CHAPTER 1

INTRODUCTION

1.1 GENERAL

The utilization of industrial waste or secondary materials has encouraged the production of cement and concrete in construction field. New by-products and waste materials are being generated by various industries. Dumping or disposal of waste materials causes environmental and health problems. Therefore, recycling of waste materials is a great potential in concrete industry. For many years, by-products such as fly ash, silica fume and slag were considered as waste materials. Concrete prepared with such materials showed improvement in workability and durability compared to normal concrete and has been used in the construction of power, chemical plants and under-water structures. Over recent decades, intensive research studies have been carried out to explore all possible reuse methods. Construction waste, blast furnace, steel slag, coal fly ash and bottom ash have been accepted in many places as alternative aggregates in embankment, roads, pavements, foundation and building construction, raw material in the manufacture of ordinary Portland cement pointed out by Teik thye luin et al (2006).

Copper slag is an industrial by-product material produced from the process of manufacturing copper. For every ton of copper production, about 2.2 tonnes of copper slag is generated. It has been estimated that approximately 24.6 million tons of slag are generated from the world copper
industry (Gorai et al 2003). Although copper slag is widely used in the sand blasting industry and in the manufacturing of abrasive tools, the remainder is disposed of without any further reuse or reclamation.

Copper slag possesses mechanical and chemical characteristics that qualify the material to be used in concrete as a partial replacement for Portland cement or as a substitute for aggregates. For example, copper slag has a number of favourable mechanical properties for aggregate use such as excellent soundness characteristics, good abrasion resistance and good stability reported by (Gorai et al 2003). Copper slag also exhibits pozzolanic properties since it contains low CaO. Under activation with NaOH, it can exhibit cementitious property and can be used as partial or full replacement for Portland cement. The utilization of copper slag for applications such as Portland cement replacement in concrete, or as raw material has the dual benefit of eliminating the cost of disposal and lowering the cost of the concrete. The use of copper slag in the concrete industry as a replacement for cement can have the benefit of reducing the costs of disposal and help in protecting the environment. Despite the fact that several studies have been reported on the effect of copper slag replacement on the properties of Concrete, further investigations are necessary in order to obtain a comprehensive understanding that would provide an engineering base to allow the use of copper slag in concrete.

1.2 BACKGROUND OF COPPER SLAG

Sterlite Industries India Limited (SIIL), Tuticorin, Tamil Nadu is the principal subsidiary of Vedantha Resources public limited company (PLC), a diversified and integrated FTSE 100 metals and mining company, with principal operations located in India and Australia.
The annual turnover of SIIL, Tutucorin, India is Rs.13,452 crores. SIIL, a leading producer of copper in India, pioneered the manufacturing of continuous cast copper roads and established India’s largest copper smelting and refining plant for production of world class refined copper. SIIL is the producer of copper slag (Figure 1.1) during the manufacture of copper metal. Presently, about 2500 tons of copper slag is produced per day and a total accumulation of around 1.5 million tons.

Figure 1.1 Appearance of copper slag sample

This slag is currently being used for many purposes. It is a glassy granular material with high specific gravity particle sizes. The various myths about copper slag is shown in Table 1.1. The size of the particle is of the order of sand and can be used as a fine aggregate in concrete. To reduce the accumulation of copper slag and also to provide an alternative material for sand and cement, an approach has been done to investigate the use of copper slag in concrete for the partial replacement of sand and cement.
Table 1.1 Concerns/ myths over copper slag

<table>
<thead>
<tr>
<th>S.No</th>
<th>Myths over copper slag</th>
<th>Performance in real</th>
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<tbody>
<tr>
<td>1.</td>
<td>Toxic material</td>
<td>Non-toxic material</td>
</tr>
<tr>
<td>2.</td>
<td>Durability</td>
<td>High durability</td>
</tr>
<tr>
<td>3.</td>
<td>Decreases concrete strength</td>
<td>Improves concrete strength</td>
</tr>
<tr>
<td>4.</td>
<td>Bleeding</td>
<td>No bleeding of concrete up to 40-50% replacement</td>
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<tr>
<td>5.</td>
<td>Leaching</td>
<td>Leaching levels are insignificant</td>
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</tbody>
</table>

1.3 PRODUCTION OF COPPER SLAG

Copper slag is a by-product obtained during the matte smelting and refining of copper has been reported by Biswas and Davenport (2002). The major constituent of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as SiO$_2$, Al$_2$O$_3$, CaO and MgO, which are either present in original concentrate or added as flux. It is Iron, Copper, Sulphur, Oxygen and their oxides which largely control the chemistry and physical constitution of smelting system. A further important factor is the oxidation/reduction potential of the gases which are used to heat and melt the charge stated by Gorai et al (2002). As a result of this process copper-rich matte (sulphides) and copper slag (oxides) are formed as two separate liquid phases. The addition of silica during smelting process forms strongly bonded silicate anions by combining with the oxides.

This reaction produces copper slag phase, whereas sulphide from matte phase, due to low tendency to form the anion complexes. Silica is added directly for the most complete isolation of copper in matte which occurs at near saturation concentration with SiO$_2$.

The slag structure is stabilized with the addition of lime and alumina. The molten slag is discharged from the furnace at 1000-1300°C.
When liquid is cooled slowly, it forms a dense, hard crystalline product, while a granulated amorphous slag is formed through quick solidification by pouring molten slag.

1.4 ADVANTAGES OF COPPER SLAG

- Reduces the construction cost due to saving in material cost.
- Reduces the heat of hydration.
- Refinement of pore pressure.
- Reduces permeability.
- Reduces the demand for primary natural resources.
- Reduces the environmental impact due to quarrying and aggregate mining.

1.5 USE OF COPPER SLAG IN VARIOUS FIELDS

1.5.1 Use of Copper Slag in Cement Clinker Production

Since the main composition of copper slag is vitreous FeSiO₃, it has low melting point and could reduce the calcination temperature for cement clinker. Thus, the use of copper slag to replace iron powder as iron adjusting material facilitates cement production and reduces or eliminates the need of mineralizes has been pointed out by (Huang 2001). The performance testing results indicated that cement produced by using copper slag performed even better than using iron powder.

1.5.2 Use of Copper Slag in Blended Cement

The use of copper slag as a pozzolanic material for ordinary Portland cement and its effects on the hydration reactions and properties of mortar and concrete have been reported in several applications (Al-Jabri et al...
2006, Tata et al 2007, Malhotra 1993, Tixier et al 1997, Arino and mobasher 1999). The copper slag in corporation into the cement mortar does not cause an increase in the leached elements reported by Sanchez de Rojas et al (2004). Another work showed that the amounts of leached elements of copper slag are significantly lower than the regulatory levels determined by United States Environmental Protection Agency (USAPA) (Alter 2005). Arino and mobasher (1999) suggested that up to 15% of copper slag can be used as a cement replacement with constant w/c ratio of 0.4. This gives higher compressive strength than ordinary cement.

1.5.3 Use of Copper Slag in Concrete

Several researchers have investigated the possible use of copper slag as a fine and coarse aggregate and cement in concrete and its effects on the different mechanical and long term properties of mortar and concrete. Hwang and Laiw (1989) evaluated the compressive strength development of mortars and concrete containing fine copper slag aggregate with different water cement ratios. The strength of mixtures with 20-80% substitution of copper slag was higher than that of control specimens. Shoya et al (1997) reported that the amount and rate of bleeding increased by using copper slag fine aggregate depending on the water to cement ratio and also they recommended using less than 40% copper slag as partial replacement of aggregate to control the amount of bleeding to less than 5 l/m². Therefore copper slag can be replaced 40% with that of sand.

The pozzolanic activity of copper slag has been investigated by Pavez et al 2002. The effect of copper slag on hydration of cement was investigated by Mobasher et al and Tixier et al 1997. Upto 15% by weight of copper slag was used as a Portland cement replacement together with 1.5% of hydrated lime as an activator to pozzolanic reaction. Result indicated a significant increase in the compressive strength.
Although there are many studies that have been reported by investigators from other countries on the use of copper slag in cement concrete, not much research has been carried out in India concerning the incorporation of copper slag in concrete and also its durability effects. Therefore to generate specific experiment data on the potential use of copper slag as sand and cement replacement in concrete, this research was performed.

In this research work, an extensive study using copper slag has been carried out to investigate the following.

1. To find the optimum proportion of copper slag that can be used as a replacement/substitute material for cement and fine aggregate.

2. To evaluate compressive and tensile strength of copper slag replaced concrete specimens.

3. To investigate flexural, axial compressive and buckling strength of copper slag replaced structural members (RCC (Reinforced Cement Concrete) beams and RCC columns).

4. To investigate corrosion and durability characteristics of copper slag admixed concrete.

5. To examine the possibility of using copper slag in resisting seismic earth pressure.

1.6 COPPER SLAG REPLACEMENT FOR SAND

The use of slag from copper smelting as a fine aggregate in concrete was investigated by Akihiko and Takashi (1996). Copper slag was also used by Ayano et al (2000) as a fine aggregate in concrete. They described the strength, setting time and durability of concrete mixtures made
with copper slag. The fundamental properties of concrete using copper slag and class II fly ash as fine aggregates were investigated by Ishimaru et al (2005). It was concluded that up to 20% (in volume) of copper slag or class II fly ash as fine aggregates substitution can be used in the production of concrete. To control the bleeding in concrete mixtures when incorporating copper slag as fine aggregates, Ueno et al (2005) suggested a grading distribution of fine aggregate based on particle density. The study investigated the maximum size of slag fine aggregate that does not significantly influence the amount of bleeding and the required plastic viscosity of paste to control the amount of bleeding by the variation of water-to-cement ratios. Shi et al (2008) presented a comprehensive review on the use of copper slag in cement, mortars and concrete. The paper was focused on the characteristics of copper slag and its effects on the engineering properties of cement, mortars and concrete. Wu et al (2010) investigated the mechanical properties of copper slag and reinforced concrete under dynamic compression. The results showed that the dynamic compressive strength of copper slag reinforced concrete generally improved with the increase in amounts of copper slag used as a sand replacement up to 20%, compared with the control concrete, beyond which the strength was reduced. Wu et al (2010) also investigated the mechanical properties of high strength concrete incorporating copper slag as a fine aggregate. The results indicated that the strength of concrete, with less than 40% copper slag replacement, was higher than or equal to that of the control specimen. The microscopic view demonstrated that there were limited differences between the control concrete and the concrete with less than 40% copper slag content.

Based on above investigations, this research study was conducted to investigate the performance of concrete made with copper slag as a partial replacement for fine aggregate. Seven test groups were constituted with replacement: 0%, 10%, 20%, 30%, 40%, 50%, and 60% of copper slag with
sand in each series. The following tests have been conducted to find the mechanical properties of concrete and structural members.

i) Compressive strength test on mortal cubes

ii) Compressive strength test on concrete cubes

iii) Flexural strength test on concrete beam specimens

iv) Flexural strength studies on RCC beams

v) Axial compressive strength test on Short columns

vi) Buckling strength studies on long columns

1.7 COPPER SLAG REPLACEMENT FOR CEMENT

The effect of copper slag on the hydration of cement-based materials was investigated by Mobasher et al (1996) and Tixier et al (1997). Up to 15% copper slag, by weight of cement was used as a Portland cement replacement together with 1.5% of hydrated lime. It was used as an activator for pozzolanic reactions. The results indicated a significant increase in the compressive strength for up to 90 days of hydration. Also, a decrease in capillary porosity and an increase in gel porosity were observed. Moura et al (1999) reported that the copper slag could be a potential alternative to admixtures used in concrete and mortars. Al-Jabri et al (2002) studied the effect of copper slag (CS) and cement by-pass dust (CBPD) replacements on the strength of cement mortars. Experimental results indicated that the mixture containing 5% CBPD + 95% cement yielded the highest 90 days compressive strength of 42 MPa in comparison with 40 MPa for the mixture containing 1.5% CBPD + 13.5 CS + 85% cement. The optimum CS and CBPD used was 5%. In addition, it was determined that using CBPD as an activating material would operate better than using lime.
The second part of this research deals with the application of copper slag as partial replacement of cement in concrete and RCC structures. Thereby, copper slag were finely ground in ball mills and partially replaced with Portland cement during the production of concrete. Five test groups were constituted with replacement: 0%, 5%, 10%, 15% and 20% of copper slag with cement in each series. To improve the strength of concrete and to activate pozzolanic reactions in cement, hydrated lime was added. 0.5% of hydrated lime was added for 5% replacement of cement with copper slag. Similarly 1%, 1.5% and 2% was added for 10%, 15% and 20% replacement. The following tests were conducted to find the mechanical behaviours of various concrete specimens at 28 days.

i) Compressive strength test on concrete cube specimens

ii) Split tensile strength test on concrete cylinders

iii) Flexural strength studies on RCC beams

iv) Buckling strength studies on columns

1.8 COPPER SLAG REPLACEMENT FOR BOTH SAND AND CEMENT

Here, copper slag has been replaced for both sand and cement in concrete. Based on investigations, optimum percentage replacement was achieved at 40% for fine aggregates and 15% for cement in concrete. Therefore one concrete mixture was prepared with 40% replacement of sand with copper slag and 15% replacement of cement with copper slag. In addition to this, 1.5% of hydrated lime also added with this mixture for activating pozzolanic reactions. The following tests were carried out for this combined mixture.

i) Compressive strength test on concrete cube specimens

ii) Split tensile strength test on concrete cylinders
iii) Flexural strength studies on RCC beams
iv) Buckling strength studies on columns

1.9 CORROSION AND DURABILITY STUDIES ON COPPER SLAG

Reinforced concrete structures have the potential to be very durable and capable of withstanding a variety of adverse environmental conditions. However, failures in the structures do still occur as a result of premature reinforcement corrosion. When reinforced concrete structures are exposed to harsh environments, deterioration of concrete will occur due to many reasons like chloride and sulphate attack, acid attack and corrosion failure. It is now recognized that the strength of concrete alone is not sufficient. The degree of harshness of the environmental condition to which concrete is exposed over its entire life is equally important.

The effects of using several types of slag on mortar and concrete reactions, reinforcing steel corrosion, abrasion, workability and slump, shrinkage, and freezing and thawing characteristics were examined by various investigators. Copper slag was also used by Ayano et al (2000) as a fine aggregate in concrete. They described the strength, setting time and durability of concrete mixtures made with copper slag. Washington Almeida Moura et al (2007) investigated and concluded that the addition of copper slag to concrete results in an increase on the concrete’s axial compressive, splitting tensile strength and decrease in the absorption rate by capillary suction, carbonation depth and hence improved its durability. The carbonated thickness, resistance to freezing and thawing, thermal resistance, shrinkage strain, creep and setting time of copper slag admixed concrete was examined by Ayano and Sakata (2000).
Copper slag contains more than 55% of ferrous content. Hence corrosion and durability factors are necessary to find out, when replaced with sand and cement in concrete. Therefore in this research, it is planned to replace upto 60% of fine aggregate with copper slag and upto 20% of cement with copper slag to develop high performance concrete. M20 grade concrete was used and the tests were conducted for various proportions of copper slag replacement with sand (0%, 20%, 40% & 60%) and cement (0%, 5%, 15% and 20%) and for both sand and cement (40% CS + 60% S and 15% CS + 85% C and 1.5% HL) in concrete. The following corrosion and durability tests were carried out for various replacement percentages.

- Water Absorption test
- Acid Resistance test
- Sulphate Resistance test
- Ultrasonic test on concrete
- Open circuit potential test
- Accelerated corrosion test
- Rapid chloride penetration test
- X-Ray diffraction studies.

1.10 COPPER SLAG APPLICATION TO REDUCE SEISMIC EARTH PRESSURE

Since copper slag has higher shear strength and density, it can be used as backfill material in retaining walls. This research mainly aims to stabilize slope in retaining walls against seismic forces using copper slag as backfill material and also presents the results of shaking table tests on model rigid face reinforced soil retaining wall in the laboratory. Madhavi Latha and Murali Krishna (2007) investigated the influence of relative density of the
backfill soil on the seismic response of reinforced soil wall models. Nova-Roesing and Sitar (2007) investigated the dynamic behavior of soil slopes reinforced with geo synthetics and metal grits using centrifuge test and observed that the magnitude of deformation is related to the backfill densities, reinforcement stiffness, spacing and slope inclination.

In this research, an extensive work has been carried out to find the influence of copper slag backfill on seismic earth pressure and displacement characteristics was studied through a series of laboratory model test on retaining wall and also compared with backfill sand results. A model retaining wall was fabricated based on Madhavi et al model (2007) and placed in the laminar box mounted on shaking table and the displacement and acceleration characteristics of retaining wall due to force vibrations were found. The influence of copper slag on lateral earth pressure and displacement on retaining wall was studied for various proportions of copper slag with sand (0% 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%). The wall constructed with copper slag backfill showed lesser faces deformations compared with sand. The results obtained from this study are helpful in understanding the dynamic performance of copper slag as backfill, when subjected to seismic lateral earth pressure.