CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Concrete is a most versatile construction material because it is designed to withstand the harsh environments. Engineers are continually pushing the limits to improve its performance with the help of innovative chemical admixtures and supplementary materials. These materials are majority by products from other processes. The use of these by products not only helps to utilise these waste materials but also enhances the properties of concrete in fresh and hydrated states.

The usage of industrial by-products especially industrial slags in making of concrete is an important study of world wide interest. Many researchers have investigated the possible use of copper slag as a concrete aggregate. For this investigation, some of the important literatures were reviewed and presented briefly.

2.2 PAPERS REVIEWED

Al-Jabri et al (2009) has investigated the performance of high strength concrete (HSC) made with copper slag as a fine aggregate at constant workability and studied the effect of super plasticizer addition on the properties of HSC made with copper slag. Two series of concrete mixtures were prepared with different proportions of copper slag. The first series consisted of six concrete mixtures prepared with different proportions of
copper slag at constant workability. The water content was adjusted in each mixture in order to achieve the same workability as that of the control mixture. Twelve concrete mixtures were prepared in the second series. Only the first mixture was prepared using super plasticizer whereas the other eleven mixtures were prepared without using super plasticizer and with different proportions of copper slag used as sand replacement.

The results indicated that the water demand reduced by almost 22% at 100% copper slag replacement compared to the control mixture. The strength and durability of HSC were generally improved with the increase of copper slag content in the concrete mixture. However, the strength and durability characteristics of HSC were adversely affected by the absence of the super plasticizer from the concrete paste despite the improvement in the concrete strength with the increase of copper content. The following conclusions were drawn from this study

- Compared to the control mix, there was a slight increase in the HPC density of nearly 5% with increase of copper slag content, whereas the workability increased rapidly with increase in copper slag percentage.

- Addition of upto 50% of copper slag as sand replacement yielded comparable strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix.

- There was a decrease in the surface water absorption as copper slag quantity increased upto 40% replacement. Beyond that level of replacement, the absorption rate increases rapidly.
• It was recommended that 40 wt% of copper slag can be used as replacement of sand in order to obtain HPC with good properties.

Al-Jabri (2009 a) investigated the effect of using copper slag as a replacement of sand on the properties of high performance concrete (HPC). Eight concrete mixtures were prepared with different proportions of copper slag ranging from 0% (for the control mix) to 100%. Concrete mixes were evaluated for workability, density, compressive strength, tensile strength, flexural strength and durability. The results indicate that there is a slight increase in the HPC density of nearly 5% with the increase of copper slag content, whereas the workability increased rapidly with increases in copper slag percentage. Addition of upto 50% of copper slag as sand replacement yielded comparable strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix. Mixes with 80% and 100% copper slag replacement gave the lowest compressive strength value of approximately 80 MPa, which is almost 16% lower than the strength of the control mix. The results also demonstrated that the surface water absorption decreased as copper slag quantity increases upto 40% replacement; beyond that level of replacement, the absorption rate increases rapidly.

Wei wu et al (2010) investigated the mechanical properties of high strength concrete incorporating copper slag as fine aggregate. The workability and strength characteristics were assessed through a series of tests on six different mixing proportions at 20% incremental copper slag by weight replacement of sand from 0% to 100%. A high range water reducing admixture was incorporated to achieve adequate workability. Micro silica with a specific gravity of 2.0 was used to supplement the cementitious content
in the mix for high strength requirement. The following conclusions were drawn from this study

- The results indicated that the strength of concrete with less than 40% copper slag replacement was higher than or equal to the control specimen.

- The microscopic view also suggest that the microstructure of concrete with more than 40% copper slag contains more voids, micro cracks, and capillary channels that accelerate the damage of concrete during loading.

- The surface water absorption decreases constantly until 40% of copper slag substitution.

Al-Jabri et al (2005) dealt with the effect of copper slag and cement by-pass dust addition on mechanical properties of concrete. Here in addition to the control mixture, two different trial mixtures were prepared using different proportions of copper slag (CS) and cement by-pass dust (CBPD). CBPD was primarily used as an activator. One mixture consisted of 5% copper slag substitution for Portland cement. The other mixture consisted of 13.5% CS, 1.5% CBPD and 85% Portland cement. Three water- to-binder ratios (0.5, 0.6 and 0.7) were studied. Concrete cubes, cylinders and prisms were prepared and tested for strength after 7 and 28 days of curing. The modulus of elasticity of these mixtures was also evaluated. The results showed that 5% copper slag substitution for Portland cement gave a similar strength performance as the control mixture, especially at low w/b ratios (0.5 and 0.6). Higher copper slag (13.5%) replacement yielded lower strength values. The results also demonstrated that the use of CS and CBPD as partial replacements of Portland cement have no significant effect on the modulus of elasticity of concrete, especially at small quantities substitution.
Caijun Shi et al (2008) reviewed the characteristics of copper slag and its effects on the engineering properties of cement, mortars and concrete and they concluded that the utilization of copper slag in cement and concrete provides additional environmental as well as technical benefits for all related industries, particularly in areas where a considerable amount of copper slag is produced. When it is 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 ordinary Portland cement having normal and even higher strength.

Al-Jabri et al (2011) investigated the effect of using copper slag as a fine aggregate on the properties of cement mortars and concrete. Various mortar and concrete mixtures were prepared with different proportions of copper slag ranging from 0% (for the control mixture) to 100% as fine aggregates replacement. Cement mortar mixtures were evaluated for compressive strength, whereas concrete mixtures were evaluated for workability, density, compressive strength, tensile strength, flexural strength and durability. The results obtained for cement mortars revealed that all mixtures with different copper slag proportions yielded comparable or higher compressive strength than that 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.

The results obtained for concrete indicated that there is a slight increase in density of nearly 5% as copper slag content increases. On the other hand, the workability increased significantly as copper slag percentage increased compared with the control mixture. A substitution of up to 40–50% copper slag as a sand replacement yielded comparable strength to that of the control mixture. However, addition of more copper slag resulted in strength reduction due to the increase in the free water content in the mix. The results
demonstrated that surface water absorption decreased as copper slag content increases up to 50% replacement. Beyond that, the absorption rate increased rapidly and the percentage volume of the permeable voids was comparable to the control mixture. Therefore, it was recommended that up to 40–50% (by weight of sand) of copper slag can be used as a replacement for fine aggregates in order to obtain a concrete with good strength and durability requirements.

Isa Yuksel and Turhan Bilir (2007) presented the results of research aimed at studying the possible usage of bottom ash (BA) and granulated blast-furnace slag (GBFS) in production of plain concrete elements. Sufficient number of briquettes, paving blocks and kerb specimens containing GBFS and BA as fine aggregate replacement were produced in laboratory. Then, a few tests were conducted for investigating durability and mechanical properties of these specimens. Unit weight, compression strength and freeze–thaw tests were conducted for briquette specimens. Compression strength, freeze–thaw, water absorption and surface abrasion tests were conducted for paving blocks. Surface abrasion and flexural tensile strength tests were conducted for kerb specimens. While compression strength was decreased slightly, durability characteristics such as resistance of freeze–thaw and abrasion were improved. The results showed that usage of partially fine aggregate of these industrial by-products have more beneficial effects on durability characteristics of plain concrete elements.

Ramazan Demirbog and Rustem Gul (2007) investigated the use of Blast furnace slag aggregates (BFSA) to produce high-strength concretes (HSC). These concretes were made with total cementitious material content of 460–610 kg/m$^3$. Different water/cement ratios (0.30, 0.35, 0.40, 0.45 and 0.50) were used to carry out 7- and 28-day compressive strength and other properties. Silica fume and super plasticizer were used to improve BFSA
concretes. Slump was kept constant throughout this study. Ten percent silica fume was added as a replacement for ordinary Portland cement (OPC) in order to obtain HSC. Results showed that compressive strength of BFSA concretes were approximately 60–80% higher than traditional (control) concretes for different w/c ratios. These concretes also had low absorption and high splitting tensile strength values. Therefore, it was concluded that BFSA, in combination with other supplementary cementitious materials, can be utilized in making high strength concretes.

Caroline Morrison et al (2003) reported that Ferro-silicate slag from the Imperial Smelting Furnace production of zinc can be used as a replacement for sand in cementitious mixes. The ISF slag contains trace quantities of zinc and lead, which are known to cause retardation of concrete set. Testing of experimental concrete mixes proves this retardation affect, although the delay in set does not appear deleterious to the eventual concrete hydration. Leaching studies demonstrated that pulverized fuel ash and ground granulated blast-furnace slag had the potential to reduce the leaching of lead and zinc ions from the ISF slag, even in highly alkaline solutions.

The following conclusions were drawn from this study:

- The replacement of sand in concrete mixes with Ferro silicate slag from the ISF production of zinc (ISF slag) caused a retardation of concrete set.
- The leaching of lead and zinc ions was increased in high pH solutions. However, the combination of ISF slag and PFA or GGBS reduced leaching, even in highly alkaline solutions containing PFA.
Byung Sik Chun et al (2005) conducted several laboratory tests and evaluated the applicability of copper slag as a substitute for sand of sand compaction pile method. From the mechanical property test, the characteristics of the sand and copper slag were compared and analyzed, and from laboratory model test, the strength of composite ground was compared and analyzed by monitoring the stress and ground settlement of clay, sand compaction pile and copper slag compaction pile.

Teik-Thye Lim and Chu (2006) conducted a study on the feasibility of using spent copper slag as fill material in land reclamation. The physical and geotechnical properties of the spent copper slag were first assessed by laboratory tests, including hydraulic conductivity and shear strength tests. The physical and geotechnical properties were compared with those of conventional fill materials such as sands. The potential environmental impacts associated with the use of the spent copper slag for land reclamation were also evaluated by conducting laboratory tests including pH and Eh measurements, batch-leaching tests, acid neutralization capacity determination and monitoring of long-term dissolution of the material. The spent copper slag was slightly alkaline, with pH 8.4 at a solid /water ratio of 1:1. The batch-leaching test results showed that the concentrations of the regulated heavy metals leached from the material at pH 5.0. They were significantly lower than the maximum concentration for their toxicity limits referred by United States Toxicity Characteristic Leaching Procedure. They finally suggested that the spent copper slag was a good fill material and it can be used as a fill material for land reclamation.

Mobasher et al (1996) investigated the effect of copper slag on the hydration of cement based materials. Upto 15% by weight of copper slag was used as a Portland cement replacement. Activation of pozzolanic reactions was studied using upto 1.5% hydrated lime. Hydration reactions were
monitored using quantitative X-Ray diffraction and the porosity was examined using mercury intrusion porosimetry. The results indicate a significant increase in the compressive strength for up to 90 days of hydration. A decrease in capillary porosity measured using MIP indicated densification of the microstructure. The embrittlement due to the addition of slag is measured using fracture parameters. Fracture properties such as critical stress intensity factor and fracture toughness showed a constant or decreasing trend with the addition of slag.

Tixier et al (1997) worked on the effect of copper slag on the hydration of cement based materials. Up to 15% by weight of copper slag was used as a Portland cement replacement. Hydration reactions were studied through semi quantitative X-ray diffraction and thermogravimetric analysis. Samples of copper slag and hydrated lime were used to test the pozzolanic properties of the slag. The porosity was examined using mercury intrusion porosimetry. A decrease in capillary porosity was observed while the gel porosity decreased. A significant increase in the compressive strength was observed.

Caijun Shi and Jueshi Qian (1999) reported that most industrial slags are being used without taking full advantage of their properties or disposed rather than used. The industrial slags, which have cementitious or pozzolanic properties, should be used as partial or full replacement for Portland cement rather than as bulk aggregates or ballasts because of the high cost of Portland cement, which is attributable to the high energy consumption for the production of Portland cement. They stated that the traditional way to utilize metallurgical slags in cementing materials is to partially replace Portland cement, which usually results in a lower early strength and longer setting times. The presence of activator(s) can accelerate the break-up of structure and hydration of slags. Many research results have indicated that
clinker less alkali-activated Slags even exhibit higher strengths, denser structure and better durability compared with Portland cement. In this paper, the recent achievements in the development of high performance cementing materials is based on activated slags such as blast furnace slag, steel slag, copper slag and phosphorus slag. They were reviewed and the following conclusions were drawn from this study:

- Copper slag such as blast furnace slag, steel slag, alkali-activated slag and phosphorus slag exhibit not only higher early and later strength, but also better corrosion resistance than normal Portland cement.
- The production of Portland cement is an energy-intensive process, while the grinding of metallurgical slags needs only approximately 10% of the energy required for the production of Portland cement.
- Activation of latent pozzolanic or cementitious properties of metallurgical Slags should be a prime topic for construction materials researchers.

Arino and Mobasher (1999) presented the effect of ground copper slag on the strength and fracture of cement-based materials. Upto 15% by mass of ground copper slag was used as a portland cement replacement. The strength and fracture toughness of concrete samples were studied using closed-loop controlled compression and three-point bending fracture tests. The compression test utilized a combination of the axial and transverse strains as a control parameter to develop a stable post-peak response. A cyclic loading-unloading test was conducted on three-point bending notched specimens under closed-loop crack mouth opening control. Test results were used to construct the Resistance Curve (R-Curve) response of the specimens
describing the dependence of fracture toughness on the stable crack length. Mechanical response of GCS concrete was also reported. The compression-test results indicated that GCS concrete was stronger but more brittle than ordinary Portland cement concrete. Fracture test results confirmed the increased brittleness of concrete due to the use of GCS. Long-term results showed equal or higher strengths for the GCS specimens without concern for degradation of other properties.

Sioulas and Sanjayan (2000) reported the results of use of slag-blended cements in the production of HSC. Slag replacement can assist in reducing high hydration temperatures, which is a problem in concrete with high cement contents. Slag replacement levels were studied of 70%, 50%, 30% and 0%. Slag replacement levels studied were of 70%, 50%, 30% and 0%. A ternary blend, containing Portland cement, slag and silica fume was also investigated in one of the columns. The study was based on square columns of size 800 x 800 mm in cross-section and 1200 mm high. Altogether, results of 11 columns are reported.

They concluded that the peak and net temperature rise encountered at the center of the columns are substantially reduced with the inclusion of slag into the binder. A progressive reduction in maximum net temperature rise was obtained with increasing slag content. The inclusion of slag into the concrete binder results in a delay in time required to attain peak temperature. The maximum thermal gradients exhibited by the general purpose columns were significantly reduced when slag was incorporated into the concrete. The removal of the formwork at 24 h exacerbated the temperature difference between the center and surface of the columns containing a slag replacement equal to or greater than 50%.

Washington Almeida Moura et al 2007 presented the results of a study on the use of copper slag as pozzolanic supplementary cementing
material for use in concrete. Initially, the chemical and mineralogical characteristics of the copper slag were determined. After this, concrete batches were made with copper slag additions of 20% (relative to the cement weight) and set properties were investigated, i.e., specific gravity, compressive strength, splitting-tensile, absorption, and absorption rate by capillary suction and carbonation. The results pointed out that there is a potential for the use of copper slag as a supplementary cementing material to concrete production. The concrete batches with copper slag addition presented greater mechanical and durability performance. The following conclusions were drawn from this study

- The addition of copper slag to concrete results in an increase on the concrete’s axial compressive and splitting tensile strengths.

- It was observed that a decrease in the absorption rate by capillary suction, absorption and carbonation depth in the copper slag concrete tested improved its durability.

Moura et al (1999) reported that the use of electric steel slag and copper slag can be a potential alternative to the admixtures used in concrete and mortars. The results of physical, chemical and physical-chemical characterizations of electric steel lags from Rio Grande do Sul and copper slags from Bahia, both in Brazil, are presented in their work. They also presented the results of compressive tests, flexural tests and Brazilian tests in concrete specimens with these admixtures, indicating the viability of their use.

Ayano Toshiki et al (2000) presented the problems in using copper slag as a concrete aggregate. One of them is excess bleeding attributed to the glassy surface of copper slag. Another problem is the delay of setting time of concrete with copper slag. Nevertheless, it produced the same refinery. The
delay of setting time is more than one week in some cases although the durability in concrete is not affected by it. In this paper, the strength, setting time and durability of concrete with copper slag was clarified. Finally, they concluded that the delay of setting time does not have a negative influence on durability.

Bipragorai et al (2003) reviewed the characteristics of copper slag as well as various processes such as pyro, hydro and combination of pyro-hydrometallurgical methods for metal recovery and preparation of value added products from copper slag. Copper slag, which is produced during pyrometallurgical production of copper from copper ores, contains materials like iron, alumina, calcium oxide, silica etc. This paper discusses the favorable physico-mechanical characteristics of copper slag that can be utilized to make the products like cement, fill, ballast, abrasive, aggregate, roofing granules, glass, tiles etc. apart from recovering the valuable metals by various extractive metallurgical routes. The favorable physico-mechanical and chemical characteristics of copper slag lead to its utilisation to prepare various value added products such as cement, fill, ballast, abrasive, cutting tools, aggregate, roofing granules, glass, tiles etc. The utilisation of copper slag in such manners may reduce the cost of disposal. This may also leads to less environmental problems.

Harvey Alter (2004) has conducted a recent comprehensive review on the characteristics and utilization of copper slag. It encourages (properly) several applications for this important pyrometallurgical byproduct. However, the review does not include possible environmental effects from these slags. Literature reports were used to accumulate data describing the chemical composition and acid leaching of commercial copper slags from three countries. From these data, average values of chemical composition and their statistical confidence limits (95%) were calculated. The variability of the
chemical analyses of three commercial slags produced over 19 or 20 months were statistically analyzed and shown to be small. He concluded that the concentrations of toxic heavy metals in the slags are low and the frequency distributions of the values are narrow and commercial copper slags have been determined to be non-hazardous.

Ke Ru Wu et al (2001) studied the effect of copper slag in coarse aggregate type on mechanical properties of high-performance concrete. Tests were carried out to study the effect of the coarse aggregate type on the compressive strength, splitting tensile strength, fracture energy, characteristic length, and elastic modulus of concrete produced at different strength levels with 28-day target compressive strengths of 30, 60 and 90 N/mm² respectively. Concrete was produced using crushed quartzite, crushed granite, limestone, and marble coarse aggregate. The results showed that the strength, stiffness, and fracture energy of concrete for a given water/cement ratio (W/C) depend on the type of aggregate, especially for high-strength concrete. It was suggested that high-strength concrete with lower brittleness can be made by selecting high-strength aggregate with low brittleness.

Alpa and Deveci (2008) reported the potential use of flotation waste of a copper slag as iron source in the production of Portland cement clinker. The FWCS appears a suitable raw material as iron source containing greater than 59% Fe₂O₃ mainly in the form of fayalite (Fe₂SiO₄) and magnetite (Fe₃O₄). The clinker products obtained using the FWCS from the industrial scale trial operations over a four month period were characterised for the conformity of its chemical composition. The physico-mechanical performance of the resultant cement products was evaluated. The data collected for the clinker products (produced using an iron ore) is currently used as cement raw material. It was also included for comparison. The results have shown that the chemical compositions of all the clinker products
including those of FWCS are typical of a Portland cement clinker. The mechanical performance of the standard mortars prepared from the FWCS clinkers was found to be similar to those of the iron ore clinkers with the desired specifications for the industrial cements. Furthermore, the leachability tests have revealed that the mortar samples obtained from the FWCS clinkers present no environmental problems while the FWCS could act as the potential source of heavy metal contamination. These findings suggest that flotation wastes of copper slag (FWCS) can be readily utilized as cement raw material due to its availability in large quantities at low cost. This has got significant benefits for waste management/environmental practices of the FWCS, reduced production and processing costs for cement raw materials.

Mostafa Khanzadi and Ali Behnood (2009) presented the results of a study undertaken to investigate the feasibility of using copper slag as coarse aggregates in high-strength concrete. The effects of replacing limestone coarse aggregate by copper slag coarse aggregate on the compressive strength, splitting tensile strength and rebound hammer values of high-strength concretes are evaluated in this work. Concrete mixtures containing different levels of silica fume were prepared with water to cementitious materials ratios of 0.40, 0.35 and 0.30. The percentages of the cement replacements by silica fume were 0%, 6% and 10%. The use of copper slag aggregate compared to limestone aggregate resulted in a 28-day compressive strength increase of about 10–15% and a splitting tensile strength increase of 10–18%. It can be concluded from the results of this study that using copper slag as coarse aggregate in high-strength concrete is technically possible and useful.

Goni et al (1994) The reactivity of hydrated portland cement pastes containing up to a 30% of a Spanish ground copper slag in an aggressive solution ($\text{Cl}^- + \text{SO}_4^{2-}$) has been studied in order to evaluate the changes in microstructural and mechanical properties of the composite material. Flexural
strength data were related to microstructural parameters, studied X-ray diffraction as well as porosity and pore-size distribution analyses.

Najimi et al (2011) investigated the performance of copper slag contained concrete in sulphate solution. In this regard, an experimental study including expansion measurements, compressive strength degradation and micro structural analysis were conducted in sulphate solution on concretes. This was made by replacing 0%, 5%, 10% and 15% of cement with copper slag waste. The results of this study emphasized the effectiveness of copper slag replacement in improving the concrete resistance against sulphate attack.

Jack et al (2003) studied the effect of carbonation on mechanical properties and durability of concrete. Ordinary portland cement (OPC) with water/cement ratios of 0.58 and 0.48 and self-compacting concretes with water/binder ratios of 0.40 and 0.36 were used in this study. Compressive strength test, splitting strength test, electrical resistivity test, rapid chloride penetration test (RCPT), open circuit potential method and alternative current (AC) impedance method were performed to estimate the properties of concrete. Test results showed that carbonation may compensate some concrete properties such as compressive strength, splitting strength, electrical resistivity and chloride ion penetration. However, corrosion test results showed that carbonation increases corrosion rate of reinforcing steel.

Schueremans et al (1999) had investigated constructions that are highly exposed to chlorides. They need to be protected by a coating, a water-repellent agent, admixtures in the mix or a thick reinforcement cover. The effectiveness of such measures was tested by means of accelerated chloride penetration tests. They found a relation between CPT-time and the expected lifetime of the construction. Reinforced concrete samples are submerged in a NaCl- solution. An external electric potential forces the chlorides to penetrate into the concrete, causing the corrosion process to start. The resulting CPT-
time varies between several minutes and about 1000 hours. A probability method was proposed for the interpretation of test results and prediction of service life, in which the chloride diffusion coefficient is a random variable. A relation is then determined between the chloride diffusion process and the CPT-time in the test. This reliability analysis was subsequently illustrated for typical conditions of exposure and protection.

McGrath et al (2001) tested an easily constructed accelerated carbonation test chamber suitable for evaluation of the carbonation rate into concrete specimens. The test chamber was constructed at low cost using readily available materials. Uniform test conditions were created within the chamber. Anti-carbonation coatings were applied to site to cast and pre-cast concrete substrates. The types of coatings included polymer additives of acrylic and styrene butadiene in both powdered and liquid form. Coatings were applied to both formed and exposed/cast surfaces. Depth of carbonation was measured using phenolphthalein solution.

A simple and inexpensive test chamber was developed which can be quickly assembled. It is used for carbonation studies of concrete. He states that the samples coated with the cement based reactive/proprietary coating tended toward the least penetration. The thick build epoxy was an effective barrier to carbonation but would not provide the necessary breath ability vapour required under the construction conditions.

McPolin et al (2000) reported the investigation of carbonation in mortars and methods of measuring the degree of carbonation and pH change. The mortars were manufactured using ordinary port land cement, pulverized fuel ash, ground granulated blast-furnace slag, metakaolin and micro silica. The mortars were exposed to a carbon dioxide-rich environment (5% CO₂) to accelerate carbonation. The resulting carbonation was measured using phenolphthalein indicator and thermo gravimetric analysis. The pH of the
pore fluid and a powdered sample, extracted from the mortar, was measured to give an accurate indication of the actual pH of the concrete. The pH of the extracted powder mortar sample was found to be similar to the pH of the pore fluid expressed from the mortars. The thermo gravimetric analysis suggested two distinct regions of transport of CO$_2$ within mortar, a surface region where convection was prevalent and a deeper region where diffusion was dominant. The use of micro silica showed decrease in the rate of carbonation, while pulverized fuel ash and ground granulated blast-furnace slag have a detrimental effect on carbonation. Metakaolin has little effect on carbonation.

Cengiz Duran Atis (2004) reported the findings of a laboratory study including compressive strength, accelerated carbonation depth and porosity properties of concrete mixtures made with fly ash and normal port land cement. The study involves two replacement ratios of fly ash, various water-to-cement ratios, use of super plasticizer, two curing conditions and four concrete ages. Statistical models that relate accelerated carbonation depth to strength and porosity were presented. The following collusions were drawn from his study:

- As compressive strength increases, the carbonation depth of a concrete decreases. It also showed that, as porosity increases, the carbonation depth also increases.

- The study confirmed that both strength and porosity should be used together for an accurate prediction of the carbonation depth of a concrete.

- The models relating compressive strength and porosity of a concrete to its carbonation are offered as models. They can be used to aid mixture proportioning for performance and durability and for assessment of concrete structures or
elements where signs of poor performance was detected even when the structural properties of the concrete were adequate.

Rathan Raj et al (2007) suggested that High-Reactivity Metakaolin and Alumina Red Mud in dry densified form can be used for the partial replacement of cement and super plasticizer. Platy shaped HRM and ARM in small percentage improved the mechanical and durability characteristics of concrete. Super plasticizer improved the workability of concrete and made possible to get sufficient workable concrete of lower water binder ratio. They reported that, out of the various percentages of HRM and ARM as admixtures, the concrete with 8% replacement of cement with admixtures gives better results. Based upon the experimental investigation carried out, the following conclusions were drawn.

- Concrete with 8% replacement of HRM and ARM behaved better than the concrete without any admixtures.

- Addition of HRM and ARM replaced cement in concrete improved the corrosion resistance of the concrete without any reduction in compressive strength.

Isa Yuksel et al (2006) presented the durability effects of concrete by using bottom ash (BA), granulated blast furnace slag (GBFS), and combination of both of these materials as fine aggregates. To assess durability characteristics of concrete, durability tests were conducted and the results were evaluated comparing with reference concrete. Three series of concrete were produced. GBFS, BA and GBFS+BA replaced the 3–7 mm-sized aggregate. Five test groups were constituted with the replacement percentages as 10%, 20%, 30%, 40% and 50% in each series. These by-products were used as non-ground form in the concrete. Durability properties of the concretes were compared in order to study the possible advantages of
different replacement ratios. According to results, GBFS and BA affect some durability properties of concrete positively. The following conclusions were drawn from this study

- As a general result, GBFS and BA affect durability properties of concrete positively when it is used as fine aggregate. Mainly, properties of the replaced byproduct and the replacement ratio are controlling the influence level and direction.

- High-temperature affects the concrete types which contain GBFS or/and BA fine aggregate replacement like reference concrete even for 50% replacement. Amount of surface cracks also decrease when these byproducts are used.

- Compressive strength loss due to freezing–thawing effect decreases for low replacement ratio (10–30%). Therefore durability against freeze–thaw cycles increases for these replacement levels. Compressive strength loss starts to increase after this level.

- BA, used as fine aggregate, increases the degree of porosity of concrete. GBFS also increases porosity but this increment occurs less than BA.

Velu Saraswathy et al (2007) analysed the corrosion characteristics of three kinds of cements: (i) Ordinary Portland Cement (OPC), (ii) Portland Pozzolana Cement (PPC), (iii) 25% Fly Ash replaced in ordinary Portland cement. M20 and M40 mixes under accelerated exposure conditions. Reinforced concrete slabs of size 900mm× 180mm ×100mm were cast, cured and pre-cracked to crack width of 0mm and 0.10 mm. Then, they are exposed to accelerated testing conditions in 3% NaCl environments and evaluated for
their corrosion resistance using various electrochemical tests like open circuit potential, linear polarization technique, and free chloride, alkalinity and weight loss measurements.

Hossain et al (2007) presented the results of investigations to assess the suitability of using Volcanic Ash (VA) as a cement replacement material to produce high performance concrete. Tests were conducted on concrete mixtures replacing 0% to 20% by mass of Ordinary Portland Cement (OPC) by VA. The performance of High Performance Volcanic Ash Concrete (HPVAC) mixtures was evaluated by conducting comprehensive series of tests on fresh and hardened properties as well as durability. The mechanical properties were assessed by compressive strength, while durability characteristics were investigated by Rapid Chloride Permeability, Drying Shrinkage, Mercury Intrusion Porosimetry, Differential Scanning Calorimetry and micro hardness tests. They suggested that HPVAC showed better durability properties compared to control concrete with 0% VA. The improved performance of HPVAC was attributed to the refinement of pore structure, and pozzolanic action of VA.

Mohamed Ismail et al (2006) investigated corrosion of reinforcing steel in concrete subjected to different conditions and chloride concentrations. A laboratory study was conducted to estimate the corrosion rate of reinforcing steel embedded in ordinary Portland concrete and high-performance concrete. One hundred and four OPC and HPC concrete cylinders embedded with a single reinforcing steel bar were exposed to sodium chloride solution with 0%, 1%, 3% and 5% concentrations. Specimens were also subjected to pre-conditioning and drying-wetting cycles. The AC Impedance technique (IS) was used to determine the corrosion rate of the reinforced concrete cylinders. The results confirmed that data obtained from AC impedance can be used to calculate the corrosion rate of reinforcing steel.
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. Here, the response of wrap face retaining wall, rigid face retaining wall and un reinforced retaining wall constructed to different densities were tested for a relatively small excitation. The response of reinforced soil wall models subjected to face excitation is compared in terms of lateral displacement of the facing. The effects of facing rigidity were also evaluated to a limited extend based on the test results, the following conclusions were derived from the above test.

- Displacements in wrap face walls are many times higher compared to rigid face walls and the density effect is more pronounced in wrap face wall.
- Face deformations are increased and accelerations are amplified at higher deviations.
- Acceleration amplifications are not much affected by the relative density of backfill at smaller base excitation for different model walls through deformations. Deformations are sensitive and decrease with increase in relative density.
- Lateral deformations of the facing decreased with the same order of increase in relative density and acceleration amplification slightly increase respectively.
- Damage to retaining walls will be more in case of stronger seismic events, if the backfill is not properly compacted.

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. Centrifuge tests were used to study the dynamic behavior of soil slopes reinforced with geosynthetics and metal grids. The main objectives were to determine the failure mechanism and amount of deformations under seismic loading and to identify the main parameters controlling seismically induced deformations. Geosynthetically reinforced soil slopes (2V:1H) and vertical walls reinforced with metallic mesh strips were subjected to earthquake motions with maximum foundation accelerations of up to 1.08g.

- The experimental results show that slope movement can occur under relatively small base accelerations and significant lateral and vertical deformations can occur within the reinforced soil mass under strong shaking.

- However, no distinct failure surfaces were observed and the magnitude of deformations is related to the backfill density, reinforcement stiffness and spacing, and slope inclination.

El-Emam and Bathurst (2004) experimentally investigated on the design and instrumentation of the series of physical experiments that was successfully used to investigate the response of reduced scale reinforced soil wall model to base excitation simulating earthquake. A large number of instruments were deployed in order to measure forces, the boundary toe forces, wall deformations, strains and displacements of the reinforcement layers and acceleration-time response at selected locations. The influence of reinforcement properties, reinforcement arrangement and wall geometry was investigated in a series of 14 different models and concluded in the following way.

- The reinforcement load in any reinforcement layer was greatest at the back of facing panel for the duration of base shaking.
• Magnitudes of the permanent lateral displacements at any time were dependent on the amplitude of the input base acceleration and the duration of base excitation.

• Response acceleration amplitudes for the model walls increased with elevation above the base and with increasing base acceleration amplitude.

Lee and Wu (2004) reported a synthesis of 10 fully instrumented case histories of flexible face reinforced soil structures with varying geometry, reinforcement, backfill type and relative density. The study indicated that the reinforcement length and reinforcement time have only secondary effect on the performance characteristics of the retaining walls, whereas backfill type and relative density plays major role in performance in terms of crest settlement, lateral movement of the face, reinforcement strain and surcharge pressure at failure.

Orense et al (2003) reported the use of 1g shaking table tests in understanding the behavior of underground structures during soil liquefaction. They have reviewed several shaking table test results from different authors on the behavior of buried structures and possible mitigation measures against liquefaction failure using gravel drains.

Karpurapu and Bathurst (1992), showed the effect of proctor density on the lateral deformations of facing for rigid-faced retaining walls with well-graded sand backfill through finite element simulations for static loading conditions. It was observed that the lateral deformations decreased by about 30% when the proctor density of the backfill sand was increased from 80% to 95%. This paper focuses on understanding the influence of relative density of the backfill soil on the seismic response of reinforced soil wall models. The response of reinforced soil wall models constructed at different
backfill relative densities and subjected to base excitation is compared in terms of lateral displacements of the facing, accelerations and lateral earth pressures on the facing.

Sukeo-O-Hra and Hiroshi Matsuda (2001) proposed the calculation of seismic earth pressure assuming that the backfill in the elastic medium with the modulus increases linearly with depth. In experiment of seismic earth pressure, a comparatively large sand box set on the shaking table was filled by sand and is vibrated horizontally. Then, the earth pressure acts on the model wall and this was measured by the pressure cells mounted on the wall surface or by the load cells which support the wall surface or by the load cells which support the wall horizontally and vertically. The authors remarked the following experimental results.

- The resultant of the seismic active earth pressure which caused by the cohesion is independent of the seismic co-efficient.

- The resultant force and the height of application point of the seismic active earth pressure were examined upon comparison with theoretical solution.

Awad and Abdulhafiz Alshenawy (2006) presented a hyperbolic mathematical model to predict the complete stress-strain curve of drained triaxial tests on uniform dense sand. The model was formed in one equation with many parameters. The main parameters that are needed to run the model are the confining pressure, angle of friction and relative density Drained triaxial tests were run on clean white uniform sand to utilize and verify this model. These tests were carried out at four levels of confining pressure of 100, 200, 300 and 400 kPa. This model was used to predict the stress-strain curves for drained triaxial tests on quartz sand at different relative density and
concluded that, the model has the advantage of considering the influence of different factors affecting the stress-strain curve characteristics including the confining pressure, angle of friction and relative density.

Prasad et al (2004) worked on the effect of the mass on natural frequency of the system. Tests were carried out by vibrating the shaking table with different masses. The height of the model ground was varied to achieve different masses. Accelerometer was placed on the platform to measure the input acceleration. From time history of input acceleration, predominant frequency of shaking was evaluated. The shaking table was designed to apply harmonic sinusoidal shaking. Along longitudinal direction, the shaking table was designed to vibrate at around 2 Hz with 0.5 g level of acceleration. This magnitude of shaking was necessary to liquefy the model ground when it was subjected to full payload of 7 kN. The average single amplitude displacement was found to be 25 mm. It can be seen that the magnitude of acceleration components in the lateral and vertical directions and were negligible compared to that in the longitudinal direction.

Huang et al (2009) studied the seismic displacement criterion for conventional soil retaining walls based on the observations of a series of shaking table tests and seismic displacement analysis using Newmark’s sliding-block theory taking into account internal friction angle mobilization along the potential failure line in the backfill. A pseudo static-based multiwedge method in conjunction with Newmark’s sliding block theory was used to perform displacement analyses on a conventional gravity-type and a cantilever-type model retaining wall subjected to stepwise increased input ground accelerations in shaking table tests. A new approach for relating the horizontal wall displacement and the mobilized friction angle along the shear band in the backfill was also developed to address the permissible seismic
wall displacement from the point of view of strength mobilization along the shear band.

Khandaker et al (2005) reported the results of experiments evaluating the corrosion resistance of plain, volcanic ash (VA) and volcanic pumice powder (VPP) concrete mixes. Variables were VA and VPP additions of 0–20% as cement replacement and cement contents. X-ray diffraction (XRD) analysis, electrochemical and electromechanical measurements and physical tests were used to monitor the corrosive behaviour of embedded steel bars in concretes. The results showed that additions of VA and VPP were effective in inhibiting corrosion of reinforcing bars.

Matsuda et al (2005) investigated the applications of Granulated Blast Furnace Slag to reduce seismic earth pressure. The granulated Blast Furnace shows a similar particle formation as a natural sand and also low weight, high shear strength, well permeability and especially a latent hydraulic property by which GBFS hardens like a rock. In this study, the model wall tests were carried out on GBFS, in which the resultant earth pressure, a wall friction and the earth pressure distribution at the wall surface were measured, and the test results were compared with those of Toyoura standard sand. It was clarified that the resultant earth pressure obtained by using GBFS was smaller than Toyoura sand, especially in the active-earth pressure side.

Veletsos et al (1994a, 1994b) developed an analytical model to compute seismic soil pressure for rigid vertical walls resting on a rigid base. The proposed model is based on the series of elastically supported semi-infinite horizontal bars with distributed mass to model the soil medium behind the wall. The model was developed for vertically propagating shear waves with the assumption that horizontal variation of vertical displacements in the soil medium is negligible. In this model, contrary to Wood’s equivalent static
solution, amplification of motion in the soil medium behind the wall is considered. The model highlights the effects of several parameters including the frequency of vibration on the seismic soil pressure magnitude and distribution. The model was subsequently expanded for application to cylindrical vaults and storage buildings.

Ostadan and White (1997) reported that the seismic soil pressure is caused by the relative motion of the structure with respect to the surrounding soil and as such it is a SSI (Soil structure interaction) response. They stated that the seismic soil pressure was not only affected by soil properties and by characteristics of the ground motion, but also the structural properties as well as the size of the structure and its foundation embedment.

Whitman et al (1979, 1990, and 1991) investigated the effect of some of the limiting assumptions used in the M-O (Mononobe-Ocabe) method. The non-yielding wall conditions and the amplifications of the motion in the soil mass were found to be significant in some cases. Judging from the results of model tests by several researchers, they found that use of the M-O method for design of relatively simple gravity walls up to 30 ft high is acceptable. However, for higher walls and non-yielding walls, they recommended a more careful analysis be performed.