CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is the most versatile man-made construction material, extensively used for most types of activities in the construction industry world wide. Concrete is essentially an artificial conglomerate, comprise aggregates that are held together by a cementing phase. The initial development of concrete technology revolved around the proportioning of four basic constituents, viz., cement, sand, crushed granite and water, which offered little freedom to the designer to impart a desirable attribute to the concrete. This highly complex mixture, which may comprise several binders, admixtures, aggregates of different types and sizes are used in modern construction and are all derived from natural resources. All these materials have been obtained from the existing natural resources and will have distinctiveness for damaging the environment due to their continuous exploitation. Therefore, extensive research is being carried out into the various aspects of this unique material globally.

In India about 960 million tonnes of solid wastes are being produced annually as by-products of industrial, mining, municipal, agricultural and other processes. In these about 290 million tonnes out of 960 million tonnes are inorganic wastes of industrial and mining sectors. Advances in solid waste management have lead to finding alternative construction materials as a substitute for traditional materials like bricks,
aggregates, cement, etc. To safeguard the environment, efforts are being made for recycling different wastes and utilising them in value-added applications. Cement, the prime constituent in concrete, demands large production, leading to emission of carbon-di-oxide and thereby global warming. The use of industrial wastes, which are pozzolanic in character, develops cementing properties when come in contact with free lime, produced during the hydration of cement, minimizes the use of cement. Pozzolanas, defined as siliceous or calcareous and aluminous materials, which are in finely divided form and in the presence of moisture, chemically react with Calcium Hydroxide (CH) at ambient temperatures to form compounds possessing cementitious properties. This secondary reaction because of the pozzolanic reaction increases the volume of Calcium Silicate Hydrate (CSH) at the expense of CH, which occupies 50-60% of the solid volume of the hydrated cement paste. Also, CSH formed is denser than that formed due to the hydration of Ordinary Portland Cement (OPC), Neville (2011), resulting in concrete having higher strength, greatly reduced permeability, potentially greater durability and better appearance in many environments than Plain Portland Cement Concrete (PPCC). These supplementary cementitious materials like fly ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Silicafume, Metakaoline, Rice husk, etc., play a vital role in high volume cement content concrete like High Performance Concrete (HPC) / High Strength Concrete (HSC). The supplementary cementitious materials, for replacing cement partially conserve natural resources, power and help in protecting the environment.

Aggregates, the other mineral constituent - which make up 70% of the concrete volume, are one of the main constituent materials in concrete production. Aggregates, defined as mineral constituents of concrete in granular or particulate form, usually comprising both coarse and fine fractions. Aggregates provide concrete its necessary property of volume
stability and exercise an important influence on concrete strength and stiffness providing rigidity to the material that is necessary for engineering use. In many countries there is scarcity of natural aggregates, while in other countries, there is an increase in the consumption of aggregate, due to the greater demand by the construction industry. Thus, the rapid growth in the construction industry is jeopardized by the lack of natural resources available. A major challenge for the aggregate and the construction industries is to find alternative aggregate source to overcome shortage. If secondary materials are identified with suitable qualities, the quantity of natural aggregate required by the construction industry would be reduced.

In view of the importance of saving of energy and conservation of resources, efficient recycling of all solid wastes is now a global need, requiring extensive research work towards exploring newer applications and maximizing use of existing technologies for a sustainable and environmentally sound management. In order to reduce dependence on natural aggregates as main source of aggregates in concrete, the artificial aggregate generated from industrial wastes provide an alternative for the construction industry. In addition, such usage will largely address the environmental concerns raised previously.

One of the fast depleting resources is the natural river sand, the cost of which made the construction costlier in the recent times. The continuous quarrying lowers the ground water table, which directly checks the greenery of the land. Natural sand is mainly excavated from riverbeds and always contains high percentages of inorganic materials, chlorides, sulphates, silt and clay that adversely affect the strength and durability of concrete and reinforcing steel thereby reducing the life of structure. All these problems led to the search for alternative materials that too eco-friendly, available in abundance, possesses similar properties as sand, besides being cost effective.
Though the construction activity causes great damage to the environment due to the consumption of large volumes of natural resources and power, this industry is also characterised by a high potential to use recycled waste in construction materials. Therefore, there is an urgent need to find suitable substitutes to reduce the reliance on sand. Hence, extensive researches are being carried out to search for alternative materials as fine aggregates in concrete leading to unprecedented up gradation so that there is utilization of natural resources at a rate not greater than that at which they can be generated and to find a proper balance between economic development and preservation of our environment. Out of various available alternative materials, the use of copper slag in concrete provides potential environmental as well as economic benefits for all related industries, particularly in places where copper slag are produced. In this context, it appears necessary to carry out a systematic research and method of development work oriented to compensating for the above-mentioned issues.

1.2 HIGH STRENGTH CONCRETE

The definition of high strength concrete is by no means static and it is not possible to define high strength in terms of universally applicable numerical value. The primary difference between High Strength Concrete and Normal Strength Concrete relates to the compressive strength and there is no precise point of separation between the two. The American Concrete Institute (ACI) defines high strength concrete as concrete with a compressive strength greater than 40 MPa. However, in India concrete possessing 28 days compressive strength of 40 MPa or more, is considered as HSC. In the present work, concrete with 28 days characteristic compressive strength of 40MPa or higher is considered as High Strength Concrete. The ACI had changed the definition of HSC from 40MPa to 80MPa, and recognised that the definition of HSC varies on a geographical basis. Over the last 50 years, the strength of
concrete used in structures has been gradually increasing. HSC has undergone many developments based on the studies of influence of cement type, type and proportion of mineral admixtures, type of superplasticizer and the mineralogical composition of coarse aggregates; hence, the threshold of HSC is in the range of 41 to 83MPa at an acceptance age of 28 days or later.

The HSC, when produced in a systematic manner, the product shows not only high compressive strength, but also superior durable concrete in aggressive environments, i.e. HSC can be an advantageous material with respect to other properties, both mechanical and durability related. Factors influencing the strength of HSC are the amount and type of cement, w/c ratio, aggregate type and grading, workability of fresh concrete, mineral admixtures, chemical admixtures, curing conditions and age of concrete.

The full benefits of this technology have yet to be utilised, due to an insufficient understanding of the behaviour of HSC.

The benefits of using HSC are;

- To put the concrete into service at much earlier age,
- To build high-rise buildings by reducing column sizes and increasing available space,
- To build superstructures of long-span bridges, and
- To satisfy the specific needs of special applications such as durability, modulus of elasticity and flexural strength.

### 1.2.1 Role of Supplementary Cementitious Materials

Supplementary cementitious materials, i.e., mineral admixtures, play a significant role in the evolution of HSC. For strength up to 50MPa, no mineral admixtures are required. The cement content required for this strength
may not possess any later age problems. However, for strength level at 70MPa binary mixtures (i.e., cement + fly ash / slag cement), has been used. For higher strength, particularly above and about 80MPa, ternary mixtures containing very fine paste densifying pozzolans such as condensed silica fume, metakaoline etc., are found advantageous (Michael, 2009). The supplementary cementitious materials are important materials that contribute to the properties of concrete when used in conjunction with OPC by reacting either hydraulically or pozzolanically. The use of these mineral admixtures is to overcome the adverse effect of calcium hydroxide produced during hydration of cement. The consumption of calcium hydroxide by the mineral admixture improves the durability of cement paste by making the paste dense and impervious. The benefits derived include

i. Higher early strength
ii. Higher later age strength
iii. Reduced permeability
iv. Control of alkali-aggregate reactivity
v. Lower heat of hydration
vi. Reduced cost

1.2.2 Role of Chemical Admixtures

The main objective of the incorporation of superplasticizer should always be to lower the w/c ratio to a minimum value to contribute to the enhancement of durability. When superplastizer is added to concrete, the workability increases considerably. In addition, it reduces water content. A uniform distribution of the dispersed cement throughout the concrete may also contribute to the improved strength.
Chemical admixtures such as superplasticizer (High-Range Water Reducer) increase concrete strength by reducing the mixing water requirement for a constant slump, and by dispersing cement particles, with or without a change in mixing water content, permitting more efficient hydration. Also it makes the concrete more compact and less permeable. It is finally more resistant to aggressive environments. Even a superplasticized mix that appears stiff and difficult to consolidate is very responsive to applied vibration.

1.3 OBJECTIVE OF THE PRESENT STUDY

HSC can be produced by incorporating supplementary cementitious materials like fly ash / silica fume, copper slag in lieu of sand and chemical admixtures to reduce water – binder ratio. The incorporation of copper slag in lieu of sand ensures as filler of void, volume stability, and durability of concrete. The chemical admixtures, i.e. superplasticizer / High Range Water Reducer, reduce the water requirement and strengthen the interfacial transition zone, thereby making the fresh concrete workable and hardened concrete with higher strength.

The objectives of the present study are as follows:

- To study the effect of copper slag as fine aggregate in various grades of concrete
- To study the following strength parameters of HSC with copper slag as fine aggregates
  a) Characteristic compressive strength of concrete
  b) Splitting tensile strength
  c) Modulus of elasticity
  d) Flexural strength
  e) Impact strength
  f) Bond strength
• To establish the relationship between the above strength parameters

• To investigate the durability of copper slag aggregate concrete in the normal environment

• To study the flexural behaviour of reinforced concrete beams made of copper slag aggregate concrete

• To study the shear behaviour of copper slag aggregate concrete beam

• To discuss the effect of cyclic loading on the copper slag aggregate concrete beams

1.4 ORGANISATION OF THE THESIS

This thesis has been arranged in five chapters. A brief description of each chapter is given below.

Chapter one presents the problems of availability of constituents of concrete, the need for the search of new aggregates, particularly from industrial wastes, i.e., the suitability of copper slag in making the HSC. The necessity for mineral and chemical admixtures in HSC is also presented.

Chapter two provides the information about the importance of seeking new aggregates from industrial wastes. A brief review of literature is included about the effect of replacement of sand by copper slag, and the effect of copper slag on strength and durability parameters, and literature related to flexural, shear behaviour of reinforced concrete beams are widely discussed.

Chapter three provides details about various tests on Copper Slag High Strength Concrete (CSHSC) to understand its behaviour in higher grades, and the necessity of conducting various tests to ensure its various
characteristics under normal environments. Also it presents the details of the ingredients used in HSC and their properties. A mix design procedure for HSC with supplementary cementitious material is elaborately discussed in Appendix A1.1 to A1.3. This chapter deals mainly with the details of strength related experimental tests conducted on M40, M60 and M80 grades of HSC trial mixes for finding the properties such as compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, impact strength, bond strength, and its homogeneity by non-destructive test (NDT). This chapter also deals with important durable properties like permeability characteristic, saturated water absorption, density, and porosity of CSHSC of three grades (M40, M60 and M80) of copper slag concrete. The results of the experimental tests are listed and discussed.

Chapter four provides the detailed flexural, shear behaviour of copper slag as fine aggregate under monotonic loads on under-reinforced concrete beam. For each grade of concrete four different proportion of copper slag were used and test results on deflection, ductility, energy absorption of beams with and without copper slag were addressed. Also, energy absorption of CSHSC beams under loads applied in a repeated manner (by loading and un-loading the members) were studied and presented.

Chapter five provides, the conclusions from the strength related, durability related, flexural, shear behaviour and repeated load behaviour of reinforced beams of control beams and CSHSC beams were studied, summarised and the valuable suggestions for future works on this study are recommended.