develop 5 different mixes of Geopolymer Concrete.

In first mix, the content of fly ash and GGBS was kept to be $F_{80}G_{20}$, Similarly for the second mix content of fly ash and GGBS was kept $F_{60}G_{40}$ and for the third mix it was kept $F_{40}G_{60}$. Firstly these three mixes were casted and then tested to know the effect of percentage of fly ash and GGBS on compressive strength of Geopolymer concrete.

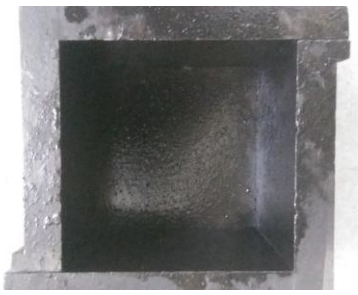
Twelve specimen of each mix were casted to know the compressive strength at 3, 7, 28 and 56 days.

After these mixes were tested, $4^{th}$ mix and $5^{th}$ mix was developed using the optimum mix obtained from the above results. These two mixes were casted to know the change in compressive strength of GPC under Ambient curing and Oven dry curing and also to check the change in compressive strength and behaviour of GPC under effect of given Rest Period.

**7.4 Size of Test Specimens: -** Test specimens cubical in shape shall be 15 X 15 X 15 cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10 cm cubes may be used as an alternative. Cubes were casted to perform check on compressive strength of Geopolymer Concrete.

**7.5 Preparation of Moulds:** Prier to mixing and casting of specimen one of the most important and time consuming work is preparation of moulds. Moulds should be prepared such that all surfaces of moulds are cleaned and oiled properly [fig 7.2 (a) and (b)] and all the bolts are tightened so that it shall not allow any leakage of mortar.

(a)



(b)

Fig 7.2: Surface cleaned and Oiled Moulds

Special care should be taken while applying oil. Excessive amount of oil can lead to presence of bug holes on the surface of concrete after demoulding. A suitable brush or cloth should be used while applying oil on the surface of moulds. Also type of oil used is very important as the purpose of oil is to provide necessary lubrication so that concrete may not stick to the surface of moulds and it should be easy to demould the specimen. If suitable oil is not used then it may break your specimens and whole procedure is to be repeated again. The oil used in this study was Waste Black Oil easily available at any workshop at no cost or very minimal charges at it shall not allow any leakage of mortar.

**7.6 Mixing:** All of the mixing of concrete was done by hand mixing only. All of the ingredients of Geopolymer Concrete like Fly Ash, GGBS, Coarse Aggregate and Fine Aggregate were first weighed as per mix design proportion and then mixed on floor which was prepared for saturated surface dry condition so that floor shall not absorb any water from the mix neither shall it release more water into the mix.

Mixing of Geopolymer concrete was carried out in two steps:

1. Dry Mix

2. Wet Mix

**7.6.1 Dry Mix:-** Firstly, fly ash, GGBS, coarse aggregate, fine aggregate were mixed thoroughly to obtain homogeneous mixture of GPC.

Fig 7.3: Constituents of Geopolymer concrete

Fig 7.4: Dry mixture

**7.6.2 Wet Mix:** Side by side, wet mix was prepared which consisted of sodium silicate solution, sodium hydroxide solution, super-plasticizer and water as specified in mix design in suitable proportion.

Fig 7.5: Wet mixture

**7.6.3 GP Mix: -** The next step after obtaining both the mixes is to combine these to mixes to finally obtain Geopolymer concrete mix. It should be kept in mind that all of the wet mix should be introduced with dry mix within 1/3rd of the total mixing time. Homogeneous mixing shall be carried out until the constituents achieve same colour and all the constituents have evenly mixed.

Fig 7.6: Homogeneous Geopolymer Concrete Mix

## 7.7 Casting and Placing of Geopolymer Concrete:-

After the concrete was evenly mixed and had achieved same colour all over the concrete was placed into the prepared cube moulds.

Concrete was placed in three layers and each layer was compacted with help of tamping rod. After filling the mould the top surface was levelled i.e. any mortar in excess was removed to maintain the dimensions of specimen. The top surface was levelled and finished with help of trowel.

Fig 7.7: Levelling and finishing of top surface

After this, the concrete filled moulds were kept on table vibrator for period of 3 minutes. This action emits out air bubbles which are entrapped inside the concrete while placing. Here compaction takes place in two stages. Firstly, the concrete vibrates and all aggregates settle down under the force of gravity. In second stage concrete behaves as a semi liquid and mortar travels to the top surface and all bubbles and air voids are emitted.

Fig7.8: Table Vibrator to emit out entrapped air

Fig 7.9 Air bubbles travelling to the top of the surface

After all bubbles are emitted, specimens are given final finishing to the level their top surfaces. The cubes are left for period of 24 hours (if rest period not considered) to attain hardening and strengthening. After this step, demoulding of specimens comes into the picture.

## 7.8 Demoulding and Curing:

After the concrete has hardened over period of 24 hours or more in case of rest period, the specimens are demoulded. However, In case of rest period specimens should be demoulded after the decided rest period has elapsed i.e. 3 days or 5 days as the case may be. In this study significance of rest period was also studied separately. The specimens under Mix 5 were studied for change in compressive strength of GPC and behaviour of GPC with and without rest period. Under this Mix, Three specimens were demoulded after 24 hours of casting whereas other three specimens were demoulded after 72 hours of casting day. It was found that Rest Period did not have any noticeable difference in compressive strength but it was necessary for the specimens demoulding in order to get clear edged cubes.

Specimens which were demoulded without rest period did not come out clear and the edges were broken and in some cases the concrete was stuck with the moulds itself as can be seen in Fig 7.10 & Fig 7.11 below.

Fig 7.10: Broken edge of cube demoulded without rest period

Fig 7.11: GPC without rest period stuck with surface of mould

**Curing:-** The curing of Geopolymer concrete does not require water curing like normal cement concrete. Rather, it can be cured at room temperature in open air or dry heat curing at high temperatures. However, in this study, both of these curing types were studied to know the difference in compressive strength in both of the cases.

The specimens of Mix 4 were studied for change in compressive strength due to Ambient and Heat Curing. In this, three specimens of cube were kept in a room under ambient condition after giving rest period of three days, and were cured further for seven days. The cubes were tested for compressive strength after 10 days from day of casting.

Similarly the other three specimen were demoulded after 3 days of rest period and kept in oven at temperature of 75° Celsius for periodof 24 hours (Fig 7.12) . Cubes were taken out of the oven very next day and were tested at the tenth day from day of casting like previous specimens.


Fig 7.12: Oven dry curing at 75°C

It was found that GPC achieved almost double compressive strength when heat cured at high temperature which is discussed in later section of this study.

**7.9 Testing of Specimens:-** All the specimen were tested as per directions given in IS 516 (1959). To check compressive strength of concrete using Geopolymer Concrete cubes, Compression Testing Machine was used. The load for compression testing machine was set as specified in IS 516 i.e. 140 kg/sqcm/minute. The load shall be applied slowly without shock and increased continuously until the resistance of specimen (Concrete Cube) to increasing load breaks.

Fig 7.13: Compression Testing Machine

**Calculation of Load:**

Load as per IS Code = 140 kg/sqcm/min

1 Kg = 9.81 N

1000 N = 1 KN

∴ (140 x 9.81 / 1000) = 1.373 KN

1 min = 60 seconds

But load specified in IS 516 is in kg/sqcm/minute

∴ 1.373 x surface area of cube

= ( 1.373 x 15 x 15 ) / 60

= **5.148 kn/sec**

# CHAPTER 8

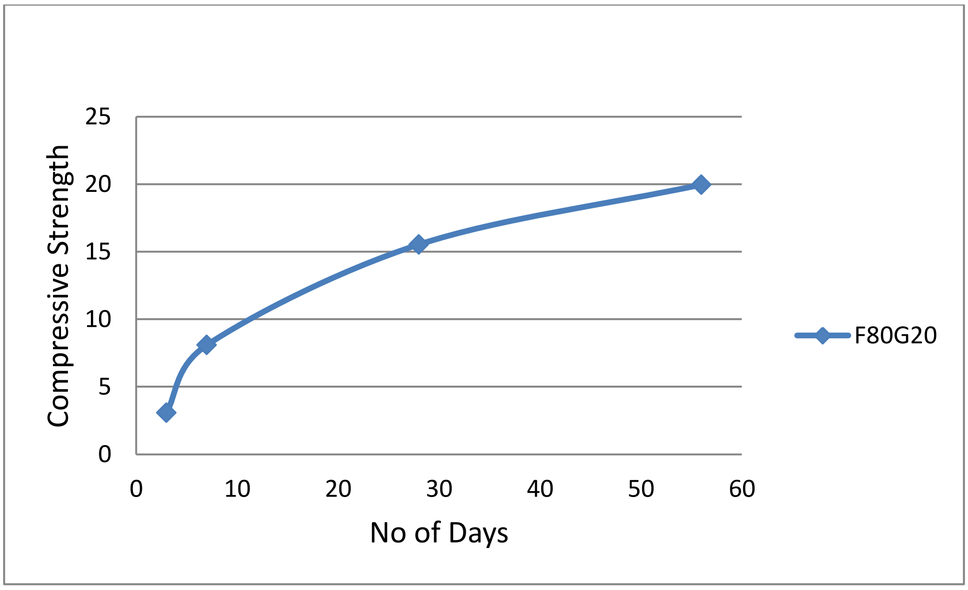
# RESULTS AND DISCUSSIONS

After all the specimens were tested for their compressive strength, following observations were made.

Table 8.1: Compressive Strength Test Results for Mix 1: $F_{80}G_{20}$

| Size of Samples : 150mm x 150mm x150mm<br>Rate of Loading = 5.148 KN/sec | | | | |
|---|---|---|---|---|
| Sr. No. | Age of Sample (Days) | Weight of Sample (kg) | Density (kg/m$^3$) | Compressive Strength (MPa) |
| 1 | 3 days | 7.710 | 2284.44 | 3.02 |
| 2 | 3 days | 7.790 | 2308.14 | 3.16 |
| 3 | 3 days | 7.790 | 2308.14 | 3.11 |
| 4 | 7 days | 7.770 | 2302.22 | 8.08 |
| 5 | 7 days | 7.780 | 2305.18 | 8.17 |
| 6 | 7 days | 7.710 | 2284.44 | 8.04 |
| 7 | 28 days | 7.750 | 2296.29 | 15.2 |
| 8 | 28 days | 7.780 | 2305.18 | 15.7 |
| 9 | 28 days | 7.790 | 2308.14 | 15.7 |
| 10 | 56 days | 7.710 | 2284.44 | 19.51 |
| 11 | 56 days | 7.770 | 2302.22 | 19.66 |
| 12 | 56 days | 7.790 | 2308.14 | 20.71 |

From the above table, it can be seen that for Mix 1 having fly Ash 80% and GGBS 20%, the average compressive strength for 3, 7, 28 and 56 days was found to be 3.09MPa, 8.09MPa, 15.53MPa and 19.96 respectively. Where average density of concrete was found to be 2300 kg/m$^3$.



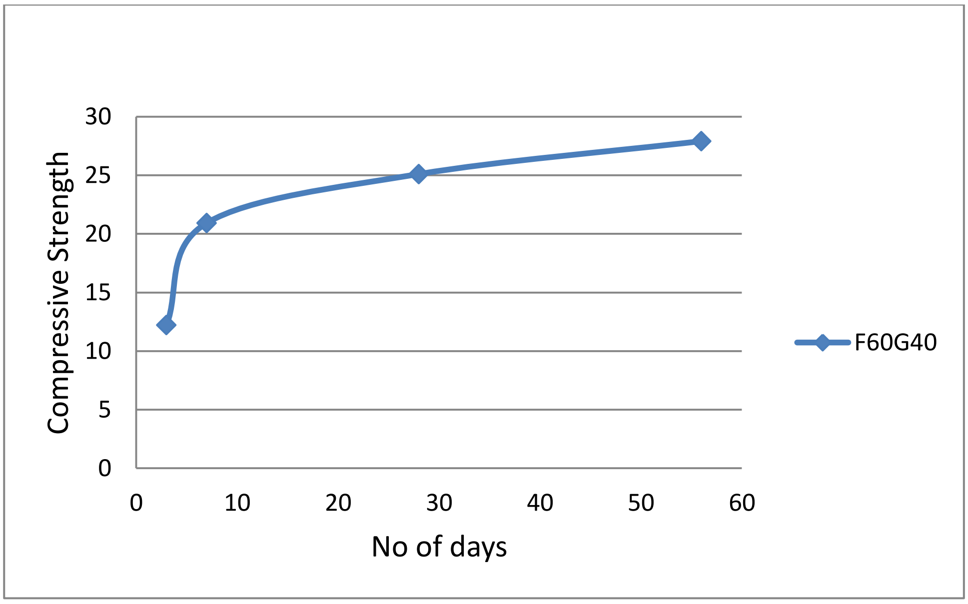

Graph 8.1: Rise of compressive strength with age of sample

From the above graph it can be seen that the compressive strength has risen rapidly for the initial 3-7 days after that a rising curve can be seen which shows that the gain in compressive strength is almost uniform for 28 days and 56 days. There was 22% increase in compressive strength after 28 days. This shows that unlike Portland cement concrete, Geopolymer concrete gains strength even after 28 days. It was also observed that the specimens gained their 41% of their total compressive strength within 7 days.

Table 8.2: Compressive Strength Test Results for Mix 2: $F_{60}G_{40}$

| Size of Samples : 150mm x 150mm x150mm<br>Rate of Loading = 5.148 KN/sec | | | | |
|---|---|---|---|---|
| Sr. No. | Age of Sample (Days) | Weight of Sample (kg) | Density (kg/m$^3$) | Compressive Strength (MPa) |
| 1 | 3 days | 7.800 | 2311.11 | 12.00 |
| 2 | 3 days | 7.790 | 2308.14 | 12.66 |
| 3 | 3 days | 7.800 | 2311.11 | 11.97 |
| 4 | 7 days | 7.850 | 2325.92 | 20.62 |
| 5 | 7 days | 7.820 | 2317.03 | 21.37 |
| 6 | 7 days | 7.790 | 2308.14 | 20.80 |
| 7 | 28 days | 7.820 | 2317.03 | 24.90 |
| 8 | 28 days | 7.820 | 2317.03 | 25.90 |
| 9 | 28 days | 7.830 | 2320.00 | 24.50 |
| 10 | 56 days | 7.820 | 2317.03 | 27.82 |
| 11 | 56 days | 7.850 | 2325.92 | 28.48 |
| 12 | 56 days | 7.820 | 2317.03 | 27.44 |

From the above table, it can be seen that for Mix 1 having fly Ash 60% and GGBS 40%, the average compressive strength for 3, 7, 28 and 56 days was found to be 12.21MPa, 20.93MPa, 25.1MPa and 27.91MPa respectively. Where average density of concrete was found to be 2316 kg/m$^3$.



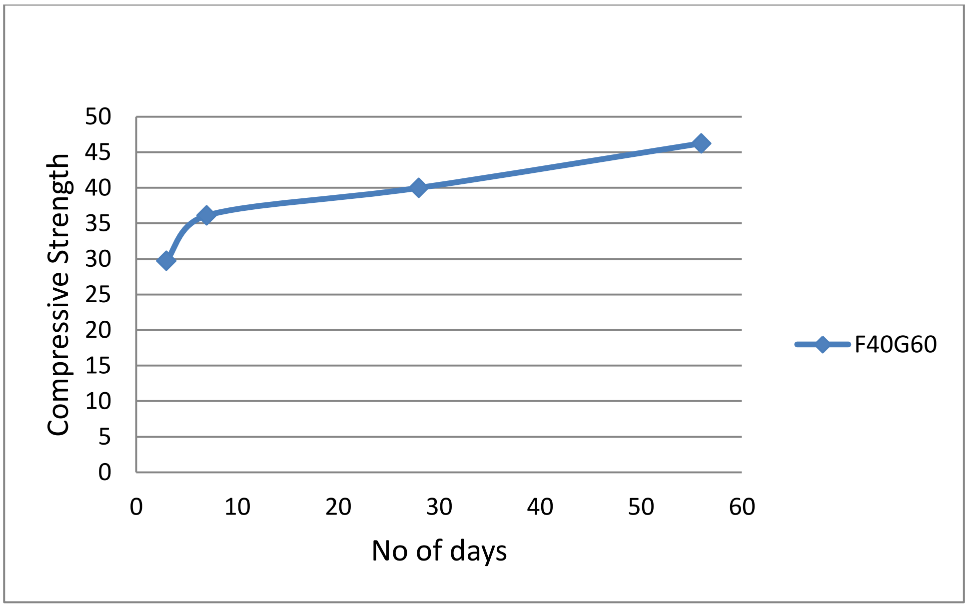

Graph 8.2: Rise in compressive strength with age of sample

Similarly, for the above graph it can be seen that the rise in compressive strength is very rapid for initial 7 days i.e. 20.93MPa after which again a straight line can be seen which shows that for 28 days and 56 days the rise in compressive strength was uniform. There was 10% gain in compressive strength even after 28 days. Again the specimens achieved their 75% of total strength within 7 days of ambient curing.

Table 8.3: Compressive Strength Test Results for Mix 3: $F_{40}G_{60}$

| Size of Samples : 150mm x 150mm x150mm<br>Rate of Loading = 5.148 KN/sec | | | | |
|---|---|---|---|---|
| Sr. No. | Age of Sample (Days) | Weight of Sample (kg) | Density (kg/m$^3$) | Compressive Strength (MPa) |
| 1 | 3 days | 7.88 | 2334.81 | 30.08 |
| 2 | 3 days | 7.87 | 2331.85 | 29.52 |
| 3 | 3 days | 7.87 | 2331.85 | 29.66 |
| 4 | 7 days | 7.86 | 2328.88 | 36.84 |
| 5 | 7 days | 7.88 | 2334.81 | 35.82 |
| 6 | 7 days | 7.88 | 2334.81 | 35.68 |
| 7 | 28 days | 7.89 | 2337.77 | 39.02 |
| 8 | 28 days | 7.86 | 2328.88 | 39.86 |
| 9 | 28 days | 7.86 | 2328.88 | 41.11 |
| 10 | 56 days | 7.88 | 2334.81 | 45.46 |
| 11 | 56 days | 7.89 | 2337.77 | 46.40 |
| 12 | 56 days | 7.87 | 2331.85 | 46.90 |

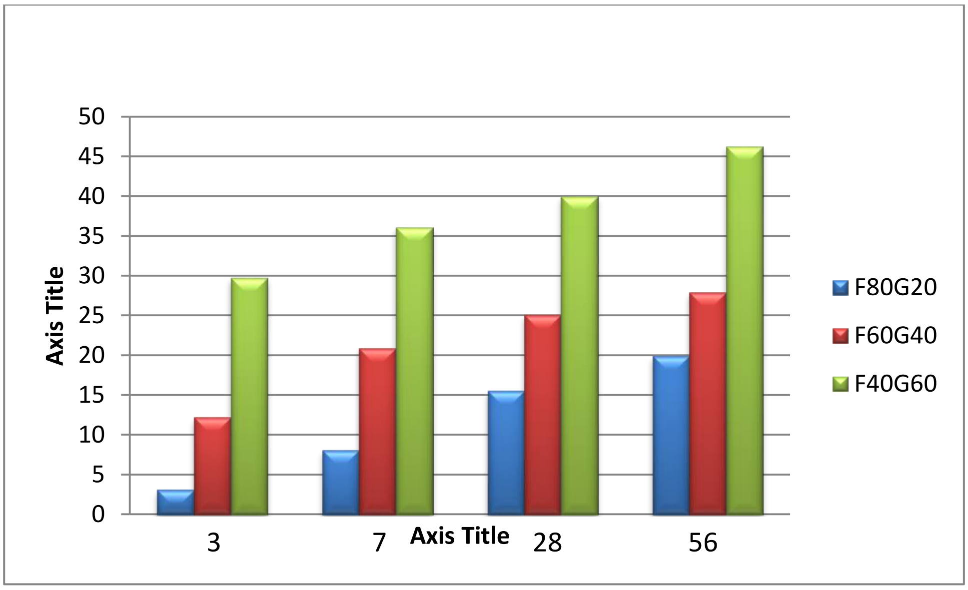
From the above table, it can be seen that for Mix 1 having fly Ash 40% and GGBS 60%, the average compressive strength for 3, 7, 28 and 56 days was found to be 29.75MPa, 36.11MPa, 40MPa and 46.25MPa respectively. Where average density of concrete was found to be 2333 kg/m$^3$.




Graph 8.3: Rise in compressive strength with age of sample

Again, for the above graph it can be seen that the rise in compressive strength is rapid for first 7 days and after 7 days a straight line can be seen which shows that the rise in compressive strength was uniform. Here the specimens achieved 16% of their total compressive strength even after 28 days of curing. The specimens gained 78% of their compressive strength within 7 days of ambient curing.

**Discussion:** With respect to above observation tables it can be clearly seen that the strength of Geopolymer Concrete has increased with the increase in proportion of GGBS and decrease in proportion of Fly Ash. Strength at 28 days increased from 15.53MPa to 25.1MPa to 40 MPa for Mix 1, Mix 2 and Mix 3 respectively. Also it was noticed that Geopolymer concrete gains its compressive strength even after 28 days. Hence, strength at 56 days of curing is made necessary to be observed. The increase in compressive strength was very rapid in all the cases for the first 7 days after which uniform rise in compressive strength was seen. Therefore, further in this study Mix design same as that of Mix 3 was used to study other properties of Geopolymer Concrete such as significance of Rest Period and effect of curing temperature on compressive strength.




Graph 8.4: Comparison for strength gained by different mixes at different days

Clearly, it can be seen from the above graph that the compressive strength for the mix F40G60 the compressive strength was found to be remarkably higher than other mixes. It can be observed that as the percentage content of GGBS increased the compressive strength of Geopolymer concrete also increased.

Table 8.4: Compressive Strength Test Results for Mix 4: $F_{40}G_{60}$: Ambient Curing and Heat Curing

| Size of Samples : 150mm x 150mm x150mm<br>Rate of Loading = 5.148 KN/sec | | | | | |
|---|---|---|---|---|---|
| Sr. No. | Age of Sample (Days) | Type of curing | Weight of Sample (kg) | Density (kg/m$^3$) | Compressive Strength (MPa) |
| 1. | 7 days | Ambient | 7.86 | 2328.88 | 32.13 |
| 2. | 7 days | | 7.81 | 2314.07 | 31.9 |
| 3. | 7 days | | 7.85 | 2325.92 | 32.25 |
| 4. | 7 days | High Temperature | 7.82 | 2317.03 | 56.7 |
| 5. | 7 days | | 7.82 | 2317.03 | 58.4 |
| 6. | 7 days | | 7.81 | 2314.07 | 56.6 |

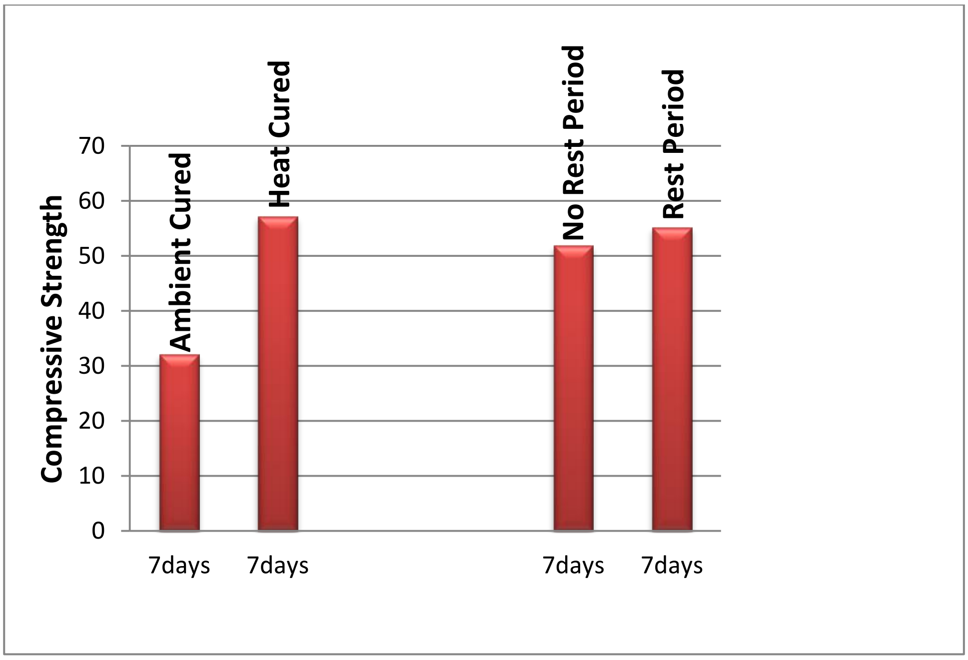
From the above table it can be seen that the first three cubes which were cured in a room at ambient conditions in open air achieved average compressive strength of 32.09MPa, whereas, the last three cubes which were cured in Hot Air Oven at temperature of 75° C achieved higher compressive strength of 57.23 MPa. It was clear from the results that under high temperature Geopolymer concrete achieves higher compressive strength and is highly recommended where high strength is required. This type of curing is possible in precast concrete industries.

Table 8.5: Compressive Strength Test Results for Mix 5: $F_{40}G_{60}$: Rest Period

| Size of Samples : 150mm x 150mm x150mm<br>Rate of Loading = 5.148 KN/sec | | | | | |
|---|---|---|---|---|---|
| Sr. No. | Age of Sample (Days) | Exposure Condition | Weight of Sample (kg) | Density ($kg/m^3$) | Compressive Strength (MPa) |
| 1. | 7 days | Without Rest Period | 7.860 | 2328.88 | 52.3 |
| 2. | 7 days | | 7.810 | 2314.07 | 51.00 |
| 3. | 7 days | | 7.850 | 2325.92 | 52.4 |
| 4. | 7 days | Rest Period of 3 days | 7.820 | 2317.03 | 54.9 |
| 5. | 7 days | | 7.820 | 2317.03 | 56.00 |
| 6. | 7 days | | 7.810 | 2314.07 | 54.8 |

From the above table it can be seen that the first three cubes which were demoulded after 24 hours of casting and heat cured had an average compressive strength of 52MPa, whereas, the last three cubes which were given rest period of three days had an average compressive strength of 55.23MPa. The difference in compressive strength was not very significant, however it was observed that cubes with rest period were demoulded with neat and clean edges and surface whereas cubes without rest period, those were demoulded within 24 hours of casting broke their edges and some of the specimen surfaces sticked with the surface of mould.

Therefore, Rest period is recommended while developing Geopolymer Concrete.




Graph 8.5: Comparison of compressive strength for different type of curing and Rest Period

From the above graph it can be clearly seen that the heat cures samples showed remarkably higher compressive strength than ambient cured samples. Therefore, Heat curing is recommended for Geopolymer concrete. However, talking about rest period there was no significant change in compressive strength between the two type of specimens but rest period had its own importance in Geopolymer concrete for e.g. it was important to provide rest period to get clear edged specimens without breaking them. Rest of the significance of rest period is studied further in conclusion.

# CHAPTER 9

# CONCLUSION

From this study several conclusions were made on factors affecting compressive strength of Geopolymer Concrete. All of these conclusions are listed as under:-

1. From this study, it was concluded that the compressive strength of Geopolymer concrete ($Na_2SiO_3$: NaOH = 1.75 and 8M NaOH solution) increased with increase in proportion of GGBS and reduction in Proportion of Fly Ash.
2. Secondly, it was concluded that the compressive strength of Geopolymer concrete after 28 days was found to be 15.53, 25.10, 39.99 MPa for the three mixes respectively which still further increased at 56 days to 19.96, 27.91, 46.25MPa respectively unlike conventional concrete.
3. Thirdly, from the above study and results it was concluded that the Rest Period does not has any significant change in compressive strength of Geopolymer concrete, however it is important to provide rest period to the specimens before demoulding to get the neat and clean edges and surface.
4. Fourthly, It was concluded that the compressive strength of Geopolymer concrete increases with increase in temperature of curing. Therefore Hot Air High Temperature curing of specimens at temperature of 75°C is recommended.
5. The oil to be used for oiling the moulds prior to placing of concrete shall not be sticky and shall be checked for its lubricating properties. In this study, Black Oil available at workshops was used. Care should also be taken to not to apply excessive oil on surface of moulds as this causes formation of bug holes on surface of Geopolymer concrete specimens.
6. Table vibrator was seen to be effective in case of Geopolymer concrete specimens to emit out the air bubbles. Any type of vibrator can be used.
7. In order to achieve good slump for workable concrete, more super-plasticizer can be added up to 10% of the total weight of cementatious material i.e. Fly Ash and GGBS in this case. Additional water shall not be added as it will change the water to Geopolymer solids ratio of the mix.

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