CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

For a variety of reasons, the concrete construction industry is not sustainable. It consumes large quantities of virgin materials in its preparation, particularly sand is traditionally used in concrete as fine aggregate. Sand mining is restricted to protect the environment from various degradations of nature like fall in ground water level, erosion of bank, which leads to failure of nearby structures, bridges, etc… Moreover natural sand is mainly excavated from river beds, always contains high percentages of inorganic materials, chlorides, sulphates, silt and clay that adversely affecting the strength, durability of concrete and reinforcing steel, thereby reducing the life of structure, strength degradation, etc…

Many suggestions came from different agencies involved in construction industry, to use the industrial waste materials. Many forms of aggregate replacement have attempted in the past, from recycled automotive tyres, slag from various refineries, glass and waste metal to pure trash. Bipra et al. (2003), Rajkumar and Hema (2011) stated that making of cement and concrete will be an important means of disposal of wastes from other activities of society. Concrete can provide through chemical binding, a safe heaven to many of the toxic elements present in industrial wastes; it is also able to provide an economical and technological solution to waste disposal in a way with least harm to our environment. The review of the recent research
showed that it is possible to use industrial by-products in the production of normal and high strength concrete when used as partial and/or full replacement of cement or/and aggregate. Also there are evidences that many of the produced concrete with industrial by-products possess superior properties when compared with the conventional concrete in terms of strength, durability, etc., Copper Slag (CS), is a by-product from copper industry, totally inert material and its physical properties are similar to natural sand. In India, three copper producers Sterlite, Birla copper and Hindustan copper produce around 6-6.5 tones of slag at different sites. Total accumulation of copper slag in India until 2007 is about 10 million tones, Havangi et al (1998). Copper slag used in this work was brought from Sterlite Industries Ltd. (SIL) Tuticorin, Tamil Nadu, India, producing 2600 tones per day (total accumulation of 1.5 million tones). As such, the need has been felt to study and compare the behaviour of HSC using CS as partial or total replacement of sand, which is the main aim of this study. In this chapter, a brief review of literature about the utilization of CS in concrete, mineral admixtures in OPC concrete, chemical admixtures, effect of compressive strength on flexure, deflection, and energy absorption under monotonic and repeated loading are given.

2.2 INFLUENCE OF MINERAL ADMIXTURES ON FRESH CONCRETE

The supplementary cementitious materials are important materials that contribute to enhance the properties of concrete when used in conjunction with OPC by reacting either hydraulically or pozzolancially. The use of these mineral admixtures is to overcome the adverse effect of calcium hydroxide produced during hydration of cement. Due to low w/c ratio, the cement / binder content will be more, which eventually produces more heat. Several
mineral admixtures are used in practice. However, fly ash, GGBS and silica fume is reported in many works and proved more apt for HSC.

Sharif et al. (2013) focused on compressive strength, drying shrinkage and sulphate attack properties of the concrete. At optimum replacement level of 15%, Silicafume and Metakaoline improve compressive strength and resistance to sulphate attack at all cement contents. However, experienced highest shrinkage among all mineral admixtures used in their study.

Reddy et al. (2012) studied the role of mineral admixture and chemical admixtures in obtaining the desired strength. In M70 grade of concrete, at w/c ratio of 0.317, it was found insufficient to provide the desired workability, hence superplasticizer was found necessary for making HPC and achieved 79.90 MPa with replacement of 20% fly ash and 10% Metakaoline at the age of 180 days curing period.

Liu and Shi (2012) validated the use of mineral admixtures, such as fly ash, silica fume, metakaoline and slag found promising features in the light of their potential benefits on the durability and sustainability of reinforced concrete. The use of industrial by-products may translate to cost savings, reduce energy use, greenhouse gas emissions and landfill waste, without sacrificing quality and long-term performance of the concrete. Additional research has suggested validating the use of such modified mixes for corrosion mitigation in chloride environments.

Khan and Siddique (2011) concluded that, owing to its fineness and high amorphous silicon dioxide content of silica fume became reactive pozzolanic material, accelerate the hydration of cement at all stages of hydration, very active at early hours of hydration, resulted in significant reduction in the chloride-ion diffusion, influenced the thickness of transition
phase and the degree of the orientation of the CH crystals. This could be attributed to considerable pore refinement. Silica fume improved the long-term corrosion resistance, alkali-silica expansion, but increased the carbonation depth.

Al-Azzawi et al. (2011) conducted an experiment to obtain the mechanical properties for two types of UHPC mixes, namely, the type of pozzolanic admixture (Silica Fume and High Reactivity Metakaolinite) in addition to three different values of steel fibre volume fraction (1%, 1.5% and 2%). In general, UHPC mixed with silica fume (SF) showed the highest value of cube compressive strength at different ages and for different steel fibres volume fraction; higher values achieved with silica fume in comparison with high reactivity metakaolinite.

With the w/b (water-binder ratio (w/b) - when supplementary cementitious materials are used to replace cement the water-cement ratio (w/c) becomes water-binder ratio) kept constant at 0.3, the compressive strength was detrimentally affected by the replacement of Portland cement with both fly ash and GGBS, Elahi et al (2010). However, the compressive strength increased at all ages due to the use of SF at 7.5% replacement level. Decrease in compressive strength was noticed at early ages when the SF content at 7.5% to 15%. It was possible to enhance the long-term compressive strength of both FA and GGBS mixes with the addition of 7.5% of SF, but there was a decrease in compressive strength at early ages. The ternary mixes containing GGBS, fly ash and silica fume, the silica fume performed the best amongst all the mixes to resist the chloride diffusion.

With previously published information as a comparative basis, the experimental results of Ismeik (2009) indicated that compressive and flexural strengths of silica fume concrete specimens were higher and gained strength more quickly than those of plain concrete at all ages. With other mix
proportioning parameters held constant, the investigation indicated that the maximum compressive strength and flexural strength occurred at about 10 to 15% silica fume and at about 15% fly ash, respectively, but not with fly ash alone.

Halit Yazici (2008) compared self-compacting concrete with fly ash 30% to 60% and with 10% silica fume in addition to other similar ingredients. The addition of 10% silica fume positively affected both the fresh and hardened stage properties of high performance high volume fly ash concrete. Although there was a little cement content these mixtures had good mechanical properties, freeze-thaw and chloride penetration resistance.

Sata et al. (2007) showed that with a constant w/c ratio of 0.28, the highest strength gained by replacing 10% SF, and 20% of FA, out of 10, 20, 30 and 40% of FA replacements.

Gonen and Yazicioglu (2007) stated that SF contributed to both short and long-term properties, but FA showed its beneficial effect in a relatively longer time. Addition of both SF and FA slightly increased compressive strength, but improved transport properties of concrete.

Agarwal and Gulati (2006) emphasized the effective applications of silica fume in high-strength concrete. The replacement up to 20% was found effective, however marble dust showed relatively better performance than the other industrial waste. The effect of superplasticizer felt better in 1:3 mortar than the 1:6.

Dhir et al. (2005) concluded that properly proportioned fly ash, GGBS and silica fume improved the properties of concrete in a way that might not be achieved through OPC alone. The resulting concrete became
strong, durable, economical, and eco-friendly because it utilised ecologically hazardous materials.

Mostofinejad and Nozhati (2005) attempted to predict the modulus of elasticity of HSC. The optimum SF percentage did not seem to be constant and increased when the ratio of w/c decreased. They indicated that the optimum SF percentage that produced maximum modulus of elasticity was not necessarily equal to that for achieving the maximum compressive strength.

Mazloom et al. (2003) obtained cube compressive strength of 67.5 MPa at 28 days and 74 MPa at 90 days with w/b ratio of 0.35 and with 10% replacement of cement by silica fume studied experimentally the short and long-term mechanical properties of High Strength Concrete containing different levels of SF. With increase of percentage of SF, the workability of concrete decreased, short-term mechanical properties and secant modulus found improved.

Babu and Natesan (2004) reported cube compressive strength of the order of 55.25 to 76.50 MPa at the age of 28 days for concrete mixes (with w/b ratio 0.32) containing 0-15% replacement of cement by silica fume.

Caliskan and Behnood (2004) explained that 20% silica fume with cement and addition of superplasticizer produced a thinner interfacial zone than plain cement mortar.

Malaikah (2003) investigated the properties of HSC with w/b ratios ranging between 0.20 and 0.35, with an increase of SF at 0, 10 and 15%, respectively. The results showed that the highest strength exceeding 100 MPa resulted from the addition of 10% SF with 0.20 w/c ratio.
Nassif et al. (2003) investigated the properties of High Strength Concrete made from mixes using various percentages of FA and SF and w/c ratio ranging from 0.29 to 0.44. The results showed that adding SF resulted in an increase in strength at early ages. In addition, adding 20% FA with various percentages of SF had an adverse effect. Also, the optimum combination that gave the highest strength was 5% SF.

Khan and Lynsdale (2002) reported that the incorporation of silica fume content at 8–12% increased the early strength, more impermeable pore structure when compared to plain cement paste. Cengiz Duram Atis (2002) found that higher replacement level of fly ash reduced the temperature rise and with high dosage of superplasticizer would cause retardation in hydration. Yunzingshi, et al. (2002) reported that up to 12% of silica fume content, plastic viscosity and yield stress became the maximum, and concrete had the lowest fluidity. Roncero et al. (2002) reported that the addition of 5% silica fume increased the superplasticizer demand due to higher specific surface area. Shighalli and Manjunath (2002) concluded that workability of concrete as measured from slump, compaction factor and vee-bee degree decreased as percentage of silica fume in concrete increased.

Joshi (2001) reported compressive strength of 75.16 MPa at the age of 28 days for M60 grade concrete mixed with w/b ratio 0.35 and with 10 % replacement of cement by silica fume. Kadri and Duval (2001) reported that the addition of silica fume counteracted the retarding effect of the superplasticizers on cement hydration. The pozzolanic reaction occurred early and played an important role in the heat of hydration at the fresh stage.

Pinto and Hover (2000) found that reductions in cement content and increment in superplasticizer dosage tended to retard setting while the increase in silica fume content tended to accelerate setting. Hassam et al. (2000) reported that mineral admixtures generally improved the properties of
HPC. Their results also concluded that, in the long term, both (SF & FA) mineral admixtures slightly increased the compressive strength by about 10% but contributed more to improve the durability properties of concrete. Shannag (2000) found that high to very high strength mortars and concretes with 15% natural pozzolans and 15% silica fume could be produced and marketed to provide technical and economic advantages. The increase in strength could be attributed to the improved aggregate-matrix bond.

It is best understood that cement alone cannot be a component to bind the aggregates, as the quantity of binder increases with increase in strength, and limiting the water requirement, it is evident from the above review that supplementary cementitious materials possessing pozzolans are inevitable and become important ingredient of HSC. From this review it has been strongly felt the advantages of industrial by-products possessing pozzolans are suitable, as the best supplementary to the cement and effective and efficient way of disposing the wastes in large quantity. It is well established that the incorporation of industrial waste products such as fly ash, ground granulated blast furnace slag (GGBS) and silica fume in concrete can significantly improve its basic properties in both the fresh and hardened states.

In particular, silica fume greatly improves the durability of concrete through pore refinement and the capabilities of pozzolanic reaction. Also it has been best understood that it not only enhances the mechanical properties of concrete but improves the durability requirement of HSC, which is one of the basic needs of HSC to meet the environmental deteriorating factors to which the HSC is exposed. In this study, ternary blend of cement, fly ash and silica fume is attempted for higher grade of concrete i.e. for grade M80 at w/b ratio of 0.295.
2.3 EFFECT OF CHEMICAL ADMIXTURES ON CONCRETE

Chemical admixtures such as superplasticizers (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. The main consideration when using superplasticizers in concrete are the high fine requirements for cohesiveness of the mix and rapid slump loss. Neither is harmful for the production of HSC. HSC mixes generally have more than sufficient fines due to high cement contents.

Reddy et al. (2012) reported that in high performance concrete mix design as water/cement ratio adopted was low, superplasticizers were necessary to maintain required workability. As the percentage of mineral admixtures was increased, superplasticizer should also be increased proportionately, for obtaining the desired strength.

Rashid and Mansur (2009) reported High strength concrete with compressive strength as high as 127 MPa could be obtainable using OPC and the naturally available coarse aggregate. However, use of lower water-cement ratio along with superplasticizer was the most vital factor in HSC productions. Bhaskar and Perumal (2009), reported that the compressive strength of concrete cubes increased by 15% with the addition of plasticizers and by 30% with the addition of superplasticizers. The optimum compressive strength in general was got when the dosage of the chemical added was kept at 0.75% by weight of cement, rather than when added by 1% or 1.25%. More addition of the chemical did not result in the increase of compressive strength of concrete.

Mirmiran, et al. (2003) reported that using superplasticizers in conjunction with set retarders, concrete with low water to cementitious
material ratio could be produced using standard practices while maintaining acceptable criteria for workability and setting time.

KungChung et al. (1999) studied the effect of addition of superplasticizer on cement adsorption and on concrete workability. They concluded that the optimum addition of superplasticizer to concrete to be in the period which corresponded to the dormant period of cement hydration. The use of retarders, together with high doses and re-doses of superplasticizers at the plant or at the job site could improve strength while restoring slump to its initial amount. Even a superplasticized mix that appeared stiff and difficult to consolidate was very responsive to applied vibration.

Dransfield and Edmeades (1989) defined superplasticizer as an admixture which when added to concrete, either imparted extreme workability without the addition of extra water to produce flowing concrete or allowed a large reduction of water content to be made without loss of workability or permitted a simultaneous increase in both workability and strength without incurring substantial extra cost. They concluded that in practice, it was important that the use of superplasticizer did not result in adverse side effects, which would result in gross retardation of setting time, low strength or impaired durability. In a study for grade M40 and M60 by Peterman and Carrasquillo (1986) superplasticizer was used and found suitable and for grade M80, High Range Water Reducer was used to make the concrete workable and maintain the required slump. However, the quantity used was very limited keeping in mind that the requirement was workability and the desired slump.

From the above review, it is evident that the production of HSC or High Performance Concrete essentially needs the chemical admixtures
according to the strength requirements. Particularly, when new materials are attempted, the role of chemical admixtures is more in making desired quality of concrete. In this present study, both superplasticizer and High Range Water Reducer are tried to achieve desired workability, strength and durability.

2.4 INFLUENCE OF COPPER SLAG AS FINE AGGREGATE IN CONCRETE

Since up to approximately 80 percent of the total volume of concrete consists of aggregate, aggregate characteristics significantly affect the performance of fresh and hardened concrete and have an impact on the cost effectiveness of concrete (Hudson 1999). Aggregate characteristics of shape, texture, and grading influence workability, finishability, bleeding, pumpability, and segregation of fresh concrete, affects strength, stiffness, shrinkage, creep, density, permeability, and durability of hardened concrete. Construction and durability problems had been reported due to poor mixture proportioning and variation on grading (Lafrenz 1997). In many countries, there is scarcity of natural aggregates, while in other countries there is an increase in the consumption of aggregates, 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 that are available. In view of the importance of saving of energy and conservation of resources, efficient recycling of all solid wastes is now a global concern, 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 aggregates generated from industrial wastes provide an alternative for the construction industry and attempts has been made since 1980 and a brief review of the same is presented here.
Alnuaimi (2012) reported that the use of CS as a replacement for Fine Aggregate is environmentally helpful due to the reduction in the waste produced from the copper manufacturing process. It also contributed to conservation of natural Fine Aggregate. Study of replacement of CS from 0 to 100%, gave better results at 40%, while other parameters were kept the same.

Al-Jabri et al. (2011) investigated the optimum replacement of CS for sand, and arrived 40-50% could potentially replace sand in concrete mixtures, 70% improvement in the compressive strength of mortars with 50% copper slag substitution in comparison with control mixture were achieved. The compressive, tensile and flexural strength of concrete was comparable to the control mixture using up to 50% copper slag substitution for sand.

WeiWu et al. (2010) reported that smooth glassy surface texture and low moisture absorption, the excellent compressibility of copper slag improved the workability and the dynamic behaviour concrete, but the presence of excess water, higher fineness and ferric oxide content decreased the quasi static compressive, flexural and tensile splitting strength. They recommended that less than 40% copper slag as sand substitution could achieve a high strength concrete comparable to or better than the control mixture. They also concluded that, 20% replacement showed increase in dynamic compressive strength of the copper slag reinforced concrete, and 40% substitution was close to that of control concrete and beyond which the strength generally reduced. Brinda et al. (2010) reported that the addition of copper slag improved the compressive strength, split tensile strength and flexural strength of concrete. The use of CS as a partial replacement for sand imparted strength up to 50% replacement level, water absorption value of CS concrete has reduced by 40%. In addition, CS concrete beams showed an increase in energy absorption values.
Al-Jabri et al. (2009a) concluded that the reduction in strength resulting from increasing CS was due to increased voids, free water that resulted from less fines and non-absorbent of CS. For cement mortars, all mixtures with different copper slag proportions yielded comparable or higher compressive strength than the strength of the control mixture. There was almost 5% increase in the concrete density, when copper slag used as a sand replacement, whereas the workability increased substantially with an increase in copper slag content. The compressive, tensile and flexural strength of concrete was comparable to the control mix using up to 50% copper slag substitution for sand, but they decreased with a further increase in copper slag contents.

Al-Jabri et al. (2009a), though recommended earlier for 40% by weight of CS replacement of sand to obtain HPC with good properties, found 50% of copper slag as sand replacement that yielded comparable strength with that of control mixture. Mixtures with 80% and 100% copper slag replacement found 16% lower than the strength of the control mixtures.

Khanzadi et al. (2009) observed that there was stronger bonding between CS and the cement paste matrix in cement concrete. This lead to higher strength in concrete and the incorporation of copper slag aggregate increased the mechanical properties of high-strength concrete. The replacement also increased the rebound hammer measurement from 2.6% to 9.3%, because of the higher hardness of copper slag aggregates, denser microstructure, and the superior bond between the matrix and the copper slag aggregates in comparison with limestone aggregates.

Al-Jabri et al. (2009b) concluded that 100% replacement of CS reduced the water demand by 22% and 20% improvement in the compressive strength with 100% CS substitution in comparison with the control mixture at the same workability. The use of CS as sand substitution improved HSC
strength and durability characteristics at the same workability while superplasticizer was a very important ingredient in HSC.

Shi et al. (2008) found that when CS used as a cement replacement or an aggregate replacement, the cement mortar and concrete containing different forms of copper slag have good performance in comparison with OPC having normal and even higher strength.

Studies by Alnuaimi (2005) indicated that replacement of fine aggregate (sand) by copper slag did not have an adverse effect on the load carrying capacity of the concrete columns. A study carried out by Pundhir et al. (2005) central Road Research Institute (CRRI), New Delhi has showed that copper slag could be used as a partial replacement for sand as fine aggregate in concrete up to 40% in pavement grade concrete without any loss of cohesiveness and the compressive and flexural strength of such concrete.

Caliskan and Behnoood (2004) investigated the compressive strength of normal-strength concrete containing CS as coarse aggregate and showed that the compressive strength of CS coarse aggregate concrete was marginally higher than that of limestone aggregate concrete. Li (1999) and Zong (2003) also reported that concrete containing copper slag as fine aggregate exhibited similar mechanical properties as that containing conventional sand and coarse aggregates.

Toshiki and Kenji (2000) critically reviewed the characteristic of CS and its effects on the engineering properties of cement mortars and concrete. They reported that the shrinkage of specimens containing CS fine aggregate was similar or even less than that of specimens without CS.

Hwang and Laiw (1989) reported that the amount of bleeding of mortar made with CS was comparatively less than that using natural sand.
However, the heavy specific weight and the glass-like smooth surface properties of irregular grain shape of CS aggregate were effective for characteristic of bleeding.

From the above review, it is learnt that the proportionate replacement of copper slag varies dynamically and consistence in the applicability is not found, due to the changes in the strategic plan of using copper slag in concrete. However, from all the reports it has been proved that replacing the natural sand by copper slag does not harm the properties of concrete as long as the proportionate replacement is well within their expectations. In this attempt, replacements from 0% to 100% at 10% increment are considered to study the variations at closer increments. Also, the free water due to non-absorbance of copper slag was well mitigated by the presence of silica fume in the ternary blend.

2.5 DURABILITY CHARACTERISTICS OF HIGH STRENGTH CONCRETE

It is a well-known fact that too much importance has been given to concrete compressive strength when designing concrete structures and not enough to the environmental factor that the concrete will have to face while performing its structural function. However, in recent years a new attitude is perceived towards durability in various national codes.

Vasumitha and SrinivasaRao (2013) reported that the chloride permeability of High Strength Self Compacting Concrete (HSSCC) showed less permeability of chlorides in concrete resulting in reduction of cracks causing interconnecting voids to be less. Denser microstructure of HSSCC contributed to a lower plastic settlement, higher bond between steel and concrete matrix, lower permeability to oxygen and lower chloride diffusion coefficient and higher tensile strength.
Falakian and Mousavi (2012) added silica fume on a replacement basis (6% silica fume of binder) which improved significantly the chloride penetration resistance compared to mix not containing any silica fume. On the average, the reduction in chloride penetration was in the range of 38-57% or 6, 4-9, 5% for each added per cent of silica fume of binder, depending on what aggregate was used.

The test results of Hamoush et al. (2011), indicated that VHSC had good freeze-thaw resistance (durability factor>85%) and could avoid freeze/thaw cycling. The use of silica fume in VHSC reduced pore size and thus made water unable to freeze at ambient temperatures.

Dinakara et al. (2008) suggested that the permeable voids present in the concrete, indirectly representing the permeability, decreased with an increase in strength and increased with increase in fly ash dosage. Self-compacting fly ash concretes showed higher permeable voids compared to vibrated normal concretes of any strength grade.

Bremner et al.(2004), Mehta (1999), and Estakhri and Saylak (2004), concluded that the resistance of a reinforced concrete structure to corrosion, alkali aggregate expansion, sulphate and other forms of chemical attack depended on the water tightness of the concrete. The use of fly ash in concrete decreased the required water and this combined with the production of additional cementitious compounds lead to a low porosity and discontinuous pore structure which reduced the permeability of the concrete.

Natesan (2003) reported that lower values of water absorption for concrete mixes with 2.5 to 15% replacement of cement by silica fume. He also reported that the porosity and sorptivity were in the order of 1% to 1.35% and 1 to 3.54mm/min$^{0.5}$, respectively, for concrete mixes containing 10 to 15% of cement replacement by silica fume. Selvaraj et al. (2003) reported that
the use of silica fume in concrete improved the resistance to corrosion of steel because of electrical resistivity by the pore filing effect. Malathy and Subramanian (2003) investigated the concrete mixes containing 10 to 15% of cement replacement by silica fume and fly ash, showed the co-efficient of permeability in the order of $6.5 \times 10^{-7}$ to $7.6 \times 10^{-7}$ cm/sec. Malhotra and Mehta (2002) obtained water absorption of the order of 2.9% to 4.78% for concrete mixes containing replacement materials.

Shannag (2000) reported that HPC containing silica fume and natural pozzalona could provide a good balance between strength and durability. Chan and Wu (2000) reported that the sorptivity and permeability of a given concrete mix found to be independent of the cement content and provide nearly the same compressive strength.

Tixier et al. (1997) HSC consisted of a more uniform microstructure and lower porosity compared to NSC. Austin and Robin (1997) found that the permeability of silica fume concrete reduced more rapidly during the first two months due to the pore refining effect in that period. Joshi and Lohtia (1997) reported that the permeability of concrete is governed by many factors such as the amount of cementitious material, water content, aggregate grading, consolidation, and curing.

SivanageswaraRao, (1996) obtained water absorption which was of the order of 2.46 to 2.8% for concrete mixes containing silica fume. Durning and Hicks (1991) reported that among the various mineral additives used in concrete structures, the silica fume was highly preferred for its superior concrete properties. The sulphate resistance of concrete was partly because of a lower permeability, and partly in consequence of lower content of calcium hydroxide and of alumina, incorporated in C-S-H. Silica fume was particularly very effective in controlling expansive alkali-silica reaction.
Wolsfier (1997) reported that among the various mineral additives used in concrete structures, silica fume was highly favoured for its superior concrete durability properties. Whiting and Kuhlman (1987) reported that the permeability of all concrete and resistance to chloride ion penetration especially that of silica fume concrete depended on the method and duration of curing. The influence of silica fume on permeability was more than on compressive strength.

In general, lower permeability means greater durability. Berry and Malhotra (1986) observed that the transformation of large pores to fine pores, due to the pozzolanic reaction between Portland cement paste and fly ash, substantially reduced permeability in cementitious systems.

Manmohan and Mehta (1981) concluded that the permeability of concrete is directly related to the quantity of hydrated cementitious material. After 28 days of curing, fly ash concretes were more permeable than OPC concrete. However, after 6 months of curing, fly ash concretes were much less permeable than OPC concretes due to the more pozzolanic reaction of fly ash.

The strength and durability of concrete become inseparable like the two sides of a coin and explain the poor performance of above two properties, were properly addressed and mitigated, by choosing the constituents in a right manner. Based on the above facts, proper care has been exercised in this experimental study to produce high strength durable concrete.

2.6 STRENGTH CHARACTERISTICS OF HSC

HSC offers many advantages over conventional concrete. The high compressive strength can be advantageously used in compression members like columns and piles. Higher compressive strength of concrete results in reduction of column size and increases available floor space. HSC can also be
effectively used in structures such as domes, folded plates, shells and arches where large in-plane compressive stresses exist. The relatively higher compressive strength per unit volume, per unit weight will also reduce the overall dead load on foundation of a structure with HSC. Also, the inherent techniques of producing HSC generate a dense microstructure making ingress of deleterious chemicals from the environment into the concrete core difficult thus enhancing the long-term durability and performance of the structure.

Katkhuda et al. (2009) studied the isolated effect of SF which increased the compressive, splitting tensile and flexure strengths. The highest increase was found in the flexure strength. The trend in the strength gain due to SF replacement in compressive strength was almost similar to that in split tensile strength for lightweight high strength concrete.

Rashid and Mansur (2009) produced HSC that consistently met requirements for workability and strength development placed more stringent requirements on material selection than that for lower strength concrete. However, use of lower water-cement ratio along with superplasticizer was the most vital factor to be considered in HSC productions.

Swamy (2008) showed a mix design strategy to develop a high durability, eco-friendly and sustainable high strength concrete based on moderate fineness of cementitious materials and without resorting to very high cements contents and very low water-binder ratios.

Gettu et al. (2002) presented in terms of the mechanical properties, the compressive strengths of the concretes obtained surpass 50 MPa at 7 days and 90 MPa at the age of 91 days.

Mittal and Kamarh (1999) obtained compressive strength of 75.9 MPa at the age of 28 days of M60 grade concrete mixes (with w/b ratio 0.32
and with 7.5% replacement of cement by silica fume). As a result, the surfaces of diagonal tension fracture were relatively smooth and less effective in aggregate interlock in contrast with through crack surfaces in lower strength concretes.

Gregerson (1991) reported that the high strength concrete was more durable and more resistant to corrosion and abrasion than that of the conventional concrete.

Peterman and Carrasquillo (1986) made a high strength concrete by the adjustments to mix proportions such as water-cement and cement-sand ratios. Swamy (1986) also made a high strength concrete with one-day strength of 60 to 80 N/mm$^2$, by using the granite aggregates and the ultrafine Portland cement with a specific surface of about 750 m$^2$/kg.

Carrasquillo (1985) observed that production of HSC might or might not require special materials, but it definitely required materials of highest quality and their optimum proportions.

From the above review, it is clear that the production of high strength concrete does not require any special materials. However choosing right materials and their proportions are the criteria for HSC, the same has been adopted in this experimental study to obtain concrete of higher strength with a newer material (which posses similar properties) in lieu of river sand. In this experimental work attempt has been made to find the behaviour of CS at three different grades of high strength concrete.

2.7 PULLOUT FOR BOND STRENGTH

High strength concrete is used mostly in the construction of bridges, high-rise buildings, marine and offshore structures. Bond strength
between high strength concrete and reinforcement is an important factor in designing any reinforced concrete structure under various kinds of loading.

Ahamed et al. (2007) found that, when compressive strength of concrete was increased, bond strength increased but relative slippage between steel and concrete decreased for the same development length, same diameter of bar and same \( c/d_b \) value, where \( c \) was distance between the ribs and \( d_b \) was the diameter of the embedded bar. Perhaps the reason was high bearing resistance of concrete keys that offered more resistance to slippage than normal strength concrete. However, they did not find any direct relationship between development length and slippage for normal strength concrete.

Alavi-Fard and Marzouk (2004) examined the influence of the concrete compressive strength on the bond behaviour. The test results revealed that the bond strength of high strength concrete was higher than the corresponding normal strength concrete. However, the bond behaviour of high strength concrete was more brittle compared to normal strength concrete.

Eligehausen et al. (1983) confirmed the nonlinear-brittle behaviour of the bond for high strength concrete. In the case of High Strength Concrete, the capacity of bond strength was higher than the normal. However, the impact of the instantaneous drop in the bond stress for high strength concrete had to be recognized.

Somayaji and Shah (1981) conducted several experimental and theoretical investigations, on the behaviour of bond for normal strength concrete. Improved tools for measurement of local bond and local slip were introduced and applied. The observations of secondary cracks were reported as well as the distribution of strain in concrete, near the reinforcing bar.
Azizinamini et al. (1999) examined bond performance of reinforcing bars and tension development length of reinforcing bars embedded in high strength concrete. They concluded that, in the case of high strength concrete, increasing the tension development length (or equivalent tension splices) was not an efficient way of increasing the bond capacity of deformed reinforcing bars, especially when the concrete cover is small. Also, they indicated that when calculating the tension development length of high strength concrete and tension splice, a minimum number of stirrups should be provided over the splice region. Darwin et al. (1996) studied development length criteria for conventional and high relative rib area of reinforcement. Based on a statistical expression, the development length and splice strength of reinforcement for concrete with strengths between 17 and 110 MPa, with and without confining reinforcement, were investigated. The effects of cover, spacing, development/splice length, geometric properties of the development and spliced reinforcement were included in their design equation.

De Larrard et al. (1993) investigated the effect of bar diameter on bond strength in high performance concrete. They concluded that bond capacity increased with the tensile strength of the concrete and it was at a higher rate with smaller reinforcement. It was also found that the bond was greater for smaller bar diameters than for larger bar diameters.

Eligehausen et al. (1983) conducted one of the main comprehensive investigations on the effect of the bar diameter embedded in normal strength concrete. They concluded that the maximum bond capacity decreased slightly with the increasing bar diameter. The frictional bond resistance was not influenced significantly by the different bar diameter, lug spacing, or the relative rib area.

Therefore, the present study proposes to investigate bond behaviour between high strength concrete made of natural sand and copper slag as fine
aggregate and steel reinforcement. However, the surface of the copper slag is smooth and glassy, when combined with other material its bond characteristics are important to know and even its bond strength becomes limiting value for its application. The studies made so far reveal enhancement in the bond strength when the strength of concrete increased.

2.8 DEFLECTION OF HSC BEAMS UNDER SHORT-TERM LOADING

The serviceability or deflection of a flexural member is a significant aspect considered in the design of concrete structures.

Arangjelovski and Atanasovski (2010) reported that bending tests using different loading history confirmed significant reduction of time dependent deflections in HSC beams in comparison with the same deflections in OSC beams. For HSC beams, the authors could not propose coefficient because proposed histories of loading causing state of cracking at level of service loads. This could be explained with the fact that for HSC beams exist in stabilized state of cracking, because moment in service was near to cracking moment.

Ferhad and Karim (2008) reported that when the longitudinal reinforcement for bending, torsion and transverse reinforcement for shear and torsion in beams were constant and under the same eccentricity, an increase in compressive strength by 111.9% caused an increase in cracking shear strength and load carrying capacity by about 131.26% and 22.9 %, respectively.

Siddique and Rouf (2006) carried out an analytical study on the effect of concrete strength on the moment-curvature response of the beams without any confinement, but with different concrete strengths. They
observed and reported that, with an increase in concrete strength increases the ultimate load carrying capacity of the beam.

Ashour et al. (1997) observed that the methods proposed in his work predicting and controlling deflection were applicable to normal strength concrete members with concrete compressive strength in the range of 21 to 42 MPa. However, the accuracy of these methods for use with high-strength concrete flexural members has not yet been fully established.

Paulson et al. (1991) found that for beams with tension reinforcement the use of high strength concrete reduced long term deflection by 30 to 50% also long-term deflections could also be reduced significantly either through use of compressive reinforcement or high strength concrete, but the use of both is redundant.

An experimental research by Lambotte and Taerwe (1990) on both NSC and HSC beams, showed that the deflections decreased by using High Strength Concrete due to the increased modulus of elasticity and cracking moment.

The review reveals the significance of strength of concrete on deflection of reinforced concrete beams. Though the flexural behaviour of HSC not established fully, the available literature reveals the improvement in the performance of High Strength Concrete, when subjected to lateral loads. This experimental study aimed to verify the above facts and to clarify the application of CS in reinforced high strength concrete beams.

2.9 DUCTILITY

Ductility is a desirable structural property because it allows stress redistribution and provides warning of impending failure. Steel-reinforced
concrete beams are under-reinforced by design, so that failure is initiated by yielding of the steel reinforcement, after considerable deformation at no substantial loss of load carrying capacity, the ultimate failure occurs. This mode of failure is ductile and is guaranteed by designing the tensile reinforcement ratio to be substantially below (ACI 318 (3) requires at least 25% below) the balanced ratio, which is the ratio at which steel yielding and concrete crushing occur simultaneously. The reinforcement ratio thus provides a metric for ductility, and the ductility corresponding to the maximum allowable steel reinforcement ratio provides a measure of the minimum acceptable ductility.

Jang et al. (2008) stated that the ductile behaviours of High Strength Concrete beam members with various concrete compressive strengths (40, 60, 70 MPa) and tensile reinforcement ratios were compared. When the tensile reinforcement ratio was the same, the load-deflection behaviour prior to the yield of tensile reinforcement hardly changed with the change in compressive strength, but it varied greatly after the yield. Thus, the general trend of increasing ductility with the increase in concrete strength was observed. The increase in concrete compressive strength under the same condition also resulted in the increase in stiffness and bending (flexural) strength due to the increase in tensile reinforcement.

Bernardo and Lopez (2003) mentioned that in spite of high-strength concrete being a more brittle material than normal-strength concrete, the ductility of reinforced concrete section increased with increasing concrete compressive strength. They noted that, though the ductile behaviour of high strength concrete beams in flexure was studied by various authors, the results on the topic were contradictory.

Sarkar et al. (1997) noted that although HSC was a less ductile material compared with NSC, the ductility index for a specified reinforcement
ratio of high-strength reinforced concrete section in flexure increased with the increase in compressive strength of concrete. According to Xie et al. (1994) the deformability was influenced by factors such as the tensile reinforcement ratio, the amount of longitudinal compressive reinforcement, the amount of lateral tie and the strength of concrete. They observed that the ductility factors were generally lower at lower concrete strengths and higher at higher concrete strengths. The results, in confirmation with previously published papers, indicated that the increase in concrete compressive strength caused an increase in the ductility.

The above review on ductility parameter of high strength reinforced concrete beams were taken and the experimental study has been proposed to understand ductile behaviour of CSHSC beams. The studies made so far reveal enhancement in the ductility, when the strength of concrete increased.

2.10 SHEAR CAPACITY OF HSC BEAMS

A reinforced concrete beam under loading was generally subjected to both bending moment and shear force. This aspect of shear was considered for research since few decades, but there is still no universally acceptable design method for finding the shear strength of beams made of high strength concrete. As the shear design procedures in the various codes and recommendations are based mainly on experimental studies conducted on structural elements made with relatively low compressive strength concrete, there is concern that these procedures may not be adequately safe for reinforced high strength concrete structures. Therefore, there is an urgent need to provide additional information on the shear capacity of high strength concrete structural elements, both without and with transverse reinforcement.

Galeota and Giammatteo (1997) stated that, in order to improve the shear capacity of reinforced concrete beams in shear, it is necessary to
evaluate the influence of different design parameters on the structural behaviour of concrete. The primary variables are the concrete compressive strength, the amount of longitudinal reinforcement, shear reinforcement and shear span-to-effective depth ratio (a/d). The secondary variables include the beam dimensions, concrete cover to-shear reinforcement cage and overall beam depth, type of load (point load or uniform load), and support conditions (pinned or fixed). Due to the influence of various parameters involved in resisting the shear in reinforced concrete beams, the estimation of shear resistance of high strength concretes is still controversial; therefore, it is a thrust area for research. The minimum shear reinforcement is also required to provide to improve the ductile behaviour prior to failure (Ozcebe et al. 1999).

Cladera and Mari (2005) concluded that HSC beams with stirrups presented a less fragile response than similar beams without web reinforcement. HSC cracks at higher shear stresses when compared to the conventional concrete and consequently requires larger amounts of minimum transverse reinforcement (Rahal and Al-Shaleh 2004). Researchers in the past showed that as the amount of stirrups increased, the beams became more ductile and failures were less sudden. Beams without any stirrups failed suddenly (Mphonde and Fruntz 1985; Elzanaty et al 1986).

In the research for evaluation of minimum shear reinforcement requirements for higher strength concrete by Ozcebe et al. (1999), found that the code specifications for minimum shear reinforcement are inadequate when high strength concrete is used. Shin et al. (1999) studied the effect of parameters such as compressive strength of concrete, the shear span-to-depth ratio and the vertical shear reinforcement ratio on the shear strength of reinforced HSC beams without stirrups.

Johnson and Ramirez (1989) proposed that more shear reinforcement be provided with increasing concrete strengths to avoid sudden
brittle failure. Elzanaty et al. (1986) from their observation, it was noted that the shear strength of the beams increased with increase in compressive strength of concrete.

The above review on shear capacity of high strength reinforced concrete beams reveals the improvement in the performance of beams under shear when the strength of concrete increased. The experimental study has been proposed to understand shear behaviour of CSHSC beams. The studies made so far reveal enhancement in the shear capacity, when the strength of concrete increased.

2.11 NEED FOR THE PRESENT STUDY

Aggregates exercise an important influence on concrete strength and stiffness, providing rigidity to the material that is necessary for engineering use. Aggregates are not only simply fillers but also significant improvements in the workability of the fresh concrete, which are contributed by proper choice of aggregates. Such a choice influences highly important properties of the hardened concrete as well, such as volume stability, unit weight, resistance to destructive environments, strength and thermal properties.

Copper slag, which is the waste material produced in the extraction process of copper metal, has low cost and its application as a fine aggregate in concrete production reaps many environmental benefits. There is no considerable work done in our country particularly in Tamil Nadu, where the disposal of copper slag is of great environmental issue at Tuticorin.

The works reported so far is limited with one particular grade. The influences of CS on strength, at various grades were not reported. The behaviour of CS in reinforced concrete beams were also not reported so far.
As copper slag improves workability, compressive strength, it is planned to find the application of copper slag as fine aggregate in the HSC and in reinforced CSHSC beams.

The aim of this study is to investigate the mechanical properties, the durability performance, flexural, shear behaviour and response under repeated loading of HSC made of copper slag in concrete as fine aggregate in three grades of concrete viz., M40, M60 and M80 in comparison to conventional concrete.