CHAPTER 1

INTRODUCTION

1.1 GENERAL

The production of cement generates large amount of carbon dioxide. Carbon dioxide could be reduced if the production of cement could be reduced as well. Concrete is the most versatile and widely used construction material in view of its wide ranging performance, suitability, applicability, and cost effectiveness. Normally, conventional concrete is manufactured with Portland cement, which acts as a binder. The production of cement releases approximately an equal amount of CO\textsubscript{2} into the atmosphere. It is also energy intensive and consumes significant amount of natural resources, leading to its depletion in due course of time. In view of this, there is a need to develop sustainable alternatives to portland cement utilizing the industrial by-products such as fly ash, ground granulated blast furnace slag which are pozzolonic in nature. Further, environmentally compatible disposal of waste materials by appropriate technologies is of increasing concern and imposes interesting technical challenges.

Construction industry is the one where bulk utilization of waste materials can be effectively done without any compromise on quality and performance. It has been established that fly ash can replace cement partially. However, efforts are on to replace Portland cement completely by synthesizing alternative binder (which later became to be known as Alkali-Activated Cement) by alkali activation of many marginal materials such as fly ash and ground granulated blast furnace slag which are rich in silica and alumina. Such an effort leads to dual goals of utilizing the marginal materials advantageously rather than just disposal and conservation of resources for sustainable development. Scientists have been doing research and development for more than 20 years on a new material called “geopolymer” to replace the use of cement. The amorphous to crystalline reaction products resulting
from the synthesis of alkali alumino-silicates and high alkaline solution is generically
known as “Geo-Polymer”. This material is made basically with the mixture of sodium hydroxide and sodium silicate solution and when it is combined with certain powder material such as fly ash results in a material with cementitious properties similar to Portland cement paste. The three components can vary a great deal, from the concentration of sodium hydroxide and sodium silicate to the ratio of the two solutions to the composition of the fly ash and there is a general consent that the reaction producing the geopolymer is in the form of polymerization.

1.2 GEOPOLYMER

Geopolymer has the potential to replace ordinary Portland cement and can produce fly ash-based geopolymer mortar with excellent physical and mechanical properties. In order to produce geopolymer, low-calcium fly ash needs to be activated by an alkaline solution to produce polymeric Si-O-Al bonds. Fly ash when in contact with alkaline solutions forms inorganic alumino-Silicate polymer product known as Geopolymer. These novel geopolymer cements, which have unique properties such as high early strength, low shrinkage, sulphate and corrosion resistance could become a viable alternative to conventional cement and hence substantially reduce CO₂ emission caused by the cement and concrete industries. The reaction mechanism of geopolymer can be described in two steps as activation and the setting reaction.

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\begin{align*}
\text{(Si-Al materials)} & \quad n(SiO_2,Al_2O_3) + 2nSiO_2 + 4nH_2O + NaOH \text{ or KOH} \rightarrow Na^+K^+ + n(OH)_3-Si-O-Al-O-Si(OH)_3 \\
\text{(Geopolymer precursor)} & \\
\text{(Geopolymer backbone)} & \quad \text{NaOH or KOH} \rightarrow (Na^+,K^+)-(Si-O-Al-O-Si-O-) + 4nH_2O
\end{align*}
\]

Figure 1.1 Schematic diagram of Geopolymer Technology
Water in a geopolymer mixture, therefore, plays no role in the chemical reaction that takes place and thus 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, the 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.

1.3 FERROCEMENT

‘Ferro - cemento' or 'Ferciment' or Ferrocement is the first invention of reinforced concrete. Among construction materials, concrete is the one single material used in very large quantity next to water in terms of utilization in the world. Ferrocement is regarded as highly versatile material possessing a degree of roughness, ductility, durability, strength, crack resistance that is greater than that found in other forms of concrete construction, Naaman (2000). It is the promising composite material for the prefabrication and the industrialization of the building industry, and is proved as an excellent material for low cost housing and the encasement of lightweight core materials to produce high performance lightweight structural sandwich panels, Memon (2006) Ferrocement is a thin walled reinforced concrete commonly consists of cement mortar, reinforced with closely spaced layers of continuous and relatively small wire meshes.

The matrix in ferrocement has 95% or more pronounced influence on the behaviour of final product, Agarwal et al (1991) which entirely depends upon the composition of the mortar mix. Thus the properties of mortar mix like compressive strength, water absorption are very important to consider during the design of thin ferrocement structural elements. Various researchers have conducted the studies to
investigate the characteristics of mortar mix to use in ferrocement elements. Recently there has been a growing trend towards the use of supplementary cementitious materials, whether natural, waste or by-products, in the production of composite cements because of ecological, economical and diversified product quality reasons. To investigate the properties of concrete and mortar with fly ash as complete replacement of cement is remained active area of research. This experimental study is aimed to investigate the compressive strength and tensile strength development as well as durability properties of high workability geopolymer mortars by replacing cement completely by fly ash. Ferrocement is highly versatile form of composite material made of rich cement mortar with layers of wire mesh or with steel rods of smaller diameter closely bound together to create a stiff structural form. It possesses high flexural strength and exhibits lesser crack width when compared to RC elements. It could be moulded into any complicated shape with the skeletal reinforcement provided wherever necessary. This is a versatile material for roofing elements with comparatively lesser thickness than the ordinary RCC slabs. Ferrocement is used in several applications such as water tanks, boats, sunscreens, pre-cast roofing slabs and repair materials etc., Ferrocement construction does not need heavy machinery and highly skilled labours. In construction field ferrocement began almost 60 year back. Behavior of ferrocement beams under shear was studied by Al-Kubaisy and Nedwell (1999). Kaushik et al (2002) conducted experimental investigations on ferrocement plates made of super plasticized fly ash mortar. The rich cement mortar mix is replaced completely by geopolymer mortar, incorporating different layers of meshes to study the flexural behaviour of ferrocement slabs.

1.4 NEED FOR ALTERNATIVE MATRIX FOR FERROCEMENT

Water which is fit for drinking may not be always available abundantly for mixing and curing. Some conditions of the environment leads to acidic or may contain salts at which the structure with cement concrete may affect its strength. The ferrocement members as they are thin may get affected in their structural behavior due to the above reasons. To reduce the heat of hydration and due to
economic reasons now a days cement is being replaced partially with the pozzolans which are usually industrial by products such as metakaolin, silica fume and fly ash etc., Durability of mortar in general is controlled by sand cement ratio, w/c ratio, and casting and compaction techniques. Moreover, the present day cement technology offers a wide choice of cement and hence a specific type of cement, based on environmental factors can be selected and used in the cement. However, such adaptations will help to delay the onset of corrosion of conventional reinforcement and will not ensure long - term service life for ferrocement elements, which has to be ensured in to-day's concept of design methodology and field conditions. So there is a need for replacing the cement matrix completely. Fly ash has positive effects if used in an environment friendly way, preserving natural resources, and above all it could produce concrete of better quality.

1.5 SCOPE AND OBJECTIVES OF THE PRESENT STUDY

The scope of the present work includes the following:

To find out the effective utilization of the abundant quantity of Indian fly ash polluting the environment: The maximum level of 100% replacement of cement with fly ash for making geopolymer mortar with the available local materials was carried out.

To determine the suitability of Geopolymer mortar in practical application of the Civil Engineering Field: All the characteristics strength tests and durability tests on geopolymer mortar were carried out. The results are presented and analysed. The flexural behaviour of ferrocement slabs using geopolymer mortar with different wire meshes was studied.

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

1. To determine the strength of geopolymer mortar mix and thus to arrive at the most workable mix.
2. To study the microstructure aspects of geopolymer mortar using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDAX).

3. To study the durability properties such as water absorption, porosity test and chemical exposure test on geopolymer mortar mixtures.

4. To study the salient properties of the meshes and evaluation of its suitability for use in ferrocement.

5. To study the flexural characteristics of Ferro Geopolymer slabs of chosen size reinforced with several layers (up to three) of the mesh are investigated for different mixes.

6. To review the existing analytical methods of analysis and select a suitable method for evaluating analytically certain flexural characteristics of meshes reinforced with Ferro Geopolymer slabs and compare them with the experimental results.

7. To validate the experimental results of the Ferro Geopolymer slabs with those of the Numerical simulation developed using ANSYS 12.

1.6 ORGANIZATION OF THE THESIS

This thesis has been organized in seven chapters. A brief description of each chapter is given below:

**Chapter 1-Introduction:** This chapter provides an introduction to fly ash, geopolymer technology, geopolymer mortar and ferrocement. The overall scope and objectives of the research work are presented.

**Chapter 2-General Literature Review:** This chapter provides information based on existing studies of fly ash. A brief review of literature about the source of geopolymer mortar, strength properties and durability are presented. The historical background of ferrocement, and flexural behaviour of the same are also discussed.
Chapter 3-Constituents used in Geopolymer mortar and Mix Proportioning:
This chapter presents the details of the ingredients used in geopolymer mortar. The properties of fly ash, river sand, water, alkaline liquid- which consist of sodium hydroxide and, sodium silicate, properties of meshes used in ferrocement and their importance are presented and discussed. There are no specific methods of mix design for the geopolymer mortar. The mortar mix design is carried out according to the guidelines of state of the art report on ferrocement.(549-R-97).

Chapter 4-Experimental investigations on basic strength and durability characteristics of Geopolymer mortar: The chapter details the experiments that are carried out to study the strength characteristics of geopolymer mortar under ambient and heat curing conditions. The cement content is replaced completely by fly ash. Mortar mixes of 1:2.5 and 1:3 are selected. Experiments are conducted on Geopolymer mortar mixes to determine the compressive strength and tensile strength. The most workable mix is selected based on the strength test. Durability studies were also conducted on geopolymer mortar specimens. The strength related developments at constant alkaline liquid to binder ratio of 0.416 at different ages is obtained as the most workable mix.

Chapter 5-Flexural Strength Studies on Ferro Geopolymer Slab: Brief outline of the analytical study for estimating the moment capacity under various stages and to estimate the deflection for ferrocement under flexural loading along with the choice of the method for estimating the theoretical moment and deflection for single, double and triple layers of mesh reinforced ferroccment elements are highlighted. Ferrocement slabs using geopolymer mortar of 1:2.5 and 1:3 is cast and curing is done under ambient and heat curing. Load Versus deflection characteristics and failure pattern are studied.

Chapter 6- Finite Element Analysis: This chapter presents the validation of the experimental results of the ferrocement slabs with those of the numerical simulation developed using ANSYS 12.
Chapter 7- Summary and conclusions: In this chapter, the conclusions drawn based on the outcome of the investigation of geopolymer mortar elements are summarized and the implications of the results are presented. Suggestions for further research are also given in this area.