CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is the most widely used construction material. It exists in diverse conditions across the globe. Concrete structures are preferred as much in normal environmental conditions as in severe climatic zones. Concrete is used not only for construction of terrestrial buildings but also in marine as well as underground structures. It is widely preferred on account of its low cost as well as its long record of satisfactory performance in service, besides its advantage of being able to be molded in any desired shape. Major performance characteristics of concrete are its water resisting capacity and its durability in diverse conditions, which is much superior to that of its main competitors, steel and timber.

Durability of concrete refers to its potential to resist deterioration during its service life on account of external factors, both chemical and physical. In the last two decades, the instances of unsatisfactory durability of concrete structures have increased at an alarming rate, particularly in the most developed parts of the world. Study reveals that the degradation of concrete structures in nature depends on the atmospheric conditions to which the structure is exposed to or the environment in which the structure is as well as the material composition of concrete.

Concrete is made up of cement, coarse aggregates, sand and water while Reinforced cement concrete refers to concrete with reinforcement steel. Ordinary cement is produced by adding gypsum (1-2 %) to clinkers which is formed by heating calcium carbonate. Gypsum is added to clinkers to enhance the setting time of cement to

facilitate its use in construction works. Cement is a fine powder which manifests binding property upon hydration reaction with water. Aggregates are embedded in concrete and are bound by cement. Fine aggregates i.e. sand are used to fill the pores of coarse aggregates in concrete to the extent possible. However, some pores may still remain which paves the way for permeability through structures.

The durability of concrete is affected by the vulnerability of cement and reinforcement steel to chemical and physical factors. Steel and cement, which are already in high energy state, formed by the expense of energy during their manufacturing process in industries, have a tendency to react and dissipate energy to arrive at low energy state and attain stability. Sand and coarse aggregates are almost in stable state, except in cases where coarse aggregates have some acidic content wherein they may be reactive with cement. This unstable state of steel and cement in concrete is the root cause of deterioration in concrete which affects its durability.

Durability

Many environmental phenomena are known to significantly influence the durability of reinforced concrete structures [Ihekwaba, 1996; Castro Moreno and Genesca, 2000; Roper and Baweja, 1991]. Durability of concrete depends on both physical and chemical factors. While physical factors broadly include, abrasion, erosion, cavitation, etc. chemical factors pre-dominantly include reaction of chemical agents with the ingredients of cement paste. Among the most pressing concerns for structural concrete durability on account of chemical factors is the corrosion of reinforcement [Concrete Society, London, 1984].Among the numerous degradation causes, corrosion of the reinforcing steel induced by deleterious substances reaching the embedded bars is one

of the most important [Saetta, Schrefler and Vitaliani, 1995, Johannesson, 1997]. Reinforcing steel corrosion is one of the most important problems related to early aging of concrete structures and of the stability and safety of structures [Helene, 1983].
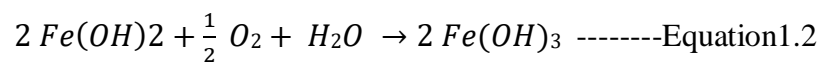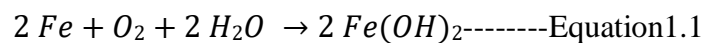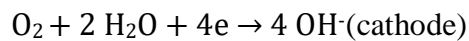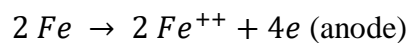
Reinforcement Corrosion

Reinforcement corrosion involves the conversion of iron into its oxides and hydroxides in the presence of oxygen and water. Corrosion of bare iron left in the atmosphere is quite a rapid process. But the same is not true for reinforcement bars embedded in concrete despite the fact that both oxygen and water are abundantly present in concrete. This is because, a dense film of γ – iron oxide (Fe_2O_3) exists around the reinforcement in a high pH environment which acts as a passivizing film. On close examination of the reinforcement bar, it is seen that the environment around the bars is basic due to hydration of cement [Bensted, 1983; Brunauer and Copeland, 1964; Frigione, 1983; Taylor, 1986].The thickness of this film is merely few microns (20-60 A^0). This film prevents the iron in the reinforcement bar to react with oxygen and water till it is intact [Somush, Boah, Leblane, Al-Tayyib and Al-Mana, 1991; Papadakis, Vayenas and Fardis, 1989, 1990, 1991 and 1992; Loo, Chin, Tam and Ong, 1994; Ihekwaba, Hope and Hansson, 1996]. The steel is prevented from corroding as long as this passive oxide film is maintained. However, when the pH of the interstitial solution contained in the concrete pores is reduced from the initial value of 12.6 to values as low as 9.0, the passive protective oxide film of steel gets destroyed, leaving the steel exposed to corrosion [Carpenter and Soretz, 1996; Richardson, 1988]. Corrosion of the reinforcing steel is principally an electro-chemical process. It can be seen that the disappearance of the passivating film sets up potential anodic sites i.e. pockets where iron ions are lost.

The pore solution of concrete acts as the electrolyte and current passes between the anode and cathode, thus setting up corrosion current which propagates to corrode the reinforcement.

In the process, iron goes into the pore solution as iron ions at the anode and two electrons are released at the anode. The electrons are consumed in the presence of oxygen and water to form hydroxyl ions in the cathode and overall it is seen that iron, oxygen and water result in corrosion products i.e. hydrate $Fe(OH)_2$, etc. At the cathodic sites, hydroxyl ions are formed that move freely into the concrete pore solution which serves as the electrolyte media. Thus, if the concrete offers high resistance, the movement of these ions shall be hindered and the corrosion current can be reduced, thus retarding the extent of corrosion of reinforcement.

Above are summarised in the following equations:

$$2\,Fe \rightarrow 2\,Fe^{++} + 4e \text{ (anode)}$$

$$O_2 + 2\,H_2O + 4e \rightarrow 4\,OH^- \text{(cathode)}$$

$$\rule{6cm}{0.4pt}$$

$$2\,Fe + O_2 + 2\,H_2O \rightarrow 2\,Fe(OH)_2\text{--------Equation1.1}$$

$$2\,Fe(OH)2 + \frac{1}{2}\,O_2 + H_2O \rightarrow 2\,Fe(OH)_3 \text{--------Equation1.2}$$

Reinforcement corrosion in concrete can happen under two conditions [Basheer, Chidiac and Long, 1996]

a) On account of chloride ingress – when the passivating film is damaged without changing the electrochemical environment, mainly found in marine structures or in such cases where sea sands are used in concrete or when admixtures containing chloride are used, etc.

b) On account of carbonation - When the electrochemical environment of the steel changes in a manner that the film is no longer thermodynamically enabled. The process of carbonation of concrete reduces the pH and destroys the passivating film [D. Beckett, 1983]. On reduction of the pH of the environment, the passivating film disappears and the surface of the reinforcement is exposed to the oxygen and water which sets in the process of corrosion.

Reinforcement corrosion is primarily induced by the de-passivation of the steel with the reduction in RCC alkalinity through carbonation [P. Schiessl, 1984; C.D. Lawrence, 1981; V.B. Jungermann, 1982].

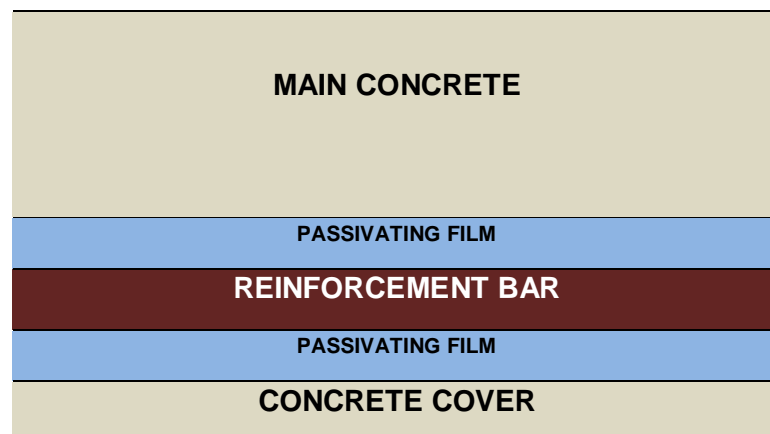| MAIN CONCRETE |
| PASSIVATING FILM |
| REINFORCEMENT BAR |
| PASSIVATING FILM |
| CONCRETE COVER |

Fig 1.1: RCC Structure Indicating Passivating Film around Reinforcement Bar

Since carbonation induced corrosion is most common in industrial areas, hence this study has been focussed on the same.
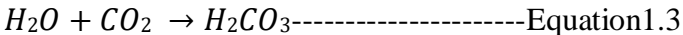
Carbonation

Carbonation is defined as the chemical reaction between Carbon Dioxide (CO_2) present in the air and cement hydration products, mainly Calcium Hydroxide ($Ca(OH)_2$) and the

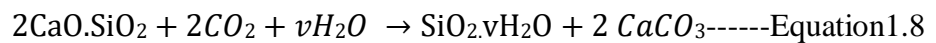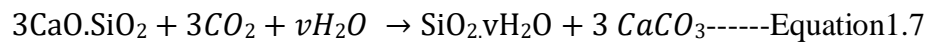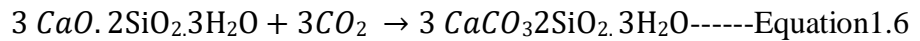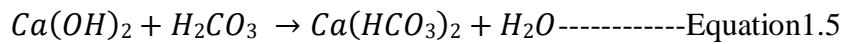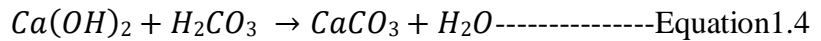Calcium Silicate Hydrate (CSH) gel phase, which results in the formation of Calcium Carbonate ($CaCO_3$), thus reducing the pH value of RCC resulting in corrosion of reinforcement steel in RCC.

Chemistry of Carbonation

Concrete structures exposed to the atmosphere are subject to interface with atmospheric carbon dioxide at a concentration of approximately 0.03 % [Neville and Brooks, 1993]. It may be reiterated that concrete structures consist of pores. As carbon dioxide enters the concrete structure through pores and penetrates into concrete it dissolves in water to form weak carbonic acid (H_2CO_3) which subsequently reacts with the calcium hydroxide to give calcium carbonates and calcium bicarbonates and some amount of water. The carbonation process starts with the diffusion of CO_2 into the concrete and its dissolution in the pore water [Jungermann, 1982; Richardson, 1988; Rosenberg, Hansson and Andrade, 1989] to form a weak acid. The acid subsequently dissociates into carbonate and hydrogen ions [Richardson, 1988; V. Jungermann, 1982], and reacts with the hydroxide compounds to form the less soluble carbonates. Upon consumption of Calcium hydroxide, the carbonic acid further reacts with CSH gel and un-hydrated C_3S and C_2S to produce carbonates and bicarbonates. Thereby, calcium hydroxide & CSH reduces and the pH value is reduced. This reduction of pH results in disappearance of the passivating film. Corrosion of reinforcement begins at this juncture.

The carbonation reactions may be summarised as follows:

$$H_2O + CO_2 \rightarrow H_2CO_3$$ ----------------------Equation1.3

$$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + H_2O \text{---------------Equation1.4}$$

$$Ca(OH)_2 + H_2CO_3 \rightarrow Ca(HCO_3)_2 + H_2O \text{------------Equation1.5}$$

$$3\ CaO.2SiO_2.3H_2O + 3CO_2 \rightarrow 3\ CaCO_32SiO_{2.}3H_2O \text{------Equation1.6}$$

$$3CaO.SiO_2 + 3CO_2 + vH_2O \rightarrow SiO_2.vH_2O + 3\ CaCO_3 \text{------Equation1.7}$$

$$2CaO.SiO_2 + 2CO_2 + vH_2O \rightarrow SiO_2.vH_2O + 2\ CaCO_3 \text{------Equation1.8}$$

The reaction begins with the surface of the concrete and progresses inside as the CO_2 diffuses and its velocity depends on several factors such as humidity, chemical composition of the cement paste, water/binder ratio (W/B), the degree of hydration, permeability and porosity of concrete, temperature and CO_2 concentration, etc.

Deterioration of RCC

The reinforcement bar is embedded within RCC. As such, the steel bar remains surrounded by pore spaces directly in contact with the bar. The inter-connection of pores and characteristics of the pores solution are important factors that determine the electrochemical behaviour of the reinforcement bars while corroding. Reinforcement corrosion leads to development of cracks in the RCC surface on account of deposition of rust on the RCC surface. It is thus relevant to study how such cracks are formed and understand therein corrosion prone structures, preventive measures, control and rehabilitation of deteriorated structures.

It may be observed that corrosion results in loss of iron and deposition of corrosion products such as oxides and hydroxides of iron , the volume of which is much larger

than the parent metal i.e. 1.5 to 2 times to about 5 to 6 times, depending upon the product formed due to corrosion. The kind of products formed depends on the quantity of available oxygen and water. These products have their own values of modulus of elasticity and Poisson's ratio and exert internal expansive pressure on the RCC surrounding the reinforcement on which they are deposited. When this expansive pressure exceeds the critical value, cracks are developed. The critical limit depends on various parameters including the cover, the diameter of the bar, the properties of concrete strength, creep modulus of elasticity and so on.

It may thus be inferred that since increase in cover increases the potential of concrete to take more radial expansive pressure hence higher cover shall increase the ability to sustain corrosion till the onset of development of cracks in concrete.
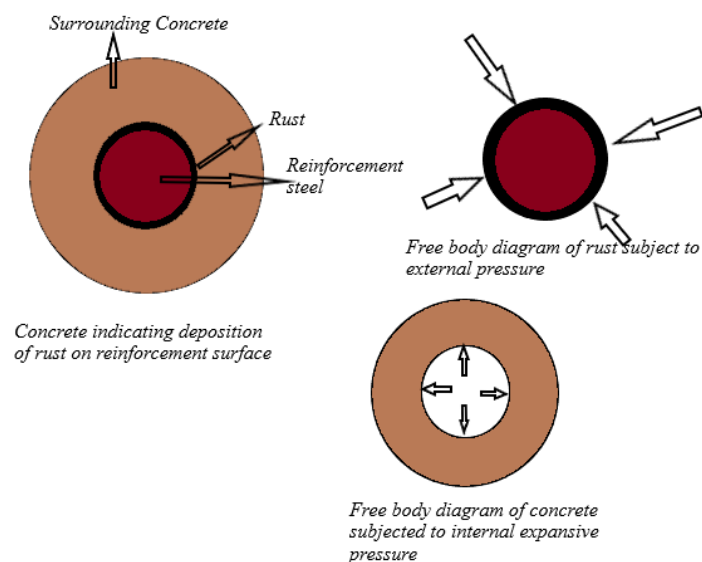
Fig 1.2 Free Body Diagram of Concrete and Rusted Bar Subject to Pressure

Once cracks are formed in the RCC, they provide easy access to deleterious material from the outside and this further accelerates the corrosion process. If two cracks are formed sufficiently close to each other, the intermediate part of concrete loosens and falls off. This phenomenon is called spalling of concrete. Spalling further exposes the reinforcement which allows corrosion to propagate further. Spalling depends on factors such as spacing between the bars cover, the diameter of the bars and so on.
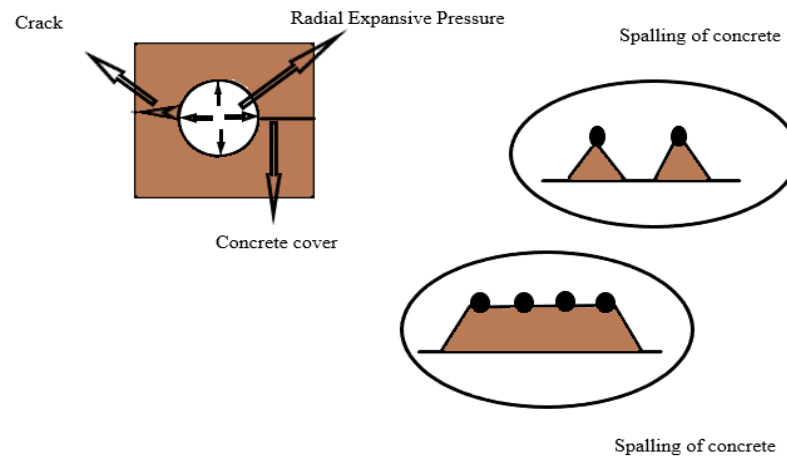

Fig 1.3 Spalling of Concrete

Corrosion can be localized when it affects a very small area or generalized when it spreads over the entire reinforcement system. It is noteworthy that the depth of corrosion in the former is greater than that in the latter. For a given loss in weight of iron i.e. a given quantum of total corrosion, the reduction in thickness of the

reinforcement bar shall be much less if the corrosion is distributed over a larger area as compared to a small area.

In practical situations, carbonation induced corrosion can affect RCC structures even at low saturation level of atmospheric CO_2. However, the rate of carbonation in such case will be low.

Factors Influencing Carbonation

Environmental conditions are considered to be the main factors responsible for affecting the durability in reinforced concrete. Particularly, CO_2 concentration and humidity–temperature cycles directly affect the long-term performance of the reinforced concrete structures [Andrade, Alonso, Costa and Merce, 1993]. Carbonation rate is controlled by the ingress of CO_2 into concrete pore system by diffusion. Factors affecting diffusion rate include the type and amount of cement, porosity of the material, time of curing, type and quantity of pozzolanic additions [Ihekwaba, Hope and Hansson, 1996; V'eleva L. et al, 1998]. Also, several mechanical properties of concrete such as compressive strength, surface hardness and resistance to aggressive agents may change due to carbonation [Verbeck, 1958].

The following factors have a significant effect on the rate of carbonation:

(a) Carbon Dioxide Concentration

Numerous experimental results indicate that concrete carbonation depth is related to diffusion rate of CO_2, external pressure and carbon dioxide concentration. The concrete carbonation depth increases under high CO_2 concentration and high external pressure. That is because under high carbon dioxide concentration and high external pressure, CO_2 can quickly diffuse into the interior of concrete which makes the reaction rapid.

The carbonation kinetics can principally be demonstrated as a diffusion process of a gas (CO_2) through a porous material at a given humidity. The increasing content of CO_2 in atmosphere with time poses potential threat to concrete structures for carbonation.

(b) Temperature

Temperature has dual effects on diffusivity. Increase in temperature enhances the CO_2 diffusion on one hand and reduces the moisture content on the other thus providing more space for gas diffusion which further increases diffusivity. At higher temperatures the solubility of CO_2 in water decreases, therefore decreasing the carbonation rate. Increase in temperature also increases the hydration of cements as a result of which more micro cracks are generated. This facilitates the penetration of external agents in concrete. Although there is no standardized condition as the effect of the temperature in the carbonation process is small but for better results it is observed that the temperature values used in accelerated tests may vary between 25°C and 30°C.

(c) Relative humidity

Water, which is always present in larger or lesser amounts in the pores of hardened cement paste, plays a key role in the process of carbonation. It plays dual role. First it blocks pores and thus hinders diffusion of CO_2; second it provides a medium for reactions. The diffusion of CO_2 is actually 104 times higher in air than in water. On the other hand, CO_2 remains in gaseous form and does not react with the hydrated cement if the pores do not contain adequate content of water.

For low values of relative humidity (RH) i.e. less than 50%, the diffusion of CO_2 into concrete is high but the water content within the pores is insufficient for carbonation. For high values of relative humidity (RH greater than 90%) the rate of diffusion of CO_2 decreases considerably thus reducing the carbonation rate. Carbonation does not occur

in dry concrete due to lack of water to form ions and react. On the other hand, the process is also slow in extremely wet conditions.

(d) Water Cement Ratio

From various research studies it was identified that water/cement ratio (W/C) is an important controlling parameter for carbonation irrespective of the mix design. It may be mentioned that the pore space increases with the increase of W/C. The number and volume of pores in concrete vary with the composition. On close examination of a reinforced concrete structure under consideration, a transition zone can be observed between the zone of aggregates and the zone of cement paste. It is this transition zone which provides an easier access to the deleterious materials travelling through concrete. Also, concrete becomes more porous with the increase of W/C. The effect of W/C on carbonation is believed to be due to the smaller volume of coarse pores for a given duration of curing, which also reflects strength development [Bier ThA, 1987]. Further, dense concrete with low W/C or W/B has less pores and thus less scope of ingress of CO_2 into the structure resulting in lower carbonation.

(e) Cement Consumption

The carbonation resistance power of concrete is related to cement consumption. If cement consumption is increased, the resistivity of concrete against carbonation increases. The increase in cement consumption increases the compactness of concrete thereby increasing the strength of concrete and in turn its anti-carbonation capacity. Heat of hydration is an exothermic reaction which takes place in concrete and liberates heat energy. Due to this process cracks are developed in structures.

(f) Curing

Curing has direct impact on carbonation. The duration and type of curing directly affects the degree of material hydration. The pore microstructure in concrete is a resultant of the curing conditions. It is this porous structure which governs the diffusion of CO_2 subsequently and strength of the concrete is decreased. This can be attributed to the fact that the longer curing period increases the degree of hydration, decreases the porosity, and hence, the permeability of the concrete [Neville and Brooks, 1993].

(g) Permeability

The permeability and porous structure of concrete are important parameters in the process of carbonation. More porous the structure, higher is the permeability resulting in faster and deeper ingress of CO_2, thus, more is the carbonation depth.

(h) Mineral admixtures

Porosity of concrete primarily depends on W/C and SCM like GGBS, Silica fume (SF), FA etc. used. Particularly, GGBS, SF and FA are used as cement replacement materials in concrete. GGBS, SF and FA form less porous concrete and offer good binding strength. SF, GGBS and FA are very effective in reducing the porosity of concrete. SF reacts with $Ca(OH)_2$ and the pH value of the pore solution is reduced and it indicates the initiation of carbonation process. Replacement of cement with GGBS and FA decreases the $Ca(OH)_2$ content of concrete. Hence SF, GGBS and FA may increase or decrease the carbonation depth. Some of the studies revealed that lower levels of replacement have beneficial effect than higher replacements.

(i) Super Plasticizers

Nowadays, super plasticizers are used widely to produce flow able, strong, and durable Portland cement concretes and mortars. The hydration behaviour of Portland cement in

the presence of superplasticizers have been investigated by a number of researchers [Yamada, Takahashi, Hanehara and MAtsuhisa, 2000; Kreppelt, Weibel, Zampini and Romer, 2002; Carazeanu, Chirila and Georgescu, 2002; Yu, Liu, Ran, Qiao and Zhou, 2013]. The dispersing effect of superplasticizers on cement particles can improve the workability of cement, thereby improving the compactness, permeation resistance, and carbonation resistance of concrete.

(j) Coating

Good protective coatings should lead to a prolonged service life of reinforced concrete structures [Fattuhi, 1986, 1987 and 1988].The use of surface protection like paint coating, and a higher strength grade of the concrete substrate enhances the durability of concrete against carbonation [Haque, Al Khaiyat, 1997; Sanjuan, del Olmo, 2001].

(k) Type of Cement

Carbonation depths in concrete made of OPC and Portland Pozzolana Cement (PPC) are found to be different under similar conditions. This is attributable to the chemical properties of different types of cement and their reaction with CO_2 under the effect of carbonation.

Carbonation Rate in Concrete (K)

Various researches have been conducted over concrete carbonation, aiming at developing empirical or semi-empirical relations for the prediction of the rate of carbonation, and hence of the time required for de-passivation of the reinforcing steel [Richardson, 1988; Hamada, 1969; Schiessl, 1976; Tuutti, 1982; Nagataki and Mansur, 1988]. The rate of carbonation depends mainly on the relative humidity, the concentration of CO_2 and the permeability of concrete [Neville, 1995].The carbonation

front advances beyond a particular point when all the materials at that point prone to carbonation have been converted to carbonates. Thus, the rate of movement of the carbonation front depends on the concrete characteristics as well as the environmental exposure condition and this follows a square-root of time law. The development of the carbonation front with time is approximately described by first Fick law of diffusion, the equation being

$$\mathbf{x = K \sqrt{t}}$$

Where: x is the distance between the surface and the carbonation front; t is the time elapsed; K is a carbonation rate.

Determination of Carbonation through Various Experimental Procedures

Phenolphthalein indicator has conventionally been used to determine the depth of carbonation in concrete. Chang and Chen (2006) conducted investigations through thermal gravimetric analysis (TGA) method, which examines the concentration distribution of $Ca(OH)_2$ and $CaCO_3$, as well as by the X-ray diffraction analysis (XRDA) which tests the intensity distribution of $Ca(OH)_2$ and $CaCO_3$. The Fourier transformation infrared spectroscopy (FTIR) test method was also conducted which detects the presence of C–O in concrete samples as a basis for determining the presence of $CaCO_3$. Concrete specimens were prepared and subjected to accelerated carbonation under conditions of 23°C temperature, 70% RH and 20% concentration of CO_2. The test results of TGA and XRDA indicate that there exists a sharp carbonation front. Three zones of carbonation were identified according to the degree of carbonation and pH in the pore solutions. The TGA, XRDA and FTIR results showed the depth of carbonation front is twice of that determined from phenolphthalein indicator and the same increases with time in both conventional as well as advanced method.

1.2 Need for Further Research

Since concrete is the mostly widely used construction material and its durability is affected by carbonation, it is the need of the hour to investigate the impact of various factors affecting the rate of carbonation in concrete. It can be observed from the literature review elaborated in chapter 2 that different conclusions have been drawn by different researchers with respect to various influencing factors such as influence of the super plasticizer, period of exposure, curing period, type of cement, replacement of cement / fine aggregate with FA and micro silica etc. For instance, while some researchers concluded that carbonation is maximum at 65 % RH, some others observed increase in carbonation at RH 0-100 % also. Similarly, different conclusions have been drawn with respect to effect of curing period on carbonation. Likewise, while some researchers find consistent linear relationship between carbonation depth and percentage replacement of cement with Fly ash, some others have observed decrease in carbonation depths at lower values of percentage replacement of cement with FA and increase subsequently.

As such, no concluding remarks may be made from the above studies since the results of different researchers are different. Since concrete structures are widely used and the issue of reinforcement corrosion demands serious concern, it is important to be able to determine carbonation accurately and to be able to design structures accordingly. Above cited discrepancies emphasize the need to review such influencing factors through experimental analysis to determine more accurate conclusions for facilitating future design aspects.

1.3 Aims of the Research Programme

This study has been aimed at determination of carbonation depth of both OPC and PPC concrete under variable factors by different methods such as phenolphthalein indicator method, XRD analysis, FTIR analysis and SEM-EDX analysis. The compressive strength of carbonated and non-carbonated concrete has also been examined.

The aims of the present study are as follows:

- To evaluate the effect of carbonation on OPC and PPC concrete

- To study the effect of mineral admixtures with various water binder ratios on Carbonation

- To analyse the optimum replacement percentage of cement with mineral admixture for enhancing carbonation resistance in view of compressive strength requirement

- To evaluate the effects of accelerated carbonation on the strength of concrete.

- To examine the influence of curing duration, period of exposure, RH and CO_2 percentage on carbonation resistance of concrete.

- To evaluate the reliability of phenolphthalein indicator in accurately determining the depth of carbonation.

1.4 Scope of Study

The scope of the study is limited to the determination of carbonation depths and compressive strength of concrete mix with OPC and PPC and cement and fine aggregate partially replaced by mineral admixtures with various water-binder ratios and subjected to accelerated carbonation. The mineral admixtures used in the present study are fly ash, micro silica and blast furnace slag. This study also deals with the influence of curing

duration, relative humidity percentage, and period of exposure, carbon dioxide concentration and external cover on carbonation resistance. The experimental analysis has been done through conventional phenolphthalein indicator method as well as advanced methods such as XRD, FTIR and SEM.

1.5 Outline of the Thesis

The content of this thesis is broadly divided into eight chapters viz. Introduction; Literature Review; Experimental Programme, material characterization and fresh properties of cement paste and concrete; Test Results of this study; Discussion of results (other than carbonation); OPC and PPC: Carbonation resistance of concrete; The way forward for using PPC in the concrete construction industry and Conclusion and scope for further research.

Chapter 1 covers the background comprising of the use of concrete in structures, its durability, vulnerability to corrosion, process of Reinforcement corrosion, deterioration of concrete, detail analysis of carbonation induced corrosion, elaboration of carbonation chemistry, factors influencing carbonation, and brief explanation of determination of carbonation through experimental procedures. It also highlights the aims and Scope of study.

Chapter 2 summarizes the literature review consisting of Development of Indian and international cement standards with respect to OPC and PPC, Physical and chemical characteristics of OPC and PPC and components, Fresh concrete properties, Hydration of cement**,** Strength development of concrete, Effect of various factors on depth of carbonation in concrete: Carbonation resistance of concrete, Test methods for determination of Carbonation.

Chapter 3 summarizes Physical and chemical properties of material used in experiment, mix proportion used in the experiment, Experimental Programme, pre - conditioning parameters, Set-Up for Carbonation test of Concrete, methods to determine carbonation depth of concrete. In this study, various mixes have been prepared for both OPC and PPC concrete samples such as W/C, curing period, percentage replacement of cement and fine aggregate with FA and. GGBS, percentage replacement of cement with micro silica, CO_2 concentration, relative humidity, super plasticizers, etc.

Chapter 4 elaborates the test result of this study. Experimental test results of carbonation depth obtained from Phenolphthalein Indicator Method, XRD Method, FTIR method and SEM method have been presented in this chapter

Chapter 5 has been focussed on discussion of test results other than carbonation i.e. the compressive strength of carbonated and non-carbonated cube samples. Compressive strength tests have been performed on different mix proportions of OPC and PPC along with cement replacement with mineral admixtures and the test results for compressive strength have been simultaneously analysed with carbonation resistance.

Chapter 6 has been dedicated to focussed analysis of Carbonation resistance of OPC and PPC concrete and discussions with respect to results obtained.

Chapter 7 demonstrates the way forward for using PPC in the Concrete construction industry i.e. a set of optimum mix proportions in accordance with the test results have been proposed to achieve both resistance to carbonation as well as strength requirement of concrete in industrial use.

Chapter 8 consists of concluding remarks with respect to the inference that can be drawn from this research and also throws light on the scope for further research in the subject.