CHAPTER 4

LITERATURE REVIEW

4.1 GENERAL

This chapter summarizes the previous investigations carried out to use copper slag for the manufacture of normal concrete or high performance concrete or self-compacting concrete. Several authors have already carried out studies on utilizing copper slag either as partial replacement for cement or coarse aggregate or fine aggregate.

4.2 LITERATURE REVIEW

An extensive literature had been carried out to study the strength and durability properties of SCC with copper slag. More than two hundred articles have been reviewed and presented in the main thesis, out of which few important reports have been presented.

4.2.1 History

Self-compacting concrete was developed at first in Japan by Prof. Okamura of Kochi university of Technology in 1986. Studies to develop SCC and its workability have been carried out by Ozawa & Maekawa (1989) at the University of Tokyo. Research scholars all over the world have reported the need of admixtures in SCC.

Okamura & Ouchi (1997) have investigated the effect of superplasticizer on the balance between flowability and viscosity of mortar in SCC. Nan Su et al. (2001)
Okamura (2003) and EFNARC guidelines (2002 & 2005) have proposed the mix design methods for SCC using different mineral admixtures. Many investigators have reported the use of fly ash, GGBS etc., as filler materials in SCC.

4.2.2 Mechanism of Blocking

Hoshimoto et al. (1999) visualized and explained the blocking mechanism of heavily reinforced section during placement of concrete and reported that the blockage of the flow of concrete at a narrow cross-section occurs due to the contact between coarse aggregate particles in concrete. When concrete flows between reinforcing bars, the relative locations of coarse aggregate particles change. The relative displacement of coarse aggregate particles develops shear stress in the paste between the coarse aggregate particles, in addition to compressive stress. For concrete to flow through such obstacles smoothly, the shear stress should be small enough to allow the relative displacement of the aggregate. To prevent the blockage of the flow of concrete due to the contact between coarse aggregate particles, a moderate viscosity of the paste is necessary.

4.2.3 Cement

Ganesh Babu & Sree Rama Kumar (2000) quantified the 28-day cementitious efficiency of ground granulated blast furnace slag (GGBS) in concrete at the various replacement levels.

4.2.4 Admixtures

The self-consolidating concrete is flowable as well as deformable without segregation by Kurita et al. (1998). Therefore, in order to maintain deformability along with flowability in paste, a superplasticizer is considered
indispensable in the concrete. With a superplasticizer, the paste can be made more flowable with little concomitant decrease in viscosity.

An optimum combination of water-to-cementitious material ratio and superplasticizer for achievement of self-compactability can be derived for fixed aggregate content concrete through laboratory trial mixture proportioning. Okamura (1997) has suggested a limiting value of coarse aggregate and fine aggregate for self-consolidating concrete at around 50% of the solid volume for concrete and 40% for mortar.

Okamura (1997) has suggested the use of mineral admixtures also usually reduces the cost of concrete, especially in countries where coal fly ash is readily and abundantly available. The incorporation of one or more mineral additives or powder materials having different morphology and grain-size distribution can improve particle-packing density and reduce inter-particle friction and viscosity. Hence, it improves deformability, self-compactability and stability of the self-consolidating concrete.

Yahia et al. (1999) and Naik and Kumar (2003) have reported a reduction in the dosages of superplasticizer by using fly ash and blast furnace slag in self-consolidating concrete requiring similar slump-flow compared to concrete made with portland cement only. The well known beneficial advantages of using fly ash in concrete such as improved rheological properties and reduced cracking of concrete due to the reduced heat of hydration of concrete can also be incorporated in SCC by utilization of fly ash as filler. SCC often incorporates several mineral and chemical admixtures, in particular a HRWRA and a VMA. The HRWRA is used to ensure high-fluidity and to reduce the water-to-cementitious materials ratio. The VMA is incorporated to enhance the yield value, reduced bleeding and segregation, and viscosity increase of the fluid mixture. The homogeneity and uniformity
of the self-consolidating concrete is not affected by the skill of workers or the shape and bar arrangement of the structural elements because of high-fluidity and segregation-resisting power of SCC.

A highly flowable concrete is not necessarily self-consolidating because self-consolidating concrete should not only flow under its own weight but also fill the entire form and achieve uniform consolidation without segregation. Fibres are sometimes used in self-consolidating concrete to enhance its tensile strength and delay the onset of tension cracks due to heat of hydration resulting from high cement content in SCC. Use of high-volume fly ash in SCC is also reported by Naik and Kumar (2003) for the development of economical and environmentally friendly SCC.

4.2.5 Mix Proportioning

Nan Su et al. (2001) proposed a new mix design method for self-compacting concrete. First, the amount of aggregates required was determined and the paste of binders was then filled into the voids of aggregates to ensure that the concrete thus obtained has flow ability, self-compacting ability and other desired SCC properties. The amount of aggregates, binders and mixing water, as well as type and dosage of super plasticizer to be used are the major factors influencing the properties of SCC. Slump flow, L-box, U-box, V-funnel and compressive strength tests were carried out to examine the performance of SCC and the results indicated that the proposed method could be used to produce successfully SCC of high quality. Compared to the method developed by the Japanese Ready-Mixed Concrete Association (JRMCA), this method is simpler, easier for implementation and less time-consuming, requires a smaller amount of binders and saves cost.

Hajime Okamura & Masahiro Ouchi (2003) addressed the two major issues faced by the international community in using SCC, namely the
absence of a proper mix design method and jovial testing method. They proposed a mix design method for SCC based on paste and mortar studies for superplasticizer compactability followed by trail mixes. However, it was emphasized that the need to test the final product for passing ability, filling ability and flowability and segregation resistance was more relevant.

4.2.6 Use of Copper Slag in SCC

Current options of management of this slag are recycling, production of value added products and disposal in slag dumps or stockpiles. Copper slag is being used as a cement replacement material by Gorai et al. (2002), fine aggregate replacement material by Ayano & Kuramoto (2000) and coarse aggregate replacement material by Tixier et al. (1997) in concrete depends upon the properties of the material. Slags containing < 0.8% copper are either discarded as waste or sold cheaply by Deja & Malolepszy (1989).

Ayano & Sakata (2002) reported that the slag component was on insoluble residue in the 0.15 mm size that could be readily removed by washing. They concluded that the effect of copper slag on the setting time was different with the particle size of copper slag (that is, the smaller size of copper slag causes the longer delay in the setting time). However, the effect of copper slag on the setting time was decreased by increasing the washing times.

Several studies have been reported by investigators from other countries on the use of copper slag in cement concrete and mortar by Al-Jabri (2002) and few studies on high strength concrete and high performance concrete (HPC) by Shoya et al. (1997). However, there is not much research done in India concerning the incorporation of copper slag in high strength concrete.
Copper slag is being used as a cement replacement material, fine aggregate replacement material and coarse aggregate replacement material by Akihiko & Toshiki (2008) in concrete depends upon the properties of the material. Slags containing < 0.8% copper are either discarded as waste or sold cheaply by Al-Jabri et. al. (2011).

From 1930 onwards much research work has been done, aimed at achieving cementitious matrix materials with high mechanical performance by Persson et. al. (2001). Research over the past decade has yielded a new classification of highly resilient concrete, called reactive powder concrete (RPC), with compressive strengths comparable to that of some steels. Now labelled and classified as ultra-high performance fibre reinforced concrete (UHPFRC), these materials address many of the durability performance deficiencies associated with both normal strength concrete (NSC) and HPC Witte & Backstrom (1951).

Until now, copper slag has been widely used for abrasive tools, roofing granules, cutting tools, abrasive, tiles, glass, road-base construction, railroad ballast, asphalt pavements and cement and concrete industries. The effect of copper slag as a partial substitute for ordinary Portland cement on the hydration reactions and its role as a pozzolanic material have been reported in different works. Several researchers have investigated the possible use of copper slag as fine and coarse aggregates in normal concrete and its effects on the different mechanical and long-term properties of mortar and concrete. Despite some benefits of using copper slag as fine and coarse aggregates, some negative effects have been reported in these works such as delaying the setting time specially when only copper slag has been used as fine aggregate.
Mayur Vanjare & Shriram Mahure (2012) carried out an experimental study on to focus on the possibility of using waste material in a preparation of innovative concrete. One kind of waste was identified: Glass Powder (GP). The use of this waste was proposed in different percentage as an instead of cement for production of self-compacting concrete. The addition of glass powder in SCC mixes reduces the self-compactability characteristics like filling ability, passing ability and by Malhotra VM et al (1993). The flow value decreases by an average of 1.3%, 2.5% and 5.36% for glass powder replacements of 5%, 10% and 15% respectively.

4.2.7 Fresh Concrete

Mehta & Neville (1986) have suggested a simple approach of increasing the sand content and reducing coarse aggregate content by 4% to 5% to avoid segregation. High flowability requirement of self-consolidating concrete leads the use of mineral admixtures such as fly ash in its manufacturing. Fly ash particles are spherical, therefore, leading to reduced friction during flow of the mortar fraction in the concrete. Use of mineral admixtures such as fly ash, blast furnace slag, limestone powder, and other similar fine powder additives, increases the fine materials in the concrete mixture Okamura (1997)

Shoya et al. (1997) reported that the amount and rate of bleeding are increased by using copper slag fine aggregate depending on the water to cement ratio, the volume fraction of slag and air content. They recommended using less than 40% of copper slag to control the amount of bleeding to less than 5 l/m².

Hwang & Laiw (1989) reported that the amount of bleeding of mortar made with copper slag comparatively is less than that using natural sand. However, the heavy specific weight and the glass-like smooth surface
properties of irregular grain shape of copper slag aggregates are effective on characteristics of bleeding. The shrinkage of specimens containing copper slag fine aggregate is similar or even less than that of specimens without copper slag Shoya et al. (1997).

Sri Ravindra rajah et al. (2003). made an attempt to increase the stability of fresh concrete (cohesiveness) using increased amount of fine materials in the mixes. They reported about the development of self-compacting concrete with reduced segregation potential. The systematic experimental approach showed that partial replacement of coarse and fine aggregate with finer materials could produce self-compacting concrete with low segregation potential as assessed by the V-Funnel test. The results of bleeding test and strength development with age were highlighted by them. The results showed that fly ash could be used successfully in producing self-compacting high-strength concrete with reduced segregation potential. It was also reported that fly ash in self-compacting concrete helps in improving the strength beyond 28 days.

Girish et al. (2010) presented the results of an experimental investigation carried out to find out the influence of paste and powder content on self-compacting concrete mixtures. Tests were conducted on 63 mixes with water content varying from 175 l/m$^3$ to 210 l/m$^3$ with three different paste contents. Slump flow, V funnel and J-ring tests were carried out to examine the performance of SCC. The results indicated that the flow properties of SCC increased with an increase in the paste volume. As powder content of SCC increased, slump flow of fresh SCC increased almost linearly and in a significant manner. They concluded that paste plays an important role in the flow properties of fresh SCC in addition to water content. The passing ability as indicated by J-ring improved as the paste content increased.
4.2.8 **Hardened Concrete**

Suresh Babu (2009) has studied elaborately about stress-strain behavior of SCC and GFRCC with different admixtures.

Several works reported that the compressive and tensile strengths of concrete specimens made with copper slag fine aggregate are almost the same as that of normal concrete or even significantly more than control mixtures Ayano et al. (1997).

Bertil Persson (2001) carried out an experimental and numerical study on mechanical properties such as strength, elastic modulus, creep and shrinkage of self-compacting concrete and the corresponding properties of normally compacting concrete. The study included eight mix proportions of sealed or air-cured specimens with water binder ratio (w/b) varying between 0.24 and 0.80. Fifty percent of the mixes were SCC and rests were NCC. The age at loading of the concretes in the creep studies varied between 2 and 90 days. Strength and relative humidity were also found. The results indicated that elastic modulus, creep and shrinkage of SCC did not differ significantly from the corresponding properties of NCC.

Paratibha Aggarwal (2008) et al. presented a procedure for the design of self-compacting concrete mixes based on an experimental investigation. At the water / powder ratio of 1.180 to 1.215, slump flow test, V-funnel test and L-box test results were found to be satisfactory, i.e. passing ability, filling ability and segregation resistance are well within the limits. SCC was developed without using VMA in this study. Further, compressive strength at the ages of 7, 28, and 90 days was also determined. By using the OPC 43 grade, normal strength of 25 MPa to 33 MPa at 28-days was obtained, keeping the cement content around 350 kg/m$^3$ to 414 kg/m$^3$. 
Cristian Druta (2003) carried out an experimental study on to compare the Splitting Tensile Strength and Compressive Strength values of self-compacting and normal concrete specimens and to examine the bonding between the coarse aggregate and the cement paste using the Scanning Electron Microscope. In this experiment, he used mineral admixtures - Blast Furnace Slag, Fly Ash and Silica Fume and chemical admixtures - Super plasticizers and Viscosity-Modifying Admixtures. It has been verified by using the slump flow and U-tube tests, that SCC achieved consistency and self-compactability under its own weight, without any external vibration or compaction. Also, because of the special admixtures used, SCC has achieved a density between 2400 and 2500 kg/m$^3$, which was greater than that of normal concrete, 2370-2321 kg/m$^3$. Self-compacting concrete can be obtained in such a way, by adding chemical and mineral admixtures, so that it’s splitting tensile and compressive strengths are higher than those of normal vibrated concrete. An average increase in compressive strength of 60% has been obtained for SCC, whereas 30% was the increase in splitting tensile strength. Also, due to the use of chemical and mineral admixtures, self-compacting concrete has shown smaller interface microcracks than normal concrete, a fact which led to a better bonding between aggregate and cement paste and to an increase in splitting tensile and compressive strengths. A measure of the better bonding was the greater percentage of the fractured aggregate in SCC (20-25%) compared to the 10% for normal concrete.

Surabhi et al. (2009) carried out an experimental study on cement content in the SCC mix replacing with various percentage of limestone powder and the fresh and hardened properties were studied. It is observed that limestone powder can be effectively used as a mineral additive in SCC. Then he concluded that result the 7 day and 28 day compressive strength increases with increase in content of limestone powder upto 20%. The improvement in compressive strength at 28 day is about 20% for a replacement of 20% of
cement with limestone powder. But further addition of limestone powder reduces the strength. All the hardened properties like cylinder compressive strength, split tensile strength, flexural strength and modulus of elasticity improves with the addition of limestone powder.

4.2.9 Durability of SCC

The evaluation of the effects of copper slag aggregate on the sulfate attack resistance and the depth of carbonation shows no significant attack and slower rate of carbonation by using copper slag Ayano et al. (1994)

4.3 OBSERVATIONS FROM LITERATURE REVIEW

Based on the literature review presented, it is concluded that

- Incorporation of copper slag aggregate increases the mechanical properties of high-strength concretes may be due to the strength characteristics of copper slag and the stronger bonding between copper slag aggregate and the cement paste matrix.

- The average of 28 and 91-day compressive strengths increased from 11% to 14%, whereas the splitting tensile strength showed an increase between 13% and 15%. The larger splitting tensile strength increases show that it is more sensitive to aggregate surface textures than compressive strength.

- Cement mortars with different copper slag proportions yielded comparable or higher compressive strength than the strength of the control mixture. There was more than 70% improvement in the compressive strength of mortars with
50% copper slag substitution in comparison with the control mixture.

- There is almost 5% increase in the concrete density, when copper slag was used as a sand replacement, whereas the workability increased substantially with an increase in copper slag content. This was attributed to the low water absorption and glassy surface of copper slag.

- The compressive, tensile and flexural strength of concrete were comparable to the control mix using up to 50% copper slag substitution for sand, but they decreased with a further increase in copper slag content.

- The surface water absorption of concrete was reduced with up to 40% copper slag replacement for sand.

- The volume of permeable voids decreased with the replacement of up to 50% copper slag.

- Copper slag, in the range of 40–50%, could potentially replace sand in concrete mixtures.