EXPERIMENTAL INVESTIGATIONS ON THE EXTENT OF CARBONATION PROBLEM IN REINFORCED CONCRETE BUILDINGS OF NORTH CYPRUS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF APPLIED SCIENCES
OF
NEAR EAST UNIVERSITY

by

SALIM IDRIS MALAMI

In Partial Fulfillment of the Requirements for
The Degree of Master of Science
in
Civil Engineering

NICOSIA, 2014

EXPERIMENTAL INVESTIGATIONS ON THE EXTENT OF CARBONATION PROBLEM IN REINFORCED CONCRETE BUILDINGS OF NORTH CYPRUS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF APPLIED SCIENCES
OF
NEAR EAST UNIVERSITY

by

SALIM IDRIS MALAMI

In Partial Fulfillment of the Requirements for
The Degree of Master of Science
in
Civil Engineering

NICOSIA, 2014

Salim Idris Malami: EXPERIMENTAL INVESTIGATIONS ON THE EXTENT OF CARBONATION PROBLEM IN REINFORCED CONCRETE BUILDINGS OF NORTH CYPRUS

Approval of Director of Graduate School of
Applied Sciences

Prof. Dr. İlkay SALİHOĞLU

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Civil Engineering

Examining Committee in Charge:

Prof. Dr. Ata Atun	Committee Chairman, Department of Civil Engineering, Near East University.
Asst. Prof. Dr. Pınar Akpınar	Supervisor, Department of Civil Engineering Near East University.
Asst. Prof. Dr. Ertuğ Aydın	Commitee Member, Department Civil Engineering, Lefke European University.

I declared that I carried out the work reported in this thesis in the Department of Civil Engineering, Near East University, Cyprus, under the supervision of Asst. Prof. Dr. Pinar Akpinar and all sources of knowledge used have been duly acknowledged in accordance with the academic rules and ethical conducts.

…………………………………

SALIM IDRIS MALAMI

20124087

ACKNOWLEDGMENT

All praise is for Allah, the exalted. It is by His grace and will that I have reached this stage. May His peace and blessings be on Prophet Muhammad, his family and companions.

My inestimable appreciation to my supervisor, Teacher and a mentor, Asst. Prof. Dr. Pınar Akpınar, whose diligence and constructive criticism made this work successful and I can say she was the direct reason behind every progress achieved during this study.

My eternal gratitude goes out to my parents, for their love, care, support, encouragement I cannot thank them enough. May Allah reward them with the best reward.

My special thanks goes to my dedicated and competent lecturers Prof. Dr. Hüseyin Gökçekuş, Prof. Dr. Ata Atun, and Asst. Prof. Dr. Rifat Reşatoğlu.

I express my deep appreciation for the efforts of Mustapha Turk (Near East University Civil Engineering laboratory technologist) and entire staffs of the Chamber of Civil Engineering (KTİMO) laboratory, Nicosia Cyprus.

I also wish to thank my siblings Najib, Zahraddeen, Sahmsuddeen (Andu), Samir, Sagir, Musa (Kawu), Ahmad, Anisa, Aisha, Khadija (Mama) and my daughters Khadija, Aisha and Fatima for always being there.

I owe a special thanks to my friends, Salim J.D, Isa A.B, Shamsu A, Sagir M, Umar A, Musa S.A, Adamu D, Fa’izu H.A, Samir B, Mustapha N.S, Anas M, Aminu Y.N, Shehu M, Mustapha D and Mahmud A. Thank you all for moral, financial and spiritual support. May Allah bless you all and replenish your purse. Special thanks goes to Haj. Dije Ado, Sunusi Shuaib, Aminu Bello, Mukhtar Adam, Nazir Garba, Lieutenant Sunusi M. Bello, Ali M. Kamil, Aminu Madugu, to my friends Abdurrahman Ado, Abubakar Abba, Misbahu Aminu, Yazid Adamu, Salihu Bello, Sadiq Madugu, Hassan Muhammad Abdullahi, Abbas Ako Daura and many whose their names are not written here for their indispensable help in different ways.

I also want to take this opportunity to thank the people and government of Kano State under the leadership of Engr. Rabiu Musa Kwankwaso for giving me this rare chance to further my studies.

I dedicated this project to the Almighty Allah who gave me the strength and guiding me the right way during the work and my entire life indeed. Then to my dad (IDRIS MALAMI), my mum (ZULAIHAT JA’FAR) for their support and assistance from my child hood up to this great achievement.

ABSTRACT

Carbonation is one of the critical concrete durability problems which leads to carbonation induced reinforcement corrosion. Carbonation occurs as a result of the reaction between CO_2 gas with cement hydration products in concrete in the presence of moisture. Being in an Island, Cyprus cities have high relative humidity throughout the year and the presence of industries and machineries that produces large amount of CO_2 gas to the atmosphere this gas remain in the atmosphere for a very long period of time. These factors increases the possibility of reinforcement corrosion induced by carbonation occurrence in Cyprus buildings.

In this research an investigation carried out on 8 existing buildings in inland and coastal area of North Cyprus, by which carbonation depth, compressive strength and density were evaluated after extracting concrete cores from walls and columns of the existing buildings. The buildings surveyed averagely carbonated at a rate of 1.10mm per year. Inland buildings carbonated at faster rate than the coastal buildings. Constant values were derived that are useful in predicting future carbonation depth of a concrete in given years based on different grades of concrete in North Cyprus. The investigation in this research indicated that manufacturing high strength and high density concrete would be the best precaution for minimizing the progress of carbonation process in concrete structures in the Island.

***Key Words*:** Carbonation depth, Compressive strength changes, Aggressive environment for carbonation problem, Concrete structures in North Cyprus, Phenolphthalein indicator

ÖZET

Karbonatlaşma betonarme binalarda donatı korozyonuna neden olan ciddi bir beton dürabilite problemidir. Karbonatlaşma, havadaki CO_2 gazının, nemin mevcut olduğu beton içerisinde çimento hidratasyon ürünleri ile reaksiyona girmesi sonucunda oluşur. Kıbrıs adasındaki şehirlerde yıl genelinde yüksek bir bağıl nem oranı gözlemlenmekte ve gelişmekte olan endüstri nedeniyle atmosfere yüksek oranda CO_2 gaz salınmaktadır. Bu durum, Kıbrıstaki betonarme binalarda karbonatlaşma sonucu donatı korozyonu yaşanması ihtimalini kuvvetlendirmektedir.

Bu çalışmada, gerek kıyı gerekse de iç bölgelerde bulunan 8 bina üzerinde ölçümler yapıldı. Bu binalardan alınan karot numunelerde basma dayanımının yanı sıra, yoğunluk ve karbonatlaşma derinliği ölçüldü. Bulgular, çalışılan binalardaki ortalama karbonatlaşma oranının 1.10mm/yıl olduğunu göstermektedir. Yine bu tez kapsamında yürütülen çalışmalar sonucunda, iç kesimlerdeki binalarda karbonatlaşma oranının kıyı kesimlerdeki binalara göre daha yüksek olduğu tespit edilmiştir. Çalışmalar kapsamında hesaplanan karbonatlaşma sabit sayıları ile binaların ileriki yıllardaki karbonatlaşma seviyelerini de belirlemek mümkün olabilecektir. Karbonatlaşma sorunun en aza indirgenmesi için yoğunluğu ve mukavemeti yüksek beton üretimi en etkili çözümdür.

Anahtar Kelimeler: Karbonatlaşma derinliği, basınç dayanımı değişimleri, karbonatlaşma problemine neden olan çevre koşulları, Phenolphtalein göstergesi

CONTENTS

CHAPTER ONE : INTRODUCTION

CHAPTER TWO : CONCRETE CARBONATION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

LS	Low Strength (Concrete core with strength below 20 Mpa)
MS	Medium Strength (Concrete core with strength 20MPa to 30Mpa)
TRNC	Turkis Republic of Northern Cyprus
ACI 318-11	Building Code Requirements for Structural Concrete
BS 8110	Structural Use of Concrete

LIST OF SYMBOLS

B	Carbonation Constant
d	Carbonation Depth
t	Time for Carbonation.
M	Mass
V	Volume
Do	Diffussion Rate

CHAPTER ONE
INTRODUCTION

1.1 Background

Durability is a major concern for concrete structures exposed to aggressive environments; it is the ability of a concrete structure to maintain its structural performance which depend on several potential interior or exterior, physical or chemical actions that may take place throughout the entire life of structure (service life).

Carbonation is one of the major problems that cause concrete structural deterioration. It is a reaction of atmospheric carbon dioxide (CO_2) with Calcium hydroxide ($Ca(OH)_2$) to form calcium carbonate($CaCO_3$). Natural carbonation is one of the processes responsible for the reinforcement corrosion problems in reinforced concrete structures which depends on both the characteristics of the materials and the surrounding environment. Generally the cement in the concrete hydrates to produce an alkaline microstructure (mainly due to Calcium hydroxide produced) which chemically protects the steel from corrosion. The chemical protection conferred on steel is through a passive protective oxide which forms on steel in it environment at higher pH above 13 (Alkaline), at this condition steel is in secure state until this passive protection is destroyed through carbonation (Roy et al, 1999).

This reinforcement corrosion due to carbonation leads to significant negative implications on the life cycle cost of structures.

Inability to determine the durability potential of concrete structures is contributing in the massive current repair and maintenance of structures all over the world, example in United Kingdom alone, the cost corresponds to around 20 billion pounds from overall construction turnover of 45 billion pounds (Jones et al, 2000).

Also the corrosion of steel rebar was described as the primary and most costly form of deterioration that have been experienced by reinforced concrete bridge structures. In the United States of America, both maintenance and rehabilitation costs for deficient bridges are very high and are counted in billions of US dollars (Namagga and Atadero, 2011).

Cyprus Island has combination of salty geology and intense Mediterranean climate which makes the environment very aggressive to concrete structures compared to many places in the globe. This aggressiveness is due to the fluctuations in both humidity and temperature in the island throughout the year.

This aggressive nature of the environment causes premature deterioration of structures made of reinforced concrete by causing cracks as a result of durability problems seems to be sulphate attack and depassivation of reinforcement due to carbonation. There is increase in the concentration of CO_2 in Cyprus atmosphere due to increase of industries that releases fossils gasses as a source of energy, increases in automobiles and air conditions as a cooling and heating systems due growth in the number of population in the island, hence demand of the energy sources is increasing and the gasses are increasing, and released CO_2 gas remains dangerous to the buildings for a very long period of time, because the gas remains in the atmosphere for a period ranging from 50 years to 200 years, today and in the future concrete structures will be at risk from carbonation-induced reinforcement corrosion that may lead to the failure of the structures and cause loss of properties and lives; therefore it deemed expedient to know the effects of these environmental conditions on the concrete structures within North Cyprus.

1.2. The Objectives of the Research

In this research, carbonation of concrete will be the main focus as a durability problem on the structures investigated.

The objective of the study is to provide insight on the status of existing buildings in Cyprus under the effect of carbonation process. The effect of Cyprus climatic conditions, both in inland and coastal areas on the concrete structures manufactured at different years using concrete materials available in the island will be studied throughout this thesis work.

1.3. Justification of the Research

The CO_2 is known to be increasing in Cyprus Island due to releases of fossils gases from burning of materials as sources of energy or from machineries and automobiles. Carbonation process is highly likely to occur under these conditions.

However no relevant previous study is carried out to determine the severity of this problem.

1.4. Contribution of the Research to Knowledge

The knowledge to be derived from this research will provide data to civil (material) engineers that will enable them to know the characteristics of materials that are to be used in reinforced concrete design in the Island, as well as the performance of the materials under Cyprus climatic conditions. With the data that will be provided with this research, a significance insight or the extent of carbonation on the Islands' existing structures will be gained. In this way strategies required to take precautions can be prepared

1.5. Research Organization

This thesis consists of five chapters. In chapter one topic background, objectives of the research and contribution of the research to knowledge are presented. Chapter two discusses carbonation problems in concrete, factors increasing its rates, method of measuring the carbonation and ways of prevention and rehabilitations, then Turkish Republic of Northern Cyprus environmental conditions are discussed. Chapter three presents types of materials for concrete in Turkish Republic of Northern Cyprus and method for carrying out the research. In Chapter four results and discussions are presented. Finally chapter five conclusions are drawn from this thesis and recommendation are suggested.

CHAPTER TWO
CONCRETE CARBONATION

2.1 Definition of Carbonation Problems in Concrete

Concrete carbonation is a reaction of carbon dioxide (CO_2) present in the air with calcium hydroxide ($Ca(OH)_2$) to produce calcium carbonate ($CaCO_3$) (Rostami et al, 2012).

Carbon dioxide (CO_2) alone is known not to be able to react with calcium hydroxide ($Ca(OH)_2$), but in the presence of water, it converted into weak carbonic acid HCO_3 that reduces alkalinity of concrete by attacking the concrete, making the steel exposed to corrosion by destroying the protective passivation layer.

There is presence of carbon dioxide (CO_2) in the atmosphere, the amount of CO_2 in air is about 0.03% by volume (Wee et al, 1999) especially in rural areas where there is no air pollutions. In large cities where there is high population density with large number of vehicles and auto mobiles and even some factories the amount CO_2 of may rise to 0.3% or in some exceptional cases it may rise up to even 1.0 %, in tunnels the intensity may be much higher than 1.0 % if not well ventilated.

The hardened concrete pore water is highly alkaline in nature with a pH value between 12.5 to13.5 according to the amount of alkali in the cement. The higher pH (alkalinity) provides a thin protective layer around the reinforcement steel, this layer prevent steel from the action of moisture and oxygen that causes corrosion in the bar (Roy et al, 1999). Provided that the steel is kept in this higher alkaline condition it will never corrode. Such condition is known as **passivation** (Roy et al, 1999).

Naturally carbon dioxide in the air in small or in large concentration, ingress through concrete and carbonates the concrete by reducing the pH value of the concrete. The pH value of pore water in the hardened concrete is reduced to a value 9.0 which actually is greater than or around 13. The pH may go down to less than 9.0 when there is full carbonation of $Ca(OH)_2$ in the concrete. In such condition of low pH value, steel is exposed to corrosion hence the protective layer gets destroyed (Chang, 2006).

It was reported carbonation results in the dropping of pore water of the concrete of higher alkalinity from 12.6 to a lower alkalinity of 8.0. The pH value of 11.4 is defined as the limit under which reinforcement bars cannot be protected from corrosion, corrosion begins at a values lower than this as long as there is adequate oxygen and moisture available in the concrete (Varjonen, 2004).

The main cause of reinforcement bars corrosion is carbonation of concrete even though moisture and oxygen are the necessary component for the corrosion to occur (Varjonen, 2004).

Concrete porosity decreases due to carbonation making the hardened concrete stronger, so carbonation is advantageous to a mass-concrete by increasing its strength relatively, when pores are filled with calcium carbonates. On the other hand, it is a disadvantage to a steel reinforced concrete making its environment front to corrosion (Rostami et al, 2012).

Occasionally concrete may undergo another type of reaction named Bi-carbonation process. This Bi-carbonation usually happen in a concrete of higher water cement ratio as a result of formation of ion of hydrogen carbonate at a pH less than 10. This type of carbonation increases concrete porosity and turn it surface layer very weak and soft that can be easily scratched and removed using finger nails. Bi-carbonation of a concrete can be identified by noticing of a large pop-corn like calcite crystal and a paste of high porosity.

Carbonation also occurs on fresh concrete (plastic state) as a result of human activities, after casting the concrete. Carbonation can occur on concrete while it is in plastic state or after it has hardened. While similar reactions are taking place, their effects are very different. Carbonation in the plastic state usually develops during cold-weather constructions. Typically, when the structure has been closed in, but the central heating plant of the building has not yet been installed. When installing, the floor slab, the builder will often choose to heat the interior of the structure using combustion heaters that are not vented to the outside. The heaters produce a large amount of carbon dioxide as part of the combustion products. Carbon dioxide, or CO_2, being a moderately heavy gas, tends to settle down to the floor, and Carbon dioxide is fairly soluble in water, it enters the mix-water readily. Carbon dioxide (CO_2) is not reactive, but when it enters the mix-water and goes into solution, it becomes carbonic acid (H_2CO_3) that reacts with the calcium hydroxide in the mix water, which is necessary for the development of strength in the cement paste and form insoluble calcium carbonate ($CaCO_3$). If this reaction is carried far enough, no calcium hydroxide will be left in the solution to react with the silica and alumina to form the hydrates that give strength to the concrete (Rostami et al, 2012). Normally, the result is, a soft powder layer is formed that can be easily removed with finger pressure as shown in Fig. 2.1 below. It is usually only about 1/8 inch thick, but that is the surface that is expected to resist traffic, and it has lost this ability. The repair to this concrete problem is not easy or economical.

Figure 2.1: Floor Slab Dusting Caused by Carbonation of Fresh Concrete

2.2 Carbonation Reactions

2.2.1 Reaction Type 1:

Carbonation reaction here is divided in to seven steps below;

1. Carbon dioxide diffusion in pore space of concrete
2. Gas sorption in pore liquid.
3. Reaction of formation of carbonic acid

$$CO_{2\,(g).} + H_2O \rightarrow H_2CO_3 \qquad (1)$$

4. Dissolution of calcium hydroxide in a liquid phase.
5. Mass transport of calcium hydroxide in a liquid phase.
6. Reaction of formation of calcium carbonate.

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O \qquad (2)$$

1- Formation of sediment of calcium carbonate ($CaCO_3$) (Brown, 2012).

2.2.2 Reaction Type 2:

$$CO_{2\,(g).} + 2NaOH \rightarrow Na_2CO_3 + H_2O \qquad (3)$$

$$Na_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2NaOH \qquad (4)$$

$$3Na_2CO_3 + 3CaO.2SiO_2.4H2O \rightarrow 3\,CaCO_3 + 2SiO_2 + 6NaOH + H_2O \quad (5)$$

The above reactions take place only in aqueous solution where, $Ca(OH)_2$ dissolves after forming $CaCO_3$ precipitate. In reaction type 2, Calcium silicate hydrate C-S-H as a xero-gel reacts with carbonate and releases hydroxyl ions (NaOH) in accordance with equation (5) which react with CO_2 again as along as $Ca(OH)_2$ and C-S-H are present in the concrete, the carbonation reaction will continue provided that moisture and CO_2 are available (Houst and Wittmann, 2002).

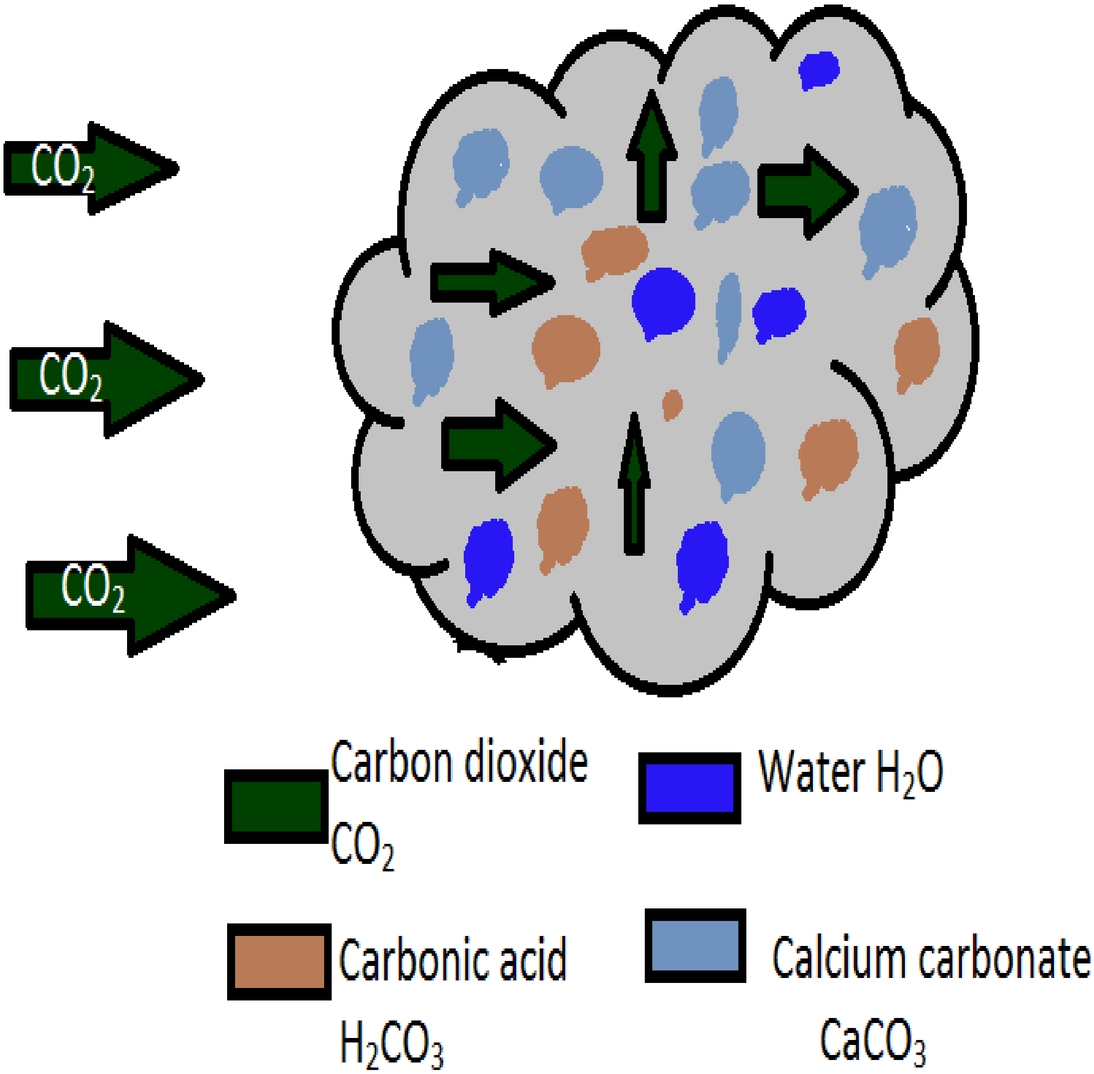


Figure 2.2: Graphically Shows the Carbonation Process in Concrete

2.3 Rate of Carbonation

Carbonation of concrete occurs progressively from outside cover to the deep inside of the concrete, when concrete is exposed to the carbon dioxide (CO_2) gas. This is occur in decreasing order from the surface down to the inner layer of the concrete since CO_2 gas must penetrates trough concrete pores before the reactions take place in the presence of moisture (Neville, 1995).

Atmospheric CO_2 diffuses in to the concrete through its surface, in the presence of moisture, it react with portlandite and calcium silicate hydrate that are formed as a result of cement hydration. These reactions produce calcium carbonate ($CaCO_3$) that reduces the concrete pH and make it vulnerable to corrosion when the passivation layer is broken (Carbonation).

This carbonation is a long term, complex and continues process which made it to have no consistent design approach in the codes of practice to reduce it rate in concrete (Shi et al, 2009) but there are many factors that speeds and affects the rate of carbonation in concrete.

Some of these factors are mentioned and explained below (Varjonen, 2004);

1) Relative Humidity(concrete's pore water)
2) Permeability of concrete
3) Concrete grade
4) Temperature
5) Cracks on concrete
6) Concentration of CO_2 in the environment.
7) Other factors like cement type, curing period and concrete cover.

2.3.1 Relative Humidity

This is moisture content usually called relative humidity (RH). It changes with the variation in ambient condition, there is fluctuation in RH in concrete cover as a result cyclic in wetting and drying exposure of concrete (Russell, 2001). In this situation carbonation of concrete stops when there is full of water in the pores of the concrete, the pores of the concrete blocked so that CO_2 gas will not have room to ingress in to the concrete for carbonation to occur (Neville, 2003) and it proceeds when the pores have moisture that will allow ingress of CO_2 in to the concrete for the reaction to occur and when pores are too dried there will be no enough moisture that will dissolve CO_2 gas to form carbonic acid which reacts with portlandite and form calcium carbonate (Russell, 2001).

Concrete carbonation reaches it maximum at a relative humidity between 50% and 70% (Neville, 2003, Varjonen, 2004 and Russell, 2001). When relative humidity is much higher carbonation rate decreases as a result of much water in the concrete pores and at relative humidity below 50% there will be insufficient amount of moisture for carbonation reactions to occur, hence rate of carbonation reaches its maximum at the range of the relative humidity of 50 to 70 %

Neville (2003) a typical picture of the influence of the relative humidity on the progress of carbonation was reported, for concrete with a water-cement ratio (w/c) of 0.6, at the age of 16 years, the average values of the depth of carbonation were at relative humidity of 100% is 0; at relative humidity of 95% is 4 mm; and at relative humidity of 60% is 15 mm (Neville, 2003).

In a research conducted by (Mmusi, 2009) the critical moisture content for carbonation was reported as 80% in three weeks exposure of meso-concrete prism and it had been studied and reported critical moisture content for both concrete and mortar is 80% RH because the region near the surface of concrete should not have $Ca(OH)_2$ available so moisture must be enough to enter and reach $Ca(OH)_2$ for reaction with CO_2, while at the RH greater than 80%, $Ca(OH)_2$ in the cement is assumed to be dissolved, the block of the pore space only stops the carbonation at this stage. In their investigation they reported that carbonation depth increased with an increase in water binder ratio (Mmusi, 2009).

2.3.2 Permeability of concrete.

The first driving force for concrete durability problems is the permeability of the concrete since it is the ability of the concrete to allow harmful chemicals and gaseous species that react with the hydration products of the cement to produce substances that hinder the durability of the concrete. Concrete with higher permeability due to presence of connected pores has the ability to allow more carbon dioxide ($CO_{2)}$ and water to ingress in to the concrete which reacts with the portlandite to produce calcium carbonate at a faster rate. It is reported that there is lower rate of carbonation on concrete with low permeability when compared with the concrete with high permeability, they also stated that there is a good relationship between concrete cover and permeability in resisting carbonation (Dhir et al, 1989).

It is concrete permeation that control the ingress of CO_2, if concrete is very permeable it can easily allow CO_2 gas to penetrate for the reactions to occur hence carbonation rate will be higher and if permeability of the concrete is low, less CO_2 penetrates in to it and low amount of CO_2 will be available for the reactions to occur, hence carbonation rate will be slow (Varjonen, 2004).

2.3.3 Concrete grade

Carbonation rate is slower on stronger concrete (concrete with higher grades), higher compressive strength is achieve by mixing concrete at lower water cement ratio.

Low water cement ratio in concrete prevent evaporation of excess water from the concrete, the excess water evaporation is responsible for the formation pore spaces that are connected together while escaping from the concrete making the concrete porous that can easily allow chemicals and gaseous species to pass through it and cause carbonation and other durability problems (Neville, 2003).

It is trivial that concrete with less water cement ratio is less permeable so the penetration of chemical and moisture is less, due to this the rate of carbonation will be slower.

2.3.4 Temperature

As the temperature in the concrete environment goes up, the diffusivity of CO_2 gas increases as a result of the increase in activation energy, when the diffusivity of the CO_2 gas in to the concrete increases carbonation rate increases and when the temperature is low the diffusivity will be low resulting low rate of carbonation. It was reported that at 8 degree centigrade temperature the carbonation of concrete seized (Song et al, 2006).

The high amount of atmospheric temperature speed the reaction of CO_2 with portlandite in the presence of moisture by increasing the heat that activate the reaction making the molecules move faster and freely, resistance to chlorides penetration also decreases by rise in temperature, this is by speeding mobility of ions and salt become soluble (Neves et al, 2013).

The global temperature at end of this century will increase by 1 degree centigrade (Shanablih, 2012)

When the temperature in a concrete rise up, the diffusion of carbon dioxide gas increases, it is confirmed that temperature effects on diffusion of CO_2 gas in to the concrete is in a direct relationship, that is diffusion of the CO_2 gas increases when the temperature is increased in the concrete (Shanablih, 2012).

2.3.5 Cracks on concrete

It is easy for concrete surface to crack as a result of excess heat of hydration, drying shrinkage and bad or improper curing of the concrete. Through the cracks external CO_2 penetrates easily in to the concretes and react with $Ca(OH)_2$ in the presence of water and cause the carbonation to occur at a faster rate (Song et al, 2006)

In a cracked concrete it was reported that carbonation is one of the major factor accelerating reinforcement corrosion, cracks serves as ways for CO_2 to ingress in to concrete (Song, 2006).

It is easy and common for a cracks to occur on concrete, these occurs due to human factors like construction negligence example inadequate curing, cracks may occur due to drying shrinkage and hydration heat. During hydration on early aged concrete cracks occurs, through this harmful chemicals like CO_2 and chlorides passes in to the concrete by this reinforced concrete structure deteriorations starts (Song, 2006).

In a research conducted by (Song, 2006) it was found that increase in width of cracks from 0.05mm to 0.45mm carbonation depth increased significantly. Crack on concrete is an influencing factor in permeation of substances in to the concrete, in their research they concluded that the diffusivity of concrete with cracks found to increase by a factor from 2 to 10, therefore presence of cracks speed the carbonation of concrete that lead to the faster rate of carbonation as far as the CO_2 to be absorbed is available, in this concrete corrosion of embedded bars occurs easily within short time.

It is reported by (Song, 2006) that increase in cracks width carbonation depth increases, this is more effective on a concrete with high water cement ratio.

2.3.6 Concentration of CO_2 gas in the environment

The higher the concentration of CO_2 gas in the atmosphere the higher the rate of carbonation since there must be a carbon dioxide gas for the carbonation reactions to occur, the risks of concrete carbonation is much higher in the urban areas than that of rural areas , the concentration of CO_2 gas in the rural atmosphere is around 0.03% which is very low compare to the cities where there is high concentration of vehicles, automobiles, industries that are releasing CO_2 gas and the percentage is much greater than 0.03%, in a tunnels where there is no ventilation CO_2 gas concentration rises up to 1.0% .Investigation on carbonation is usually conducted under accelerated conditions, with higher CO_2 concentrations, for example 4%-volume, to speed up the process. Four weeks of accelerated carbonation in 4%-volume of CO_2 gas was reported and often considered as equivalent to approximately 4 years in natural conditions (Varjonen, 2004).

The effect of CO_2 on concrete have greater effect on concrete with high water to cement ratio, therefore less water cement ratio is to be used in constructions since the concentration of CO_2 gas is increasing in the atmosphere.

In many research conducted it is shown that experimental accelerated carbonation gave more carbonation depth than the natural condition, this is as a result of less concentration of CO_2 in the atmosphere of 0.03%, which is mostly less than that are using in accelerated carbonation in the laboratory. Also increases in CO_2 concentration results in an increase of percentage weight of concrete due to carbonation reaction, this is showing more $CaCO_3$ formed in the concrete when x-ray diffraction method is used, hence this is showing carbonation rate is increasing at higher CO_2 concentration (Varjonen, 2004).

2.3.7 Other factors

Another factor influencing carbonation in concrete is the diffusivity of the hardened cement paste. Carbonation rate is controlled by the ingress of CO_2 into concrete pore system by diffusion with a concentration gradient of CO_2 acting as the driving force. Also factors affecting diffusion rate includes, the amount and type of cement, porosity of the material, curing time, type and quantity of pozzolanic additions. Moreover. How curing effects carbonation rate; when concrete is cured in wet condition it allows the hydration of cement to continues (faster) resulting in producing denser micro structures that make the concrete less porous and make it resistance to attacks high, so less carbon di oxide penetrates to the concrete and formed calcium carbonate, hence the carbonation rate is slower. And if the concrete is cured in dried conditions the hydration of cement will be slower and carbon di oxide penetration rate will be increase and formation of calcium carbonate will be higher, hence the rate of carbonation is higher in this condition (Neville, 1995).

Time of curing of concrete before exposed to carbonation environment plays an important role in the rate of carbonation, because the longer the curing time before testing the less the rate in carbonation since greater micro structure are formed in the hydration that inhibit the gas diffusions(Neville, 1995).

Curing period effects carbonation depth, curing of concrete for 7 days reduce carbonation depth by 50%, there is conclusion that, extending water curing time from 7 days to 14 days show merging resistance of concrete to carbonation, experiment showed that 1 day and 3 days water curing of concrete produce higher carbonation depth than that of 28 days curing period (Abdelaziz, 1997).

Cover of concrete give vital role in the prevention of carbonation of reinforced concrete, the carbonation induced corrosion of embedded reinforcement bars starts when the distance between bars and un-carbonated front is less than 5mm (Yoon et al, 2007).

2.4 Methods of Measuring Carbonation

Several methods are available for the carbonation depth determination whether in the field or in the laboratory, these methods include; the phenolphthalein indicator test, the optical microscopic test and The Fourier-transform Infrared Spectroscopic (FT-IR) method.

2.4.1 The phenolphthalein indicator test

Phenolphthalein indicator use in measuring carbonation depth is a standard solution of 1g of phenolphthalein dissolved in 50ml of alcohol and diluted to 100ml with de-ionized water or 1% phenolphthalein in 70% ethyl alcohol (Neville, 2003).

In order to determine carbonation on concrete using this method, the concrete cubes are broken using hammer or by hand saw, then a Phenolphthalein indicator solution is applied to a fresh fracture (broken) surface of concrete or mortar. If the indicator turns purple, the pH of the concrete or mortar is above 8.6 showing no carbonation. When the solution remains colorless the pH is below 8.6 showing carbonation.

Normal concrete pore solution is always saturated with calcium hydroxide also potassium and sodium hydroxide, which the pH is typically 13-14.

Concrete with pore solution pH of 10-12 is less alkaline than sound concrete but it still produce a strong color change using phenolphthalein indicator. So using indicator test is likely to underestimate the depth to which carbonation occurred. In verification of this, microscopy- either optical microscopy using thin sections or scanning electron microscopy shows carbonation effects at greater depths than indicated by phenolphthalein indicator. However, this test is very useful as a way of making an initial measurement and it is easy, quick and widely used. Below is Figure 2.3, are pictures showing typical fresh broken carbonated concrete with a phenolphthalein indicator applied to them. The purple colour portion is a region where there is no carbonation while the colourless portion is the region where the concrete is carbonated (Houst and Wittmann, 2002).

2.4.1.1 Variations

Carbonation depth will be found to vary at difference surfaces of concrete, less carbonation depth will be found on the concrete surface that are exposed to rain water and greater depth may be found on the sheltered surfaces (Houst and Wittmann, 2002).

2.4.1.2 Limitations

Application of phenolphthalein to concrete measures pH only not the extent of the carbonation, this method only show the area that is fully carbonated and area that is partially altered by reduction in pH. To know the extent of carbonation other methods of testing carbonation like optical microscopic test and The Fourier-transform Infrared Spectroscopic (FT-IR) methods are to be used

Below in Figure 2.3 is example of carbonated concretes which phenolphthalein indicator solution was applied to their afresh broken surfaces.

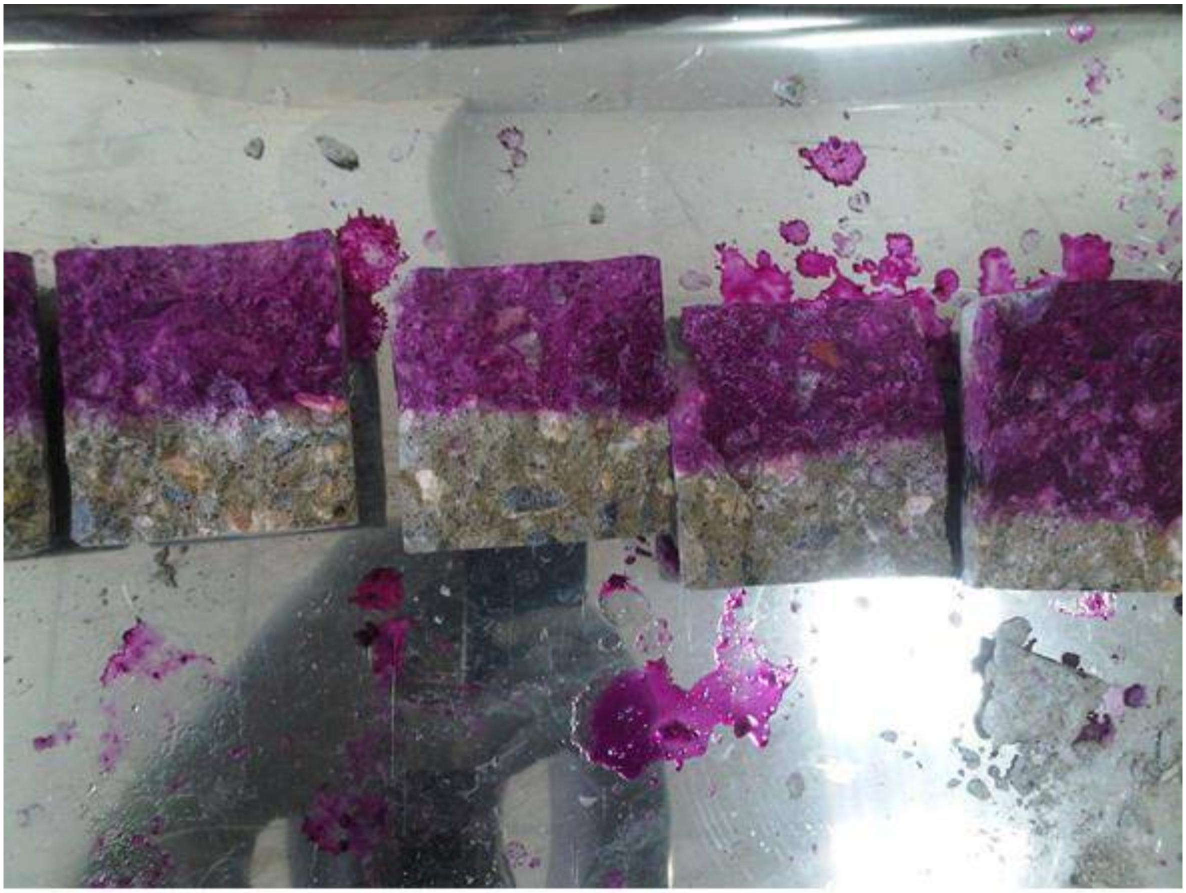


Figure 2.3: Phenolphthalein Indicator Applied to Carbonated Concrete

2.4.2 The Optical microscopic test

In this method the carbonation is determine by using microscope by identifying the calcite crystals in the concrete with the absence of portlandite in it, also identifying non-hydrated grains of cement and ettringite as shown in the Figure 2.4 below (Rostami et al, 2012), The picture is showing carbonated area with a crystal by the aide of optical microscope.

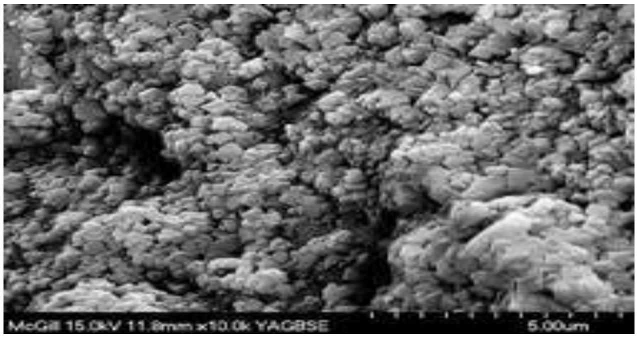


Figure 2.4: Carbonated Area with a Crystal by the Aide of Optical Microscope (Rostami et al, 2012)

2.5 Prevention and Rehabilitation to Carbonation

2.5.1 Prevention

Many methods of prevention or minimizing carbonation on concrete are available, some methods of prevention are explained below

1. The concrete mix should be made with optimum cement content with a low water cement ratio which will results in producing hardened concrete with low porosity that prevent gaseous CO_2 to penetrate in to the concrete and cause carbonation. Producing concrete with low water to cement ratio reduces concrete pores which are formed as a results of escaping and evaporation of excess amount of water in a concrete added during mix, these pore are linked together through the mass of the concrete, to produced durable concrete these pores has to be minimised.
2. Producing concrete with denser micro structure, this is achieve by adding supplementary cementitious materials like GGBSC, Fly ash, Silica fume, Fillers to the concrete mix to replace cement. Care has to be taken when supplementary cementitious materials are added because there is need for extra curing of the concrete for hydration of cement to occur on time in order to achieve desired strength.

   When concrete with denser micro structure is formed it become less permeable so ingression of CO_2 in to the concrete will be difficult, concrete will take long time without any risk of concrete carbonation that causes carbonation induced reinforcement corrosion.

3. An adequate concrete cover for the concrete protects embedded reinforcement bars from the attack of CO_2 gas, because it will take longer time for the harmful gasses and water to reach the level that will break the passivity of the concrete. The carbonation products that neutralise the concrete pH will take more time to carbonate concrete up to level of the reinforcement bars. This will increase the durability of the concrete structure for a longer service life.
4. Using protective coatings or sealers like siloxane and silane reduce permeability of the concrete and prevent the ingression of CO_2 and other harmful chemicals in to concrete structure causing problems like carbonation that induce corrosion which reduce the strength and durability of the structure

2.5.2 Rehabilitation

When the passivation layer of the reinforced concrete is broken carbonation occur and reinforcement became front to corrosion, application of coatings or sealants to the concrete will not be enough since it will not stop the corrosion process inside the concrete, the only way to stop the problem is by removing the carbonated area and corroded steel then replace it with coated steel and new concrete cover. For a placed with a high damage of the concrete with high cracks and spalling the cost of repair will be high, the best way is to demolished the structure and make another one.

2.6 Previous Studies

In their research (Haque and Al-Khaiat, 1997) reported after studying 50 buildings in state of Kuwait that, coastal buildings carbonated more than the near coastal and inland buildings which is as a result of high humidity that is favorable to carbonation at the coast this statement was not supported by (Fookes, 1995.) " In hot dry environments carbonation penetrates at about 1mm per year depending on the concrete, it may be less in wetter situation an little more in in dry situation, as we know costal buildings are wetter than near coastal and inland buildings" (Haque and Al-Khaiat, 1997).

They also computed the values of carbonation coefficients **B**, which can be used to predict carbonation of concrete of a given properties in some years. They recommended that in a severe environment like Kuwait (high temperature, fluctuating humidity) building should be made with concrete with 30Mpa to 50Mpa for it to take longer service life (Haque and Al-Khaiat, 1997).

In their research (Al-Khaiat et al, 2002) by exposing different mixes of concretes to Kuwait natural environmental conditions 8.6 years, confirmed that carbonation coefficient (K) increase with an increase in w/c ratio, K values ranged from 2.1 to 7.8 as the water cement ratio increased from 0.45 to 0.8, increase in carbonation is as a result of the increase in the pores of the concrete which lead to the less compressive strength and increase of the CO_2 ingress to the concrete, they reported that w/c ratio is the main parameter effecting the rate of carbonation (K) in concrete. Also 6 days water curing was found necessary and adequate to lower the carbonation depth comparable to 13 or even 27 days of water curing. Carbonation depth depend upon the type of cement, concrete made white Portland cement showed least carbonation depth which I think is due to the presence of limestone ($CaCO_3$) in the cement, so less amount of $Ca(OH)_2$ to react with dissolved CO_2 in the concrete, followed by ordinary Portland cement concrete while sulphate resistance cement concrete found to have highest carbonation depth which I think is due to less C_3A in the cement that form denser micro-structure (Al-Khaiat et al, 2002).

Chang and Chen (2006) studied the extent of carbonation and depth on concrete at 23°C, 70% RH and 20% CO_2 environmental conditions for 8 and 16 weeks, reported using (X-ray diffraction analytical) XDM that as the carbonation increases more $CaCO_3$ developed and less $Ca(OH)_2$ in the concrete, this prove that carbonation is removing $Ca(OH)_2$ mix decreasing its pH, Also depth of carbonation measured using(Thermogravimetric analysis) TGA method is twice that measured using phenolphthalein indicator, showing that the indicator show only some extent of concrete carbonation,

They reported that carbonation was measured in 3 different region that is fully carbonated layer of degree greater than 50% with pH less than 7.5, partially carbonated of degree 0% to 50% with pH between 9.0 to 11.5 and non-carbonated region where no carbonation detected.

Namagga and Atadero (2011) reported that, previous studies done proved an improvement in the impermeability of concrete by the optimum use of fly-ash in concrete, there is reduction in the effects of harmful chemicals in a concrete which causes its deterioration. In his thesis, Burden studied the effects of curing on the carbonation and permeability of high volumes of Class C and Class F fly-ashes, and discovered that the rate of carbonation increased and permeability decreased over time with an increment in the amount of fly-ash used (Namagga and Atadero, 2011) They suggested that carbonation-induced corrosion could be offset by extending the moist curing time and increasing the concrete cover (Namagga and Atadero, 2011).

When not exposed to any chemical environment, fly-ash concrete serves as a very durable material since its water permeability and void content are reduced with an increase in fly-ash used. This is due to the pore refinement that is provided by the fineness of the fly-ash. The fly-ash concrete matrix is also able to reduce the permeability to chlorides, sulfates and carbon dioxide penetration in concrete, hence reducing corrosion of reinforcement bars embedded within and improving the durability of the concrete (Namagga and Atadero, 2011).

Rostami et al (2012) Studied cement paste subjected to carbonation at 25^{o}C, 60% relative humidity and 95% CO_2 for two hours after initial setting of 18 hrs in order to understand the behavior of concrete subjected to the same process (early aged) carbonation Rostami et al (2012).

They reported that, natural carbonation of ordinary Portland cement for hundred days after 28 day hydration, only lower the Ca/Si of C-S-H this is due to lower percentage of CO_2 in the atmosphere but using the same sample with 10% (100% pure) CO_2 removed CSH completely showing that concrete in an area with higher CO_2 concentration like cities, tunnels etc. will be more vulnerable to carbonation induce reinforcement corrosion,. Also reported that, the early carbonation behavior of cement paste was characterized by strength gain and it does not hinder the subsequent hydration of the cement paste so the cement will continue to gain strength in the presence of moisture, so early age carbonation can be at its best if the water is sprayed to regain the water loss during curing, The early age carbonation cement paste maintained its high pH showing no depassivation that causes steel corrosion, hence it can be used in making precast reinforced concrete to produce stronger and durable concrete with low permeation as a result of $CaCO_3$ solids formation.

Roy et al (1998) Studied durability of concrete under accelerated carbonation and weathering studies. They studied carbonation on 3-difeerent parts, on 3-differents parameters (humidity, grade and pore size), carbonation depth were measured using ruler after phenolphthalein indicator was sprayed on freshly broken surface of concretes.

- They reported after plotting graph of humidity and carbonation depth, carbonation depth keeps increasing from 52% relative humidity up to 75% then decrease in carbonation depth was noticed from 75% to 84% this may be as a result of blockage of the concrete pores with water at high relative humidity. Larger depth of carbonation was found on concrete with low grade (low compressive strength) and higher w/c ratio.
- Carbonation depth in accelerated carbonated concrete is higher than that of natural carbonated concrete, this is as a result of high volume of CO_2 gas of 6% in the chamber which much higher than that in the atmosphere (0.03%), Also the smaller the pore size of concrete the less carbonation depth, by decreasing the movement of CO_2 gas through the concrete (Roy et al, 1998).

Sheng et al (2009) in their research titled Influence of Mineral Admixtures on Compressive Strength, Gas Permeability and Carbonation of High Performance Concrete under 20^{o}C, 75% relative humidity conditions for 14, 28 and 56 days, reported that, 30% and 15% is the optimum amount replacement for fly-ash and GGBFC respectively, the compressive strength starts to decrease at this amounts, the effect is higher on concrete with higher w/b ratio and is much greater on concrete with fly-ash than that containing GGBFC this is due to use of finer GGBFC than fly-ash the experiment, resulting in pozzolanic action of GGBFC greater than fly-ash mineral admixture, also higher compressive strength was observed on concrete with longer curing periods showing that the pozzolanic activity in concrete is slow and faster in the presence of moisture (Sheng et al, 2009).

When blended cement containing slag with the replacement less than 50% with 0.03% CO_2 there is no increase or only marginal increase in carbonation will be observe, this occurs when there is well curing of the concrete, but with higher percentage or less curing the depth of carbonation will be higher, for sulphate resistance cement 50% increase of carbonation observe compare to ordinary Portland cement (Neville, 1995).

The is no general agreement on the effect of fly-ash on concrete carbonation (Atis, 2003) it was reported that the higher carbonation rate was found on concrete with 70% replacement with fly-ash than 50% fly-ash and natural Portland cement which is for both moist and dry curing conditions. So they reported that fly-ash replacement should not exceed 50% to produce concrete with low carbonation potential. Also long initial curing condition reduces carbonation depth on concrete and also moist curing condition shows less carbonation than dry curing (Chi et al, 2002), this is as a result of reaction of silica in the fly-ash with the $Ca(OH)_2$ product of cement hydration. Also the blended cement have low content of $Ca(OH)_2$ so small amount of CO_2 gas is required to remove all $Ca(OH)_2$ resulting in increase in carbonation (Neville, 1995).

But pozzolanic reaction of silica with $Ca(OH)_2$ produces denser micro structure which reduces the diffusivity of concrete, hence carbonation decreases, but which is dominant , its depend on the curing of concrete since pozzolanic activity is slow and occurs in moist condition so good curing is required for concrete with fly-ash (Atis, 2003).

Below in Figure 2.5a, 2.5b and 2.5c are some pictures of carbonated induced corrosion concretes taken in Nicosia, Cyprus.

Figure 2.5 a: Reinforced Concrete Corrosion Expected Due to Carbonation

Figure2.5 b: Reinforced Concrete Corrosion Expected Due to Carbonation

Figure 2.5 c: Reinforced Concrete Corrosion Expected Due to Carbonation

2.7 Characteristics of Cyprus Environment

2.7.1 Topography

The island named Cyprus covered 9251km^2 and is the 3rd largest island in the Mediterranean Sea also the largest in the in the region of eastern Mediterranean. The north part of the island covers 3299km^2. The island geographically located between junction of African, European and Asian continents. The island possessed three different features stretched mostly in east direction, they are; The Kyrenia range, the troodos range and the Meaoria plane. The largest among is Trodos range with the height of 1951 meters, by location is at the central south of the island followed by Kyrenia range with height of 1023 meters at the north of the island (Kilic, 2006).

Figure 2.6 showing map of Cyprus and plans within the Island (Kilic, 2006).

Cyprus have Mediterranean climate with a semi-arid and arid character and seasonal pattern strongly marked with respect of rainfall, temperature and weather generally. It have hot and dry summers from mid-May up to mid-September and rainy. Winter starts from November to mid-March which is separated by short autumn and spring seasons of rapid change in weather conditions. It is at latitude 35^o North and longitude 33^o east, day length change from 9.8 hours in the month of December to 14.5 hours in the month of June (Metrological Service, 2014).

Table 2.1 below shows geographical characteristics of North Cyprus.

Figure 2.6: Showing the Map of Cyprus Island (Kilic, 2006)

Table 2.1: Geographical Characteristics of North Cyprus

Name	Turkish Republic of Northern Cyprus
Capital	Nicosia
Area	Total area of the island: 9251km^2 Northern Cyprus: 3299km^2
Climate	Temperate; Mediterranean with hot, dry summers and cool winters.
Location	Middle east, Island in the Mediterranean sea, south of Turkey.
Geographic coordinates	35 00 N, 33 00 E
Coastline	648km
Terrain	Central plain with mountains to north and south, scattered but significant plains along south coast
Elevation extremes	Lowest point: 0m Mediterranean sea Highest point: 1951m Olympus.

2.7.2 Temperature and Humidity

The Cyprus climate is regarded as highly aggressive for concrete durability due to the hot and humid salt loaded condition favorable for concrete deteriorations such as carbonation. The Island experiences very long summer extended from mid-May to mid-September with the temperature ranging from 25^{o}C to 37^{o}C (Metrological Service, 2014) with a wide fluctuation in the day and night temperature. Radiation increases the temperature resulting in increased in concrete temperature. This intense heat during summer period may create difficulties in producing high quality concrete. It was recorded that from 1976 to 1998 an average temperature increase of 0.035°C in towns, and 0.015°C in rural areas (Metrological Service, 2014), this increases in temperature may leads to the condition that may favor concrete carbonation within coming years.

The humidity on the Cyprus coastal area continuously supplies concrete structures moisture required for carbonation that leads to corrosion of reinforcements. Relative humidity varies approximately between 65% to 95% during winter and 30% to 15% during summer and an average annual relative humidity of 61.7%, Tables in appendix i shows the Maximum, Minimum and annual relative humidity in Girne and Nicosia, Cyprus. From 1960 to 2006 (Abu Dagga, 2009).

2.7.3 Precipitation

There is low precipitation in the region as a result of decrease in precipitation in the region. The decrease in the quantity of precipitation was notable. 559 mm was the average annual precipitation in the first 30-year period of the century, and the average precipitation in the last 30-year period was 462 mm, this amount corresponds to a decrease of 17%. It is recorded that, the rate of decrease of the average precipitation in Cyprus during the 20th century and at the beginning of the 21st was 1.0 millimeter in a year (Metrological Service, 2014).

The low precipitation rate in Cyprus combined with the high rate of evaporation, increases in possibilities of salts accumulations on concrete surfaces, ground water and even the soil that covers concrete foundations, are the factors contributing to the deterioration of concrete, with these factors, small amount of CO_2 may cause carbonation and the salts may speed the process of corrosion in reinforcement bars of concrete structure, Tables in appendix i shows the Maximum, Minimum and annual average rainfall in Girne and Nicosia, Cyprus. From 1960 to 2006 (Abu Dagga, 2009).

Concentration of carbon dioxide in the atmosphere is increasing due to the release of gases from automobiles and industries, in a global scale concentration of CO_2 gas in the air is increasing by 0.5% each year and the condition is more critical in cities than rural areas. Figure

3.6 is showing increase in atmospheric CO_2 concentration on a global scale. In 125 years concentration of CO_2 gas in the air increased from 280ppm to 360ppm (Yoon et al, 2007).

The effect of CO_2 on concrete have greater effect on concrete with high water to cement ratio, therefore less water cement ratio is to be used in constructions since the concentration of CO_2 gas is increasing in the atmosphere.

In Cyprus, increase of atmospheric CO_2 is because of large number use of air conditioners as a both cooling and heating system, also burning of fossils fuels in the generation of electricity, these human activities releases large amount of CO_2 which is dangerous to both human and reinforced concrete structures (Azizian, 2008). The demand of electricity in north Cyprus is increasing by the increase of population in the island most of which are tourist and students so there is increase in burning of fuels to reach the demand.

Released of CO_2 gas remains dangerous to the buildings for a very long period of time, because the gas remains in the atmosphere for a period ranging from 50 years to 200 years.

The Figure 2.7 below shows the emission of CO_2 due to burning of fossils-fuels in Cyprus.

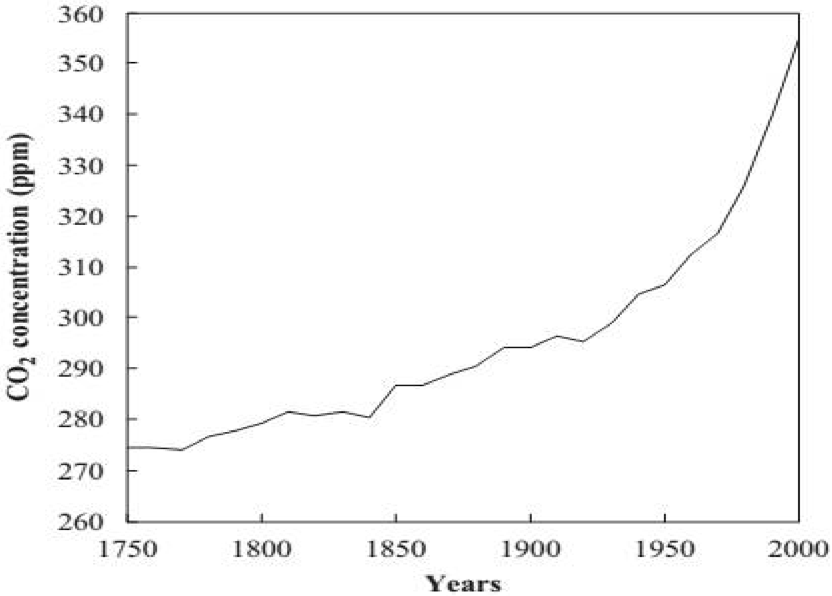


Figure 2.7: Change in Atmospheric CO_2 in a Global Scale (Yoon et al, 2007)

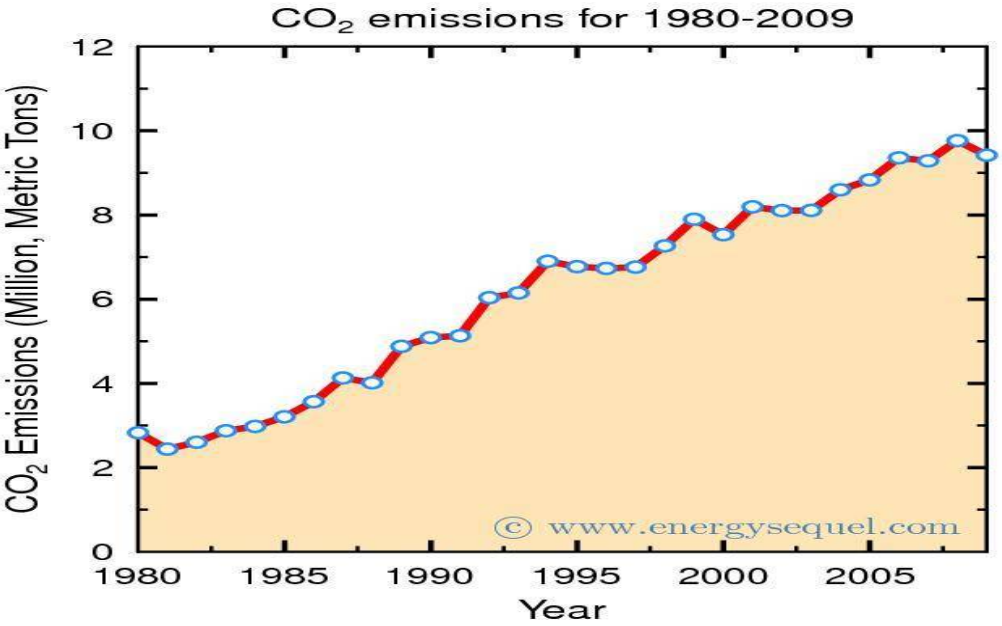


Figure 2.8: Cyprus Fossil Fuel Carbon Dioxide Emissions, for years 1980 to 2009 (Yoon et al, 2007)

2.7.4 Wind

The predominant direction of wind in eastern Mediterranean are westerly or southwesterly in winter and northerly in summer. It is of light weight and moderate strength. Over the island of Cyprus wind is variable in direction. There is difference in temperature between land and sea breeze, this is marked near the costs which penetrate far inland in summer and even reaching the capital of Nicosia and causes increase humidity which that may be favorable to concrete carbonation (Metrological Service, 2014)

Annual mean speed of wind of Cyprus is stated below (Michaelides, 2012);

- Coastal areas: mainly the southwest, south and southeast, are more windy than the plain inland areas with an annual mean speed of 4 to 5 m/s
- 0 Various mountainous areas have an annual mean wind speed of 4 to 5 m/s

- Semi mountainous areas near the coasts have an annual mean wind speed of 4 to 5m/s
- Isolated mountainous peaks present an annual mean wind speed of more than 6m/s

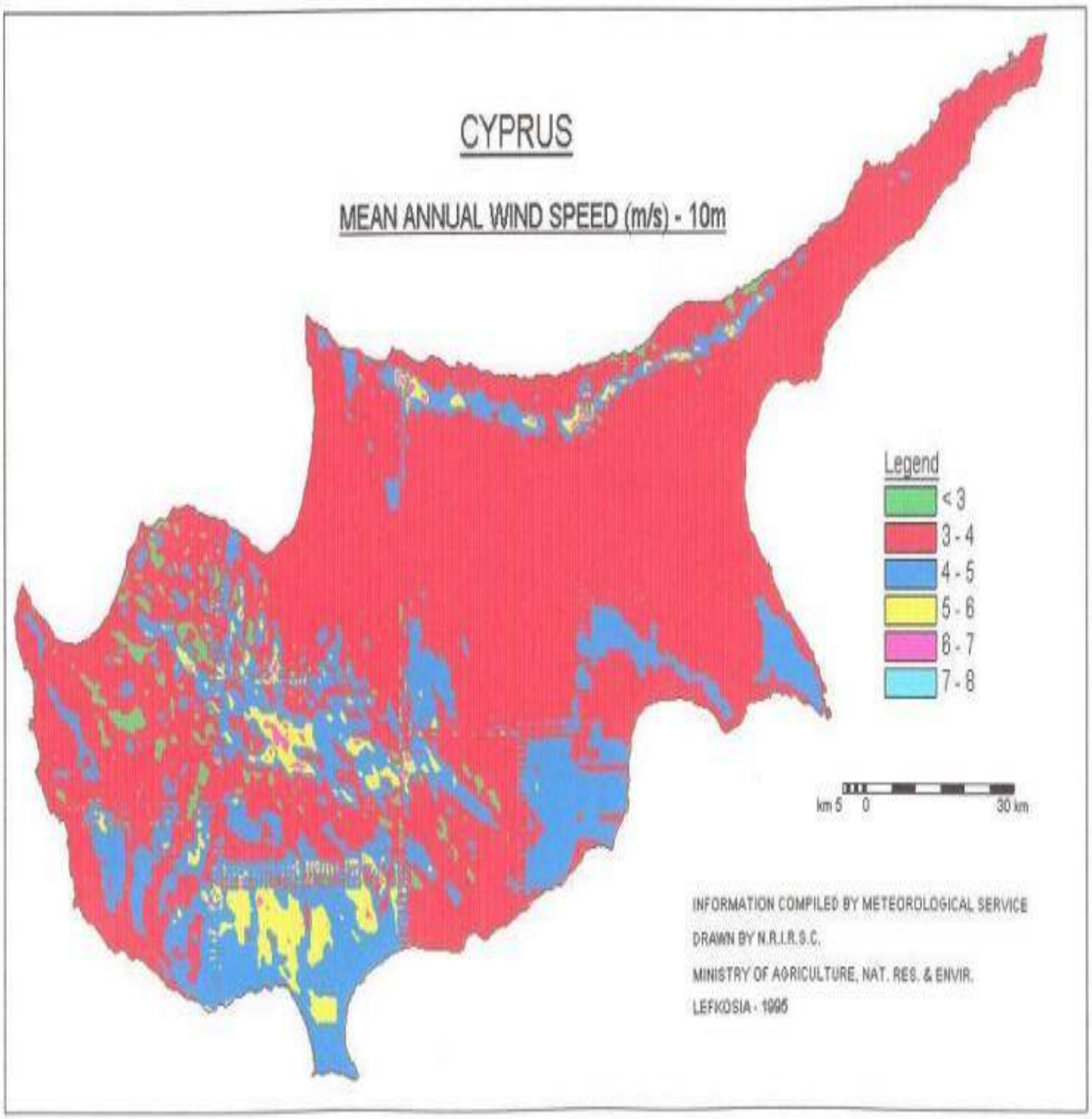


Figure 2.9: Wind Potential map – Data of Cyprus 1985-1992 (Michaelides, 2012)

Some of the effects of environmental conditions on concrete durability are summarized in Table 2.2, below (Al-Gahtani and Maslehuddin, 2002).

Table 2.2: The Effects of Climatic Condition on Concrete

CLIMATIC CONDITIONS	EFFECTS ON CONCRETE
High temperature	Plastic shrinkage cracks;
Fluctuation of temperature	Drying shrinkage cracks;
High salt-laden humidity	Rapid slump loss and high water/cement ratios;
Hot and dry-dusty winds from inland	
Low precipitation and high evaporation rate	Low strength and durability properties;
	Thermal and moisture cracking;
	Salt deposits on concrete surfaces.

2.8 Current Status of Existing Structures in Cyprus

2.8.1 Weather

Cyprus weather is a Mediterranean weather that is associated with a hot summer and a cold winter which favorable to most concrete durability problems that causes concrete degradation and in the Cyprus Island there is high wind blowing with a carrying salt from sea and a high solar radiation with high temperature especially during summer. Temperature fluctuation is one of the characteristics of Cyprus Island with a high temperature around $40^{o}C$ during summer and low temperature around 5ºC during winter, relative humidity ranging between 15% and 95% all over the island (Metrological Service, 2014).

Structures made up concrete in this island are likely to experience durability problems due to aggressive behavior of the environment and the temperature is increasing due to global warming.

Hot weather during summer affects hydration of cements; when the temperature of the cement during construction rises hardened concrete does not reach the required strength, there is also risk of plastic shrinkage to the structures due to cycles in the environmental condition, presence of high temperature with low relative humidity and low temperature with high relative humidity that are capable to increase the speed of concrete durability problems like carbonation.

The island is surrounded by Mediterranean Sea that supply salts carrying by blowing wind from the sea. The high rate of evaporation causes cracks that give room to the ingression of salts, carbon dioxide in to the structures.

2.8.2 Ground Conditions

Most of buildings in the Cyprus island are built on clay soil, because more than half of the island is covered by clay, the clay contains high amount of calcium carbonate, the types of clay is of high and intermediate swelling potentials (Kilic, 2006), these properties is very dangerous to concrete structures in the island, swelling of clay soil lead to the differential (non-uniform) settlement of structural foundations, when this happened on buildings foundation, cracks occurs on the structures which serve as a passage to harmful gaseous species and other chemical to ingress in to concrete. Within the island there are presence of damages on both buildings and highways due to swelling of the clays soil (Kilic, 2006).

The city of Nicosia is covered by a deposited clayey soil which is very poor in terms of bearing capacity.

The swelling clays over the island are divided in to five different types, Table 2.3 below shows the clay types in Cyprus and their swelling potentials.

Table 2.3: Clay Types in Cyprus and Their Swelling Potentials

Clays	Swelling potentials
Nicosia Formation	High – Extreme high
Kythrea Group	Intermediate – High
Mamonia Complex	Intermediate - Extreme high
Bentonitic	High – Extreme high
Alluvium	Low - Extreme high

2.8.3 Type of Structures Exposure Conditions

1. Based on Degree of Threat to Concrete

This is according to classification in BS 8110 part 1:1985 as shown Table 2.4 below.

Table 2.4: Classification of structure according to their exposure BS 8110 Part 1:1985.

EXPOSURE	DESCRIPTION
Mild	Structures that are protected from harsh condition except for a brief period of exposure to normal weather condition during constructions
Moderate	Structures submerged in water, sheltered from rains, salt spray and heavy winds, structures exposed to dry winds and underground structures.
Severe	Structures exposed to spray of abrasive actions of sea water, alternate wetting and drying, structures exposed to corrosive fumes and industrial areas, underground structures.

2. Classification Based on the Proximity to Sea

Previously a research was conducted by (Haque and Al-Khaiat, 1997) on the 50 building in Kuwait and buildings are classified in to coastal structures (0-2km), near coastal structures (2-10km) and inland structures (>10km) according to their distances from the sea and conclusion was made on how distance affect the durability of structures. It's using their method that we get useful information and distinction of between conditions of inland and coastal area structures used in this thesis.

2.8.4 Construction Problem

In previous ages reinforced concrete structures are built using old construction methods, this method affects the quality of the concrete, made them vulnerable to durability problem

2.9 Construction Materials in North Cyprus

2.9.1 Cements:

In north Cyprus there are different type cements available in the market prepared by engineers to meet the needs that might appear regarding the conditions of the Island. The use of these cements in TRNC is because, there is a need of producing a concrete with low permeability, concrete with less amount of C_3A for sulfate resistance and able form a denser micro structure with the adequate curing of the concrete. Due to conditions of the Cyprus environment these properties mentioned contributed in the increase of strength and durability of concrete structures in the area. Most of the cements in TRNC markets are blended cements.

2.9.1.1 Blended Cements:

Blended cements are manufactured by adding or grinding ordinary Portland cement with cementitious materials at a given proportion in order to produce cements with special properties from ordinary Portland cements.

Cementitious materials: Are materials that are as fine or less as ordinary as Portland cement that are mix with ordinary cement in a specified proportion to form blended cements. Examples of cementitious materials are; Ground granulated blast furnace slag, pozzolanas and Fillers.

Below name of these available cement in Turkish Republic of Northern Cyprus market base on market surveyed carried out in this study are mentioned and some of their characteristic and properties are explained.

1- CEMIII/A42,5N,EN197-1:2000 (Blast Furnace Slag- Sulphate Resistance Cement)
2- CEM IV/B (P) 325 R, TS-EN 197-1 (Pozzolanic Cement)
3- CEM II/B-M(S-L) 32,5R, TS-EN 197-1 (Portland Composite Cement)
4- TS 21/BPC 525R/85 (White Cement)

1- CEMIII/A42,5N,EN197-1:2000 (Blast Furnace Slag-Sulphate Resistance)

This type of cement from the name it contains ground granulated blast furnace slag (GGBFS) grinded with ordinary Portland cement. GGBFS is a waste product of industrial manufacture of pig iron, it's a mixture of silica, alumina and lime, which are the oxides that made Portland cement but at different proportions (Neville, 1995).

EN 197-1 :1992 acknowledge 3-classes of Portland blast furnace cement as follows; blast furnace cement III/A, III/B and III/C all of which the percentage of filler by their total mass should not exceed 5% with a percentages of GGBS replacement by their total mass below;

Class III/A	36% - 65% (type to use in this research)
Class III/B	66% - 80%
Class III/C	81% - 95%

The fineness of GGBFS is usually above 350m^2/kg using cement containing slag increases workability of fresh concrete, making it more mobile and cohesive with low heat generation that results in low peak temperature, also produces concrete with denser microstructure with long term strength and durability more than ordinary Portland cement due to filled spaces with calcium silicate hydrate (C-S-H) from reaction of silica (SiO_3) and calcium hydroxide ($Ca(OH)_2$) (Neville, 1995).

Neville (1995) says using GGBS in cement reduces concrete permeability of about one hundred (100) times, significant reduction in concrete diffusivity that reduces the injections of harmful chemicals to the concrete like chlorides solution, carbonic acid (HCO_3) from carbon dioxide (CO_2).

Previous studies showed that when blended cement containing slag with the replacement less than 50% with 0.03% CO_2 there is no increase or only marginal increase in carbonation was observed, this occurs when there is well curing of the concrete, but with higher percentage or less curing the depth of carbonation will be higher, for sulphate resistance cement 50% increase of carbonation observed compared to ordinary Portland cement (Neville, 1995).

2- CEM IV/B (P) 325 R, TS-EN 197-1 (Pozzolanic Cement)

This is a blended cement that content both fly-ash and silica fume with a replacement from 36% to 55% of the total mass of the Cement.

Pozzolanas: According ASTM Pozzolanas is a siliceous or siliceous and aluminous material which itself only possessed little or no cementitious value but in finely divided, in the presence of moisture and at normal temperature chemically react with calcium hydroxide ($Ca(OH)_2$ to form other compounds possessing cementitious properties and they are cheaper than the ordinary Portland cement they replace (Neville, 1995).

Use of pozzolanas in concrete increases it resistance to sulfate attack as a result of decrease of the amount C_3A in the cement, so less secondary ettringite could be formed. Pozzolanas reacts with calcium hydroxide ($Ca(OH)_2$) and form C-S-H making concrete denser, less permeable and reduce its diffusivity against harmful chemicals like CO_2, Cl and S from outside environment.

Fly ash: Fly-ash is a precipitated ash mechanically or electrostatically from the exhaust gases of coal-fired power stations. Fly ash is the most common artificial pozzolanas, it has particles that are spherical in shape which is advantage to the mix-water requirement, and it has higher fineness of 250-600m^2/kg and a diameter of 100 micro meter (Neville, 1995).

The most important property of fly ash is reducing water demand in a concrete mix which is due to spherical nature of its particles, since the less the water cement ratio the higher the strength and less permeability of the concrete.

Previous studies done showed that the utilization of fly-ash in concrete provides improves impermeability within the concrete (Burden, 2006).

Namagga and Atadero (2011) studied the effects of curing on the carbonation and permeability of high volumes of Class C and Class F fly-ashes, and discovered that the rate of carbonation increased and permeability decreased over time with an increment in the amount of fly-ash used. Then he suggested that carbonation-induced corrosion could be offset by extending the moist curing time and increasing the concrete cover.

Silica fume: Silica fume is waste product of the manufacture of silicon and ferrosilicon alloys from high purity quartz and coal. It has very high fineness of about 20000m^2/kg and a very low bulk density, these properties provide better parking effect to concrete with silica fume when it enters and full empty spaces of cement particles, and a small amount is required in mix due to its high reactivity with $Ca(OH)_2$.

Cement with silica fume produces concrete with less permeability, early strength gain, it reduces bleeding and it has less C_3A so it has high resistance to sulphate attack and less ingression of chemicals (Neville, 1995).

3- CEM II/B-M(S-L) 32,5R, TS-EN 197-1 (Portland Composite Cement)

This is a blended cement that content fly-ash, silica fume, fly ash, bunt-shale and lime stone replacement from 21% to 35% percent of the total mass of the Cement.

It possess all the properties that two other cements has.

4- TS 21/BPC 525R/85 (White Cement)

White cement is mainly used for architectural purposes. It’s made from china clay which contains little iron oxide and manganese oxide, together with chalk or limestone free from impurities, which could affect the color. Special precaution are taken during the preparation in order to avoid contamination of the cement. It has high cost which is about two times the cost of OPC (Neville, 1995).

In appendix ii is a table showing cements compositions stated by European Standard EN 197-1

2.9.2 Aggregates

Concrete mixture contains both coarse and fine aggregates. At the early time in Cyprus sand and gravels from deposits of river and marine are used as aggregates in making concrete.

The origin of the rivers are from Trodos Mountains. After long time using this aggregates, they are found not suitable for concrete production due to their chemical and physical characteristics, because they have the ability to reacts with hydration products and other substances and cause durability problems. So using these natural aggregate is regulated within the Cyprus.

Suitable aggregate for use in Cyprus is crushed limestone from Pentadakytols range in north Cyprus region, this type of aggregate is very good in production of concrete in the island due to it mechanical and physical properties.

Fine aggregate (sand) is from Nicosia and Athalassa formation from calcite formation of the area, the sand is ready for concrete, after it is collected by digging pits, crushing the limestone and washed.

CHAPTER THREE
MATERIALS AND METHODOLOGY

3.1 Methodology

3.1.1 Survey of the Existing Structures in Nicosia

An independent random observation was carried out in this research on concrete buildings within Nicosia in which damages that are relevant to carbonation exists on existing structures everywhere in the city. Figure 2.5a-2.5c are pictures showing some damages exists on some buildings within Nicosia.

Concrete cores used in this study were extracted from different existing buildings surveyed by the Chamber of Civil Engineering (KTİMO) laboratory, Nicosia.

Eight (8) reinforced concrete structures are surveyed within TRNC in which five of them are from Nicosia (Inland) area and other three from Girne (Coastal) area, ages of the structures at the time of the study are recorded.

Most of the studied structures are constructed between 1980 and 2010, they are built using the available construction materials in North Cyprus.

Majority of detected problems found on the structures observed within some parts of North Cyprus are; presence of cracks, spalling and corrosion of reinforcement. There are presence of efflorescent on the structures especially at the affected areas of the structures, some of the affected areas of the buildings which random observation was carried out with the relevant damages are shown on Figure 2.5 even though they are not the structures which concrete core samples are extracted and used in the study.

The locations of the surveyed structures and their positions (A and B) from Mediterranean Sea are shown in Figure 3.1 below.

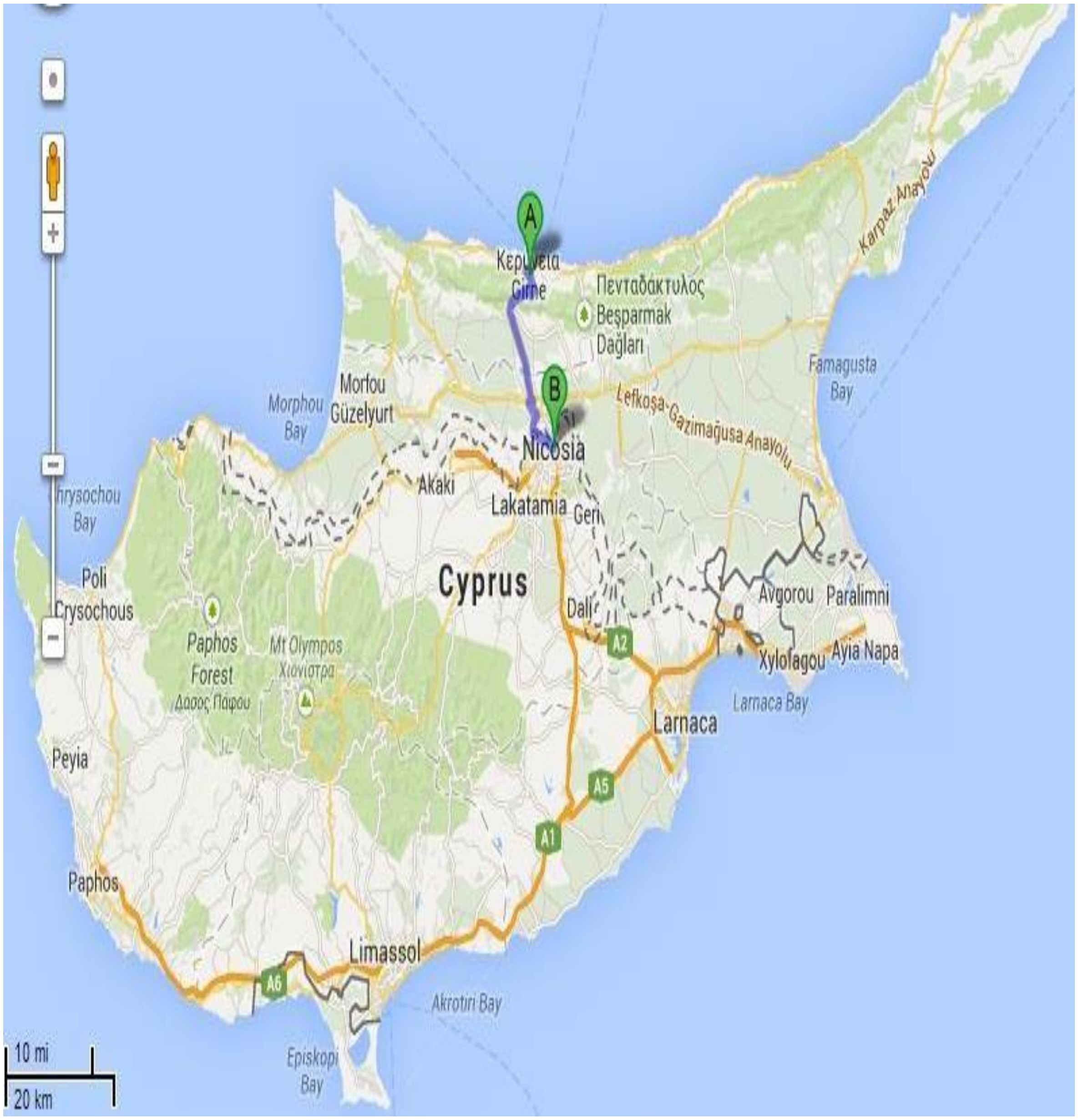


Figure 3.1: Picture Showing Location of the Surveyed Structures in North Cyprus

3.1.2 Method of Testing

From the structures surveyed cores of 65mm diameter and 70mm height were extracted from walls and columns by the Chamber of Civil Engineering (KTİMO) laboratory, Nicosia. These cores can be extracted from exposed and un-painted members of the buildings, some core samples extracted are shown in Figure 3.2.

Method adopted in the extractions of cores is according to TS-EN 12504. Cores can be extracted horizontally from walls and columns (perpendicular to the direction of casting of the concrete).

After samples are extracted from existing buildings by the Civil Engineering Chamber (KTİMO) Laboratory, Nicosia, Compressive strength of concrete cores was determined and reported by the chamber in accordance with TS-EN 13791.

The remaining samples are delivered for further studies at the Civil Engineering laboratory of Near East University, Cyprus for the determination of carbonation depth and density of the cores.

Density of the concrete cores was determined according to TS-EN 12390-7: 2009 to know the level of the present density of the concrete at the time of the study.

Carbonation depth of the structures are assessed from the cores after it was broken by uniform spread of phenolphthalein indicator which is a mixture of 1g phenolphthalein dissolved in 50ml ethanol and diluted to 100ml with de-ionized water.

Measuring Carbonation Depth:

The phenolphthalein indicator used in the determination of carbonation depth was prepared in the laboratory using the following procedures;

- 1 gram of phenolphthalein pH indicator powder was measured using digital weighing machine.
- 50 ml of ethanol was measured using measuring cylinder
- 100 ml of de-ionized water was measured using measuring cylinder
- Measured ethanol and de-ionized water were mixed together in a glass cup.
- Phenolphthalein pH indicator powder was transferred in to the glass cup were the mixture of ethanol and de-ionized water are. The mixture was stir using string glass rod until colorless homogeneous mixture was obtained in which the phenolphthalein powder completely dissolved in the mixture.

- The mixture was transferred in to spraying can for the carbonation test.

The concrete was split in to two halve by using split tensile testing machine and some by knocking top side of the core using hammer and chisel, then mixture of phenolphthalein pH indicator was applied to each halve of the split cores using the spraying can after cleaning the split surface.

Some part of the core changed its color to purple indicating non- carbonated portion with higher pH while some part remained unchanged indicating carbonated portion with low pH.

The distance of the un-changed colored portion was measured using steel ruler in which measurements were taken at three evenly distributed positions within the unchanged portion as X_1, X_2 and X_3 as shown in Figure 3.3, averaged of these measured distances was recorded as the carbonation depth of each halve ($d = \frac{X_1 + X_2 + X_3}{3}$).

Then the average of the two halve of the core was calculated and recorded as the carbonation depth for one core sample. Then average depth of all cores from the same structure is calculated and recorded as shown in Table 4.2

Pictures of the method adopted in measuring the depth is shown in Figure 3.4. Then Figure 3.3 shows the distances measured which their average was taken.

Measuring Density:

The density of the extracted concrete core samples are measured using the procedures below;

- The original mass of the core before immersed in water was recorded as M
- The concrete cores were completely immersed in water inside container for some minutes and removed after it was saturated.
- The mass of the saturated core samples was recorded as Mass in air (M_a)
- The mass of the stirrup was recorded after it was completely immersed in water as M_s

- The saturated samples was hold using stirrup and immersed it fully in water in which the stirrup was not touching the bottom of the container and no bubbles was trapping on the surface of the core and stirrup and their mass at this condition was recorded as M_c.
- The mass of the completely immersed core was recorded as mass in water (M_w) after deducting that of immersed stirrup mass from it ($M_w = M_c – M_s$)
- Then the volume of the core was calculated using the equation 3.1 below.

$$Volume(V) = \frac{M_a - M_w}{1000} \text{ (m}^3\text{)} \qquad 3.1$$

Where 1000 is density of water in Kg/m^3.

Then the density of the core was calculated using the equation 3.2 below

$$\text{Density} = \frac{M}{V} \text{ (Kg/m}^3\text{)} \qquad 3.2$$

Figure 3.2: Sample of Drilled Cores from Existing Buildings

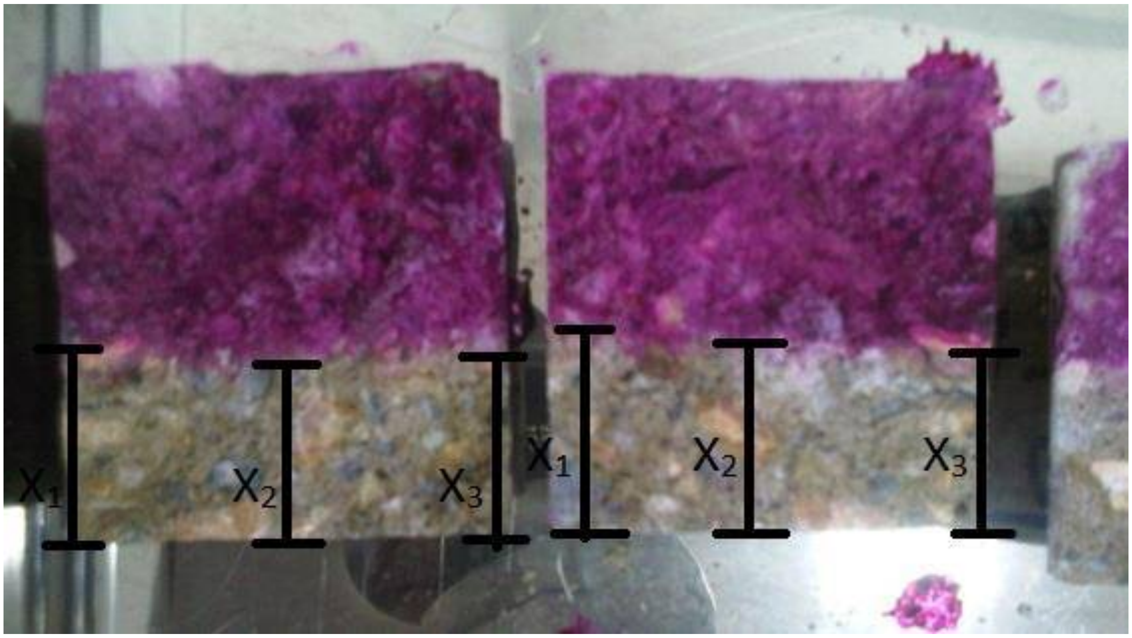


Figure 3.3: Split Samples Treated With Phenolphthalein Indicator

In this research compressive strength, density and carbonation depth of the extracted cores were discussed.

Results of the measured and calculated values are presented in Tables 4.1 - 4.5 in chapter four.

Figure 3.4: Measuring Carbonation Depth with Steel Ruler

3.1.3 Calculations Performed

Equation 3.4 is the accepted equation of measuring carbonation depth with respect to the ages of the concrete structure used in many literatures (Neville, 2003, Varjonen, 2004, Al-Khaiat et al, 2002, Neves et al, 2012, Roy et al, 1999, Houst and Wittmann, 2002 and Song et al, 2006)).

Carbonation is a diffusion process which propagates in to the concrete in accordance with the diffusion laws

Concrete carbonation penetrates in to the concrete depth according to Fick's Law which suggested that, the rate of diffusion in concrete and the distance between concrete surface and reinforcement bars (Concrete cover thickness) have inverse relationship as shown in equation 3.3 below (El-Reedy, 2010).

$$\frac{d_x}{d_t} = \frac{D_o}{x} \tag{3.3}$$

Where;

x = Distance from surface of the concrete

t = time

D_o = Diffusion rate, it depends on concrete quality

When concrete carbonated there is changes in the characteristics pore voids and reduction it base contents result in decrease in pH, due to these changes, the equation is integrated to include these changes and to deviate the values from previous law.

$$\frac{d_x}{d_t} = \frac{D_o}{x}$$

$$\frac{d_x}{d_t} x = D_o$$

$$\int x \frac{d_x}{d_t} d_t = \int D_o d_t$$

$$\frac{x^2}{2} = D_o t$$

$$x^2 = 2D_o t$$

$$x = 2\sqrt{D_o t}$$

Let B = $2\sqrt{D_o}$,

$$X = B\sqrt{t} \qquad (3.4)$$

Where; **B** is the carbonation constant that depends on the concrete quality and building exposure conditions in mm/year$^{0.5}$, **d** is the measured carbonation depth in mm and **t** is the age of the concrete in years.

Equation 3.4 above was modified and used by Sim for temperate climate (Sims, 1994), also (Haque and Al-Khaiat, 1997) used it in their study for carbonation in hot and dry environment (Kuwait)

Equation 3.5 below is the modified equation.

$$d = 10B\sqrt{t} \qquad (3.5)$$

Above equation was applied in this study to predicts future carbonation since North Cyprus have environmental conditions which are favorable to high carbonation rate (high humidity, high temperature and CO_2 gas in the atmosphere).

Using equation 3.5, the expected carbonation depth of these 8 buildings at the age of 50 years was predicted, also the expected time at which these buildings will carbonate to a depth of 25mm concrete cover was predicted, and all the values are included in Table 4.3.

3.1.3.1 Carbonation Constant of the Buildings

From equation 3.5,

$$B = \frac{d}{10\sqrt{t}} \qquad (3.6)$$

Considering structure No.1 from Table 4.2

d = 22.72mm, t = 21years

$$B_1 = \frac{22.72}{10\sqrt{21}} = 0.50\ mm/year^{-0.5}$$

Considering structure No.2 from Table 4.2

d = 39.0mm, t = 18years

$$B_2 = \frac{39.0}{10\sqrt{18}} = 0.92\ mm/year^{-0.5}$$

Similarly for the all the 8 buildings, their corresponding B values are included in Table 4.3

3.1.3.2 Predicted Carbonation depth in 50 years

Substituting t = 50 years in equation 3.3

d = 10B$\sqrt{t}$, where t = 50 years

Considering structure No.1 from Table 4.3

$$d_1 = 10 \times 0.50 \times \sqrt{50} = 35.46mm$$

Considering structure No.2 from Table 4.3

$$d_2 = 10 \times 0.92 \times \sqrt{50} = 65.05mm$$

Similarly for all the 8 buildings, their corresponding B values are included in Table 4.3

3.1.3.3 Predicted time to carbonate 25mm concrete cover

From equation 3.5

$$t = \left(\frac{d}{10B}\right)^2 \tag{3.7}$$

Where; d =25mm

Considering structure No.1 from Table 4.3

$$t = \left(\frac{25}{10 \times 0.50}\right)^2 = 25years$$

Considering structure No.2 from Table 4.3

$$t = \left(\frac{25}{10 \times 0.92}\right)^2 = 7.38years$$

Similarly for all the 8 buildings, their corresponding time to carbonate 25mm cover are included in Table 4.3.

3.1.3.4 Variation of carbonation depth and the location of buildings from the coast

For Coastal buildings (structures no. 1, 7 and 8)

Average Compressive strength of Coastal buildings = 23.81MPa

Average Carbonation depth of Coastal buildings = 20.09mm

For inland buildings (structures no. 2, 3, 4, 5 and 6)

Average Compressive of inland buildings = 23.91MPa

Average Carbonation depth of Coastal buildings = 24.30mm

The above values are presented in Table 4.4

3.1.3.5 Predicted B Values for Buildings Surveyed

MEDIUM STRENGTH (MS) 20-30MPa (structures no. 1, 4, 5, 6, 7 and 8)

Average Compressive strength =26.24MPa

Average current carbonation depth = 22.50mm

Average B = 0.52mm/yr0.5

Predicted Carbonation depth in 50 years for MS

$$d_{MS} = 10 \times 0.52 \times \sqrt{50} = 36.77mm$$

LOW STRENGTH (LS) up to 20MPa (Structures no. 2, and 3)

Average Compressive strength =16.76MPa

Average present carbonation depth = 21.56mm

Average B = 0.53mm/yr0.5

Predicted Carbonation depth in 50 years for LS

$$d_{LS} = 10 \times 0.53 \times \sqrt{50} = 37.5mm$$

Predicted B values for the concrete buildings designation are presented in Table 4.5

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

Table 4.1a: Depth of Carbonation and Strength of Cores Taken from Structure NO.1.

STRUCTURE NO. 1 Coastal	AGE (years)	REPORTED COMPRESSIVE STRENGTH (MPa)	CARBONATION DEPTH (mm)	DENSITY (Kg/m^3)
1	21	33.95	24.67	2384
2		17.49	10.67	2257
3		19.08	32.83	3095
Average		23.51	22.72	2578
Standard Deviation		9.08	11.2	451.64

Table 4.1b: Depth of Carbonation and Strength of Cores Taken from Structure NO.2.

STRUCTURE NO. 2 Inland	AGE (years)	REPORTED COMPRESSIVE STRENGTH (MPa)	CARBONATION DEPTH (mm)	DENSITY (Kg/m^3)
1[1]	18	18.93	39.0	3000

---

[1] Other two cores are totally destructed in the compressive strength tests and they were not available for the chemical analysis.

Table 4.1c: Depth of Carbonation and Strength of Cores Taken from Structure NO.3.

STRUCTURE NO. 3 Inland	**AGE (years)**	**REPORTED COMPRESSIVE STRENGTH (MPa)**	**CARBONATION DEPTH (mm)**	**DENSITY (Kg/m^3)**
1	31	14.62	5.0	3156
2		14.54	10.50	2306
Average		14.58	7.75	2731
Standard Deviation		0.07	3.89	601.04

Table 4.1d: Depth of Carbonation and Strength of Cores Taken from Structure NO.4.

STRUCTURE NO. 4 Inland	**AGE (years)**	**REPORTED COMPRESSIVE STRENGTH (MPa)**	**CARBONATION DEPTH (mm)**	**DENSITY (Kg/m^3)**
1	18	22.65	47.0	2701
2		40.40	24.3	2424
3		24.29	27.0	2352
Average		29.11	32.77	2492
Standard Deviation		9.81	12.40	184.26

Table 4.1e: Depth of Carbonation and Strength of Cores Taken from Structure NO.5.

STRUCTURE NO. 5 Inland	AGE (years)	REPORTED COMPRESSIVE STRENGTH (MPa)	CARBONATION DEPTH (mm)	DENSITY (Kg/m^3)
1	18	22.65	24.0	2401
2		34.79	23.70	2407
Average		28.72	23.85	2404
Standard Deviation		8.58	0.21	4.24

Table 4.1f: Depth of Carbonation and Strength of Cores Taken from Structure NO.6.

STRUCTURE NO. 6 Inland	AGE (years)	REPORTED COMPRESSIVE STRENGTH (MPa)	CARBONATION DEPTH (mm)	DENSITY (Kg/m^3)
1	10	21.08	26.20	2501
2		36.47	4.0	2155
3		27.01	24.16	2023
Average		28.19	18.12	2226
Standard Deviation		7.76	12.27	246.85

Table 4.1g: Depth of Carbonation and Strength of Cores Taken from Structure NO.7.

STRUCTURE NO. 7 Coastal	AGE (years)	REPORTED COMPRESSIVE STRENGTH (MPa)	CARBONATION DEPTH (mm)	DENSITY (Kg/m^3)
1	10	23.92	5.2	2500
2		17.21	25.5	2640
3		31.92	5.8	2141
4		32.35	4.8	2056
Average		26.35	10.33	2334
Standard Deviation		7.22	10.13	280.31

[2]**Table 4.1h:** Depth of Carbonation and Strength of Cores Taken from Structure NO. 8.

STRUCTURE NO. 8 Coastal	AGE (years)	REPORTED COMPRESSIVE STRENGTH (MPa)	CARBONATION DEPTH (mm)	DENSITY (Kg/m^3)
1	40	17.62	32.50	2185
2		21.66	30.34	2164
3		25.44	18.33	2300
Average		21.57	27.22	2216
Standard Deviation		3.91	7.63	73.21

---

[2] Structure No. 8 was built before 1974 but the actual age of the building is unknown , 40 years was used in the calculation that is years from 1974 to the time of the study

Table 4.2: Average Depth of Carbonation and Compressive Strength of the Buildings.

STRUCTURE NO.	LOCATION OF THE BUILDINGS	AGES (years)	AVERAGE COMPRESSIVE STRENGTH (MPa)	AVERAGE CARBONATION DEPTH (mm)	AVERAGE DENSITY (Kg/m^3)
1	Coastal	21	23.51	22.72	2384
2	Inland	18	18.93	39.0	2407
3	Inland	31	14.58	7.75	3156
4	Inland	18	29.11	32.77	2501
5	Inland	18	28.72	23.85	2500
6	Inland	10	28.19	18.12	2257
7	Coastal	10	26.35	10.33	3000
8	Coastal	40	21.57	27.22	2216

Table 4.3: Expected Carbonation in 50 years and time to Carbonate 25mm Concrete Cover.

STRUCTURE NO.	CURRENT CARBONATION DEPTH (mm)	CARBONATION CONSTANT "B" (mm/yr$^{0.5}$)	EXPECTED CARBONATION DEPTH WITHIN 50 YEARS (mm)	EXPECTED CARBONATION TIME FOR 25mm COVER (years)
1	22.72	0.50	35.46	25.0
2	39.0	0.92	65.05	7.4
3	7.75	0.14	9.90	318.9
4	32.77	0.77	54.45	10.5
5	23.85	0.56	39.60	19.9
6	18.12	0.57	40.31	19.2
7	10.33	0.33	23.33	57.4
8	27.22	0.43	30.41	33.8

Table 4.4: Variation of Carbonation Depth and Locations of Buildings from the Coast

LOCATION OF BUILDINGS FROM COAST (Km)	AVERAGE REPORTED COPRESSIVE STRENGTH (MPa)	AVERAGE CARBONATION DEPTH (mm)
Coastal Structures	23.81	20.09
Inland Structures	23.91	24.30

Table 4.5: Predicted B Values for Buildings Surveyed

CONCRETE DESIGNATION	COMPRESSIVE STRENGTH RANGE (MPa)	AVERAGE REPORTED COMPRESIVE STRENGTH (MPa)	CURRENT AVERAGE CARBORNATION DEPTH (mm)	B $(mm/yr^{0.5})$	EXPECTED CARBONATION DEPTH AFTER 50 YEARS (mm)
MEDIUM STRENGTH	20-30	26.24	22.50	0.52	36.77
LOW STRENGTH	< 20	16.76	23.38	0.53	37.5

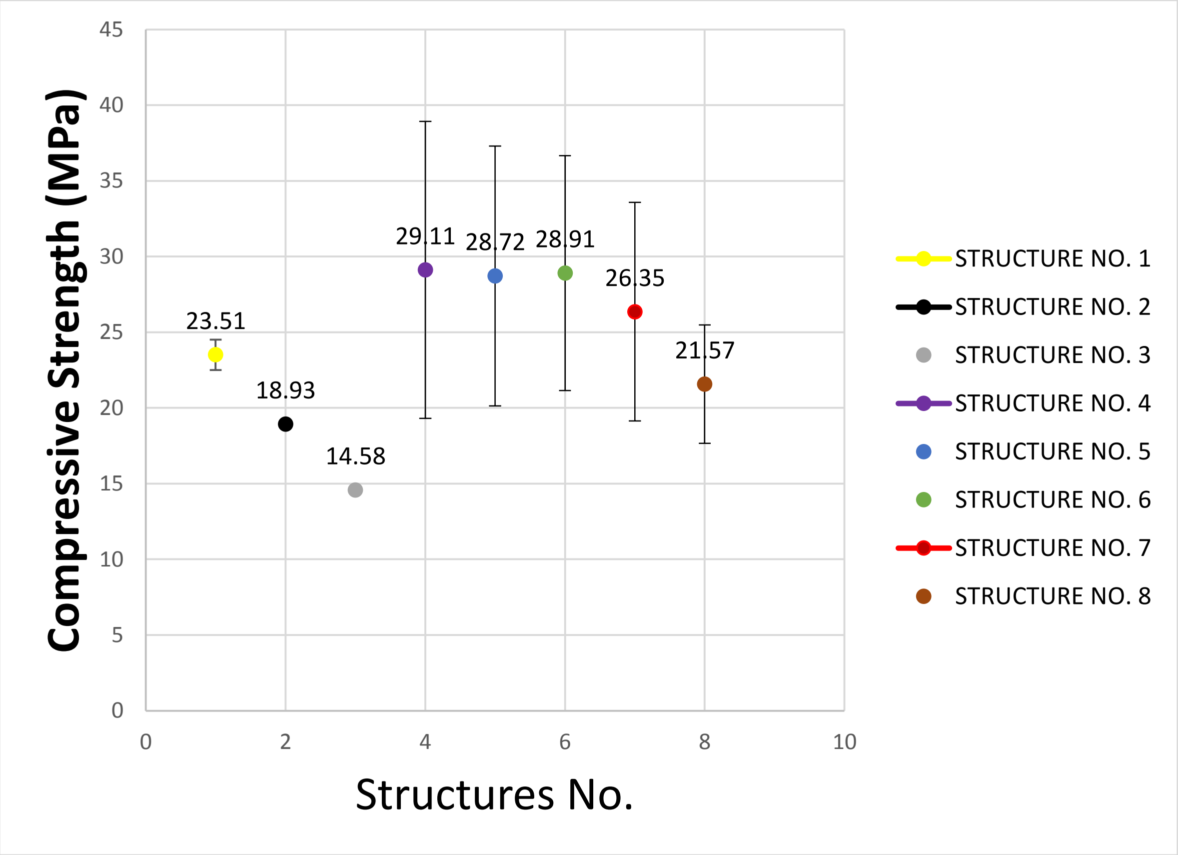


Figure 4.1: Variations in Compressive Strength of the Structures Surveyed

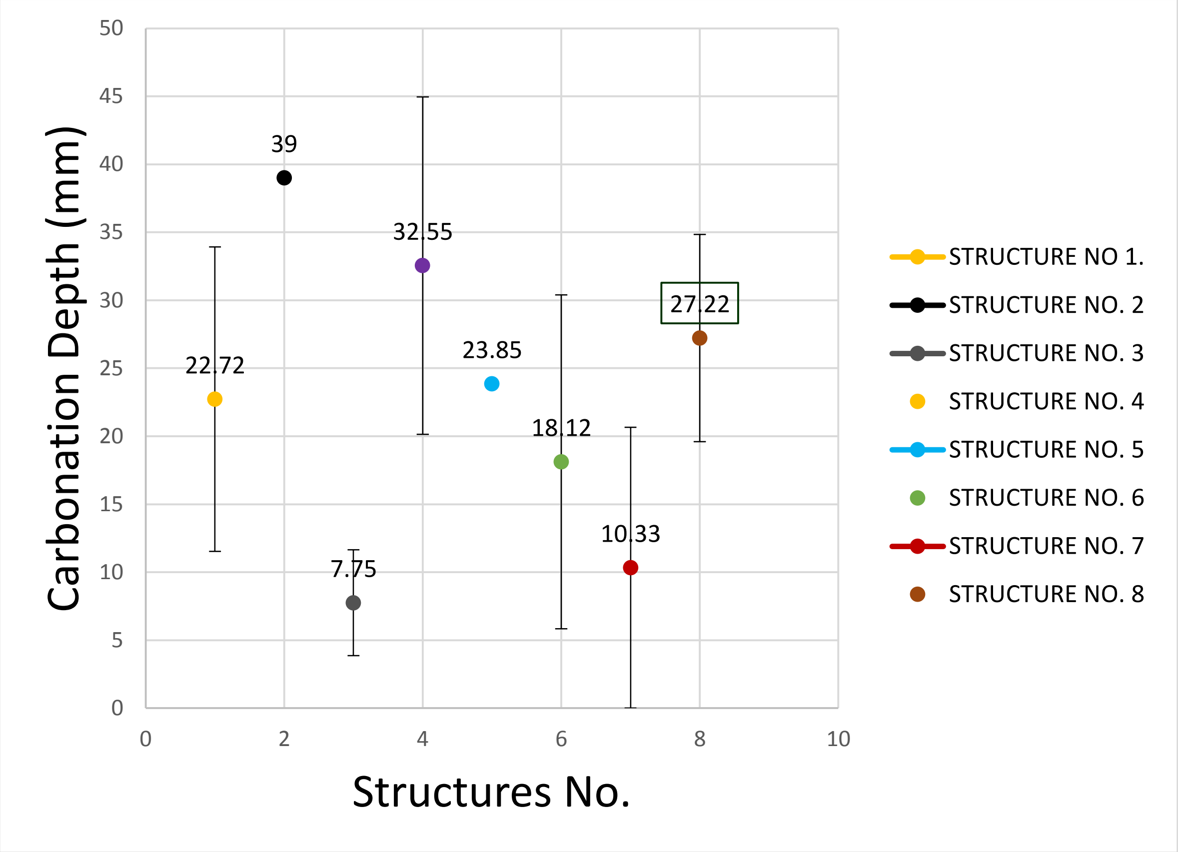


Figure 4.2: Variations of Carbonation Depth of the Structures Surveyed

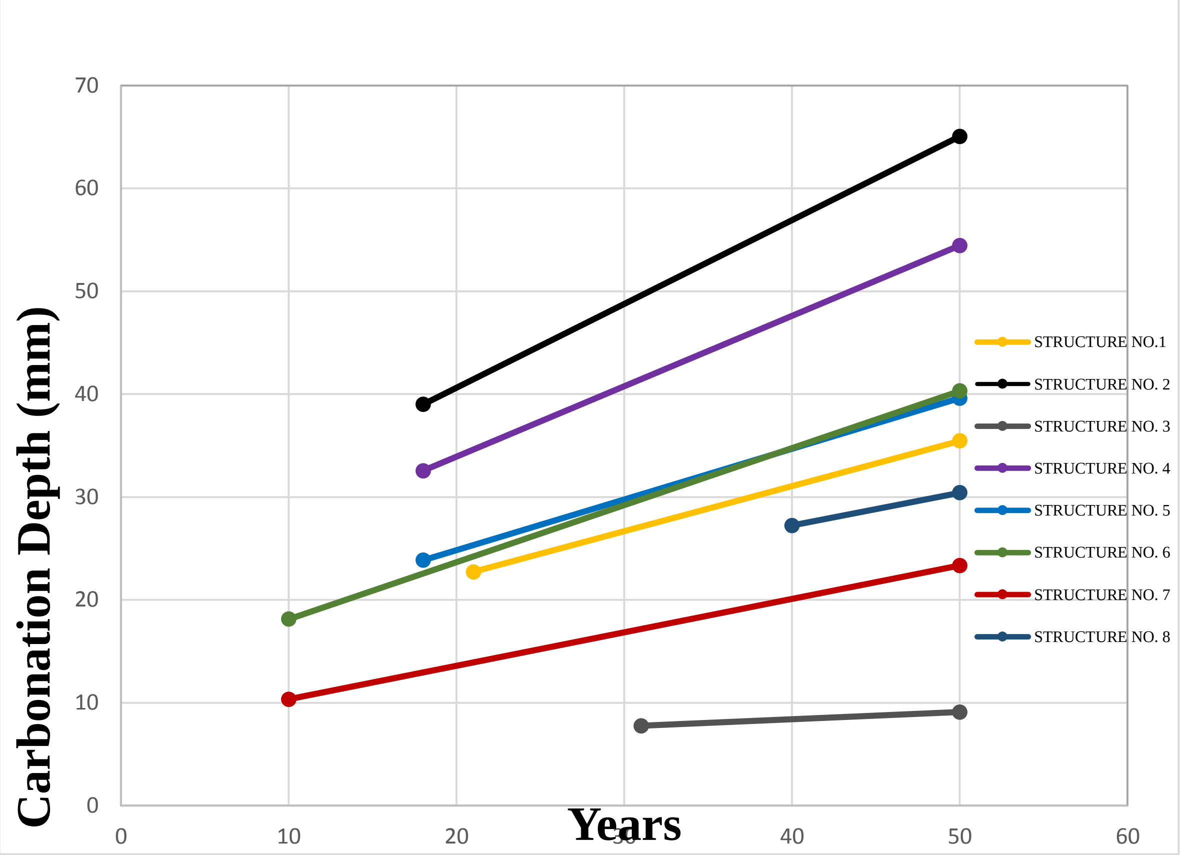


Figure 4.3: Variations of Current and 50 Years Predicted Carbonation Depth

4.2 Discussions

For easy discussion the following terminologies are used

1- Low Strength (LS): Concrete cores with strength below 20 MPa

2- Medium Strength (MS): Concrete cores with strength 20MPa to 30MPa

4.2.1 Density of the concrete

Traditionally high density is accepted to indicate a well compacted and a high quality concrete. However, in the cases where carbonation problem is detected, majority of the buildings surveyed have higher density with higher depth of carbonation, in which 2538kg/m^3 was found to be the average density of all the cores which is higher than 2400kg/m^3 density of normal weight concrete. Higher density values detected from the cores is expected to be due to deposited calcium carbonate in the concrete pores as a result concrete carbonation.

4.2.2 Compressive Strength

Concrete cores compressive strength are included in Table 4.2.

It is shown that 2 out of the eight buildings surveyed are found to have compressive strength below 20MPa, both located in inland areas, these two buildings out of eight represents 25% of the structures surveyed.

Remaining 6 of the eight buildings surveyed were found with compressive strength between 20-30MPa which represents 75% of the buildings surveyed,

Low carbonation depth was detected on concrete cores with high compressive strength. The low carbonation depth detected may be due to high quality concrete, high density with low porosity at the beginning of the structures which prevent the ingressions of CO_2 and moisture in to the concrete that causes carbonation, however the concrete can be that of moderate quality and moderate density with moderate pores at the beginning, but later on the pores of the concrete being blocked by the carbonation products resulting in increased of the compressive strength and stopped further ingressions of CO_2 and moisture which hinder the carbonation progress in the concrete that lead to detection of low carbonation depth. This is showing that increases in compressive strength lead to the decrease in carbonation depth since concrete of higher density and higher compressive strength has low and small pores which allow CO_2 gas, moisture to ingress in to the concrete causing carbonation and other durability problems.

4.2.3 Carbonation Depth

The carbonation depth determined from extracted concrete cores of the 8 buildings surveyed are included in Table 4.2. At the time of this study more than two-third of the buildings surveyed were between 10 to 18 years old and their carbonation depth varies between lowest of 7.7mm to the highest value of 39.0mm on 31 years and 18 years old buildings respectively (check structure no. 3 and 2 in Table 4.2). This is indicating that concrete carbonation is not only related to the ages of the structure but also depend on quality of the concrete and exposure conditions of the structure.

Considering all the buildings surveyed at the time of the study carbonation depth is higher than expected in the majority of the buildings which is greater than 1mm per year as reported by Fooke (Haque and Al-Khaiat, 1997) that carbonation in a dry hot environment penetrate about 1mm per year which may be little more in dry condition and moderate wet condition. But concrete carbonation is a diffusion process it depends upon the concentration of CO_2 gas in the environment, exposure condition and quality of the concrete. Also Roberts (Haque and Al-Khaiat, 1997) reported that concrete that are made with average Portland cement shows carbonation depth of 5-8mm in 8-10 years and 10-15mm in 50 years. This carbonation rate is severe and dangerous to reinforced concrete structures.

In all the buildings surveyed, 22.72mm was found to be the average carbonation depth of the structures and 20.75 years was the average year of the structures, taking the average, these building carbonated at 1.10mm in a year which is greater than 1mm per year as reported by Fookes (Haque and Al-Khaiat, 1997) for a dry hot climate and greater than what is reported by Roberts (Haque and Al-Khaiat, 1997) in temperate climate which is not safe for imbedded bars in reinforced structures

The predicted carbonation depth in 50 years of the buildings are greater than 25mm commonly used concrete cover thickness, except structure No. 3 which have carbonation depth of 8mm, this is sign showing that the exposure conditions of the North Cyprus are favorable to carbonation that may lead to depassivation of concrete causing reinforcement corrosion before the end of service life of buildings.

The variation in average of carbonation depth of the buildings with respect their location with respect to the coast are shown in Table 4.4. Also average compressive strength of these structure with respective to these location was determined, the average compressive strength of coastal and inland buildings at the time of the study are almost similar that is 23.81MPa and 23.91MPa respectively. Using average strengths it was assumed that concrete used for both coastal and inland are of the same quality at the time of investigation, by this assumption it can be seeing that inland buildings carbonated more than the coastal buildings (see Table 4.4) with carbonation depth of 24.3mm and 20.09mm respectively.

This findings did not support that of (Haque and Al-Khaiat, 1997) which found coastal buildings carbonated more than inland buildings in Kuwait.

The higher carbonation depth in the inland buildings is expected, due to higher concentrations of CO_2 gas within the city of Nicosia and Haspolat than that of Girne since they have larger number of industries, population that are using heating and cooling agent, automobiles that directly releases CO_2 gas to the environment, also the average relative humidity in both Nicosia and Girne is within the range of higher rate of carbonation (50%-70% RH) throughout the year. It is also well known water and CO_2 are the necessary factors for carbonation reaction to occur.

Looking at Structure No.2 and No.4 from Table 4.3, the time expected for these two structures to carbonate 25mm cover depth is 7.4 and 10.5 years respectively, while both structures are 18 years old at the time of the study, so these structures are expected to have ongoing reinforcement corrosion induced by concrete carbonation.

The eight (8) buildings surveyed are categorized in to LS and MS concrete where their average values of compressive strength are 16.76MPa and 26.24MPa with corresponding present carbonation depth of 23.38mm and 22.50mm respectively. This is an indication that a moderate carbonation depth can be detected on concrete with high compressive strength, with time cracks occurs resulting in low compressive strength with too much carbonation depth on concrete. Both carbonation depth of LS and MS have reached the level closer to the concrete cover depth, indicating that these concrete are at risk of corrosion of reinforcement induced by carbonation, so concrete of high strength and higher density is required for the protection of concrete from similar damages, this finding is similar to that of (Haque and Al-Khaiat, 1997).

On the structures surveyed the carbonation depth was found to be higher on the structures made of concrete that are built with natural aggregate of rounded stones than the structures that are built with concrete made using aggregates from crushed rocks.

As stated before majority of the buildings will reach depassivation level before 50 years, by these prediction it safer to use concrete with higher strength and higher density to prevent the risk of carbonation induced corrosion of the reinforcement in aggressive environment like North Cyprus, this will prevent easy ingression of CO_2 gas, moisture and salts in to the concrete.

It was mentioned that buildings surveyed are categorized based on their compressive strength ranges i.e. LS and MS.

In table 4.5 values of the average compressive strength of each group and their corresponding average B values are included.

Using the average B values, carbonation depth for low strength (LS) and medium strength (MS)) for 50 years are predicted to be 37.50 mm and 36.77mm respectively which implies that all structures are expected to be susceptible to reinforcement corrosion induced by carbonation before the end of their designed service lives. The predicted carbonation depth of both LS and MS for 50 years is presented in Table 4.5.

Reader of this thesis will observe significant wide range in standard deviation of samples data of the extracted cores as shown in Figure 4.1 and 4.2, this is because, the samples from each structure are extracted from different members of different positions and exposure conditions which can affects carbonation of the concrete and concrete compressive strength. Also mixture of the concrete of a given structure may differ this may cause difference in concrete quality of the members in the same structure.

From Figure 4.1 and 4.2, Structure No. 2 has no standard deviation because only one core sample was available for the chemical analysis other core sample were totally destructed in the compressive strength tests.

CHAPTER FIVE

CONCLUSSIONS AND RECOMMENDATION

5.1 Conclusions and Recommendation

Reinforced concrete structures in North Cyprus are exposed to severe environmental conditions that are favorable to concrete carbonation which leads to corrosion of reinforcements and affects the performance of structures through their designed service lives. In this study chemical investigation was carried out in the Civil Engineering laboratory of Near East University, Cyprus on the extracted concrete cores from walls and columns of the surveyed existing buildings within Nicosia and Girne of North Cyprus by the support of Chamber of Civil Engineering (KTİMO), Nicosia

In this collaboration carbonation depth, compressive strength and density of the cores samples were evaluated.

The following conclusions and recommendations were drawn;

1. A detailed literature survey was made in this study: there is no available data found for the status of concrete buildings in Cyprus exposed to the problem of carbonation. Therefore, this is the first time such a study was carried out in North Cyprus.
2. Concrete in Northern Cyprus buildings carbonated averagely at a rate of 1.10mm per year which is severe and more than expected for normal concrete in hot climate conditions and temperate climate conditions
3. In Northern Cyprus, inland buildings (Nicosia) carbonated at higher rate than coastal building (Girne).
4. Detected concrete carbonation and compressive strength are inversely proportional in relation that is concrete carbonation rate decreases with an increase in concrete compressive strength.
5. The assessment results yielded B values that may be useful in prediction of carbonation depth of concrete based on compressive strength grades (i.e. Medium strength and Low strength concretes)

6. In severe environment like North Cyprus concrete structures should be built with a concrete of high compressive strength, having a higher density.
7. It is recommended to extend the research on further existing buildings from all cities of North Cyprus in order to find out the carbonation progress and the constant values for predicting future concrete carbonation to prevent premature degradation of concretes as a result of carbonation induced corrosion within the Cyprus Island.

REFERENCES

Abdelaziz, G. E. (1997). Microstructural analysis of surface and interface zones in concrete *(Doctoral dissertation, Aston University)*.

Abu Dagga W.M, (2009) Comparison of Ready Mix Concrete Techniques and Achieved Results in Turkish Republic of North Cyprus, Department of Civil Engineering, Near East University, Nicosia Cyprus, *Master Thesis*.

Al-Gahtani, A. S., & Maslehuddin, M. (2002, December). Characteristics of the Arabian Gulf environment and its impact on concrete durability-an overview. *In the 6th Saudi Engineering Conference*, KFUPM, Dhahran, Saudi Arabia (Vol. 3, pp. 169-184).

Al-Khaiat, H., Haque, M. N., & Fattuhi, N. I. (2002). Concrete carbonation in arid climate. *Materials and Structures, 35* (7), 421-426.

Atiş, C. D. (2003). Accelerated carbonation and testing of concrete made with fly ash. *Construction and Building Materials, 17* (3), 147-152.

Atun, A., & Ünsalan, D. Epmr-2002 International Conference Environmental Problems of the Mediterranean Region.

Azizian, M. R., Assefi, H., & Agboola, O. P. A (2008) Prospective Study of PV Cells and its Effect on Global Warming, Case Study: North Cyprus.

B Song, H. W., Kwon, S. J., Byun, K. J., & Park, C. K. (2006). Predicting carbonation in early-aged cracked concrete. *Cement and Concrete Research, 36* (5), 979-989.

British Standards B.S. 1981. Part 114. *Methods for Determination of Density of Hardened Concrete, 198*, pp. 2661-2666.

British Standards, B.S.1981. Part 120. *Method for Determination of the Compressive Strength of Concrete Cores, 1983,* pp. 2679-2685.

Brown J. “Concrete Carbonation – A Guide to the Different Types”, Posted on June 21, 2012.

Chang, C. F., & Chen, J. W. (2006). The experimental investigation of concrete carbonation depth. *Cement and Concrete Research*, *36* (9), 1760-1767.

Chi, J. M., Huang, R., & Yang, C. C. (2002). Effects of carbonation on mechanical properties and durability of concrete using accelerated testing method. *Journal of marine science and technology*, *10* (1), 14-20.

Cyprus geological heritage educational tool
http://www.cyprusgeology.org/english/EN/index.htm last visit 31/05/2014

Cyprus Metrological service, “Cyprus Climate” Government official website. Last accessed 30/01/2014.
http://www.moa.gov.cy/moa/ms/ms.nsf/DMLcyclimate_en/DMLcyclimate_en?OpenDocument

El-Reedy M. (2010), Steel-Reinforcement concrete structure: Assessment and Repair of Corrosion.

Ertek, T. A., Erginal, A. E., Bozcu, M., & Türker, G. (2008) The formation of beach rock on the North Cyprus Coast Kuzey Kıbrıs Kıyılarında Yalıtaşı Oluşumu.

Ferreira, R. M. (2004). Probability-based durability analysis of concrete structures in marine environment.

Hamam, I. M. A. (2008). Rehabilitation Needs for Existing Buildings in Gaza Strip. Master of Science Thesis, Civil Engineering Department, Deanery of High Studies, The Islamic University Of Gaza, Gaza Strip, Palestine.

Haque, M. N. (2005). Provisions in the African concrete code for designing durable structures. *In Proceedings of the 1 st African Concrete Code Symposium*, Tripoli, Libya (pp. 127-144).

Haque, M. N., & Al-Khaiat, H. (1997). Carbonation of concrete structures in hot dry coastal regions. *Cement and Concrete Composites, 19* (2), 123-129.

Haque, M. N., Al-Khaiat, H., & John, B. (2006). Proposals for a draft code for designing durable concrete structures in the Arabian Gulf. *Arabian Journal for Science and Engineering, 31* (1), 205.

Haque, M. N., Al-Khaiat, H., & John, B. (2008). Durability Design in the African Concrete Code. *Kuwait Journal of Science & Engineering, 35* (2 B), 39-54.

Houst, Y. F., & Wittmann, F. H. (2002). Depth profiles of carbonates formed during natural carbonation. *Cement and Concrete Research, 32* (12), 1923-1930.

Ivan, E., Solis, R. G., & Lopez-Salazar, L. R. (2005). Carbonation Induced Corrosion in Urban Concrete Structures. *CORROSION 2005*.

Jones, M. R., Dhir, R. K., Newlands, M. D., & Abbas, A. M. O. (2000). A study of the CEN test method for measurement of the carbonation depth of hardened concrete. *Materials and Structures, 33* (2), 135-142.

Karatas, E., & Kuhlwein, E. (2010). Climate Change-*A Challenge for Europe and Cyprus. Tredition.*

Key Facts on Cyprus: Essential Information on Cyprus (2013) By Nee P.W

Kilic, C. A. R. (2006). Geotchnical properties of Cyprus clays.

Kleanthous, S., Vrekoussis, M., Mihalopoulos, N., Kalabokas, P., & Lelieveld, J. (2014). On the temporal and spatial variation of ozone in Cyprus. *Science of the Total Environment, 476*, 677-687.

Lee, H. J., Do Gyeum Kim, J. H. L., & Cho, M. S. (2012). A study for carbonation degree on concrete using a phenolphthalein indicator and Fourier-transform infrared spectroscopy. *WASET J, 62*, 184-190.

Lin, X. (2007). Effect of early age carbonation on strength and pH of concrete. *In Masters Abstracts International* (Vol. 46, No. 06).

Lionello, P., Dalan, F., & Elvini, E. (2002). Cyclones in the Mediterranean region: the present and the doubled CO_2 climate scenarios. *Climate Research*, *22* (2), 147-159.

Mesda, Y. (2012). Heat Transfer Coefficient Analysis of the Chamber of Cyprus Turkish Architects Office Building on the Zahra Street in the Walled City of Nicosia in Cyprus. *Architecture Research*, *2* (4), 47-54.

Michaelides S.C “Meteorological Service Contribution Toward Renewable Energy Sources” *Director Cyprus Meteorological Service. Cyprus Physicists Union, Nicosia*, 4th February, 2012.

Mmusi, M. O., Alexander, M. G., & Beushausen, H. D. (2009). Determination of critical moisture content for carbonation of concrete.

Namagga, C., & Atadero, R. A. (2011). Valuable utilisation of spray dryer ash and its performance in structural concrete. *International Journal of Sustainable Engineering, 4* (02), 153-163.

Nasser, A., Clément, A., Laurens, S., & Castel, A. (2010). Influence of steel–concrete interface condition on galvanic corrosion currents in carbonated concrete. *Corrosion Science, 52* (9), 2878-2890.

Neves, R., Branco, F. A., & de Brito, J. (2012). A method for the use of accelerated carbonation tests in durability design. *Construction and Building Materials, 36,* 585-591.

Neves, R., Branco, F., & de Brito, J. (2013). Field assessment of the relationship between natural and accelerated concrete carbonation resistance. *Cement and Concrete Composites, 41*, 9-15.

Neville A., En: *Concrete International* Vol.25, No. 12 Dic-2003

Neville, A.M. (1995) Properties of Concrete, 4th Edition, Longman Group Limited, England, UK.

Price, C., Michaelides, S., Pashiardis, S., & Alpert, P. (1999). Long term changes in diurnal temperature range in Cyprus. *Atmospheric Research, 51* (2), 85-98.

Rostami, V., Shao, Y., Boyd, A. J., & He, Z. (2012). Microstructure of cement paste subject to early carbonation curing. *Cement and Concrete Research, 42* (1), 186-193.

Roy, S. K., Poh, K. B., & Northwood, D. O. (1999). Durability of concrete—accelerated carbonation and weathering studies. *Building and environment, 34* (5), 597-606.

Roziere, E., Loukili, A., & Cussigh, F. (2009). A performance based approach for durability of concrete exposed to carbonation. *Construction and Building Materials, 23*(1), 190-199.

Russell, D., Basheer, P. A. M., Rankin, G. I. B., & Long, A. E. (2001). Effect of relative humidity and air permeability on prediction of the rate of carbonation of concrete. *Proceedings of the ICE-Structures and Buildings, 146* (3), 319-326.

Shanablih, K. A. (2012). Determination of Energy Efficient Construction Components for Houses in Northern Cyprus (*Doctoral Dissertation, Near East University*).

Shi, H. S., Xu, B. W., & Zhou, X. C. (2009). Influence of mineral admixtures on compressive strength, gas permeability and carbonation of high performance concrete. *Construction and Building Materials, 23* (5), 1980-1985.

Sims, I., The assessment of concrete for carbonation Concrete, 28 (1994) 33-38.

Song, H. W., Kwon, S. J., Byun, K. J., & Park, C. K. (2006). Predicting carbonation in early-aged cracked concrete. *Cement and Concrete Research, 36* (5), 979-989.

Varjonen, S. (2004). Accelerated carbonated concrete as corrosion environment. *Nordic Concrete Research-Publications-*, *31*, 1.

Waters, J. (2010). Deciphering climatic controls on sedimentation in a tectonically active area, Cyprus (*Doctoral dissertation, Durham University*).

Wee, T. H., Suryavanshi, A. K., & Logendran, D. (1999). Pore structure controlling the carbonation of a hardened cement matrix blended with mineral admixture. *Advances in cement research, 11* (2), 81-95.

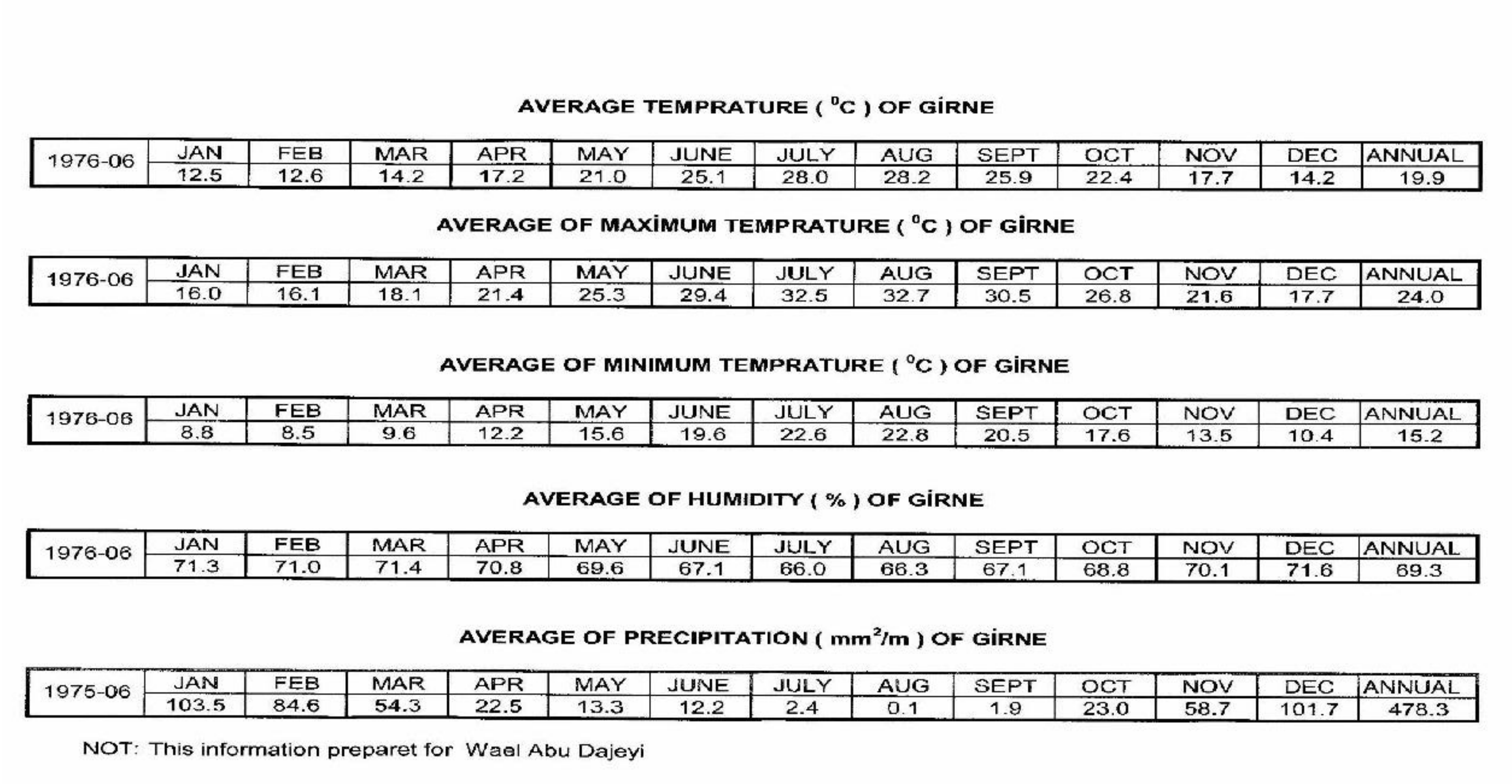
Yoon, I. S., Çopuroğlu, O., & Park, K. B. (2007). Effect of global climatic change on carbonation progress of concrete. *Atmospheric Environment, 41* (34), 7274-7285.

Zachariadis, T. (2012). Climate Change in Cyprus: *Impacts and Adaptation Policies. Cyprus Economic Policy Review, 6* (1), 21-37.

APPENDICES

APPENDIX I

Cyprus Weather Conditions [2]



AVERAGE TEMPRATURE (^{0}C) OF GİRNE

1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	12.5	12.6	14.2	17.2	21.0	25.1	28.0	28.2	25.9	22.4	17.7	14.2	19.9

AVERAGE OF MAXİMUM TEMPRATURE (^{0}C) OF GİRNE

1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	16.0	16.1	18.1	21.4	25.3	29.4	32.5	32.7	30.5	26.8	21.6	17.7	24.0

AVERAGE OF MINIMUM TEMPRATURE (^{0}C) OF GİRNE

1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	8.8	8.5	9.6	12.2	15.6	19.6	22.6	22.8	20.5	17.6	13.5	10.4	15.2

AVERAGE OF HUMIDITY (%) OF GİRNE

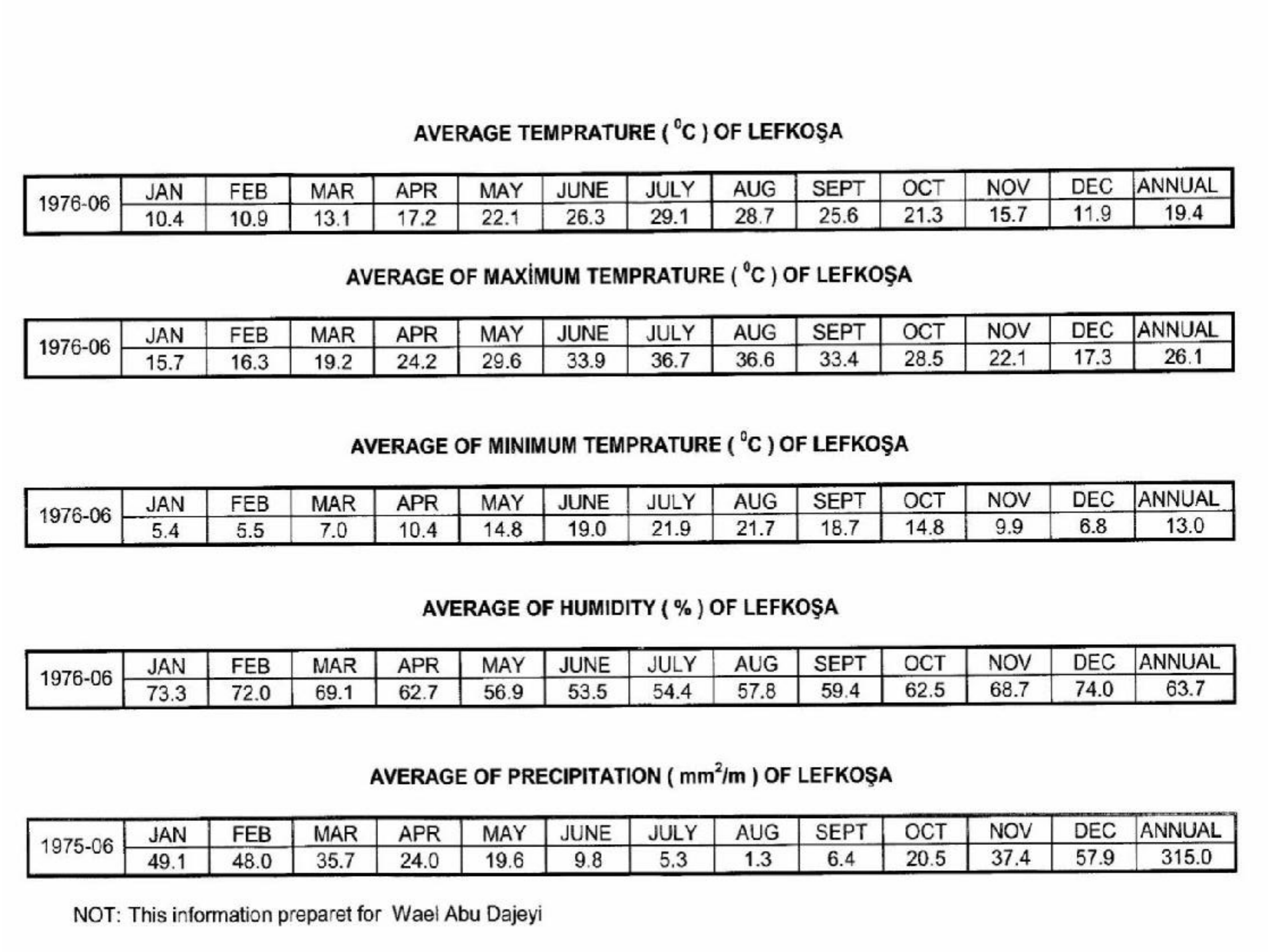
1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	71.3	71.0	71.4	70.8	69.6	67.1	66.0	66.3	67.1	68.8	70.1	71.6	69.3

AVERAGE OF PRECIPITATION (mm^{2}/m) OF GİRNE

1975-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	103.5	84.6	54.3	22.5	13.3	12.2	2.4	0.1	1.9	23.0	58.7	101.7	478.3

NOT: This information preparet for Wael Abu Dajeyi

GIRNE WEATHER CONDITIONS.



AVERAGE TEMPRATURE (^{0}C) OF LEFKOŞA

1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	10.4	10.9	13.1	17.2	22.1	26.3	29.1	28.7	25.6	21.3	15.7	11.9	19.4

AVERAGE OF MAXİMUM TEMPRATURE (^{0}C) OF LEFKOŞA

1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	15.7	16.3	19.2	24.2	29.6	33.9	36.7	36.6	33.4	28.5	22.1	17.3	26.1

AVERAGE OF MINIMUM TEMPRATURE (^{0}C) OF LEFKOŞA

1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	5.4	5.5	7.0	10.4	14.8	19.0	21.9	21.7	18.7	14.8	9.9	6.8	13.0

AVERAGE OF HUMIDITY (%) OF LEFKOŞA

1976-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	73.3	72.0	69.1	62.7	56.9	53.5	54.4	57.8	59.4	62.5	68.7	74.0	63.7

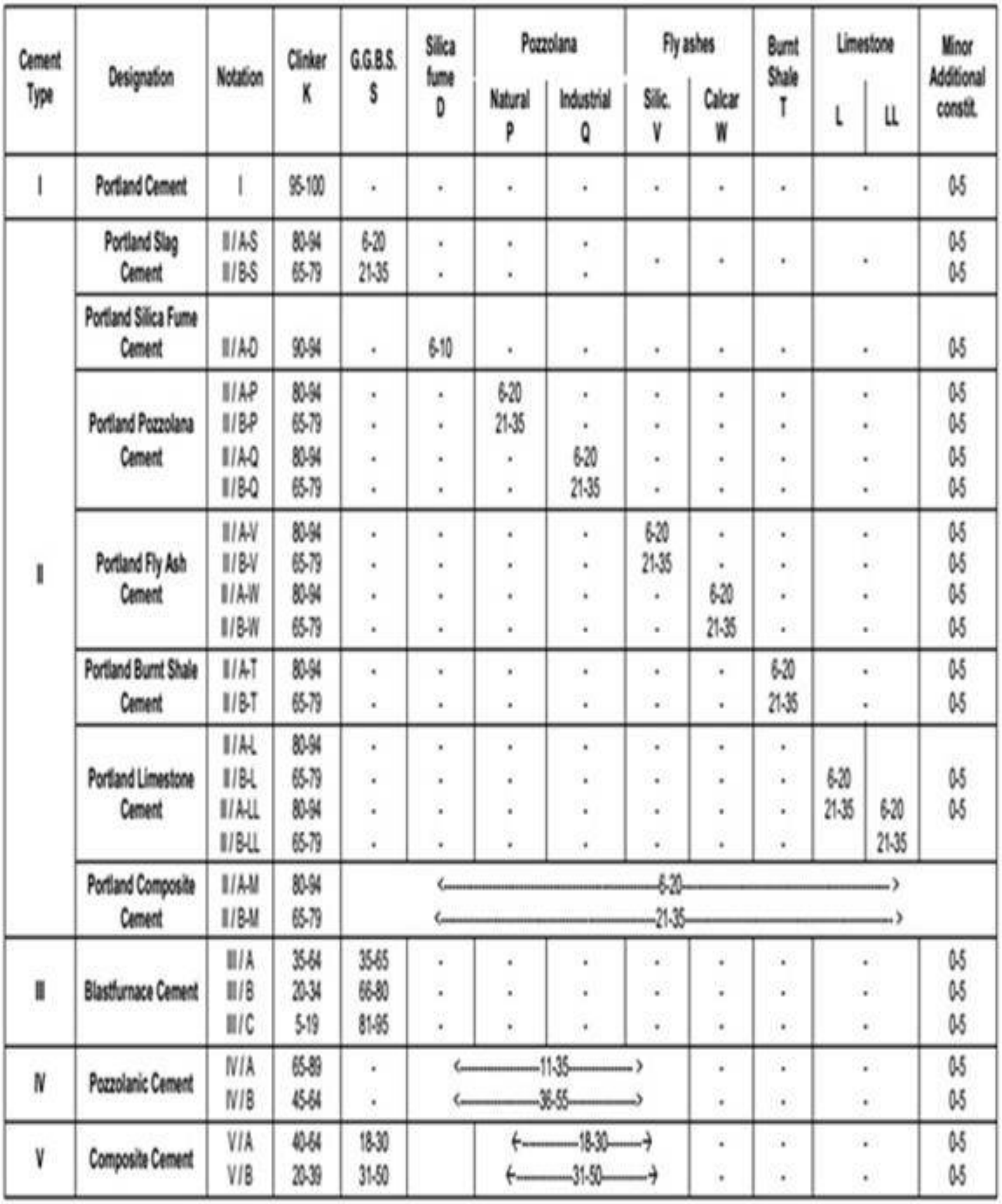
AVERAGE OF PRECIPITATION (mm^2/m) OF LEFKOŞA

1975-06	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
	49.1	48.0	35.7	24.0	19.6	9.8	5.3	1.3	6.4	20.5	37.4	57.9	315.0

NOT: This information preparet for Wael Abu Dajeyi

NICOSIA WEATHER CONDITIONS.

APPENDIX II



Cement Type	Designation	Notation	Clinker K	G.G.B.S. S	Silica fume D	Pozzolana		Fly ashes		Burnt Shale T	Limestone		Minor Additional constit.
						Natural P	Industrial Q	Silic. V	Calcar W		L	LL	
I	Portland Cement	I	95-100	-	-	-	-	-	-	-	-		0-5
II	Portland Slag Cement	II / A-S	80-94	6-20	-	-	-	-	-	-	-		0-5
		II / B-S	65-79	21-35	-	-	-						0-5
	Portland Silica Fume Cement	II / A-D	90-94	-	6-10	-	-	-	-	-	-		0-5
	Portland Pozzolana Cement	II / A-P	80-94	-	-	6-20	-	-	-	-	-		0-5
		II / B-P	65-79	-	-	21-35	-	-	-	-	-		0-5
		II / A-Q	80-94	-	-	-	6-20	-	-	-	-		0-5
		II / B-Q	65-79	-	-	-	21-35	-	-	-	-		0-5
	Portland Fly Ash Cement	II / A-V	80-94	-	-	-	-	6-20	-	-	-		0-5
		II / B-V	65-79	-	-	-	-	21-35	-	-	-		0-5
		II / A-W	80-94	-	-	-	-	-	6-20	-	-		0-5
		II / B-W	65-79	-	-	-	-	-	21-35	-	-		0-5
	Portland Burnt Shale Cement	II / A-T	80-94	-	-	-	-	-	-	6-20	-		0-5
		II / B-T	65-79	-	-	-	-	-	-	21-35	-		0-5
	Portland Limestone Cement	II / A-L	80-94	-	-	-	-	-	-	-	6-20		0-5
		II / B-L	65-79	-	-	-	-	-	-	-	21-35	6-20	0-5
		II / A-LL	80-94	-	-	-	-	-	-	-		21-35	
		II / B-LL	65-79	-	-	-	-	-	-	-			
	Portland Composite Cement	II / A-M	80-94	←6-20→									
		II / B-M	65-79	←21-35→									
III	Blastfurnace Cement	III / A	35-64	35-65	-	-	-	-	-	-	-		0-5
		III / B	20-34	66-80	-	-	-	-	-	-	-		0-5
		III / C	5-19	81-95	-	-	-	-	-	-	-		0-5
IV	Pozzolanic Cement	IV / A	65-89	-	←11-35→				-	-	-		0-5
		IV / B	45-64	-	←36-55→				-	-	-		0-5
V	Composite Cement	V / A	40-64	18-30		←18-30→			-	-	-		0-5
		V / B	20-39	31-50		←31-50→			-	-	-		0-5

CEMENT TYPES AND THEIR COMPOSITIONS ACCORDING TO EUROPEAN STANDARD EN 197-1