CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is the most commonly used construction material. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. The manufacturing of the Portland cement releases enormous amount of greenhouse gas emission to atmosphere, which is an energy intensive process.

India is the second-largest cement producing country in the world after China. The country’s cement production was 300 million tonnes during the year 2010 and the figure is expected to double, to reach almost 550 million tonnes by 2020, as per the estimates by the Cement Manufacturers Association (CMA). On the other hand, global warming has become a major concern due to the climatic changes. The global warming is the increase of Earth's average surface temperature due to the effect of greenhouse gases. Among the greenhouse gases, CO$_2$ contributes about 65% of global warming. Therefore, efforts are being taken to develop the other forms of cementious materials for producing concrete. One such material, Geopolymer Concrete is produced with activated fly ash as a binder there by eliminating Portland cement. The base material, such as fly ash, is activated by alkaline solution to produce the binder, which is rich in Silica (Si) and Aluminium (Al).

The emission of CO$_2$ to the atmosphere is approximately one tonne, and this is due to the production of one ton of Portland cement, and hence, the
cement industry is held responsible for \( \text{CO}_2 \) emissions to a greater extent. In order to address the global warming issues, several efforts are in progress to reduce the use of Portland cement in concrete. These include the utilization of supplementary cementing materials such as fly ash, granulated blast furnace slag, silica fume, metakaolin and rice-husk ash, and the development of alternative binders to Portland cement.

1.2 GEOPOLYMER

Davidovits (1982) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, and thus he coined the term ‘Geopolymer’ to represent these binders.

Geopolymer is a member of the family of inorganic polymers. The chemical composition of the Geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous.

The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, resulting in a three-dimensional polymeric chain and ring structure consisting of O-bonds. To date, the exact mechanism of setting and hardening of the Geopolymer material is not clear; as well as the last term that reveals that water is released during the chemical reaction that occurs in the formation of Geopolymers. This water, expelled from the Geopolymer matrix during the curing and further drying periods, leaves behind discontinuous nano-pores in the matrix, which provide benefits to the performance of Geopolymers.
The water in a Geopolymer mixture, therefore, plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mixture during the hydration process. There are two main constituents of Geopolymers, namely - the source materials and the alkaline liquids.

The source materials for Geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc., could be used as source materials. The choice of the source materials for making Geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users.

The Schematic Diagram of Geopolymer Concrete is shown in Figure 1.1.
The alkaline liquids are from soluble alkali metals that are usually sodium based. The most common alkaline liquid used in Geopolymerisation is a combination of sodium hydroxide (NaOH) and sodium silicate.

1.3 CONSTITUENTS OF GEOPOLYMER CONCRETE

Low-calcium (Class F) fly ash obtained from coal-burning power stations can be used for the manufacture of Geopolymer concrete. Globally, most of the fly ash available is low-calcium formed as a by-product of burning anthracite or bituminous coal. Even though coal burning power plants are considered to be environmentally unfriendly, the extent of power generated by these plants is on the increase due to the low cost of power produced from these sources with the enormous raw materials of good quality coal available worldwide. Consequently, huge quantities of fly ash will be available for many years in the future.

The particle size distribution and the chemical composition of the fly ash must be established prior to use. To determine the chemical composition of the fly ash an X-Ray Fluorescence (XRF) Analysis may be used, and to determine the particle size Distribution Sieve Analysis may be used.

1.4 SCHEMATIC FORMATION

The schematic formation of Geopolymer material can be shown as described by the following Equations (van Jaarsveld et al 1997; Davidovits 1999) shown in equation 1.1.
1.5 GEOPOLYMERIZATION MECHANISM

Step 1: Alkalination and formation of tetravalent Al in the side group sialate -Si-O-Al-(OH)$_3$-Na$^+$. 

Step 2: Alkaline dissolution starts with the attachment of the base OH- to the silicon atom.

Step 3: Cleavage of the oxygen in Si-O-Si through transfer of the electron from Si to O.

Step 4: Further formation of silanol Si-OH groups and isolation of the ortho-sialate molecule, the primary unit in Geopolymerization.

Step 5: Reaction of the basic siloxo Si-O- with the sodium cation Na$^+$ and formation of Si-O-Na terminal bond.

Step 6: Condensation between reactive groups Si-O-Na and aluminum hydroxyl OH-Al, with production of NaOH, creation of cyclo-tri-
sialate structure, further polycondensation into Na-poly(sialate) nepheline framework.

**Step 7:** In the presence of soluble Na-polysiloxonate one gets creation of ortho-sialate-disiloxo cyclic structure, were by the alkali NaOH is liberated and reacts again.

**Step 8:** Further polycondensation into Na-poly(sialate-disiloxo) albite framework with its typical feldspar crankshaft chain structure.

### 1.6 SCOPE OF THE PRESENT THESIS

Analysis and Design of Geopolymer Concrete Beam is a broad field which involves many factors, where a lot of research has been carried out with different assumptions and concepts, and conclusions are drawn mainly based on experimental investigations. The basic aim in these investigations is to reduce the Green house effects by replacing the cement by alternative material. The uncontrolled and arbitrary mining of river beds for ‘sand’ which is one of the inevitable elements in the construction sector has led to the death of the rivers. They have great influence on the vegetation, animal life and climate. As a result of the increase in the construction work the ever-rising demand for sand is killing many rivers while this unhealthy practice results in acute drinking water storage and the drying up of the river itself. A review of the research works relevant to the present problem was carried out, and is discussed below.

The present investigation aims to develop a modified guideline, which can be used as an easy reference in Design offices, to analyse and design Reinforced Geopolymer Concrete Beam using sand and M-sand, based on BIS. This thesis also provides the suitability of using an existing constitutive model originally proposed by Popovics (1973) for OPC concrete.
It was found that the equation of Popovics can be used for Geopolymer concrete with minor modification to the expression for the curve fitting factor. The modified expression provided better correlation between the calculated and experimental stress-strain curves. The modified constitutive model was then incorporated into a nonlinear analysis for reinforced Geopolymer concrete beams. A good correlation was achieved between the experimental and analytical ultimate loads and corresponding deflections for the tested forty eight reinforced Geopolymer concrete beams. This shows the suitability of using the modified constitutive model for Geopolymer concrete to analyse structural members as well.

Further, a design procedure is developed to design Geopolymer RC beam based on the proposed theory, and the procedure has been simplified with design charts for easy application by the practicing Design Engineers on their day to day applications.

- To formulate the modified guidelines for Geopolymer Concrete using sand and M-sand based on compressive strength, using trial and error method.

- To find a relationship between the Compressive strength and Split tensile strength of Geopolymer Concrete. The commonly accepted 0.5 power relationship as per IS 456-2000 was investigated to develop similar kind of relationship for Geopolymer Concrete.

- To find a relationship between the Compressive Strength and Modulus of Elasticity of Geopolymer Concrete. The commonly accepted 0.5 power relationship as per
IS 456-2000 was investigated to develop similar kind of relationship for Geopolymer Concrete.

- To investigate the suitability of using existing constitutive model proposed by Popovics for OPC concrete, and to correlate the experimental and calculated stress-strain curves.

- To formulate the modified Constitutive model to analyse the Reinforced Geopolymer Concrete Beams.

- To evaluate a simple and realistic value of EI based on
  
  - Non linear material properties (by choosing a suitable stress-strain relationship for the concrete) and
  
  - Actual sectional properties (actual position of Neutral Axis and Moment of Inertia)

- To formulate a Design criteria and to prepare design charts/Interaction diagrams for direct application of the theory by Design Engineers.

In order to meet the above requirements the following are set as objectives:

- Rigorous trial-and-error method was adopted to find the basic properties of Geopolymer Concrete like Compressive Strength, Split Tensile Strength, Flexural Strength and Static Modulus of Elasticity for both sand and M-sand.

- It is intended to identify the mix ratios for different grades of Geopolymer Concrete by trial and error method. A new
Design procedure was formulated for Geopolymer Concrete which was relevant to Indian Standard (IS 10262-1982).

The applicability of existing Mix Design was examined with the Geopolymer Concrete. Two kinds of systems were considered in this study using 100% replacement of cement by ASTM class F flyash and 100% replacement of sand by M-sand. It was analyzed from the test result that the Indian standard mix design for proportioning of Concrete mixes itself can be used for the Geopolymer Concrete with some modifications.

1. The developed theory is validated with experimental investigations of flexural behavior of Reinforced GPC concrete using sand and M-sand for different types of curing.

2. Twenty four reinforced GPC with cross section size 100mm × 200mm × 2000mm for both sand and M-sand in Ambient curing and equal number of beams for heat curing with different reinforcement ratios were cast and tested.

   - The experimental outcomes such as Ultimate Load, Maximum Deflection, First Crack Load, Moment Vs Curvature and The Ductility parameters namely Displacement Ductility, Curvature Ductility are discussed in detail.

   - The Ultimate load of beams tested are calculated and compared with the theoretical load calculated as per the theory proposed in this study.

3. Design charts are developed, for both GPC using sand and M-sand reinforced beams for both the curing.
- Load (P) Vs. Deflection ($\delta$)
- Moment (M) Vs. Curvature (\(\varphi\))
- Flexural strength of singly reinforced section (\(\frac{Mu}{bd^2}\)) Vs steel ratio (\(\rho\)) for sand
- Flexural strength of singly reinforced section (\(\frac{Mu}{bd^2}\)) Vs steel ratio (\(\rho\)) for M-sand

So that these charts can be readily used for the design application

4. Numerical Analysis using ANSYS 13 software is performed for the specimen tested and the Critical Load, Deflection, Mode of Failure were studied and compared with experimental results.

5. Design examples are presented to evaluate the strength of RGPC beams cast with sand or M-sand based on the present approach.

1.7 ORGANIZATION OF THE THESIS

The details of the work done in this investigation, for the formulation of theory and design, applications of the theory including experimental investigations carried out are grouped below:

Chapter 1. The Introduction presents the problem under investigation in detail, and the importance of the present problem. This chapter also discusses the scope and objectives of the investigation.

Chapter 2. Review of Literature presents a brief review of the literature on the available information about Geopolymer Concrete.
Chapter 3. This chapter describes the experimental program carried out to develop the mixture proportions, the mixing process, and the curing regime of Geopolymer concrete. The tests performed to study the behaviour and the short-term engineering properties of the fresh concrete and the hardened concrete are also described. Based on the results the modified guidelines for Geopolymer concrete using sand and M-sand were formulated using Indian standards for both sand and M-sand.

Chapter 4. Theoretical investigation discusses the development of stress-strain curve for Geopolymer concrete, evaluation of ultimate stress and strain, and incorporating the effect of cracking. In addition, the present theory is validated by comparing the ultimate loads obtained from experiments (sand and M-sand for both the curing), with that of ultimate loads calculated based on the constitutive model. Design criteria provide the design charts and relevant curves for the design of Flexural behaviour of GPC Beam using sand and M-sand for both the curing.

Chapter 5. Experimental investigations present the details of the test specimen details, experiments conducted, testing procedure and the type of observations.

Chapter 6. Finite element Analysis of experimental results presents the details of result analysis and discusses on the influence of the various types of GPRC like over reinforced, under reinforced and balanced sections on the flexural behaviour of reinforced GPC beams.

Chapter 7. Summary and Conclusions presents a detailed summary of the work done and the conclusions arrived from the present investigations. Scope for further research work is also included.