The use of supplementary cementitious (SCM) dates back to the ancient Greeks who incorporated volcanic ash with hydraulic lime to create a cementitious mortar. The Greeks passed this knowledge onto the Romans, who constructed such engineering marvels as Roman aqueducts and the Coliseum, which still stand today. Early SCMs consisted of natural, readily available materials such as volcanic ash or diatomaceous earth. More recently, strict air-pollution controls and regulations have produced an abundance of industrial by-products that can be used as SCM such as fly ash, silica fume and blast furnace slag. The use of such byproducts in concrete construction not only prevents these products from being land-filled but also enhances the properties of concrete in fresh and hydrated states.

SCMs can be divided into two categories based on their type of reaction: hydraulic or pozzolanic. Hydraulic materials react directly with water to form cementitious compounds, while pozzolanic materials chemically react with calcium hydroxide (CH), a soluble reaction poroduct, in the presence of moisture to form compounds possessing cementing properties. Pozzolanic SCMs can be used either as addition to the cement or as a replacement for a portion of the cement. Most of the SCMs will be used to replace a portion of the cement for economical or property-enhancement reasons.

SCMs can be used to reduce the heat of hydration and reduce the potential for thermal cracking in massive structural elements. These materials modify the microstructure of concrete and reduce its permeability, thereby reducing the penetration of water and water borne salts into concrete. Less permeable concrete will reduce various forms of concrete deterioration such as, corrosion of reinforcing steel and chemical attack. Most of the SCMs can reduce internal expansion of concrete due to chemical reactions such as alkali - aggregate reaction, sulfate attack. The optimum combination of materials will vary for different requirements and type of SC

The use of supplementary cementitious materials, such as fly ash, silica fume, slag, and natural pozzolans, in concrete bridge decks has become a widely accepted practice by many state highway agencies, primarily due to the favorable effects on durability. Also, a great deal of research has been performed on properties of concrete
containing one or more supplementary cementitious materials. However, research has not provided clear conclusions concerning the optimum use of these materials to reduce permeability and cracking and thus enhance durability.

**Fly ash:**

Beneficial effects of supplementary cementing materials like fly ash (or slag, silica fume etc.) on reducing the incidence of corrosion of reinforcement in concrete are due to the following factors:

1. Formation of a denser microstructure of calcium silicate hydrate (CSH) due to the additional hydration products formed by pozzolanic reactions.
2. Modification of the pore structure of the cement paste. The products of reaction of fly ash particles taking place within the capillary pores of the cement hydrate may block some pores and make them discontinuous. The average pore size becomes smaller, although the total porosity may remain the same.
3. Increased impermeability of concrete. This results from denser microstructure of the cement paste, increased volume of reaction products and improvement in the workability of concrete, which permits fuller compaction.
4. Lower electrical conductivity of concrete. Addition of fly ash has been found to increase the resistance to the flow of (electrochemical) corrosion currents in concrete.
5. Increased chloride binding. Presence of aluminate phases in fly ash encourages binding of chloride ions in the pore solutions. Chloride binding is also aided by adsorption on the surfaces of the fly ash.
6. pH value of the pore solution is maintained. Alkalinity in pore solutions in the cement paste is not due to Ca(OH)$_2$ alone. Alkalies, aluminate and silicate hydrates also contribute to the pH value. This has been established by elaborate tests, which showed the pH value in hydrating systems with pozzolana or slag to be at least 12 or more.

Because of the reduction in permeability and chloride diffusivity by and the addition of fly ash, penetration of chloride ions from external sources inside concrete is reduced. 4 % NaCl solution was alternately ponded and dried on the surface of the concrete slab in which 30 % cement was replaced by fly ash. After 50 cycles, the chloride
concentrations at different depths from the surface of the slab were measured. Addition of fly ash reduced the penetration of chloride ions.

Bouzoubaâ et al. [88] compared the durability of several types of high-volume fly ash concrete with plain concrete. All mixtures performed satisfactorily from the freeze-thaw resistance standpoint. High-volume fly ash concrete displayed low scaling resistance, but an improved chloride ingress resistance.

Naik et al. [89] compared drying shrinkage, abrasion resistance, salt scaling resistance, and chloride ion penetration of concrete with both Class F fly ash and a blend of Class F / Class C fly ash and also reported that addition of fly ash caused a decrease in chloride permeability of concrete up to 50% cement replacement.

Thomas [90] proved that the threshold chloride level decreased with increasing fly ash content in concrete showed a better performance against the diffusion of chloride ions and seawater attack.

A more recent study on the performance of fly ash concrete in marine environment indicated that the concretes containing fly ash up to 50% cement replacement were more resistant to the penetration of chloride ions than the ordinary Portland cement concrete. Several investigations at CANMET indicated that high-volume fly ash concrete has very high resistance to penetration of chloride ions [91,92]. An investigation on fly ash cement pastes concluded that fly ash blended cement has higher potential to prevent diffusion of chloride ions at 40% replacement level [93]. At CANMET Malhotra has developed high volume fly ash concrete, which incorporates about 56% fly ash by weight of concrete and has a low water to cementitious material ratio. It has superior resistance to freezing & thawing cycles, chloride ion penetration, sulfate attack, carbonation and marine environment.

The ASTM C1202-94 test method for electrical indication of concretes ability to resist chloride ion penetration is the most commonly accepted technique for testing the chloride permeability of fly ash blended concrete. Permeability is inversely linked to durability in that the lower the permeability the higher the durability of concrete. Different procedures have been used for accelerated chloride diffusion test. A modified version of rapid chloride permeability test of AASHTO (T–277) and ASTM C1202 - 94 was used [94,95]. Limits of acceptability are as shown in the following Table.2.1
Table 2.1: Charge passed vs. chloride permeability

<table>
<thead>
<tr>
<th>Charge passed (Coulombs)</th>
<th>Chloride permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 4000</td>
<td>High</td>
</tr>
<tr>
<td>2000 – 4000</td>
<td>Moderate</td>
</tr>
<tr>
<td>1000 – 2000</td>
<td>Low</td>
</tr>
<tr>
<td>100 – 1000</td>
<td>Very low</td>
</tr>
<tr>
<td>&lt; 100</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

Good concretes are reported to have effective chloride diffusion coefficient of the order of $10^{-12} \text{ m}^2/\text{sec}$ or less [96,97]. The chloride diffusion coefficient was much lower than that of control concrete mix for all the mixes containing fly ash. It is observed that the chloride ion permeability values fall in the range of very low (100 – 1000 coulombs) to almost negligible (<100 coulombs). It is also reported that the HPC mixes could be rated as Grade III mixes 169 – 97 MPa, permeability (< 800 coulombs) as per the rating used in the Strategic Highway Research Program (SHRP). Wangwichit et al. [98] found that higher temperature curing decreased chloride penetration depth for mortars made with low or high-calcium fly ash.

Ampadu et al. [99] reported that the diffusion coefficient of chloride ions for cement – fly ash pastes lie within the range of $10^{-7}$ and $10^{-9} \text{ cm}^2/\text{s}$. It was also found that blending cement with fly ash significantly decreases the diffusion coefficient of chloride ions only at the later ages of curing. Furthermore, it was observed that fly ash replacement ratio of 40% gives the best results with respect to chloride diffusivity through cement- fly ash pastes. Water to binder ratio was also found to affect the chloride ion diffusion coefficient through cement-fly ash pastes appreciably at the early ages of curing, but became less important at the later ages of curing.

Shi et al. [100] compared sulfate resistance of cement and cement-fly ash mortars for difference water/cement ratios and curing temperatures. Increasing the water/cement ratio and/or curing temperature led to a higher permeability and effective diffusion coefficient and thus reduced the resistance to sulfate attack.
Gilliland [101] noted that most of the sulfur in fly ashes is present as sulfates and therefore would have in effect similar to the sulfate components in Portland cement. Further he pointed out that corrosion of steel is greatly affected by pH; at the high pH prevailing in concrete, corrosion rates would be expected to be slow.

Berke et al. [102] reported the long-term effects of fly ash on chloride ingress, electrical resistivity, microstructure and corrosion of steel in concrete. The corrosion of steel in concrete after 3 years of exposure to 3% NaCl with fly ash was effective in lowering the corrosion rates. However at a higher water / cementations materials fly ash concretes showed higher corrosion rates than the other concretes.

Hussain and Resheeduzzafar [103] reported that, partial cement replacement by fly ash caused significant pore reinforcement, reduced permeability to water and chloride ions and increased electrical resistivity was observed. Superior corrosion resistance performance of fly ash blended cement concrete when compared to plain cement concrete in terms of corrosion initiation time and corrosion rate is attribute to the improved physical structure of the cement matrix due to fly ash blending.

Dass [104] observed that low amount of chloride fixation in fly ash cement concrete with low alkalinity might result in crossing the threshold ratio of chloride to a value which may cause corrosion. Further, when this concrete was exposed to marine coastal or highly industrial atmosphere lower initial alkalinity of fly ash concrete would be further slashed down due to penetration of Cl$_2$, SO$_2$, CO$_2$ etc.

Haque et al. [105] studied the long-term behavior of concrete with and without fly ash containing chlorides. The extent of carbonation, cracking and corrosion of unreinforced and reinforced concrete specimens have been monitored up to a period of 7 years for 35 and 45 MPa concretes. The results suggest that an arbitrary replacement of cement by a class-F fly ash on 1 to 1 basis results in a concrete, which carbonates, cracks and corrodes more than the corresponding plain concrete. Accordingly it is recommended that economic and technical advantages of using fly ash in concrete making should be exploited very judiciously. The fly ash concretes should be proportioned of their own as design procedures available which treat fly ash as an additional concrete making ingredient.

Montemor [106] studied the influence of fly ash addition on reinforced concrete corrosion, comparison between laboratory and field tests under the influence of chloride ions. Results have shown that fly ash addition improved corrosion resistance initiated by chlorides due to a decrease in concrete porosity, which hinders chloride diffusion. A good
agreement was found between laboratory and natural exposure tests. Apparent capacitance values determined by EIS suggest a corrosion process controlled by diffusion.

Byfors [107] observed that 15 to 40% replacement of cement with fly ash decreases the chloride diffusion and increased the corrosion resistance in spite of slight reduction in pH value of the pore solution.

Mohammed [108] studied the corrosion of steel bars in cracked concrete made with ordinary Portland and fly ash cements. Chloride ingress was found to be higher for the specimens made with OPC and lowest for the specimens made with fly ash cement.

Salta [1094] reported that fly ash addition decreases the diffusion rate of chlorides both in paste and concrete. Addition of fly ash around 30% reduced chloride diffusion rate in such a manner that the effect of w/c ratio becomes less important. It was also confirmed that curing time has great influence, when fly ash is present. When curing time

Montemor et al. [110] studied the corrosion process of steel embedded in concrete with various amounts of fly ash (up to 50% of the total binder) was tested under complete and partial immersion, in sodium chloride solution. The corrosion process was followed by monitoring of open circuit potential measurements (OCP) and electrochemical Impedance Spectroscopy (EIS). He concluded that fly ash addition has led to a raise of concrete resistivity and of the time for corrosion initiation and to a decrease of corrosion rate.

Saraswathy et al. [111] carried out investigations on composite corrosion-inhibiting admixture system comprising of fly ash (25%) along with chemical admixtures was evaluated for its corrosion performance under macro cell corrosion conditions. The authors concluded that the steel embedded in OPC suffered severe corrosion under macro cell conditions. However fly ash admixed concrete improved the corrosion resistance properties of steel. The alkalinity of concrete was not at all affected by adding such corrosion inhibiting admixtures.

A recent study carried out [112] on activated fly ash cement concrete revealed that, steel embedded in OPC and OPC with unprocessed fly ash incorporated cements suffered severe corrosion under macro cell corrosion conditions. But OPC containing activated fly ashes improved the corrosion resistant properties to a greater extent. Chemically treated fly ashes showed superior performance when compared to thermally treated and physically treated fly ashes. The tolerable limit of replacement level for various treated fly ashes under aggressive macro cell corrosion condition is found to be
20-30%. Under 30% replacement level, chemically activated fly (CFA) system showed lowest corrosion rate, highest durability factor and lowest macro cell current under accelerated macro cell corrosion conditions.

Saraswathy et al. [113] carried out corrosion performance studies of activated fly ash blended cements in concrete by adopting various activation techniques such as physical, thermal and chemical methods. Corrosion resistant properties were studied by conducting rapid chloride ion penetration test (RCPT), gravimetric weigh loss, potential time measurement, linear polarization measurement (LPR) and electrochemical impedance spectroscopy (EIS) for various replacement levels of fly ash (10, 20 30 and 40%). Table 3.9 shows the results of RCPT test. From the tale it is observed that the activated fly ash replaced concretes have shown lesser Coulomb values when compared to the control and unactivated fly ash replaced concrete. It is also observed that as the replacement increases the charge passed is found to decreases.

Silica fume:

It has also been reported that, the addition of silica fume in concrete leads to reduction in porosity in the fresh concrete [114]. Investigation on the aggregate-matrix interface concluded that, in concrete with silica fume, a transgranular fracture is observed. Hence, cracks usually traversed the aggregates, pointing to a lower porosity of the interfacial zone as a result of silica fume inclusion [115]. The silica fume can produce both chemical and physical effects, which cause meaningful changes in the microstructure of concrete, diminishing its permeability and improving its strength. Matte et al. [116], carried out pore structure measurements by using Mercury Intrusion Porosimetry (MIP), showed that the cement paste pores were between 0.01 and 0.02µm and for the cement paste containing silica fume.

Ronne and Maage [117] tested the rate of carbonation depending on silica fume dosage in different types of fly ash and slag blended cements by varying the curing, exposure conditions and concrete quality. Increasing the dosage of silica fume increased the carbonation rate dependent of the type of cement, especially for the highest water to cementitious ratio (w/cm). Higher w/cm has a greater negative effect on concrete with silica fume than concretes without.

Yamato et al. [118] tested the carbonation in mortar and concrete with up to 30% silica fume by weight of cement. The samples were cured in water for up to 84 days prior
to exposure in 5% CO₂ and it was concluded that incorporation of silica fume results in significant increase in carbonation depth.

Studies [119-123] have been conducted on the corrosion of steel in concrete made with cement containing SCM was found that the use of SCM can significantly reduce the corrosion rate.

The potentially beneficial effect of SCM, such as silica fume has been attributed to the refined, less continuous pore structure which leads to the decrease in permeability and chloride ion penetration [124]. The slight reduction in the alkalinity of concrete by the addition of silica fume which may cause depassivation of the protective oxide layer of steel is sometimes regarded as a problem. Dotto et al. [125] have studied the influence of silica fume addition on concrete physical properties and corrosion behavior of reinforcement bars and in experiments they found that the addition of silica fume significantly improved the corrosion resistance properties.

Andrade et al. [126] found that a steel fibre reinforced concrete with silica fume addition had low capillary suction, a much reduced diffusion coefficient and almost no detectable rate of corrosion. Also Ping et al. [127] found that there was no significant corrosion of reinforcing steel when silica fume and slag were added to concretes after six months of exposure to 3.4% solution of sodium chloride.

Also, Gu et al. [128] found that there was no significant corrosion of the reinforcing steel when silica fume and slag were added to concretes after 6 months of exposure to a 3.4% solution of sodium chloride. It has been reported [129] that the addition of 15% silica fume produces an improvement in corrosion property.

Hassan et al. [130] studied the effect of SCM on the short-term and long-term properties of high performance concrete made with different binders such as OPC, OPC/SF and OPC/FA by comparing the porosity, strength, permeability and diffusion character of the different mixes up to the age of one year. The results showed that silica fume can enhance the long term properties of concrete. It reduces the permeability by 71% and 87% at 1 and 365 days respectively when compared to OPC concrete. Following Table 2.3 shows the permeability of silica fume and fly ash.
Table 2.3: Permeability as fractions of OPC concrete [130]

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>OPC</th>
<th>Fly ash</th>
<th>Silica fume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.65</td>
<td>0.29</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.57</td>
<td>0.22</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0.53</td>
<td>0.18</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>0.30</td>
<td>0.14</td>
</tr>
<tr>
<td>365</td>
<td>1</td>
<td>0.16</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Thomas et al. [131] evaluated the durability of concretes containing ternary blends of Portland cement, silica fume and a wide range of fly ashes using the chloride diffusion test and concluded that the concrete produced with ternary cementitious blends has a very high resistance to the chloride ions as given in the Table 2.4 below.

Table 2.4: Effect of fly ash and silica fume on chloride diffusion coefficients [131]

<table>
<thead>
<tr>
<th>Cement type</th>
<th>$D_{28}(m^2/s)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>$4.3 \times 10^{-12}$</td>
</tr>
<tr>
<td>25% fly ash</td>
<td>$4.4 \times 10^{-12}$</td>
</tr>
<tr>
<td>Type 10SF(8% silica fume)</td>
<td>$6.6 \times 10^{-13}$</td>
</tr>
<tr>
<td>Type 10SF + 25% fly ash</td>
<td>$3.7 \times 10^{-13}$</td>
</tr>
</tbody>
</table>

*aType 10SF = blended cement with 8% silica fume interground with Portland cement*

Inhibitors:

There are generally three groups of inhibitors: anodic, cathodic and mixed inhibitors. Anodic and cathodic inhibitors develop their action on the respective anode (reacting with the corrosion products by forming a protective film) and cathode sites (as an oxygen-barrier) on the steel. Passivating inhibitors like nitrites represent special types of anodic inhibitors and they are generally very effective inhibitors if present in sufficient concentrations [132].

Mixed inhibitors both influence the anodic and cathodic reaction sites, by forming an adsorptive film on the metal surface. These adsorption type inhibitors are typically organic compounds (e.g. amines and fatty acids). Research on corrosion inhibitors has increased substantially during the last 20 years and various chemicals have been investigated, among these are benzoates of amines and morpholine [133]. Amines and
alkanolamines and salts thereof have been described and patented for different applications such as for the protection of steel in cementitious matrices [134,135].

Calcium nitrite-based corrosion inhibitors have been widely used since the middle of 1970s. Its prominent inhibiting effect has been reported in the majority of previous studies [136-140] showing an increase in the chloride threshold level and in the corrosion-free life of concrete structure. Moreover, calcium nitrite has been preferred over other corrosion inhibitors (sodium nitrite, sodium benzoate), because of its compatibility with concrete properties. When added to concrete, sodium nitrite and sodium benzoate lower concrete strength [141], and the inhibition effect of stannous chloride was marginal [142].

In determining the minimal dosage of calcium nitrite to prevent corrosion, the concentration ratio of nitrite to chloride ions has been generally preferred, which is often regarded as being 0.5–1.0 [143-145]. Besides calcium nitrite, which is the traditional commercial inhibitor used for application in reinforced concrete structures [146,147] many substances have been tested as inhibitors against the corrosion of reinforcing steel rebars [148-150].

Sodium monofluorophosphate has been widely studied and applied in the field to prevent the onset of corrosion or to reduce the corrosion rates, both in the presence of chlorides [151,152] and in the presence of carbonation [153]. It is used by penetration from the concrete surface because, as an admixture, it induces a strong retardation of the concrete setting and can be transformed into insoluble compounds.

Alkanolamines such as diethanolamine, dimethylpropanolamine, monoethanolamine, dimethylethanolamine, methylidethanolamine, and triethanolamine were tested as corrosion inhibitors and their effect on the concrete mechanical properties was evaluated [154]. An inhibitive effect was experienced particularly with triethanolamine, monoethanolamine, and methylidethanolamine. Alkanolamine salts of organic and inorganic salts were also found to reduce the steel corrosion rates and to be compatible with the concrete matrix [155]. Alkanolamines are the active agent in many proprietary inhibitive formulations [149].
Other organic substances, which are claimed to have an inhibitive effect, are based on ternary mixtures of aldonic acid, benzoic acid, and a triazole [156], carboxylic or bicarboxylic acids [157,158], tannins [159]. It has been reported that the long-term performance of zinc oxide as a corrosion inhibitor reduced the concrete porosity and also chloride content at rebar level [160].

Study of diffusion coefficient of chloride is carried over for a long period but, the methodologies used are refined from previous studies. The latest technology is that using electro chemical impedance spectroscopy, the changes in impedance values are taken and they are related to the diffusion coefficient of chloride. In connection to this, the procedures and methodologies carried out by various authors were given in this literature review.

**Chloride diffusion coefficient:**

Byung Hwan Oh [161] studied that on the basis of the transport mechanism of chloride ion, a prediction model of chloride penetration into concrete structures has been developed. The model includes the diffusion of chloride and its dependences on temperature, age, relative humidity, chloride binding and chloride convection by moisture transport. The experimental program has been set up to verify the model developed in the present study. Several series of concrete specimens were immersed in 3.5% chloride solutions for 15 weeks, and the chloride profiles of the specimens were measured and compared to the predicted chloride profiles. In addition, field measurements have been also conducted. From 10-year-old bridge piers, the chloride profiles in concrete under tidal zone were measured and compared with the predicted chloride profiles. The effects of chloride binding, relative humidity, temperature, exposure condition, and age-dependence on the chloride penetration in concrete were clarified from the present analyses. It was found from the present study that all these variables affect greatly the chloride penetration profiles in concrete. The comparison of the laboratory and field test data with the present theory confirms that the proposed model can be realistically used to predict the penetration of chloride ions into concrete structures under sea environments. Further, these results may be efficiently used for the realistic assessment and design for durability of concrete structures.
Erdogdu [162] studied that the rate of chloride ion ingress into concrete is of great importance for the performance of reinforced concrete structures exposed to chloride-contaminated environments. The service life of reinforced concrete structures subjected to such exposure conditions is closely related to the rate of chloride ion diffusion through the concrete. This paper presents the determination of the apparent chloride diffusion coefficient of concrete using open-circuit potential measurements. The chloride diffusion coefficients obtained are in the range of $6.4 \times 10^{-8}$ to $12.4 \times 10^{-8}$ cm$^2$/s for a simulated seawater tidal condition, which is quite consistent with those reported in the literature. This indicates that open-circuit potential measurements can be considered as an approximate but simple method of assessing the diffusivity of chloride through the concrete. Limited with the testing conditions and the characteristics of concrete used, results indicated that the time necessary for corrosion initiation of concrete with a cover depth of 7 cm ranges from 3 to 6 years for the seawater exposure, whereas it is only 1.5 years for a 3% sodium chloride exposure.

Loche [163] studied that during the last decade, electrochemical impedance spectroscopy (EIS) started to be effectively exploited to investigate the electrical properties of hydrated cement pastes. This paper is devoted to the study of the high- and medium-frequency regions of the impedance spectrum and focused on determining the relationship between chloride migration and impedance spectroscopy in accelerated diffusion tests carried out on samples of mortar. After introducing an experimental protocol based on a four-electrode arrangement, we present the results of a parametric study which is related to the thickness and water–cement ratio (W/C) of the samples. Firstly, all our measurements show that the presence of chloride ions modifies the impedance response of mortar and reveals a small loop as of modification of the composition of the upstream solution. This loop is probably due to the development of interfacial phenomena between material and the solution. Secondly, as the migration of chloride process progresses, an increase followed by a decrease of the bulk electrical resistance is observed, whereas the second loop, due to the presence of chlorides, remains constant. An equivalent electrical circuit is then proposed to fit the different experimental data.

Meilun Shi [164] studied a new method of determination of the diffusion coefficient $D$ of chloride in concrete has been proposed. It has been shown that the AC impedance technique is a powerful tool for the determination. For most simple electrochemical
reactions, a Nyquist plot of AC impedance spectra are of the Randles type, which is characterized by a straight line of slope 1 in the low-frequency region. Impedance of diffusion known as Warburg impedance $Z_W$ can be obtained from the intersection of the straight line on the real axis. From the coefficient of Warburg impedance $Z_W$, the diffusion coefficient can be calculated. For the determination of chloride diffusion coefficient, a special ideal non polarized electrochemical reaction was chosen. The results are in good agreement with those reported in the literature. The advantage of the new method lies in its simplicity and reproducibility. Due to changes in microstructure, it was found that the diffusion coefficient of chloride in concrete changes with time in the hydration process.

Olivier Poupard [165] studied that chloride penetration in reinforced concrete induces depassivation of the steel rebars and initiation of the corrosion process leading to degradation of the structure. The coupling of ‘‘low-frequency’’ impedance response with SEM observations and multi elementary analyses emphasized that the strong decrease of the capacitive part is related to the corrosion initiation. This experimentally determined incubation period is used in an electro diffusion model based on Fick’s second law to quantify the chloride concentration threshold responsible for corrosion initiation on the reinforcing steel surface. This work thus allowed quantifying the incubation period and the critical chloride concentration, referred to in Tutti’s diagram [K. Tutti, Corrosion of steel in concrete, CBI Research Report no. 4.82, Swedish Cement and Concrete Research Institute, Stockholm, Sweden, 1982].

Sang-Hun Han [166] proposed a modified diffusion coefficient that considers the effect of chloride binding and evaporable water on the diffusion coefficient. A finite element method (FEM) program based on the modified diffusion coefficient estimates chloride concentration according to concrete depth, and external and internal conditions. The predicted chloride concentrations were compared with experimental values. The modified diffusion coefficient, which is a function of chloride binding, evaporable water content and diffusion coefficient, varies greatly according to the water–cement ratio. Also, C3A content, which has an influence on the chloride binding content, changes the modified diffusion coefficient. The FEM program using the modified diffusion coefficient estimates experimental chloride concentrations within a good accuracy. The numerical analysis of the internal and external conditions shows that the most effective way to reduce chloride ion penetration is to decrease water–cement ratio.
In the present investigation the durability of concrete was studied by using fly ash, silica fume blended concrete and inhibitor admixed concrete. The corrosion evaluation was done by using various electrochemical, short term and longterm accelerated techniques.