CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A review of previous investigation was done on the following topics.

- Durability Studies
- Mechanical Properties
- Transport Properties
- Electrical Resistivity
- Drying Shrinkage

2.2 DURABILITY STUDIES

The durability aspect of six combination concrete mix exposed to magnesium brine was monitored for 24 months by Tumidajski and Chan (1996). From the study, they concluded that the mineral admixtures, in combination with a long initial cure, provided the most durable concrete. Concrete with 65% slag had the best overall durability.

Vivekanandam and Patnaikuni (1997) investigate the relationship between transition zone microstructure and compressive strength property of high performance concrete using Australian Industrial silica fume and Australian aggregates. Based on the scanning
electron microscopic studies of transition zone, it has been found that high performance concrete transition zone thickness increases while compressive strength increases. Further high performance concrete transition zone thickness is much less than the thickness of transition zone of normal strength concrete. From the test, they concluded that the transition zone thickness increases while compressive strength increases. High performance concrete transition zone thickness is much less than normal strength concrete and is up to approximately 15µm. Silica fume particles strengthen the transition zone structure by the consumption of calcium hydroxide.

Weber and Reinhardt (1997) introduce a new type of high performance concrete. The most important mechanical properties of the concrete under various curing conditions and the microstructure of the hardened cement paste were investigated.

The microscopic investigation explains the improved mechanical properties.

Bentz et al (1998) examine a series of conventional high performance concretes, with and without silica fume additions, with respect to their adiabatic heat signature. The measure responses are compared with predicated values from the NIST 3-D cement hydration and micro structural model which has been modified to incorporate the pozzolanic reaction of silica fume and to simulate hydration under adiabatic conditions. The NIST 3-D micro structural model has been used successfully to predict the adiabatic temperature rise of a variety of concrete mixtures.
Yang (1999) examine the inner relative humidity (RH) and degree of saturation (S) of high performance concrete cured for 2 years in water or 3% NaCl solution were measured at three different levels from the concrete surface. The effects of many factors, such as water to cement (w/c) ratio, content of silica fume and air content were investigated, and the following observations are made.

- Inner RH values of high performance concrete decrease with decrease in w/c ratio and with increase in silica fume content
- RH and S values of the outer layer of concrete are higher than those of the inner layer, and the difference increases with decrease in w/c ratio and with increase in silica fume content
- Air content has little influence on RH of the inner layer, but as expected, reduces degree of saturation of the concrete
- For concretes cured in 3% NaCl solution, the RH values of the inner layer are higher than concrete cured in water, and the S Values of the three layers of concrete are markedly higher than concrete cured in water

Scrivener et al (1999) examine the calcium aluminate cements resistance to acid attack and particularly biogenic corrosion and abrasion resistance in hydraulic structures. From the test results, they concluded that calcium aluminate cement concretes show high performance and extend the range of applications for cementitious materials.

Gudmundsson and Olafsson (1999) examine the purpose of utilising silica fume in Icelandic cement to reduce the risk of damaging Alkali Silica Reaction (ASR) in concrete. The homogeneity of
silica fume in cement is not always as good as expected, because small lumps of silica fume are found in hardened concrete. There is some concern that these lumps may reduce the beneficial effect of silica fume against ASR in concrete. The alkali content of Icelandic cement is very high and the climate in Iceland is favourable for ASR (high humidity and many freeze/thaw cycles, which may promote ASR). Therefore, the risk of ASR is always imminent. However, 20 years of experience have proven silica fume is very useful in fight against ASR in concrete. The utilization of silica fume is the major factor in the reduction of ASR damage in concrete.

Li et al (2000) examine from previous studies that the incorporation of calcium nitrite inhibitor (CNI) together with mineral admixtures could weaken the resistance of mixtures to sulfate attack. To better understand the mechanism of this phenomenon, the influence of CNI on the microstructure of cement based materials is studied by means of quantitative X-ray diffraction, mercury intrusion porosimetry and scanning electronic microscopy technique. The test results demonstrate that the incorporation of CNI accelerates the formation of calcium hydroxide and ettringite crystals and weakens the pore refinement effect caused by the secondary hydration reaction of fly ash and micro silica. At the age up to one year, the relative crystal quantity in mixture containing CNI is always higher than that in control mixture without CNI. Based on the experimental results, it was concluded CNI should be used continuously when high resistance to sulfate attack is required.

Chang et al (2001) investigate the harmful effects of maritime climate on the durability of concrete structures built in coastal areas. Singly reinforced beam specimens of traditional design and those of densified mixture design algorithm (DMDA) were employed to study the potential problems of concrete structure. Results indicate that cracks on the concrete
structure, if unnoticed, may cause failures. Thus it is important to know the methodology of achieving high strength and durable concrete in order to avoid formation of cracks in structural member.

Gruber et al (2001) Thomas discusses laboratory evaluations to assess the long term performance of concrete containing high reactivity metakaolin (HRM) for resistance to chloride penetration and reduction in expansion due to alkali silica reactivity. They concluded that the appropriate use of pozzolanic materials and slag can significantly improve the long term durability of concrete. It is demonstrated here that the use of moderate levels (8-12%) of HRM can be used to dramatically increase the resistance to chloride ion penetration and higher concentrations (10-20%) can reduce the risk of deleterious expansion from Alkali Silica Reactivity (ASR). This study concluded the following points.

- The use of 8% and 12% HRM significantly lowered the chloride ion diffusion coefficient of concrete.

- Bulk diffusion values continue to reduce with increased periods of chloride exposure and support the beneficial effects of HRM.

- The use of 10% HRM was sufficient to prevent deleterious expansion in concrete prisms containing highly reactive aggregate after 1 year of storage at 38°C.

- The time dependent reduction in apparent diffusion coefficients appears to be more pronounced with increased levels of HRM.

Aitcin (2003) discusses the durability problems of ordinary concrete with the severity of the environment and the use of inappropriate high water/binder ratios. High performance concrete that have a water/binder
ratio between 0.30 and 0.40 are usually more durable than ordinary concrete not only because they are less porous but also because their capillary and pore networks are somewhat disconnected due to the development of self – desiccation. He concluded that the durability of concrete structures depends on several factors, one of which is the durability of the concrete itself. As the durability of concrete is essentially linked to its permeability, HPC with its dense microstructure and very low permeability, should obviously be more durable than ordinary concrete.

Saricimen et al (2003) examines the laboratory study under accelerated conditions as well as a two year field study of CC and SC in a waste water lift station. In the laboratory investigations, 50 mm cube mortar specimens prepared using 1) SC 2) CC 3) Type I + 8% Silica fume cement 4) Type I +20% fly ash cement 5) Type I cement. They were exposed to 2% sulphuric acid for 150 days. Performance of liner materials was monitored for sulfate content and alkalinity after 6, 12 and 24 months of exposure. The analysis and evaluation test data generated from the accelerated laboratory study and the field study, which lasted for 24 months, showed that SC performed better than other materials tested in this investigation.

Cwirzen and Penttala (2005) studied the influence of the cement paste aggregate interfacial transition zone (ITZ) on the frost durability of high performance silica fume concrete (HPSFC). Investigation was carried out on eight non – air entrained concretes having water to binder (w/b) ratios of 0.3, 0.35 and 0.42 with different combination of condensed silica fume. Studies on the microstructure and composition of the cement paste have been made by means of Environmental Scanning Electron Microscope (ESEM) - and Mercury Intrusion Porosimetry (MIP) analysis. The results showed that the transition zone initiates and accelerates damaging mechanisms by enhancing movement of the pore solution within the concrete
during freezing and thawing cycles. Cracks filled with ettringite were primarily formed in the ITZ. Moderate additions of silica fume seemed to densify microstructure of the ITZ.

2.3 MECHANICAL PROPERTIES

Sandrik and Gjorv (1986), studied the effect of condensed silica fume on the strength development in concrete was studied by replacement of 0 -25% cement by silica fume. No chemical admixtures were used. The compressive strengths were determined after 18, 24, 32 hrs as 2, 3, 5, 7, 10, 14, 21, 28 and 98 days. With these results they gave the following conclusion

- Using the same water binder ratio the compressive strengths of concrete mixes containing silica fume (0-20%) are almost the same up to 7 days. This is explained by the accelerated rate of hydration of cement due to the presence of silica fume
- After 7 days of curing the pozzolanic effect of the silica fume dominates strength development. Upto 20% cement replacement by silica fume increases the compressive strength at 28 days and 90 days respectively, at about 43% and 55%.
- In the presence of silica fume, relationships between short term and long term strengths based on pure Portland cements are not valid.

Zhou et al (1995) developed a set of high performance concrete mixes of low water/cement ratio and fixed mortar composition, containing six different types of aggregates of constant volume fraction has been used to check modulus of elasticity at 7, 28 and 90 days. The results have shown that,
apart from the aggregates of very low and very high modulus, concrete modulus at 28 days can be predicted quite well by known models. Cube strength (about 90 N/mm² at 28 days with normal aggregates) is drastically reduced as expected by the weaker aggregates and is also reduced (by about 9%) by the stiffer (steel) aggregates.

Persson (1996) developed an experimental and numerical study on the hydration, internal relative humidity and strength of high performance concrete. The long term development of internal relative humidity, strength and hydration was studied for eight concrete mix during sealed curing, air curing or water curing at 28, 90 and 450 days. The water cement ratio of the concrete varied between 0.2 and 0.58. Half of the concrete contain 10% silica fume. The specimen consisted of 1m diameter rims with the thickness of 100 mm. The flat sides of the large specimen were sealed epoxy plastic resin. The large specimen stimulated a column with the diameter of 1m. The internal relative humidity was measured. The self desiccation affected the hydration process. For concrete without silica fume, the degree of hydration increased continuously. For concrete with silica fume, the degree of hydration decreased after an age of approximately 90 days. Finally, the expressions were also found between the strength of the concrete and the development of relative hydration.

Mirza and Johnson (1996) provide a simple approach for compressive strength testing of high performance concrete cylinders. This method employs standard concrete laboratory testing equipment and an inexpensive customized capping apparatus for preparing the cylinder ends. The method ensures cap refinement without tight controls on the cylinder end roughness prior to capping and on the cap thickness itself. The method has been successfully used for concrete having compressive strength in excess of 100MPa. Compressive strength results obtained for cylinders both
150mm × 300mm and 100mm × 200mm in size tested using confined caps are in good agreement with the standard measured compressive strength of cylinders 150mm × 300mm in size, with ground end conditions.

Naik et al (1998), studies the effects of blend fly ash on mechanical properties and durability of concrete. In this investigation two reference mixtures were used. One was a mixture without fly ash and the other contained 35% ASTM class C fly ash. Additional mixtures were composed of three blends of ASTM class C and class F fly ash. A total fly ash content of 40% of the total cementitious materials was used. Mechanical properties such as compressive strength, tensile strength, flexural strength and modulus of elasticity were determined. Durability related properties such as drying shrinkage, abrasion resistance, salt scaling resistance and electrical production of chloride ion penetration were also studied. The conclusions are as follows:

- In general up to 50% replacement of the class C fly ash with a class F showed favorable strength and durability related properties.

- The higher compressive strength was observed for blended fly ash mix B1 (40% cement replacement by a mixture of 75% class C and 25% class F fly ash) all ages. Followed by blended fly ash Mix B2 (with 40% cement replacement by a mixture of 50% class C and 50% class F fly ash), at the ages of 7 days and up to 91 days.

- All the concrete with and without fly ash exhibited excellent resistance to abrasion at the 28 day at 91 day ages. At the age of 28 day, the depth of abrasion was slightly higher for fly ash concretes than the control concrete mixture. At 91 day’s
blends B2 and B3 showed excellent resistance of abrasion accompanied to the reference mixture (mix C1 and C2) and blend B1.

- The salt scaling resistance of the blended ash concreted was equivalent to the control concrete (mix C1) up to 50% class fly ash with class F fly ash replacement. The 35% class C fly ash concrete (Mix C2) has better performance than all mixture including the control concrete.

- The blended ash mixtures showed significantly better resistance to chloride ion penetration than the control concrete (mix C1)

Persson (1998) outlines an experimental and numerical study on Poisson’s ratio of high performance concrete subjected to air or sealed curing. Eight qualities of concrete (about 100 cylinders and 900 cubes) were studied. Parallel studies on strength and internal relative humidity were carried out. The results indicate that Poisson’s ratio of high performance concrete is slightly smaller than that of normal strength concrete.

Chan et al (2000) carried out a experimental program to study the mechanical properties and pore structure of high performance concrete (HPC) and normal strength concrete after exposure to high temperature. Tests results show that HPC had higher residual strength, although the strength of HPC degenerated more sharply than the normal strength concrete after exposure to high temperature. The changes in pore structure could be used to indicate the degradation of mechanical property of HPC subjected to high temperature.
Peiwei et al (2001) presents a study on the change of workability, strength and durability including the resistance to freezing and thawing, salt attack and diffusion coefficient of chloride of high performance concrete (HPC) in which part of the ordinary Portland cement (OPC) was replaced by superfine mineral powder of phosphoric slag (SFPS). The results of this study shows that the partial replacement of OPC by SFPS can increase the fluidity, improve the compressive strength, decrease the chloride diffusion coefficient of concrete and obtain good durability of HPC.

Picandet et al (2001) developed experimentally the effect of axial compressive loading on the permeability of three different types of concrete: Ordinary concrete (OC), high Performance concrete (HPC) and high Performance Steel reinforced concrete (HPFC). The results show that, for each drying stage, the gas permeability of the discs increases with the load induced strain. From the study, they concluded that the increase in permeability is directly related to the maximum applied strain during loading and is due to the formation of a connected network of micro cracks, which does not close down completely after the samples are unloaded. The effect of this nonreversible damage on permeability correlates, for each concrete type, with the applied – strain/yield strain ratio. The permeability of HPC is lower than the permeability of OC. The absolute increase in permeability of HPC is lower, but after a moderate drying phase, the relative increase in permeability is bigger.

Qian and Li (2001) reports the results of a study of stress strain relationships (tension and compression) and bond strength measurements for concrete incorporating 0%, 5%, 10% and 15% metakaolin. The test results show that the tensile strength and peak strain increase with increasing metakaolin content whereas the tensile elastic modulus show only small changes. The descending area of over peak stress is improved when 5%
and 10% of cement is replaced by metakaolin. Also, the bond strength and compressive strength increase with increasing metakaolin content. The compressive elasticity modulus of concrete shows a small increase with increasing metakaolin replacement. Therefore, the metakaolin is a very efficient strength enhancing addition. The workability of concrete is little influenced by small metakaolin contents. At higher metakaolin contents workability can be controlled effectively by superplastizer additions.

Kaszynska (2002) examine the analyses and results of tests on heat of hydration and compressive strength of high performance concrete cured in variable thermal conditions. Investigations carried out proved that a close relation exists between the advancement of hydration process expressed by the amount of heat generated and the development of mechanical properties of concrete, hardening under variable thermal conditions. The increase in temperature concrete depends on the amount of hydrated cement but does not depend on the total amount of cement present in the concrete mixture.

Ajdukiewicz and Kliszczewicz (2002) examine that the aggregates derived from demolished concrete structures were of relatively low strength and applications were of secondary importance. The aggregates obtained from crushing of such structures retained some binding abilities as may be activated by means of silica fume or fly ash admixtures. From the study, they concluded that

- Properties of original concrete have significant influence on mechanical properties of recycled concrete. It is possible to obtain recycled concrete with higher compressive strength than the original one.
• Mix design of recycled concrete is very similar to the procedure for concrete with natural (new) aggregate, corrections in water content are necessary to obtain proper workability, but the changes in water/cement ratio may be relatively small.

• The replacement of fine fraction 0 - 2mm in recycled aggregate by natural sand always changes for the better properties of recycled concrete.

• Properties of recycled concrete may be significantly improved by admixtures of super plasticizers and silica fume, similarly to cases of concrete with natural aggregates.

Oztekin et al (2003) conducted experimental studies on concrete that have compressive strength of less than about 40 MPa. Therefore in this study, stress strain and equivalent block parameters were obtained from experimental stress strain diagrams for calculation of high performance reinforced concrete beams in flexure. The conclusions obtained from this study showed that determined rectangular stress block parameters can be used in the design of high performance reinforced concrete members in flexure.

2.4 TRANSPORT PROPERTIES

Ludirdja et al (1989), developed a simple test to estimate the permeability of concrete to describe movement of water under gravity through a 12.5 × 10 mm disk of concrete is monitored at atmospheric pressure until steady state conditions are reached typically in 7 to 14 days and the value of permeability can be determined reliably in 14 to 20 days. The conclusions drawn are:
• Under favorable conditions, the permeability coefficient can be determined with in 7 days. Evaluation test determined the permeability of a sample concrete (w/c = 0.6) to be about $15 \times 10^{-12}$ m/sec with between – batch coefficient of variation of 19%. The variation with in a single batch was lower, with in the range of 10 to 15%

• Examinations of the same concrete showed that changes in the permeability could be detected for loading above 75% of ultimate load.

Detwiler et al (1994), investigated the chloride penetration of 0.4 and 0.5 water binder ratio concretes containing either 5 percent silica fume or 30% blast furnace slag (substitution by mass) cured at elevated temperatures. Plain Portland cement concrete was used as controls. The concretes were cured at constant temperatures of 23, 50 (or) 70°C to degree of hydration of approximately 70%. From the result obtained the following conclusions and recommendations were given: Both silica fume and slag have a significant effect on chloride ion penetration. Regardless of the curing regime for any given curing conditions, the use of either 5% silica fume or 30% slag has a more pronounced effect on chloride permeability than lowering the w/b ratio from 0.5 to 0.4.

Naik et al (1994), studied the influence of addition of class C fly ash on concrete permeability. An air entrained reference concrete mixture without fly ash was proportioned to have 28 days strength of 41 MPa. Concrete mixtures were also proportioned to have cement replacement with fly ash in the range of 0-70% by weight. For each concrete mixture, compressive strength, chloride permeability, air permeability and water permeability were determined. The air and water permeability were evaluated
by using the Fig method. Chloride permeability of the concrete was measured in accordance with the ASTM C 1202. From the results obtained, the following conclusions are drawn

- The high – volume fly ash concretes attained lower strengths compared to the reference concrete without fly ash.

- At lower ages up to 40 days, the high volume fly ash concretes showed higher levels of ingress of air relative to the plain Portland cement concrete. When curing was extended to 91 days, the 50% fly ash concrete mixture outperformed the reference concrete without fly ash.

- Water permeability values of the high volume fly ash concrete mixtures were comparable to that for the control concrete for ages below 40 days. At age of 91 days, the high volume fly ash concrete mixtures exhibited lower water permeability relative to the plain cement concrete

- The high volume fly ash concrete having 50% cement replacement showed the lowest permeability to chloride ions compared to all the mixtures tested. The concrete mixtures with 50 and 70% cement replacement with fly ash were superior to the control concrete at the age of 91 days with respect to chloride ion permeability

Khatri and Sirivivatnanon (1994), studied two test methods successfully to determine the water permeability of different concretes. The methods are based on the determination of coefficient of permeability using either a constant flow or a depth of penetration technique. The flow method
has generally been found to suit concretes with higher permeability. But the penetration method is used for concrete with very low permeability. Presently no clear guidelines exist for the selection of the appropriate method for a particular type of concrete. This study was carried out to examine the correlation between two methods. A broad guideline has also established for the selection of the appropriate method for a particular concrete with respect to its binder, composition, 28-day compressive strength and age. The concretes examined were prepared from five types of binders and with a grade range of 35 – 50 MPa. From this investigation, it was conclude that both methods (flow and penetration) are important, as they are appropriate for concrete of different quality. The penetration method is appropriate for low permeability concrete (higher 28 days strength and greater age) and the flow method is suitable for higher permeability concrete (lower 28 days strength and lesser age).

Gagne et al (1996), studied the effect of superplasticizer dosage on the compressive and flexural strength, permeability and freezing and thawing durability of typical high strength concrete. Two type of cement was used: a Canadian type 10 Portland cement (ASTM Type I) and Canadian blended cement containing 7.5 ± 0.5 percent silica fume. Water – to – binder ratio of 0.3 was selected to produce air – entrained and non – air – entrained concretes having a compressive strength ranging between 60 and 100 MPa. The superplasticizer dosages (ranging from 0.7 to 1.6 percent, expressed as dry mass of superplasticizer per mass of cement or blend) were selected to produce concrete having slumps ranging from 70 to 240mm. The effect of superplasticizer dosage on compressive strength, flexural strength, permeability and freeze thaw durability of HSC made with and without silica fume was investigated. The following conclusions were drawn from this study.
Compressive strength, flexural strength, air permeability and rapid chloride permeability of HSC made with silica fume blended cement were not effected by the workability of fresh concrete (slump – 80 to 240mm) or by the superplasticizer dosage (0.9 to 1.14 percent [expressed as the ratio between the dry mass of the superplasticizer solids and the mass of cement or cement silica fume]).

High – slump (220±20mm) HSC made with ordinary type 10 (ASTM Type i) Portland cement containing large amount of superplasticizer can cause significantly lower compressive and flexural strength than similar concrete with usual slumps (170±20mm) lower compressive strength were measured at all ages (1, 28 and 91 days).

The air permeability test method reveals that the permeability of concrete without silica fume can be approximately 3 to 5 time higher than the normal concrete with superplasticizer dosage of 1.0 percent of dry superplasticizer per mass of cement (or cement + silica fume).

The rapid chloride permeability test method is not sensitive enough to detect the micro structure difference between high – strength concrete with different slumps and variable dosage of superplasticizer.

The silica fume appears to be very effective in preventing strength losses and permeability increase in high slump high strength concrete.
Sariciemen et al (1998), investigated the effects of field and laboratory curing on permeability and durability characteristics of plain and pozzolanic cement concretes. The field specimens were subjected to moist curing for 7 days while the laboratory specimens were water cured. Water penetration and absorption tests were used as indicators for cement concrete permeability. The performance of the field and laboratory cured specimens was determined by conducting an accelerated chloride permeability test. The research variables include cement type (i.e. plain and fly ash blended cements), specimen size and curing conditions. From the results obtained from the tests that gave the conclusions as follow:

- Fly ash concrete specimens were less permeable than similarly cured plain cement concrete specimens from the initial test period of days in almost all cases. Results of this investigation indicate that use of properly characterized pozzolans can lead to technological and economical benefits, even in arid regions where curing is very inadequate.

- As expected the laboratory – cured specimens were less permeable than the block cylinders and cubes cured in air in the field after the initial 7 days of wet curing. This behavior was observed in case of all concrete specimens, both plain and pozzolanic. The fly ash cement concrete was more sensitive to poor curing, especially in these components. Therefore, it is particularly important to apply extra attention to the curing of thin concrete components in hot and dry environment.

Grautefall (1986), measured the diffusivity of chloride ions in hardened cement paste. The experiments were carried out at 20°C using ordinary Portland cement and blended cement with 10% fly ash was
investigated. Other experimental variables were water – to – (Cement + condensed silica fume) binder ratio of 0.5, 0.7 and 0.9. The condensed silica fume was used as a cement replacement, the replacement level being 5, 10 and 15% by weight of cement.

The chloride concentrations were analysed at 3 - 7 days interval over a period up to 100 days depending upon the diffusivity of the cement paste. From the results, the conclusions available are, (i) the effective diffusion coefficient of cement without condensed silica fume is higher for ordinary Portland cement than for the blended cement (ii) its magnitude increases by a factor of three the W/C+p increases from 0.5 to 0.9 for both cement types.

Alhozaimy et al (1996), conducted experiment to study the effect of fly ash type, fly ash content, period of moist – curing, and age on mortar permeability. Three different fly ash types,(two class F and one class C) three different fly ash contents, (in addition to the control 10, 20, 30%) two different moist – curing periods (7 and 14 days) at two different ages of testing (28 and 90 days) were investigated. The following conclusions were reported from the generated test results:

- All factors considered in this investigation (fly ash type, fly ash content, moist – curing period and age) had important effects on mortar permeability at a 99% level of confidence
- Class F fly ash reduces permeability even at relatively low levels of cement substitution (10% by weight). In the case of C fly ash, however, relatively high cement substitution levels (20 to 30% by weight) were required to produce any significant reduction in permeability.
• Alternatively, class C fly ash was effective in reducing water demand. It gave higher permeability than class F fly ashes except 30% substitution level at 28 day testing age.

• Extended moist – curing periods lead to reduced concrete permeability. The effect of moist – curing period in concrete permeability was more pronounced in the presence of fly ash particularly at higher replacement levels (20 to 30% by weight).

Nagesh and Bhattacharjee (1998) evaluated a new form of mathematical model for chloride ingress in saturated and unsaturated concrete. Materials parameters reviewed are the ion diffusions coefficient and solution diffusion coefficient both of which have been shown to be concentration dependent, rendering the chloride diffusion process to be nonlinear. The conclusions obtained from this investigation are:

• The form of mathematical model established in this study clearly distinguishes between the chloride diffusion process in saturated and unsaturated concrete and it also in corporate the major mechanism involved in chloride transport process.

• The setup is simple and the methodology is efficient. The chloride penetration profiles can estimate the diffusion coefficient as demonstrated.

• The methodology is based on natural diffusion process rather than the diffusion process under impressed electric field.

• Further, it has been confirmed that the diffusion coefficient involved in the model are concentration dependent.
Aitcin et al (1998) investigate the effect of ultra fine particles used as partial replacements for cement on the rheology of high strength concrete. High strength can be made easier to place by substituting proportions of ultra fine particles for cement. In the presence of super plasticizers, the finer the micro filler the lower will be the flow resistance and torque viscosity of the mixture up to 20% ground silica or limestone did not increase the super plasticizer requirement to achieve a constant workability, even though one of these fillers had a surface area as high as 10,000 m²/kg. Silica fume, however, while being the most effective filler from a rheological point of view, increased the superplasticizer demand at a constant workability. This may suggest that a high surface area is not the sole parameter influencing the superplasticizer demand of silica fume mixtures, and that silica fume may have a strong affinity for multilayer adsorption of superplasticizer molecules. Micro fillers did not seem to reduce significantly the slump loss of fresh HSC and were advantageous in some instances in maintaining better workability over time. Micro fillers were also successful in inhibiting the induced bleeding of fresh concrete. Therefore, it is possible to design triple – blended composite cements including different fillers to achieve improved rheological characteristics.

Chan and Ji (1999) evaluate the effectiveness of zeolite in enhancing the performance of concrete in comparison with silica fume and Pulverized Fuel Ash (PFA). In the first series of experiments zeolite, silica fume and PFA were all used to replace 5%, 10%, 15%, and 30% of cement by weight in concrete with water to total cementitious material ratio (W/(c + p)) kept at 0.28. From the test, they concluded that zeolite decreased bleeding and increased marginally the viscosity of concrete without significantly compromising the slump. And at 15% replacement level, it resulted in 14% increase in concrete strength at 28 day compared with control concrete. The test results also showed that an optimum replacement level for
zeolite to affect a decrease in initial surface absorption and in chloride diffusion of concrete. The test results of the second series of experiments where zeolite, silica fume and PFA were in turn used to replace 10% cement in concrete with \( W/(c + p) \) in the range of 0.27 to 0.45 appeared that zeolite performed better than PFA but was inferior to silica fume in terms of increasing strength, decreasing initial surface absorption and chloride diffusion. It was further found that when \( W/(c + p) \) was greater than 0.45, the strength of the concretes incorporating zeolite or PFA was lower than that of the control concrete. The micro structural study on concrete with zeolite revealed that the soluble SiO\(_2\) and Al\(_2\)O\(_3\) could react with ca (OH)\(_2\) to produce C-S-H which densified the concrete matrix. Pozzolanic effect of zeolite improved the microstructure of hardened cement paste and reduced the content of the harmful large pores, hence made concrete more impervious.

Yen et al (1999) investigated experimentally the effects of materials and proportioning on the rheological properties. A new rheometer was established by conducting a two point test to investigate the flow behavior of high strength HPC. From the test, they concluded that the high strength HPC with good uniformity and without tendency of segregation can possess the properties of rheology according to Bingham’s equation. An increase of the fraction of mortar in HPC can lead to more stable results than any other test method which describes the flowability of high strength HPC.

Wee et al (2000), studied correlation between the charge passed data derived from rapid chloride permeability test (RCPT) and the chloride penetration coefficient K derived through a 90 day soaking test for the concrete containing mineral admixture is elucidated. For this purpose concrete specimens containing varying proportions and fineness of mineral admixtures, such as ground granulated blast furnace slag (GGBFS) and silica fume (SF) and moist cured for different periods were subjected to a 90 - day soaking test
and RCPT. To supplement the results, electrical resistivity and compressive strength of concrete mixture were also evaluated. The following conclusions were derived.

- Addition of mineral admixture such as GGBFS and SF to concrete, even as low as 30 and 5% respectively by mass of cement (replacement of OPC) enhanced the resistance of the mixture to chloride penetration compared with the plain cement concrete mixture of similar w/b ratio and moist curing age. The concrete mixture containing a large proportion of mineral admixture (GGBFS 70% SF – 10%) of higher fineness GGBFS 8000 cm$^2$/g; SF – 250000 cm$^2$/g when moist – cured for a longer duration (28 days) attained the maximum resistance to chloride penetration.

Matte et al (2000) examine the ultra high performance cement based materials expected to be used in nuclear waste containers were submitted to a leaching test in order to evaluate their long term durability. Reactive powder concretes (RPC) were attacked by de-ionized water. To predict the long term durability of RPC, the hydration rate of cement minerals, pozzolanic reactivity of silica fume, pore structure and mechanisms of chemical reactions were needed. So first, the microstructure of RPC matrix was simulated using the NIST microstructure model. Then the transfer of Ca ions through percolating water was estimated using DIFFU-Ca, a model based on the local chemical equation. This double modeling validates the damage process related to instantaneous dissolution of anhydrous cement silicates at the degradation front which results in a higher connected pore space and is in good agreement with experimental results. The long term behavior is expressed as the depth of the altered zone, the leaching kinetics and the evolution of Ca concentration in the material. From the test, they concluded
that the hydration rate of each phase given by the NIST model is used in the DIFFU-Ca model for predicting the RPC long term behavior. There is a good agreement between experimental and estimated data regarding Ca concentration in the solid, degraded depth evolution and leached Ca amounts.

Snyder and Marchand (2001) examine the theoretical and experimental study of the effect that concentration and ionic speciation have on the apparent diffusion coefficient is performed using a non reactive porous material in a divided cell diffusion apparatus. Varying the ionic species concentration over two orders of magnitude changes the apparent diffusion coefficient by no more than 20% for the systems studied. By contrast, a fixed ionic concentration, varying the ionic species changes the initial apparent diffusion coefficient by a factor of two. Over longer periods of time, the apparent diffusion coefficient varies in time, increasing by a factor of ten or more. For one system, the macroscopic diffusion potential across the specimen induces a transient negative apparent diffusion coefficient; iodide ions are transported from regions of low iodide concentration to regions of high iodide concentration. The theoretical analysis show that, in non reactive porous systems, the behavior of all the concentrations and species studied can be completely characterized by an electro diffusion system of equations that contain two times – independent constants: the porosity and the formation factor.

Oh et al (2002) investigate the resistance to chloride penetration of different types of concrete and to develop high performance concrete that has very high resistance to chloride penetration, and thus, can guarantee high durability. A large number of concrete specimens have been tested by the rapid chloride permeability test method as designated in AASHTO T 277 and ASTM C 1202. The major test variables include water – to – binder ratios, type of cement, type and amount of mineral admixtures
(Silica fume, Fly ash and blast furnace slag), maximum size of aggregates and air – entrainment. From the test, they concluded that concrete containing optimal amount of silica fume shows very high resistance to chloride penetration and high performance concrete developed in this study can be efficiently employed to enhance the durability of concrete structures in severe environments such as nuclear power plants, water retaining structures and other offshore structures. They concluded the following points

- Rapid chloride permeability test is adopted in this study that is relatively simple, time saving and more realistic to measure the permeability of high strength and high performance concrete.

- Concrete containing fly ash shows good performance in the rapid chloride permeability test. It is found that the addition of fly ash gently decreases the permeability of concrete even though the strength of fly ash concrete at 28 days is not improved.

- The replacement of cement with blast furnace slag also decreases the chloride permeability since the secondary chemical reaction of blast furnace slag contributes to make the microstructure denser.

- Finally, high performance concrete proposed in the present study has very low permeability, of which permeability is about 1/100 of the conventional concrete. This can provide a firm basis for the use of high performance concrete having very low permeability and high durability in the actual structures under severe conditions.
Poon et al (2006) examine the mechanical and durability properties of high performance metakaolin (MK) and silica fume concretes to their microstructure characteristics. The compressive strength and chloride penetrability of the control and the concretes incorporating with metakaolin or silica fume at water to binder ratios (w/b) ratios of 0.3 and 0.5 are determined. The pore size distribution and porosity of the concretes are also measured. The effect of metakaolin and silica fume on the interfacial porosity is discussed based on test results. It is found that metakaolin concrete has superior strength development and similar chloride resistance to silica fume concrete, and the metakaolin concrete at a w/b ratio of 0.3 has a lower porosity and smaller pore size than the control (plain) concrete. The resistance of the concrete to chloride ion penetration correlates better with the measured concrete porosity than with the paste porosity. The differences between the measured and calculated concrete porosity is smaller for metakaolin and silica fume incorporated concrete than for the control concrete, indicating an improvement in the interfacial microstructure with the incorporation of pozzolans.

2.5 ELECTRICAL RESISTIVITY

Tashiro et al (1994) studied the pozzolanic activity by electric resistance measurement method. The measurement of electric resistance and the amount of Portlandite were carried out in accelerated curing conditions by preparing pastes fine ceraments (finely ground granulated blast furnace slag), fly ash, silica fume, kaolin, acid clay, zeolite and quartz activated with Portlandite. The Pozzolan /activator mixing ratio was generally 9 to 1. The pastes made with W/B ratio 0.5 or 0.7. The electrode assembly was immediately embedded in the sample and the measurements were performed every 15 minutes until 72 hours was reached. From this study the following conclusions were drawn,
• The electrical resistance measurement method was very useful to rapid evaluation of Pozzolanic activity i.e., Pozzolanicity. Pozzolanic materials studied in this work can be classified into four categories in respect to the variation of the resistivity. This is characterized by the occurrence of sharp rise or by no occurrence. Fine ceraments, silica fume, acid clay and fly ash showing a retarded rise in category and quartz in category 3, having also no sharp rise. Quartz is considered to be inactive.

• Also the Pozzolanic materials studied in this works were classified with respect to resistivity versus consumption of Portlandite. Fine ceraments form group A, silica fume, acid clay and zeolite form group B and fly ah and kaolin form group C. Group A has low reactivity to Portlandite and high resistivity. Whereas group B has very high reactivity and intermediate to low resistivity. Group C has intermediate reactivity and intermediate resistivity. Hence concluded that higher resistivity indicates superior character of Pozzolans. As a consequence, optimum pozzolans can be selected from each group in practical application.

2.6 DRYING SHRINKAGE

The effects of a recently developed shrinkage reducing admixture on high performance concrete properties are described by Folliard and Neal (1997). ‘High performance concrete mixtures containing silica fume were cast with and without shrinkage reducing admixture. The mechanical properties, drying shrinkage and resistance to restrained shrinkage cracking were investigated. The results show that the shrinkage reducing admixture
effectively reduced the shrinkage of high performance concrete and resulted in a significant decrease in restrained shrinkage cracking.

Persson (1998) outlines experimental and numerical studies on shrinkage of high performance concrete (HPC). Carbonation shrinkage especially may induce surface cracking in concrete, which affects the durability. In order to study shrinkage, cylindrical specimens of eight combination mix of HPC were investigated. The results indicate that carbonation shrinkage may be avoided by addition of silica fume.

Persson (2002) conducted an experimental and analytical exploration on the effect of water binder ratio (w/b) Silica fume and age on autogenous, carbonation, drying and total shrinkage of high performance concrete. Six types of HPC were studied. Carbonation, Internal Relative Humidity (RH) and strength were studied on specimens from the same batch of HPC that was used in the studies of shrinkage. He concluded that

- Autogeneous shrinkage was defined and calculated at no loss of weight. It was fairly good to correlated with w/b ratio and RH.

- Carbonation shrinkage started when the weight of the specimen increased. This was observed by length measurement and weighing in parallel. The best correlation was made to the carbonated part of the specimen.

- Carbonation shrinkage did not occur in HPC with water/cement ratio less than 0.30 and 10% silica fume which was observed on six specimens.
- Both drying and total shrinkage had minimum water/cement ratio equal to 0.33 increasing at smaller and larger water/cement ratio. Measured long term shrinkage was larger than others observed.

Bentz and Jensen (2004) examine the fundamental parameters contributing to the autogeneous shrinkage and resultant early age concrete. Mitigation strategies discussed in this paper include: the addition of shrinkage reducing admixtures more commonly used to control drying shrinkage, control of the cement particle size distribution, modification of the mineralogical composition of the cement, the addition of saturated lightweight fine aggregates. From the study, they concluded that a basic underlying physical phenomenon will lead to either selecting appropriate materials or adapting the structural design to control cracking due to autogeneous shrinkage.