CHAPTER 3

COPPER SLAG

3.1 GENERAL

Copper slag is a waste material, produced during the smelting and refining process of copper ore. Copper slag is black in colour, a glassy, granular material, having a shiny appearance, shown in Figure 3.2. It is partially crushed to smaller particles and stockpiled after the refining process as shown in Figure 3.1.

3.2 COPPER SLAG

For every ton of copper produced, roughly 3 tons of copper slag gets generated (Gorai et al. 2002). Sterlite Industries India Limited (SIIL), Tuticorin, Tamil Nadu, a diversified and integrated metals and mining company, having principal operations located in India and Australia. SIIL, a well known producer of copper in India, pioneered the manufacturing of continuous cast copper rods and has established India’s biggest copper smelting and refining plant for production of world class refined copper. SIIL manufactures copper and subsequently copper slag as well. Presently, about 2500 tons of copper slag is produced per day and a total accumulation of approximately 1.5 million tons per annum.
Figure 3.1 Copper slag stockpile

Figure 3.2 Enlarged view of copper slag
3.3 CHEMICAL COMPOSITION OF COPPER SLAG

During smelting and refining of copper, silica is added directly for the complete isolation of copper. Adding silica during smelting process forms strongly bonded silicate anions by combining with the oxides. Copper slag contains highly toxic elements like arsenic, barium, cadmium, copper, lead and zinc. Copper slag can release these elements into the environment causing pollution of soils, atmospheric air, surface waters and groundwater. Copper smelter releases copper selenium. They are highly toxic if present overabundant. They contaminate the soil in the vicinity of smelters, destroying the vegetation. The complete chemical composition analysis of copper slag is given in Table 5.7.

3.4 DISPOSAL OF COPPER SLAG

Copper slag is used for several purposes, mainly for the manufacture of abrasive tools and grid blasting. This process consumes about 15% to 20% of the slag generated by Al-Jabri, K.S et. al. (2011). The remaining quantity is disposed of without any further reuse or reclamation. The disposal of copper slag is one of the major issues for environmentalists as dumping of copper slag as a waste material may cause severe environmental problems / hazards.

3.5 APPLICATIONS OF COPPER SLAG

Copper slag possesses physical and chemical characteristics that qualify the material, to be used in concrete as an excellent substitute for portland cement or as a partial replacement for aggregates. For example, copper slag has a number of favourable engineering properties for using as aggregate like excellent soundness characteristics, good abrasion resistance and good stability by Gorai et al. (2002). Copper slag also has pozzolonic
properties since it contains low CaO. Under activation with NaOH, it exhibits cementitious property and can be used as partial or full replacement for Portland cement. Using copper slag for the manufacture of portland cement or concrete has multiple benefits of eliminating the cost of disposal and reducing the cost of producing cement/concrete.

3.5.1 Use of Copper Slag in Cement

Since the main composition of copper slag is SiO$_2$ and Fe$_2$O$_3$, it has low melting point and could decrease the calcination temperature for the manufacture of cement clinker. Thus, the use of copper slag to replace iron powder as iron adjusting material facilitates cement production (Huang, K 2001). The performance test results indicated that strength and durability of cement made using copper slag performed better than using iron powder. The chemical composition of cement and copper slag is similar in many aspects, hence copper slag may be used as a supplementary cementing material as well (Alnuaimi, W et al. 2012).

The use of copper slag as a pozzolanic material in ordinary portland cement and its effects on the hydration and properties of mortar and concrete have been presented in several articles (Al-Jabri et al. 2006, Tata et al. 2007, Ario and mobasher 1999, Tixier et al. 1997, Malhotra 1993). Arino and Mobasher (1999) suggested that up to 15% of copper slag may be used for cement replacement with constant water cement ratio of 0.4. This gives higher compressive strength than ordinary cement. Alpa et. al. (2008) reported that due to the addition of copper slag, leached elements are significantly lower than the permissible levels determined by United States Environmental Protection Agency (USAPA). Sanchez de Rojas et al. (2004) stated that copper slag incorporation into the cement mortar didn't cause any increase in the leached elements.
3.5.2 Use of Copper Slag in Concrete

Copper slag has pozzolanic properties since it contains low CaO content and other oxides such as Al\textsubscript{2}O\textsubscript{3}, SiO\textsubscript{2}, and Fe\textsubscript{2}O\textsubscript{3}. Utilization of copper slag in applications such as portland cement substitution and / or as aggregates has dual benefits of eliminating the costs of dumping, reducing the cost of concrete and minimizing air pollution problems. Copper slag also has a higher strength to weight ratio, thereby making it an effective option to be used in concrete.

Many researchers have reported the possible use of copper slag as a fine and coarse aggregate in concrete and its influence on mechanical and long term properties of mortar and concrete. Hwang and Laiw (1989) investigated the compressive strength of cement mortar and concrete containing fine copper slag aggregate with variable water cement ratio. The strength of concrete mixes with 20-80% substitution of copper slag was better than that of control specimens. Shoya et al. (1997) suggested that the amount and rate of bleeding increased by utilizing copper slag fine aggregate depending on the water cement ratio and also they suggested using less than 40% copper slag as partial substitute for fine aggregate to control the amount of bleeding to less than 5.0 l/m\textsuperscript{2}. Therefore copper slag may be replaced 40% with that of sand. The pozzolanic property of copper slag has been studied by Persson et al. 2001. The effect of copper slag on hydration of cement was verified by Mobasher et al. and Tixier et al. (1997). Up to 15% by weight of copper slag can be used as a portland cement replacement along with 1.5% of hydrated lime as an activator to pozzolanic reaction. Result showed a potential increase in the compressive strength.
3.6 RESEARCH SIGNIFICANCE

Conventional concrete casting depends on compaction, to guarantee adequate strength and durability. Often conventional concrete is compacted manually using vibrators, sometimes operated by unskilled labour with insufficient supervision. Insufficient or over compaction results in voids that reduce the strength and durability of concrete. Also the presence of voids influences the protection of embedded steel afforded by concrete. Whereas SCC flows freely, becomes compact and dense due to its own self-weight, filling every corner of the formwork and passes through even restricted space of any size and shape without bleeding or segregation. This property of SCC is very much useful when placing of concrete is difficult as in the case of heavily reinforced concrete elements or in complicated thin formwork. Also this result in improved quality of concrete, reduction of on-site repairs, faster placement, less finishing time, shortens the construction period, lesser construction cost, leading to improved productivity. Another noticeable factor of improvement towards health and safety is the elimination of vibrators that substantially reduces the environmental noise in the site.

Despite the above advantages, there are many difficulties in producing SCC to meet the requirement in many parts of the world. Issues like

i) Lack of sufficient research or published data pertaining to locally produced SCC

ii) Potential problems for the production of SCC with local aggregates which may be characterized as porous, absorptive, relatively soft, dustier, coefficient of thermal expansion may be different from that of the hardened cement mortar.
iii) Optimum mix proportions to meet the harsh environmental conditions, prevailing in several countries.

Awareness of SCC has spread throughout the world, prompted by concerns with poor compaction and durability in case of conventionally vibrated normal concrete. However, the awareness in some parts of the world regarding SCC is somewhat muted and this explains the lack of any commercial use of SCC as well.

Unless SCC is properly designed, static and dynamic segregation of aggregates weaken its strength and durability. Investigations for establishing a rational mix design method and self-compactability testing methods need to be carried out from the viewpoint of making SCC a standard concrete. Hence there is an urgent need to conduct studies on SCC, formulate guidelines, specification for the production and use of SCC to suit the different regions of the world.

3.7 NEED FOR THE PRESENT INVESTIGATION

Increase in human population and urbanization have contributed to enormous requirement of energy, infrastructure development, transportation and production sectors of the economy during the twentieth century. Population growth, urbanization, different technologies and their influence on the environmental are unquestionably among the key forces that are shaping today’s world. Unfortunately, our technology choices have been reductionistic. The main reason being that decisions were made based on short-term goals of an enterprise rather than on the full range of consequences from the use of a clean technology. Hence the present economic and industrial development seems to be unsustainable.
In the society, change is inevitable due to the current life style. However, it is the faster rate of change often becomes disruptive in life. This is why, all of a sudden, we are confronted with the present situation. Sustainability of construction industry is of concern, considering the use of natural materials, energy and man power, emission of carbon dioxide and durability failure in concrete structures.

Although there are many investigations that have been reported on the effect of copper slag as coarse aggregates on the performance of normal strength concrete, there has been no research concerning the use of copper slag as fine aggregates to produce SCC. Laboratory testing and field trials have been conducted in many countries, no complete technology for using copper slag as fine aggregate in the production of SCC and perfect results are available. The technology available in other countries may be uneconomical for other countries. Hence a detailed experimental investigation is necessary to determine the optimum mix proportion of copper slag for the commercial manufacture of SCC. Thus this research work was performed to evaluate the potential use of copper slag as sand replacement in the production of SCC.

Currently, field and laboratory testings on SCC are conducted in several countries but technical investigation results are still not approved for commercial production of concrete. Also sometimes, the suggestions may not be economical for Indian conditions of living. Hence a detailed experimental investigation is necessary to determine the optimum mix proportion of the waste recycled materials for the commercial manufacture of concrete as per Indian conditions.

Tailoring concrete sometimes includes weak points to negative benefits to be expected. For example, unless SCC is properly designed, static and dynamic segregation of aggregates weakens its strength and then
durability. Increase in formwork pressure exerted by SCC also lessens economical merits.

Advancements in concrete science and technology have led to the development of high performance cementitious materials with strength, toughness, ductility and durability far exceeding those of normal concrete. However these materials are also more expensive than conventional concrete. It is therefore important to propose with novel designs in which costly materials are used only in selected parts of the structure to achieve the highest performance/cost.

Despite good performance of copper slag as aggregates in normal concretes, there is little research regarding the use of copper slag as fine aggregate to produce SCC. Thus, this research was performed to determine the feasibility of utilizing copper slag as a fine aggregate in SCC and to investigate its effect on the mechanical properties of SCC. The ability to use copper slag aggregates in SCC provides additional environmental as well as economical benefits for all interrelated industries, particularly in areas where a large volume of copper slag is produced.

Although there are several studies that have been reported by investigators from other countries on the utilisation of copper slag in normal concrete, not much research has been carried out in India concerning the incorporation of copper slag in SCC 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.
3.8 CONCLUSIONS

Copper slag has properties that suit as a partial replacement for fine aggregate. This investigation concentrates on the feasibility of using copper slag as a substitute for fine aggregate in the manufacture of SCC.