FUNDAMENTAL CHARACTERISATION OF IMPREGNATION ON CONCRETE STRUCTURES

By

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A thesis submitted in partial fulfilment of the requirements of

Nottingham Trent University for the degree of

Philosophy of Doctorate

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June 2017

DEDICATION

I dedicate this thesis to God almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge, and understanding. He has been the source of my strength throughout this program. This thesis is dedicate to both my father and mother did not only raise and nurture me but also taxed himself dearly over the years for my education and intellectual development. I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, M.Narayanaswamy and V.Saroja whose words of encouragement and push for tenacity ring in my ears. I also dedicate this work to my philosopher Dr.M.C.Nataraja, Professor of Sri Jayachamarajendra College of engineering, Karanata, India for his valuable guidance during my research work time.

“I have not failed 700 times. I have not failed once. I have succeeded in proving that those 700 ways will not work. When I have eliminated the ways that will not work, I will find the way that will work.”

Thomas Edison

DECLARATION

I hereby declared that no portion of the research referred to in this thesis has been submit in support of an application for another degree or qualification at this or any other University or other institution of learning. I declare that, the work in this thesis was conduct in accordance with the regulations of NTU. The following publications have resulted from the work carried out for this degree.

Signed…………………………………… (Candidate), Date: 16/06/2017

PUBLICATIONS

1. M.M.Rahman., D.A. Chamberlain., and M.N. Balakrishna, and Kipling Judith., "**Performance of Pore-Lining Impregnates in Concrete Protection by Unidirectional Salt-Ponding Test**", TRB 92 Annual meeting, Washington, D.C, 2013.
2. M.M. Rahman, D.A. Chamberlain, and M.N. Balakrishna., "**Prolong Rainy Condition in the Efficacy of Concrete Protection**" Construction material, V.2, No. 4, November, 2013.
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4. M.N. Balakrishna, M.M. Rahman, D.A. Chamberlain., Fouad Mohammad and Robert Evans. "**Interpretation of hydrophobicity in concrete by impregnation**" Int. J. Struct. & Civil Engg. Res**,** V.2, No. 4, November 2013.
5. M.N. Balakrishna, M.M. Rahman, D.A. Chamberlain, Fouad Mohammad and Robert Evans, "**Effectiveness of impregnation on self-compacted concrete**" Int. J. Struct. & Civil Engg. Res**,** V.2, No. 4, November 2013.
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7. M.N. Balakrishna, M.M. Rahman, D.A. Chamberlain, Fouad Mohammad and Robert Evans., "**Determination of flow rate of water in concrete by Rilem tube method**" Int. J. Struct. & Civil Engg. Res, V. 2, No. 4, November 2013.
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CERTIFICATION

This is to certify that the thesis entitled "FUNDAMENTAL CHARACTERISATION OF IMPREGNATION ON CONCRETE STRUCTURES", which is submitted by Mr M.N. BALAKRISHNA, in partial fulfilment of the requirements for the award of degree of Philosophy of Doctorate, in Civil Engineering Department of Nottingham Trent University. Nottingham is a record of the candidate's own independent, and original research work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submit in part or full to any other university or institute for the award of any degree.

ABSTRACT

The corrosion of reinforcing steel arising from contamination by chlorides from de-icing salt is the major cause of deterioration of concrete bridges in the UK and many parts of the world. In fact, the main long-term deterioration mechanism involves moisture movement and the transport of chlorides within the concrete. In order to build durable and reliable structures, it is necessary to predict the movement of moisture and chloride within the concrete. Thus, an objective of this present research are fourfold. First, this research will examine an influence of conditioning such as drying condition, on the results of Schmidt hammer test and Ultrasonic pulse velocity test. Secondly, this research will examine an influence of conditioning such as wetting and drying condition on the results of ISAT. Third, this research will examine an influence of pre-conditioning in turn wetting/drying process on the results of Sorption tests. Fourth, the primary focus of this study is to examine effects of cyclic wetting (Fully and partially saturated) as well as drying on Chloride absorption for long-term duration with/without hydrophobic impregnation. In fact, chloride profiles of samples exposed to various pre-determined cycles of wetting, and drying were determined as well as assess chloride diffusion coefficient in pre-conditioned concrete cubes/slabs for a designed six mixtures type of concrete. Actually all tests were conducted under two different conditions such as slump, and w/c ratio value was varied with constant compressive strength as in the first case. Compressive strength, and w/c ratio value was varied with constant slump as in the second case.

The concrete hardness value could be increase with higher compressive strength and varied slump. Whereas the concrete hardness value was decrease slightly with lower, compressive strength and constant slump value and goes on increases with increased compressive strength. The ultrasonic pulse velocity could be increased or slightly deceased with higher compressive strength and varied slump. An ultrasonic pulse velocity was decrease with, lower compressive strength and constant slump value and goes on increases with increased compressive strength. The sorptivity coefficient (rate of absorption) was very lesser with higher compressive strength and varied slump value in designed mixtures type. However, average sorptivity coefficient was higher for lower compressive strength and constant slump and reduced with higher compressive strength value. In addition to that, it is possible to established power type of equation between sorptivity coefficient and square root of time for designed different mixtures type. The water diffusion coefficient was correlate with square root of time, in turn, the average variation of water diffusion coefficient was more for in case of higher compressive strength and varied slump. However, in the case of lower compressive strength and constant slump, the water diffusion coefficient was slightly higher in varied compressive strength and slump. In fact from this research work that, it is possible to establish logarithmic relationship between water diffusion coefficient and square root of time. From this research work, it is possible to establish a power type of equation relationship between water diffusion coefficient and sorptivity coefficient. Moisture content can have negative influence on measured results of various types of concrete. The ISAT value in DCC concrete cubes was more as when compared to PSC and FSC concrete cubes. Similarly, the ISAT value was more in PSC as when compared to FSC concrete cubes.

For higher compressive strength and varied slump value, an average chloride concentration at drill depths in control concrete cubes was slightly higher in magnitude as when compared to impregnation concrete cubes. It is observe that, for lower compressive strength and constant slump value, the average chloride concentration at drill depths in control concrete cubes was to be slightly more as when compared to higher compressive strength. For higher/lower compressive strength and varied/constant slump value, the average chloride concentration at drill depths in control/solvent/water based impregnation pre-partially/fully saturated concrete cubes was found to be slightly lower in magnitude as when compared to dry conditioned control/solvent/water based impregnation concrete cubes. It’s also clear that, for higher/lower compressive strength and varied/constant slump value, the average chloride concentration at drill depths in pre-partially saturated control/solvent/water based impregnation concrete cubes was slightly higher in magnitude as when compared to fully saturated conditioned control/solvent/water based impregnation concrete cubes. The chloride concentration could be increase in DCC control slabs as when compare to control as impregnation PSC/FSC slabs. Similarly, the chloride concentration in control concrete slabs could be increase for in case of PSC concrete slabs as when compared to FSC slabs. Similarly, the chloride concentration in PSC control concrete slabs could be increase as when compared to FSC solvent/water based impregnation concrete slabs. An average chloride concentration from different drill depths could be increase in DCC control concrete slabs with higher compressive strength and varied slump value as when compare to control PSC, and FSC concrete cubes. Chloride concentration (average) from drill depths in DCC (SB)/(WB) based impregnation concrete slabs with higher compressive strength, and varied slump value could be increased as when compared to (SB) impregnation DCC/PSC/FSC concrete slabs and goes on reduces with higher compressive strength and constant slump value.

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LIST OF SYMBOLS

ν = Apparent velocity of flow or volume of water per unit time per unit area (m/s)

Q = Flow rate (m^3/s)

A = Cross-sectional area of the sample (m^2)

Δh = Drop in hydraulic head through the sample (m)

L = Thickness of the sample (m)

η = Dynamic viscosity of the fluid ($kg/m.s$)

ρ = Density of the fluid (kg/m^3)

g = Acceleration due to gravity (m/s^2)

k = Intrinsic permeability of materials (m^2)

K = Coefficient of permeability or hydraulic conductivity (m/s)

J = Diffusion flux ($mol/m^2.s$)

D = Diffusion coefficient (m^2/s)

C = Chloride concentration at distance x from the surface after exposure time t

C_0 = Initial concentration of chloride

erf = Error function

t = Exposure time

t' = Concrete age

V = Velocity of the wave, km/sec.

L = Distance between transducers, mm.

T = Traveling time, µ sec.

f = Rate of flow (ml/m^2/sec)

T = Total test time in seconds

t = Test point time period in seconds

D = Number of scale divisions during period t

S = Sorptivity (mm)

i = Cumulative absorption at time (t), m/s

Δw = Change in weight

$W1$ = Oven dry weight of cube in grams

$W2$ = Weight of cube after specified time minutes' capillary suction of water in grams

A = Surface area of the specimen through which water penetrated

d = Density of water

b = Initial absorption

P_e = Capillary pressure (Pa)

Υ = Surface tension ($Pa.m$)

Θ = Wetting angle ($\Theta = 0$ for water)

r = Effective radius of capillary tube (m)

Q = Flow rate (m^3/s)

V = Volume of liquid (m^3)

p = Pressure gradient (Pa)

l = Length of tube (m)

$D(\Theta)$ = Capillary diffusivity (m^3/s)

$K(\Theta)$ = Unsaturated hydraulic conductivity (m/s)

Ψ = Capillary potential (m)

D_s = Coefficient of Desorptivity ($Kg/m^2/h^{1/2}$)

i = Mass loss/exposed surface area (Kg/m^2)

V_1 = Volume of the ammonium thiocyanate solution used in the titration (ml)

V_2 = Volume of the ammonium thiocyanate solution used in the blank titration (ml)

m = Mass of the concrete sample (g)

f = Molarity of the silver nitrate solution (0.02M)

LIST OF APPENDICES

ACKNOWLEDGEMENTS

First and foremost I am offer my sincere appreciation and deep gratitude to all my supervisors, **Dr. Fouad Mohammad, Dr. Robert Evans,** and **Dr. Mujib Rahman** for their supervision, valuable guidance, continuous encouragement, constructive advices and ultimate patience throughout the entire course of this research. They offer advices and suggestions whenever need immediately. Without their support, this thesis would not be possible. Professor **Dr. Denis Chamberlain** and **Dr. Mike Hoxley** deserve special thanks as my external supervisor and thesis committee members for their helpful suggestions, constructive comments, and valuable discussions.

This research would not have been successfully complete without the kind assistance from lab technicians in the School of Architecture, Design and the Built Environment. Acknowledgements were also offer to those, who have in one way or another contributed to this research and to the authors of various papers and materials quoted in the references. Great thanks go to those friends and colleagues, seniors and juniors, from the School of Architecture, Design and the Built Environment for their help and encouragement. Without all of you, the study life in NTU would not be so enjoyable. This study would not be possible without the unconditioned love, incredible moral support and encouragement from my family for these years. Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of this thesis and my study life in NTU. I would also like to thank all staff and the members of the research community for their encouragement and criticism over the last three years.

In addition, my deepest gratitude and indebtedness to my advisor, **Dr.M.C. Nataraja**, SJCE, India (Mysore) for his valuable advice, continuous guidance, constructive suggestions, enduring patience and encouragement provided throughout the course of this study. My deepest thanks for my father, **M. NARAYANA SWAMY** and mother, **V. SAROJA**, for their help, assistance, support, and love throughout my research and life. The author gratefully acknowledges the financial support for the research from the **State bank of Mysore, India,** Sampangiramanagar branch, Bangalore. Finally, above al1 else I would like to say thanks to the LORD, whom without I could never have finished this project. For during those long days and nights of work when I was discouraged, He gave me the strength to keep trying to do my best, and helped me to realize. I was also never call to be the best.

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CHAPTER 1 INTRODUCTION

1.1 Background

The concrete is an extremely versatile construction material which was seems to be considerable use in construction worldwide [Treadaway, K. W. T, 1984]. In the majority of cases, it is an entirely satisfactory. Unfortunately, in a small proportion of concrete, problems occur either because the concrete is not adequate for the particular conditions of use or because it does not achieve its full potential. The concrete deterioration is not a new problem, but it has become more prevalent in recent years. An extensive use of concrete, changes in material properties, construction techniques, and design approaches have resulted in a large amount of concrete uncertain durability. The by-product of this era is the concrete repair industry, which has grown to meet the demand, caused by widespread deterioration, and increased maintenance costs. This industry has been faced with the problem of producing cost effective durable repairs rather than merely an aesthetic patching up of deteriorated concrete [Johnson, S. M, 1965]. This has resulted in the development of new materials and improved techniques to meet the demand, but unfortunately, lesser evidence is yet available to support the claims that these new materials and methods can be use to produce durable repairs [Shaw, J. D. N, 1984]. As a result of an increased deterioration, there has been an increase in the use of preventive measures either in the form of concrete additives or protective coatings, which are applied to the concrete to try stop it progressing to a critical condition [Leeming, M. B, 1985].

This in turn itself has introduced a new problem of how to assess concrete to determine the likelihood of deterioration occurrence [Browne, R. D, et al 1983]. In fact, there are two approaches are available for assessing this. The first factor relies on having an understanding of the deterioration processes, which are occur, so that it is possible to determine the rate of deterioration by periodic measurements [Idorn, G. M, 1967]. This is rather inexact and required that the deterioration occurs at a known rate. The surface is frequently consider as the weakest part of the concrete due to ingress of aggressive agents. Producing impermeable concrete or treating concrete to make it impermeable is probably one of the best ways of achieving durability [Valenta, O, 1970]. Because of this, an extensive emphasis has made on measuring permeability, hence there is a widely held belief that this affects an ingress and movement of fluids as well as ions, which must be relate to durability [Lawrence, C. D, 1985].

An extensive research work was conduct in recent years to introduce non-destructive in-situ permeability test, which can be use for assessing durability. These tests have advantages as well as being non-destructive and assess the surface properties of the concrete. There are number of tests have been developed which tests either at the surface or just below it. These tests do not give permeability values, but rather time's rates of absorption or rates of flow, which in fact none of the tests value can be easily convert to true permeability and relate to durability [Lawrence, C. D, 1985]. The concrete is an extraordinary and key structural material in the human history. As written by [Brunauer and Copeland, 1964], "Man consumes no material except water in such tremendous quantities". It is no doubt that with the development of human civilisation, concrete will continue to be a dominant construction material in the future. However, the development of modern concrete industry also introduces many environmental problems such as pollution, waste dumping, emission of dangerous gases, depletion of natural resources etc. [Brunauer, S. and Copland, L. E, 1964].

The bridge structure is one of the integral components in any transportation network. For instance, that, Canada is a young nation, but its bridges and other infrastructure are ageing and confront the traveling public, engineering community with problems, concerns about maintenance and rehabilitation. Maintenance and repair of bridges has become a constant and major concern of public works Officials [Organization of Economies co-operation and Development, 1989]. Its estimate that, around 50% of the national wealth of most countries is invest in their infrastructure within Europe and North America. Therefore, the degree and rate of degradation of the built environment is of economically, technical and competitive importance. In fact, 50% of the expenditure in the construction industry is incur on repair, maintenance and remediation. Canada with the large-scale use of de-icing salts dictated by the cold climate, the situation is serious. Canada's concrete infrastructure, of which significant portion is near the end of its design life, has a replacement value of over half a trillion dollars [High Performance Concrete, 1993]. The deterioration of concrete bridges in the United States is a monumental problem. The problem has been steadily growing in magnitude presented by the Strategies highway research program and research plans estimate the Iiability of corrosion-induced deterioration in bridges at $20 billion, increasing by a rate of $500 million annually [Federal Highway Administration, 1991]. United Kingdom alone, it is estimated that repairs to damaged concrete cost over f500 million (CND$1 trillion) each year [Page, C.L., Bamforth, P. and Figg, J.W, 1996]. Hence, the corrosion of reinforcing steel in concrete is a major problem faced by civil engineers today as they maintain an ageing infrastructure. In summary, premature deterioration of concrete structures is a costly in a multibillion-dollar problem in all countries around the world. Consequently, the inherited problems of corrosion in existing concrete structures are likely to increase as the 21st century approaches. Hence, the evaluation of corrosion activity of steel in reinforced concrete field structures is not an easy task because the steel is not visible, the concrete has a high resistivity and the structures are in use. There have been active efforts to detennine the corrosion rates and other factors such as ingress of chloride as well as other concrete properties that could affect performance.

There is a growing and continuous evidence that the major phenomenon threatening the durable service-life performance of reinforced concrete (RC) structures exposed to aggressive environments is the penetration of chlorides, which, beyond a certain concentration level, can destroy the passivation of the steel reinforcement. This deterioration process is aggravate by carbonation where the environments also undergo large, rapid daily and seasonal changes in temperature/relative humidity. Another typical concrete deterioration process associated with hot, and marine environments, is the attack of the surface of the concrete by the precipitation of chlorides, especially in the splash zones. Chloride ions can be brought into concrete through a variety of ways–through the concrete mix constituents, and outside environment if the concrete is in contact with sea water, if the structure is in the tidal zone or in the splash zone, or when de-icing salts are used as in bridge structures and parking garages. Apart from the shortage of good quality aggregates, there is also shortage of good quality mixing water in many parts of the world and often the mixing water is not free from chlorides because of the high water table especially in the coastal regions. So while chlorides from contaminated aggregates can be control, and those from the mix water may still contaminate concrete.

Thus, there are in practice many situations where concrete-containing chlorides is also expose to salt weathering in a hot and marine environment. While salt weathering is a physical process, concrete containing chlorides and then exposed to seawater can thus be subject to a wide range of physical and chemical interactions, all-occur more or less simultaneously over a period. The chlorides are to accelerate the hydration process of Portland cement at early ages, and change the porosity and microstructure of the concrete. Salt weathering, on the other hand, will cause gradual mass loss and external surface damage. Concrete containing chlorides and then exposed to salt weathering will thus be subject to both internal and external interactions. The durable service life and the structural integrity of RC structures under such conditions will depend only on the performance of the salt contaminated concrete but also on the ability of the concrete to resist further external chloride penetration effectively and for a sufficiently long period.

The moisture content or water content is a critical indicator of concrete durability and its evaluation is very relevant for the prediction of structure aging. The presence of water in concrete structures is important for the penetration of chloride ions and concrete carbonation, which are two causes of embedded steel corrosion. In addition, concretes porosity makes it possible for some endogenous chemical reactions to occur leading to concrete cracking, such as alkali aggregates reaction and sulphate attacks. Therefore, concrete water content must be correctly evaluate for service life prediction of concrete structures. The moisture in building materials represents an important issue in building science. There is evident that the rising of moisture content in buildings leads to the serious negative events, like degradation of materials (disintegration of inorganic plasters, porous stones, ceramic bricks, binder decomposition, and surface erosion). It has also negative effects on biological degradation of constructions, and on the hygienic conditions of interior climate. There is need to consider the effectiveness of moisture rising on mechanical properties of bearing-structures material, and on the thermal performance of materials. On that account, it is necessary to prevent the presence of higher moisture content in building structures during their service life. In the case of moisture induced damage of buildings, there is need to access and monitor moisture content and to classify its amount in respect to optimisation of restoration process. The knowledge of moisture distribution is also important for the material research especially for determination of moisture transport and storage properties of materials.

Furthermore, the bridges are commonly design working before for a life of 120 years and with regular maintenance are expect to remain safe and serviceable over this period. However, many concrete highway bridges have suffered severe deterioration after only 20 or 30 years of service life [Wall bank, 1989]. Corrosion of embedded reinforcing steel caused by de-icing salts used during winter is one of the main reasons. The resulting corrosion damage is a major problem in the U.K [Pritchard, 1992]. The Department for Transport (DfT) has estimated the annual cost of salt-induced corrosion damage is £616.5 million on motorway and trunk road bridges in England and Wales alone in [Wallbank, 1989]. These bridges represent about 10% of the total bridge inventory in the country. The eventual cost may therefore be of 10 times in the DfT estimate and [Broomfield, 2007].

The problem of chloride-induced corrosion of steel reinforcement in bridges is not limited to the U.K, but it is a worldwide phenomenon with serious economic and safety implications. According to the U.S. DOT Federal Highway Administration (FHWA) report, corrosion costs and prevention strategies in the United States, presented to Congress in 2002. Corrosion of highway bridges costs the U.S. economy $8.3 billion annually; with a yearly outlay of $3.8 over the next 10 years to replace structurally deficient bridges, $2 billion for maintenance and the cost of capital for substructures and superstructures (minus decks)[K.R. Larsen, 2008]. Nevertheless, despite the high cost of maintaining bridge structures, the advantages of using de-icing salt are too great to be discontinue. Alternative de-icing chemicals do exist (such as calcium magnesium acetate and encapsulated calcium chloride added to bituminous road surfacing), but they are too expensive for most situations. De-icing salts are the most readily available and least expensive de-icer, are consider non-toxic, harmless to skin, clothing, harmless to the environment when handle and stored properly. It has been report that over 10 million tonnes of salt are use to melt ice on highways in the U.S. every year [Paddock, and Lister, 1990]. When concrete structures are expose to chloride, contaminate environments, chloride ions can penetrate into concrete cover, and reach the reinforcing steel. At a critical concentration of chlorides, provided there is sufficient oxygen and moisture, corrosion will initiate. There are two consequences of corrosion of steel. First, the products of corrosion occupy a volume several times larger than the original steel and cause cracking, spalling or delamination of the concrete. As a result, the bond between the concrete and the reinforcement is weak. Furthermore, this makes it easier for aggressive agents to penetrate toward the steel and thus the rate of corrosion increases. Secondly, the cross-sectional area of the steel decreases as the reinforcing bar corrodes, with a consequent reduction in their load-carrying capacity [Neville, 2003]. In addition, salt re-crystallization causes salt scaling and exfoliation and damages the concrete. Those elements of structure which are exposed to cyclic wetting and drying i.e. exposure class XD3 [BS 8500-1] have proven to be the most vulnerable to corrosion damage. Concretes exposed to wet/dry cycles, it is believe that chloride will enter the concrete initially by absorption and produce a reservoir of chloride ions a relatively short distance from the concrete surface from which diffusion can occur. This reservoir will be top up by periodic absorption events. If the concrete dries out to a greater depth, subsequent wettings carry the chlorides deeper into the concrete [Hong, and Hooton, 1999]. Therefore, diffusion of chloride ions through pore liquid and absorption, whereby bulk solution containing chloride ions is suck into concrete pores, are the two main transport mechanisms involved in chloride ingress in concrete. Diffusion occurs due to the chloride concentration gradient and is a relatively slow process and continuous, once some chloride has entered the concrete, provided the pore liquid does not completely evaporate. This mechanism is quite well under stable, although for land based civil engineering structures and in turn, the following factors complicate our understanding:

- The coefficient of diffusion decreases with age and most diffusion equations assume a constant coefficient.

- The periodic surface wetting with chloride solution means that the surface chloride concentration will increase with age instead of being constant as is normally assumed.

Absorption occurs due to surface tension and involves a liquid being suck into originally empty or partially filled pores in the concrete by capillary forces. There will be no absorption if the pores are fully saturate in the concrete matrix. Thus, absorption continues until saturation or until there is no more reservoir of solution [Hong and Hooton, 1999]. In fact, an absorption is a discontinuous process. It also results in a relatively rapid transport of chloride ions. Despite the fact that, during the last decade, considerable attention were paid to an absorption, there is still a lack of understanding of this mechanism of chloride ingress in concrete exposed to cyclic wetting and drying. The relationship between absorption and depth of chloride penetration in concrete exposed to chloride and wetting/drying environment has not been establish yet. The majority of prediction of chloride penetration model are base on diffusion and ignore the effect of absorption. There are also complications interpreting sorptivity values, a measure of capacity of concrete absorption. Absorption of concrete is very sensitive to the moisture state of concrete and therefore specimens should be condition to a defined initial state of moisture, before taking any measurements. This sensitivity to an initial moisture content causes problems and difficulties in measuring the absorption properties of concrete and comparing the values of sorptivity reported in different works.

In order to solve the corrosion problem and achieve the desired working service life of concrete bridges and other reinforced concrete structures, it is necessary to ensure the time to corrosion of the reinforcing steel is close to the design life of the structure. One simple and cost effective solution is the use of better quality (less permeable) concrete. For example, concrete made with a low water-cement ratio or cement replacement materials had shown to have a reduced permeability. Another economical solution is to increase the depth of concrete cover to the steel reinforcing bars. However, this increases surface cracks width. To be able to estimate the minimum thickness of concrete cover required for a given service life of a structure, it is necessary to understand the mechanism of chloride transport due to cyclic wetting/drying and establish how quickly chloride ions penetrate into concrete. A better understanding of the absorption characteristics of concrete is a step forward to establish the rate of chloride penetration into concrete accurately and develop a more appropriate prediction of chloride transport model. As mentioned earlier, the existing prediction models for chloride transport in concrete are mostly based on the diffusion equation and do not take into account the absorption properties of chloride into concrete. It is necessary to consider the effect of absorption on chloride ion penetration in order to determine the rate of penetration.

The need to protect concrete structures against moisture and chemicals has always been necessary as it affects the service life of the structure. One of the many factors that can substantially reduce the design working life of reinforced concrete structure is chemical attack. Marine structures, tunnels, retaining walls, concrete pipes and bridges are susceptible to chemical attacks from the ocean, harmful exhaust fumes, acid rain, and most commonly from de-icing salts. The de-icing salts, mainly sodium chloride are being use in increasing amounts, as the road network increase in size and winter periods become harsher. The spreading of de-icing salts although has a significant beneficial effect on keeping the roads safe during icy conditions, they pose a great threat to highway structures, due to the chloride ions from the salt penetrating through the pores of the concrete structure [Roberge, P. R., 2008]. This mechanism involves chloride ions from the de-icing salt penetrating through the pores in the concrete bridge piers and other structures, which over time cause the steel reinforcement to start corroding and the concrete spalling/bursting. The most effective approach to preventing chloride ions from penetrating through the pores of the structural elements and corroding the reinforcement is by providing a protective hydrophobic barrier around the concrete member’s surface. This can be achieve by making the surface of the concrete element water repellent but also vapour permeable. This helps protect the concrete from chloride ion penetration, hence reducing the risk of corrosion to the reinforcement [DMRB HD43/03, 2003]. Impregnates are frequently applied directly to the surface of the element via low pressure sprays which once dry do not affect the visual appearance of the structure and also allow ease of application [Fastglobe, 2012]. The use of surface protection for concrete is a possible way of increasing the service life of reinforced concrete structures exposed to marine environments. This type of protection inhibits the penetration of aggressive agents by diffusion and capillary absorption. The surface protection materials for concrete can be classify into three groups: Pore liners (make the concrete water-repellent), pore blockers (react with some of the soluble concrete constituents and form insoluble products) and coatings (form continuous film on the concrete surface), [J. G. Keer, 1992].

Today we are using different types of coatings or hydrophobic impregnations. Water repellent agents, now mainly consisting of alkylalkoxysilanes, are often use on concrete to prolong the service life of the structure. This is accomplish by protecting the reinforcement bars from chlorides or by changing the moisture content. When the concrete is treat with a water repellent agent, the properties of the surface layer turn from hydrophilic to hydrophobic and thereby water droplets are stop from entering, still allowing water vapour to pass through. This property change can reduce chloride ingress and stop moisture movement from penetrating through the surface layer. Unlike conventional sealants, such as epoxy or acrylic paints, this surface treatment is open to diffusion and the risk for frost damages caused by entrapment of water is, therefore, eliminate or decreased. Hydrophobic impregnations have the highest ratio between breathability and reduction in water absorption in comparison with other surface treatments for concrete [A.J. Forbes, 1986].

1.2 Motivation of research

The de-icing salt is not only the cheapest form of de-icing material, it is also non-toxic and residual salt is gradually dilute and disposed of through natural processes. Worldwide, the use of de-icing salt has been common since 1960's in areas where snow/ice is a seasonal roadway safety hazard. Automobile and highway bridge corrosion and ecosystem changes caused by de-icing salt are documented and the focus of considerable study. In fact, there is a need to establish a clear design methodology or guidelines for concrete structures that do not meet the specified minimum requirements need to be established. Presently, no such guidelines exist owing to the lack of knowledge on the deterioration prevention mechanisms of various repair materials and system and especially the durability of the repair system itself. The maintenance costs of reinforced concrete infrastructure (bridges, tunnels, harbours, parking structures) are increasing due to aging of structures under aggressive exposure. Corrosion of reinforcement due to chloride ingress is the main problem for existing structures in marine and de-icing salt environments. Corrosion cannot be ruled out completely for new infrastructure, even with today's emphasis on design for long service life due to local effects such as leakage of joints, consequently, repairs may be necessary. Now several preventive measures are available: using stainless steel reinforcement, hydrophobic treatment of the concrete surface, cathodic prevention, or admixing inhibitors. Objections against such preventive measures concern the additional costs and lack of experience. Their economic effects on the long term and strengths and limitations are unclear. Hydrophobic impregnation often referred to as water repellent agents, today mainly consisting of alkylalkoxysilanes, are often use on concrete structure to prolong the service life of the structure. The motivation for this research is to determine the effectiveness of water repellent material (solvent/water based) against chloride ingress under pre-conditioned concrete cubes/slabs such as dry/partially/fully saturated condition which was salt ponded for about 160 days. Thus, finally it is possible to establish relationship between concrete diffusion coefficient and varied drill depths in concrete cubes/slabs under pre-conditions with/without impregnation. It is also possible to assign the effectiveness of moisture condition on chloride absorption under different exposures condition in concrete cubes for long-term duration with/without impregnation. In addition to that, it is also possible to establish relationship between concrete chloride diffusion coefficient/chloride absorption in concrete cubes/slabs, with/without impregnation under various exposures condition for long term time duration.

Also an extensive efforts have been directed towards improving basic concrete properties and since the water penetration starts from the surface, in turn near surface characterization of concrete is needed in ordered to evaluate different designed mixtures type. The initial surface absorption test is vital as the surface of a structure needs impermeable so that water would not absorb into the specimen and corrode reinforcement inside. In this research, ISAT is carried out on dry/wet concrete cubes with moisture content for in case of dry concrete cube (Mc = 0%) and wet concrete cube (Mc = 2.5% and 5%). It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally, such testing was conduct without damaging the concrete. The main aim of this present research work was to ascertain proper co-rrelation between chloride diffusion coefficients, chloride absorption in concrete cubes/slabs with/without impregnation under various exposures condition, and ascertain proper near surface characteristics in pre-conditioned concrete cubes. In ordered to achieve this, concrete specimens matrix was characterized without damaging the inner structure by non-destructive tests by rebound hammer/ultrasonic pulse velocity test for their hardness value and compressive strength for in case of different designed mixtures type.

1.3 Aim and objectives

A need has therefore emerged to understand the engineering, durability and microstructural properties of chloride contaminate concrete exposed to chlorides, and to define the limits of initial chloride content that can be tolerate in a concrete mix.

- Thus, the objectives of this present research are four fold. First, this research will examine the influence of conditioning such as drying condition on the results of Schmidt rebound hammer and Ultrasonic pulse velocity test for in case of concrete cubes.

- Second, this research will examine the influence of conditioning such as wetting and drying condition on the results of Initial surface absorption test (ISAT) in concrete cubes.

- Third, this research will examine the influence of pre-conditioning on concrete cubes in turn wetting and drying process on the results of Sorption tests.

- Fourth, the primary focus of this study is to examine the effects of cyclic wetting (Fully and partially saturated) as well as drying conditioned concrete specimens (slabs & cubes) with sodium chloride solution for long term duration (160 days) with/without hydrophobic impregnation.

- There is a need to develop more detail understanding of chloride absorption in concrete cubes subjected to wet/dry cycles and the effect of different moisture content (2 %, and 3 %,) on the chloride ingress.

- Finally interpret chloride concentration and diffusion coefficient at different drill depths in concrete cubes/slabs for in case designed mixtures type of concrete. Actually all tests were conducted with different mixtures proportion under two different conditions such as Slump, and w/c ratio value was varied with constant compressive strength as in the First case and compressive strength, and w/c ratio value varied with constant slump as in the Second case. Seventy-two concrete cubes (100x100x100 mm) and eighteen concrete slabs (450x450x100 mm) with grades of concrete ranges from 25 to 40 N/mm^2 were prepared and tested in ordered to achieve desired objectives.

- The present research work evaluates the performance concerning how the properties of concrete are affect by a hydrophobic impregnation. The word hydrophobic comes from the Greek roots hydro (meaning water) and phobia (meaning fearing or hating). Nonpolar substances do not combine with water molecules. Water is a polar molecule, which means that it carries a partial charge between its atoms. Oxygen, as an electronegative atom, draws the electrons of each bond closer to its core, thus creating a more negative charge. Therefore, any materials with a charge be it negative or positive will be able to interact with water molecules to dissolve. (Salt dissolves in water). This is due to the charges of the ions sodium and chlorine. So essentially, hydrophobic molecules are molecules that do not have a charge, meaning they are non-polar. By lacking a charge, these molecules do not have any charge-to-charge interactions that will allow them to interact with water. Hydrophobic materials often do not dissolve in water or in any solution, which contains a largely aqueous (watery) environment. This characteristic of being hydrophobic or nonpolar is important for many of the molecules found in nature. The moisture transport and fixation in the surface layer of the concrete are study in this research work.

1.4 Scope of work

- The corrosion of reinforcing steel arising from contamination by chlorides from de-icing salt is the major cause of deterioration of concrete bridges in the UK and many parts of the world. The research presented in this thesis reviews current knowledge, mathematical models and test methods pertinent to the movement of moisture and transport of chloride ions in dry, partially and fully saturated concrete.

- In fact, there is a need to quantify the permeation characteristics of the near surface concrete, which is of paramount importance. In physics and engineering, permeation or imbuing is the permeate penetration (liquid, gas, or vapour) through a solid. It is directly relate to the permeate concentration gradient, a material's intrinsic permeability, and the materials' mass diffusivity.

- The present research work attempted to assess the water absorption of concrete by Initial surface absorption test (ISAT) in ordered to interpret different concrete mix designs, which gives a test method for structural health assessment by a suitable relation between Initial surface absorption value, and Time.

- In the present research work, an attempt had made to study an effect of cyclic wetting, and drying on the durability properties of concrete such as sorptivity, weight change, and water absorption. The process (absorption) by which one substance, such as a solid or liquid, takes up another substance, such as a liquid or gas, through minute pores or spaces between its molecules. The scope of the present research work included chacterization of fluid transport using primary tests that included water absorption under wetting and drying conditions respectively.

- The present research work made aim to interpret different concrete mix designs by surface hardness method which gives a test method for structural health assessment by a suitable correlation between Rebound hammer number as well as Ultrasonic pulse velocity and concrete compressive strength.

- Furthermore, develop a more detailed understanding of chloride concentration in concrete cubes, and slabs, which are subject to pre-conditioning such as dry, fully saturated as well as partially saturated conditions. Identify the effect of water absorption on chloride ingress; to produce reliable numerical model for chloride penetration due to this transport process; identify exposure conditions effectiveness and proposed methods, which require alternative methods of protection.

- Thus in turn to develop a more detailed understanding of chloride penetration/diffusion coefficient in concrete subjected to wet (Fully and partially saturated)/dry cycles for in case of slabs and dry cubes. Then identify the effect of absorption on chloride ingress as well as to produce reliable numerical model for chloride penetration due to this transport process with different impregnation materials.

- In addition, the present research work evaluates the performance concerning how the properties of concrete are affect by a hydrophobic impregnation. An effectiveness of water repellent treatments on a number of different concrete mixture proportions are evaluate.

1.5 Layout of Thesis

Thus following the literature review, the materials and experimental methods are describe. Then data on water and chloride transport properties of the concrete were investigate for in case of different mixtures type. The thesis is divide into five chapters:

Chapter 1: There is a need to protect concrete structures against moisture and chemicals has it affects the service life of the structures. The most effective approach to preventing chloride ions from penetrating through the pores of structural elements and corroding of reinforcement is by protective hydrophobic barriers around concrete member surface were discuss with their mechanisms.

Chapter 2: After the introductory Chapter 1, a critical review of the literature is carry out. In turn, reviews concrete infrastructure, de-icer effects, mechanisms of corrosion, chloride transport mechanisms, it will also touch on the other factors that influence resistance of concrete to chloride ingress. Current durability standards and guidance documents are also review before finally commenting on the available chloride, and existing protection techniques, reviews about sorptivity test methods, which includes Initial surface absorption test, factors influencing sorptivity of concrete, effect of chloride binding on absorption, modelling of chloride penetration into concrete, reviews about scientific and empirical models.

Chapter 3: Details an experimental work flow chart consider for this study and covers concrete mix proportions, impregnate materials and description of the test method such as workability test. Non-destructive testing method is a worldwide group of analysis techniques used in science and this research will examine the influence of conditioning on 72 concrete cubes such as drying condition on the results of Rebound hammer test (RHT) and Ultrasonic pulse velocity test (UPVT). It is possible to interpret the fundamental parameters in 72 concrete cubes, such as water absorption, moisture content, cumulative absorption, sorptivity coefficient. Diffusion coefficient and de-sorptivity coefficient. The designed six mixtures type was characterized in 72 concrete cubes by initial surface absorption test (ISAT) in dry/wet condition (Mc =2.5%, and Mc =5%) with water in order to evaluate near surface characteristics of concrete. In this research work, 72 concrete cubes with six mixtures type were design and pre-conditioned the concrete cubes with water to investigate their effect on chloride diffusion in dry, fully saturated, and partially saturated conditioned concrete cubes with/without impregnation. In turn analysed the chloride concentrations at different drill depths. Furthermore, 18 concrete slabs with six mixtures type were design and pre-conditioned the concrete slabs to investigate their effect on chloride diffusion in dry, fully saturated, and partially saturated conditioned concrete specimens with/without impregnation. Evaluate the performance of an impregnation material material on concrete slabs under pre-determined conditions such as dry/fully saturated/partially saturated condition. In turn analysed the chloride concentrations at different drill depths (30, 40, and 50) mm for different mixtures type after salt ponding test for about 160 days. Finally interpret an effectiveness of wetting and drying pre-conditioned concrete cubes/slabs on chloride diffusion coefficient was evaluate in control/impregnation concrete cubes for about 160 days in all designed six mixtures type. Chloride absorption test was carry out on 66 pre-conditioned concrete cubes such as dry/fully/partially saturated condition concrete cubes in order to evaluate the effectiveness of impregnation materials. In turn to interpret an effectiveness of impregnation concrete cubes with control cubes for six mixtures type under various exposure conditions for in the case of constant compressive strength, and varied slump in one case as well as varied compressive strength with constant slump in second case. Thus, there is a need to develop more detail understanding of chloride absorption in concrete cubes subjected to wet cycles and the effect of different moisture content (2%, and 3 %,) on the chloride ingress.

Chapter 4: An extensive critical evaluation of experimental results were carried in this present research work on the non-destructive tests, initial surface absorption test, salt ponding test on concrete cubes/slabs, and salt ponding test on concrete cubes with finite moisture content.

Chapter 5: Conclusions and recommendations for future work on the performance of impregnation in the concrete structures.

1.6 Summary

- There is a tremendous growing and continues evidence that, the major phenomenon threatening the durable service-life performance of reinforced concrete structures exposed to aggressive environments is the penetration of chlorides in cold countries.

- As concern to the scope of the present research that, interpret the non-destructive characteristics of the dry concrete cubes (rebound hammer number, and Ultrasonic pulse velocity). In addition to that, an extensive investigation of near surface characteristics of concrete cubes under dry/wet condition was carry out by an initial surface absorption test.

- Furthermore, sorptivity test was conduct on concrete cubes in order to assess the fundamental factors such as water absorption, moisture content, sorptivity coefficient, water diffusion coefficient, and desorptivity coefficient.

- Finally, evaluation of chloride concentration and chloride diffusion coefficient in concrete cubes/slabs with/without impregnation at different drill depths in ordered to interpret designed mixtures type. Similarly evaluate the chloride absorption with differential moisture content in concrete cubes in ordered to determine the effectiveness of designed mixtures type.

- The present research work comprises of the following chapters, such as introduction to the deterioration of concrete infrastructure, literature review, experimental methodology, and discussion about the results.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The soft water was aggressive to concrete primarily because of their "ion hungry" nature. This water occur naturally in springs emanating from igneous rock formations in mountainous areas or in lowland streams or rivers, which have not passed through calcareous strata. Soft water are therefore characterised by their low dissolved ion content. When concrete is place in contact with this water, the calcium hydroxide (Ca $(OH)_2$) in the hardened cement paste is leached out as the water tries to establish an ion balance. Under these conditions, the rate of Ca $(OH)_2$ removal is determine by the concentration gradient (difference in concentrations of calcium compounds between the concrete and water phases). The hardness of water, as it is apply to concrete corrosion, is determine by the temporary hardness, which is a measure of the concentration of the bicarbonate ion (HCO_3). This is different from the concept of total hardness, which measures the concentration of calcium and magnesium cations. The aggressiveness of soft water as measured by the rate at which $Ca(OH)_2$ is leach from the cement paste is increase if the water contains dissolved carbon dioxide (CO_2). CO_2 dissolves in water to form carbonic acid (H_2CO_3) as follows (1):

$$H_2O + CO_2 \rightarrow H_2CO_3 \qquad (1)$$

This CO_2 assists by first converting the Ca $(OH)_2$ to poorly soluble calcium carbonate (carbonation reaction) and then to soluble calcium bicarbonate, which is remove by the water. These reactions are represent as follows (2 and 3):

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (2)$$

$$CaCO3 + CO2 + H2O \rightarrow Ca(HCO3)2 \qquad (3)$$

Carbon dioxide exists in water mainly in the dissolved form with a small proportion combining to form carbonic acid. The effect of CO_2 in pure water is therefore to reduce the pH (i.e. increase the acidity). The solubility of CO_2 in water increases with decrease in temperature and at 18^0 C, pure water saturated with CO_2 has a pH of around 3.95. In natural soft water, the acidity is usually a function of the CO_2 content but this can be distort by the presence of organic acids or polluting mineral acids. It should be note that a certain amount of dissolved CO_2 is required to stabilize the carbonate-bicarbonate equilibrium in the water as represent in equation (2). This CO_2 is therefore not available for $Ca(OH)_2$ leaching from concrete and it is only the CO_2 in excess of this amount, which contributes to corrosion of concrete. This excess CO_2 is termed aggressive CO_2. The pore water solution in hardened cement is highly alkaline with a pH of around 12.5. In this environment the calcium silicate, aluminate and ferrite hydrates, the main binding components of cement, are stable. However, as $Ca(OH)_2$ is leach by the soft water, the pH of the pore water decreases, causing the hydrates to become unstable and release calcium oxide (CaO) in order to re-establish the alkalinity. In this manner, the binding agent in the cement phase is attack, causing a decrease in strength. The high pH of the pore water in concrete also maintains the presence of a layer of gamma-ferric oxide on reinforcing steel, which passivates the steel and inhibits corrosion. If the leaching action of soft water reduces the pH around the reinforcement, this protective layer is destroy and the steel is expose to possible corrosion.

2.2 Deterioration of concrete

The concrete can deteriorate due to many causes; however, it typically occurs when the material is expose to the weather, water or other chemicals over an extended period. If correctly constructed and protect from these elements, the structure will last for decades with very few maintenance issues. However, in the real world some sections of a concrete structure are expose to many of these environments regally, these include industrial structures, multi-storey car parks and balconies. Once deterioration has begun, it can occur in the embedded steel as well as the surface of the concrete. All construction materials suffer some degree of deterioration with time. The problems occur when deterioration occurs to an unsatisfactory degree. In such cases, the concrete is not durable enough for the environment in which it is place. It is important to realise that most concrete is durable, and that only a small amount suffers from problems. However, this small amount is of sufficient proportion to be of concern [Jones, C. J. F. P, 1984]. Under adverse exposure condition, concrete will deteriorate. This is expect, so measures are consider to reduce the deterioration as much as possible if not completely [Perkins, P. H, 1980].

2.3 Types of deterioration of concrete

The physical causes of concrete deterioration can be divide into two categories: • Loss of mass from a concrete surface due to abrasion • Cracking due to temperature and humidity gradients, pressure due to crystallization of salts and structural loading. Abrasion is due to the wear that takes place on the surface of the structure when severe abrasion conditions exist. In addition to the use of hard aggregate, the concrete mixture should be proportion to develop at least 40 MPa compressive strength after 28-days. Structural cracks at an early age generally arise due to shrinkage and drying, depending on the factors like size of the member, characteristics of concrete materials, and their mix proportions. Thermal shrinkage is of greater importance in large concrete elements. Some of the induced elastic stress is relive due to the visco-elastic (creep) behaviour of the material. In porous materials, crystallization of salts from their supersaturated solution can produce pressure that is large enough to cause cracking

The chemical causes for deterioration of concrete can be grouped as follows: • Hydrolysis of the components present in cement paste • Reaction between aggressive fluids and cement paste • Reactions involving formation of expansive products, such as ettringite in sulphate attack, alkali-silica gel in alkali-aggregate attack, and iron hydroxide in the corrosion of reinforcing steel in concrete. In a well- hydrated Portland cement, the solid phase that is compose of calcium compounds (such as calcium silicate hydrate and calcium hydroxide) exists in a state of equilibrium with a high-pH pore fluid. That is why it is in a state of chemical equilibrium when it is expose to an acidic environment. When it is expose to water, it tends to dissolve and leach away calcium compounds, thus causing a great loss in strength. With regard to reactions, most common are those involving acidic solutions containing anions which form soluble calcium salts, such as mineral acids (HCI, $H_2 SO_4$, HNO_3) and organic acids found in food products (acetic, lactic acids). Un-reinforced concrete structures, such as pavements, retaining walls and dams would expand and crack because of Sulphate attack or alkali- aggregate reaction when the resulting expansion exceeds 0.05%, which is the limit for tensile strain in concrete. Deterioration of concrete due to corrosion of embedded steel manifests itself in the form of expansion, cracking, and loss of cover, steel–concrete bond and reduction of the cross-sectional area of reinforcement leading to the collapse of the structure. Corrosion of reinforcing steel occurs because of an electrochemical process in which a part of the metal acts as an anode, whereas another part acts as a cathode. The anode process begins only after the protective or the passive iron oxide film normally present at the surface of steel is either remove by an acidic environment (carbonation of concrete)/made permeable by the action of chloride ions. The cathode process cannot occur until sufficient supply of oxygen and water is available at the steel surface. Electrical resistivity of unsaturated or dry concrete is high; however, it is reduce in the presence of moisture and salts. The mechanism by which concrete expands and cracks because of corrosion of reinforcing steel is due to an increase in the volume of solids, which happens when metallic iron transforms into iron hydroxide rust, or due to the swelling of poorly crystalline iron hydroxide which increases the hydraulic pressure of the pore fluid. Expansion will occur when the strength and the elastic modulus of concrete is significantly reduced due to the exposure of hydration products of cement such as carbonate, sulphate, and chloride to acidic ions.

2.4 Background to deterioration of concrete

The premature deterioration of reinforced concrete bridges is a worldwide problem. Corrosion of embedded reinforcing steel caused by the use of de-icing salts on highways is the root cause of the problem in many countries. Chloride ions derived from de-icing salts penetrate into concrete and in the presence of oxygen and moisture can cause corrosion. The penetration of chloride into concrete occurs via different mechanisms depending on the exposure environment. In order to tackle this problem, it is necessary to understand how chloride ions are transport through concrete. In highway structures and bridges, concrete is subject to wetting events due to rain and condensation and dries out in between these wetting events. Chloride penetration under these conditions occur mainly by absorption and diffusion [Hong and Hooton, 1999]. There is still a lack of understanding of the processes involved, in particular the role of absorption in chloride ingress. Therefore, there is a needed to review the current state of knowledge on chloride penetration in concrete exposed to cyclic wetting and drying and identify the theoretical foundation for the experimental and modelling work.

The types of deterioration commonly found in concrete bridges are scaling, spalling, abrasion damage, alkali aggregate reactivity, and cracking, which is frequently, cause by a combination of factors. The six main causes of bridge deterioration cited by [Wallbank, 1989] in “A survey of 200 highway bridges” are alkali-silica reaction (ASR), carbonation, frost action, sulphate attack, and high alumina cement (HAC) and chloride attack. In addition, other effects such as structural stress, thermal stress, shrinkage, poor quality of detailing, materials and poor workmanship may have exacerbated the situation. Frost action is unlikely to cause a major problem on new bridges since it is normal practice in the UK to specify air entrained concrete for structural components. Corrosion of embedded steel arising from contamination by chlorides from de-icing salt is the major cause of deterioration of concrete bridges in the UK. A survey of 200 concrete highway bridges [Wallbank, 1989] confirmed that chloride contamination is widespread. In fact, 144 of the 200 bridges inspected were observe to have a total chloride level of 0.2% or more (by weight of cement). The risk of corrosion depends upon the degree of exposure to de-icing salt, which in turn depends on the geometry, design and location of individual structural elements. The most severely affected elements of bridges have proven to be those which are most frequently exposed to de-icing salt (directly or indirectly) and subject to wet/dry environments or exposed to other humidity conditions but sheltered from the rain as there will be no wash out of the chlorides from the concrete surface by rain.

2.5 Causes of concrete deterioration

There are many causes of concrete deterioration. They are usually of a complex physico-chemical nature [Bicsok, I, 1972], and most processes are water dependent, which means that without water present, the deterioration cannot occur. Deterioration may be conveniently subdivide into processes, which are of a chemical nature and those, which are physical in nature. The processes, which affect steel reinforcement, combine both physical and chemical processes.

2.5.1 Chemical deterioration

Most forms of chemical attack are well document and in most cases, concrete can be specify to resist them. Problems may occur if a particular feature of the environment has been particular feature of the environment has been overlook.

2.5.1.1 Sulphate attack

This is a problem suffered especially by concrete underground in sulphate bearing ground water [BRE Digest, 1981], or in open water containing dissolved sulphates. It suggests five classes of exposure for sulphate contents in soil ranging from 0.2- 2.0% SO_3. In which (>2.0%) total sulphate content is consider as class 5, (1.0-2.0%)-class 4, (0.5-1.0%)-class 3, (0.2-0.5%)-class 2, <0.2%-class 1 respectively. To resist these conditions, requires increases in the minimum cement content from 330-370kg/m^3, and a reduction in the maximum w/c ratio from 0.45-0.55. Degradation of concrete because of chemical reactions between hydrated Portland cement and Sulphate ions can manifest in expansion and cracking or a progressive loss of cohesiveness and strength. The most vulnerable being the Sulphate attack which is due to calcium hydroxide and the alumina-bearing phases, hence protection against this can be done by using dense, quality concrete with a low w/c ratio. Expansion and cracking of un-reinforced concrete leading to loss of cohesiveness, strength, and elasticity can also result from chemical reaction between certain reactive aggregates and alkalis in the cement paste. Aggregates containing amorphous or poorly crystalline forms of silica are consider most vulnerable, although all silicate and silica minerals including some siliceous dolomite and limestone is confirm to suffer to some extent from the alkali-aggregate attack. Sulphate attack is the deterioration of concrete by means of reactions between sulphate ions and hydrated cement products. Generally, sulphate attack is divide into two categories: External and internal. External sulphate attack is when; the source of sulphate ions is external to the concrete, such as when it is from ground water or seawater. Na_2SO_4, $MgSO_4$, $CaSO_4$ and $(NH_4)_2SO_4$ are some detrimental sulphate sources that are primarily found in ground water contaminated with industrial effluents and agricultural products. Internal sulphate attack, on the other hand, occurs when a late release of sulphates within concrete takes place. In this case, the formation of ettringite occurs after the concrete has hardened, and this results in distress.

2.5.1.2 Acid attack

This can occur in a number of ways, either from natural or manufactured acids. Naturally, occurring acids are often mild and usually affect large areas for example acidic ground water or acidic rainwater. Manufactured acids are usually concentrated, being relate to handling or processing of acidic chemicals. There are- two solutions to this which can help to improve the resistance of the concrete such as use of soluble aggregate (limestone), and acid resisting coatings (epoxy resin). Attack by sulphuric acid occurs most commonly in sewers, where many sulphide gases exist owing to the large degree of microbial action. Sulphuric acid creates an acidic environment in the concrete, in which the primary cement phases (C-S-H, ettringite) are extremely unstable. Gypsum formation occurs when sulphuric acid reacts with CH. The loss of integrity and softening of the structure occur because of gypsum formation and destabilization of C-S-H respectively. Sulphuric acid can be present or produced in different environments that surround concrete infrastructures. The places in which sulphuric acid can exist and have detrimental effects on concrete are as follows. Groundwater usually contains many different sulphates and free sulphuric acid may be one of the products. Free sulphuric acid can be produce by oxidation of pyrite (FeS_2) or other sulphides, which may exist in soils with the help of air oxygen under weathering circumstances as indicate in equation (4).

$$4\mathrm{Fe}S_2 + 15O_2 + 2H_2\mathrm{O} \rightarrow 2Fe_2\,(\mathrm{S}O_4)_3 + 2H_2SO_4 \qquad (4)$$

It should be note that the rate of the deterioration of concrete structures close to groundwater is dependent on the concentration of the sulphuric acid and the amount of water that can reach the concrete surface. The permeability of the soil that is in contact with concrete also plays an important role [Skalny et al. 2002]. Industrial waste can contain a considerable amount of sulphuric acid. Strong mineral acids, such as hydrochloric and sulphuric acids, were use to remove rust and prepare the surface in the final treatment before the iron and steel could sold to manufacturers for in the iron and steel industry. Therefore, the wastewater that is usually discharge into the underground sewage system can contain waste sulphuric acid that is very hazardous for concrete pipes and may cause severe corrosion in the short or long-term period.

2.5.1.3 Chloride attack

It has become a major problem with concrete subjected to de-icing salts in concrete infrastructures. Many of the problems associated with chlorides in these conditions result from reinforcement corrosion. In addition to these long-term effects, chlorides cause an accelerated hardening, which can lead to micro cracking due to the more rapid shrinkage and heat generation [Power, T, and Hammersley, G, 1980]. The corrosion of reinforcing steel is base on the chemistry of cement, steel and chlorides. Corrosion is an electrochemical process, which involves the oxidation and reduction equations shown in equations (5) and (6) below, respectively [Silva 2013].

$$Fe \rightarrow Fe^{2+} + 2e^- \qquad (5)$$

$$H_2O + ½O_2 + 2e \rightarrow 2OH^- \qquad (6)$$

The overall reactions demonstrating the formation of rust as $Fe(OH)_2$, $Fe(OH)_3$, and $Fe_2O_3.3H_2O$ are as shown in equations (7), (8) and (9) below [Silva 2013].

$$H_2O + ½O_2 + 2e \rightarrow 2OH^- \qquad (7)$$

$$2Fe(OH)_2 + ½O_2 + H_2O \rightarrow 2Fe(OH)_3 \qquad (8)$$

$$2Fe\ (OH)_2 + ½O_2 + H_2O \rightarrow Fe_2O_3.3H_2O \qquad (9)$$

Rust is the corrosion product of the steel, which damages the concrete via two main methods. Firstly, since rust is a compound of iron, it is less dense and approximately 60% heavier than iron from which it is produced [Rust and Rust Prevention, 2013]. As a result, rust occupies approximately three times more volume than the original iron reactant [Rust and Rust Prevention, 2013]. This increase in volume causes expansive stresses in the concrete, which may result in cracks, spalling and delamination [Rajabipour, 2003]. In addition to expansive stresses, the production of rust causes a decrease in the effective steel available to act as reinforcement. As the cross sectional area of the steel decreases, the load carrying ability of the reinforced concrete also decreases [Rajabipour 2003]. The decrease in cross sectional area is the deterioration method most common in chloride induce corrosion [ARRB, 1998]. Concrete damage by chloride attack is a consequence of steel corrosion alone, as chlorides do not contribute to cement deterioration

[Neville 1995]. Reinforcing steel in concrete reacts with oxygen to produce the passivity layer, made from insoluble ferrous oxide [Rajabipour 2003]. The passivity layer works to protect the steel from corrosion when the alkalinity of the concrete and cement matrix is above a pH of 12 [Rajabipour 2003]. Chloride presence causes the passive film to break down at specific sites, leading to acceleration of anodic steel dissolution at these locations [ARRB 1998]. Chloride ions are not immediately involved in the corrosion reaction, but instead leave steel vulnerable to corrosion. The decomposition of the passivity layer is represent in equation (10) below [Talero et al. 2010].

$$Fe^{2+} + 2cl^{-} \rightarrow Fecl_2 \qquad (10)$$

The ability of ions to permeate through the concrete and reach the reinforcing steel is an indication that the cement matrix contains defects [ARRB 1998]. Therefore, it may be necessary to understand the mechanisms of cement damage in order to prevent chloride transport through concrete and hence concrete damage caused by steel corrosion.

2.5.1.4 Other causes

Chemical attack are not of major concern from a structural point of view, but they can affect the aesthetics [Lea, F. M, and Davey, N, 1949] and they may be of the form such as leaching; the formation of stalactites and stalagmites; staining; and growths of algae or lichen. These are dependent on and caused by water on the surface of the concrete or seeping through it. When a cement-based material experiences humidity for a long time, water may penetrate into the material, causing leaching of calcium hydroxide. Penetrating water in cement-based materials along the path of capillary pores renders a ubiquitous ion concentration unbalanced. High concentration ions sequentially move forward to low concentration ions, inducing leaching of hydration products [Saito, H, and Deguchi, 2000]. In addition, underground oil storage composed of cement-based materials also requires care against leaching of calcium ions because concentration ions leach out from cement-based materials to soil or rock, which is in contact with ground water. Leaching of calcium hydroxide was confirm to be a common case in the underground environment. During the leaching process, calcium hydroxide was consider the first hydration product leached from the cement-based material due to its solubility. Calcium hydroxide is slightly soluble, and can be leach out because of enlarging capillary pores [Agostini, F. et al, 2007]. Leaching of calcium ions increases the porosity of cement-based material, thus resulting in degradation including damage to the pore structure. Increasing porosity results in a weakened matrix and lower compressive strength of the cement-based material. Leaching of calcium ions also has a detrimental effect on durability, since the occurrence provides an entry for aggressive harmful ions into the cement-based material, causing reinforcing steel corrosion.

2.5.2 Physical deterioration

The physical deterioration can be either natural or manufactured. It can affect the concrete by wearing away the surface, or by disrupting the concrete from the inside. Some chemical processes do not directly affect the concrete chemistry, but in turn cause disruption.

2.5.2.1 Abrasion and Erosion

These are processes, which result in removal of the concrete at the surface. They are 'caused by movement across the concrete surface, or by impacts on it. In structural concrete, especially in industrial environments, vehicles can cause damage by wear either from the wheels or by impact with the concrete. Where damage due to abrasion is likely to be problem, a good quality concrete wearing course is usually the best option. If large areas of concrete are at risk such as roads, or sea defences, then a degree of deterioration may be acceptable when combined with a planned programme of maintenance [McDonald, J. E., & Liui, T. C, 1980]. Most of the abrasion damage is cause by the action of water-borne particles (silt, sand, gravel, and other solid) impacts and rolling against the concrete surface during hydraulic structure operation. Research work carried out by (Yu-Wen Liu, Shi-Wei Cho, and Tsao-Hua Hsu, 2012) on the solid-particle abrasion of concrete containing slag. Test results show that the abrasion rate to be a strong function of erodent size and waterborne sand content. As the erodent size increased from 0.6 mm to 1.2 mm, 2.5 mm, then to 5mm, the abrasion rate of concrete increased from 100% to 217% and 367%. The waterborne sand content was 110, 230 and 340 kg/m3 and the abrasion rate of concrete is 22-56 times of none sand water. Moreover, the abrasion rate of concrete impacted at 90° was higher than of that of 30°, 45° and 60°. According to ACI ''Abrasion erosion is a process of friction and impact of water borne particles such as silt, sand, gravel, rocks, ice and other kind of debris over a concrete surface of a hydraulic structure'' [ACI 2003]. The abrasion erosion impact can be easily recognize it creates a smooth, worn-appearing surface where erosion due to cavitation leaves small holes and pits on the surface. There are several factors, which affect the rate of abrasion erosion, and these factors can be categorize into two types. The first type is relate to the characteristics of flow and water-borne particles and the second type is relate to the properties of concrete itself. The major factors of the first type are size, shape, hardness and density of particles being transport in the water, the flow velocity and impact angle of water on concrete surface. Bridge piers, spillway aprons, sluiceways, stilling basins and tunnel linings are most vulnerable to abrasion erosion [ACI 2003].

2.5.2.2 Fire damage

The Fire damage is a special case, which has always to be treat differently [Long, W. B, 1984]. Damage can be merely discolouration, or it may be disruption of the structural elements of the concrete [Smith, L, 1985]. Fire can cause damage directly by the effects of differential expansion and contraction of the constituents, as well as a pressure build-up of steam. In addition, the heat may lead to a breakdown of the cement hydrates, and in reinforced concrete, it may lead to a loss of strength of the steel. Concrete can sustain various degrees of damage depending on the severity of the fire and the high temperature levels reached. The effects on concrete components of high temperature fire includes: reduction in compressive strength; micro-cracking within the concrete microstructure; colour changes consistent with strength reductions; reduction in the modulus of elasticity; possible loss of residual strength of steel reinforcement and possible loss of tension in prestressing tendons [Andrews-Phaedonos, F, 2007, Concrete Society,1990 and Alberta Infrastructure-Transportation, 2005]. The more severe fire damage would also involve the total exposure of main bars, significant exposure of prestressing tendons, significant cracking and spalling, buckling of steel reinforcement and even significant fracture and deflection of concrete components.

2.5.2.3 Freeze-Thaw

The freezing in itself may not be detrimental to concrete; however, a combination of freezing and thawing will produce scaling or general deterioration. The problem is because by an expansion of water as it freezes, followed by repeated expansion as the ice melts, and the water refreezes. This has the effect of breaking down the pore walls and enlarging any cracks or defects, until the material crumbles. Many factors affect a concretes ability to resist freeze-thaw action, these include aggregate type, curing conditions, and the time of year that the concrete was cast [Weaver, W. S., and Isabelle, H. L, 1968]. Due to the need of practical application, many reinforced concrete structure were (will be) built in cold regions that inevitably subjected to freezing and thawing action [Özgan, E, and Serin, S, 2013]. One main reason of durability problem in reinforced concrete structures in cold environment is the damage caused by action of freezing and thawing. Many current research works were confirm to deal with the durability of concrete, especially the freeze-thaw resistance in cold environment [Shang, H.S, Yi T.H, and Song, Y.P, 2012]. However, this question still needed further investigations.

2.5.2.4 Alkali aggregate reactions

The alkali silica reaction is essentially a chemical reaction between the alkali metals in the cement compounds, principally the sodium and potassium, with certain types of reactive silica, which may be present as aggregate within the mix. The reaction can only take place in the presence of water and leads to the formation of a gel, which expands and so disrupts the concrete. It is possible that the presence of free chloride increases the risk of this reaction [Byrd, T, 1985]. Alkali carbonate reaction is a reaction between certain types of carbonate aggregates such as dolomites and the cement compounds [French, W. J, and Poole, A. R, 1976]. The reaction can be compare to the pozzolanic reaction , which would be catalyse by the undesirable presence of too high concentrations of alkali hydroxides (NaOH and KOH) in the concrete. It is a mineral acid-base reaction between NaOH or KOH, calcium hydroxide, also known as Portlandite, or ($Ca(OH)_2$), and silicic acid (H_4SiO_4, or $Si(OH)_4$). When complete and to simplify, this reaction can be schematically represent as in the following equation (11):

$$Ca\,(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2\,H_2O \rightarrow CaH_2SiO_4 \cdot 2\,H_2O \qquad (11)$$

ASR reaction significantly differs from the pozzolanic reaction by the fact that it is catalyse by soluble alkali hydroxides (NaOH/KOH) at very high ph. It can be represented as follows using the classical geochemical notation for fully hydrated dissolved silica ($Si\,(OH)_4$ or silicic acid: H_4SiO_4), but an older industrial notation also exists (H_2SiO_3, hemihydrate silica (does not exist), by analogy with carbonic acid) as shown in equations (12 and 13):

$$2\,Na(OH) + H_4SiO_4 \rightarrow Na_2H_2SiO_4 \cdot 2\,H_2O \qquad (12)$$

$$Na_2H_2SiO_4 \cdot 2\,H_2O + Ca(OH)_2 \rightarrow CaH_2SiO_4 \cdot 2\,H_2O + 2\,NaOH \qquad (13)$$

The combination of the two above mention reaction, as shown in equations (12 and 13) gives a general reaction resembling the pozzolanic reaction. But it is important to keep in mind that this reaction is catalyse by the undesirable presence in cement, or other concrete components, of soluble alkaline hydroxides (NaOH /KOH) responsible for the dissolution of the silicic acid at high pH as indicate in equation (14):

$$Ca(OH)_2 + H_4SiO_4 \rightarrow CaH_2SiO_4 \cdot 2\,H_2O \qquad (14)$$

Without the presence of NaOH or KOH responsible for a high pH (~13.5), the amorphous silica would not be dissolve and the reaction would not evolve. Moreover, the soluble sodium or potassium silicate is very hygroscopic and swells when it absorbs water. The only way to avoid ASR in the presence of siliceous aggregates and water is to maintain the concentration of soluble alkali (NaOH and KOH) at the lowest possible level in concrete, so that the catalysis mechanism becomes negligible. Damage and defects observed in concrete elements, such as a network of micro cracks, pop outs and efflorescence could be cause by a variety of deleterious processes. The causes can include mechanical (overloading), physical (freeze-thaw cycle) or chemical exposure (sulphate corrosion, alkali-aggregate reaction). The analysed concrete elements exhibited cracking, exudations and surface pop outs. Identification of the presence of hydrated sodium-potassium calcium silicate gel can be consider the primary symptom suggestive of an alkali-silica reaction attack as analysed by (Owsiak, Z, 2015). Other damage-causing mechanisms can occur simultaneously and analyses distress due to alkali-silica reaction, detected in selected concrete structures.

2.5.2.5 Shock waves

The heterogeneous nature of concrete makes it prone to damage from shock waves, and shock induce forces cannot be transmit through the material adequately [Johnson, S. M., 1965]. Common shock forces are pile driving, and impacts of ships or ice on coastal structures. Experience from earthquakes and blasts shows that the best way to protect concrete against shock loads is through extensive use of reinforcement. Earthquakes produce shock waves. These travel through the Earth and can be detect using a device called a seismometer. There is an urgent need to protect civilian structures from blasts. The major effect of a terrorist-type bomb is from the blast, particularly from blast wave reflection when the pressure is amplify through multiple reflections in multiphase media or in confined geometries. Protective strengthening and hardening are the two measures that can be consider preventing or minimizing damage to a structure from blast waves [National Academic Press, Washington D.C, 1995]. The best way to protect an existing structure is hardening like building a protective barrier built around it. In order to withstand the transient loads generated by bomb blasts, the elements of a structure need to be both massive and able to absorb large amounts of energy. For this reason, nearly all purpose-built protective structures are construct of concrete or reinforced concrete.

There have been a few studies on the blast and projectile impact on concrete. Lepaanen, 2005 used spherical fragments to shoot against concrete blocks from various distances and at various speeds. Analyses of these structures were carry out to study both global and microscopic effects. It was confirm that greater damage occurred at the point of impact. This has been attribute to the fact that fragment impact causes only local damage whereas the blast wave impact causes global damage. Therefore, it is fair to assume that a shock wave impact has the same global effect as that of a blast wave impact. Warren et al., 2004 developed a numerical model for the penetration depths of projectiles impacts low-strength concrete. They found a 2-15% difference between the numerical model and the experimental data obtained. Certain effects such as dynamic fracture processes are very complex that are presently not well model.

2.5.2.6 Other causes

Concrete defects may occur before the concrete sets such as settlement of the subgrade; formwork movement; vibration; setting shrinkage; and, premature support removal [Johnson, S. M., 1965]. These can all lead to defects, which could be avoid by good site practice. Other defects may be the result of poor design detailing, which again could be avoid such as rapid changes of section, rigid joints, excessive deflections, leaking joints, poorly designed drips, poor drainage, inadequate movement joints, thermal stresses, and incompatible materials [Johnson, S. M., 1965]**.**

2.5.3 Reinforcement corrosion

The reinforcement corrosion is one of the major cause of concrete deterioration in the UK [Warner, C. D, 1983], and it is considered to be the main cause of bridge deterioration [Figg, J. W, 1980]. Reinforcement corrosion has been closely relate to the process of carbonation, and to the presence of chlorides in the concrete. Both have different effects on the concrete and so affect the reinforcement in different ways. In recent years, demands on extending the service life and increased traffic loads have heightened the interest in the durability and structural assessment of existing infrastructures, in particular owing to economic considerations. Meanwhile, ageing and deterioration due to aggressive environment have been occurring in many existing reinforced concrete (RC) structures. Deterioration may affect both serviceability and ultimate load-carrying capacity. Consequently, understanding the actual behaviour of an impaired structure and a realistic estimation of its remaining service life are of great importance to responsible authorities, stakeholders, engineers and researchers. The corrosion of embedded reinforcement in concrete is consider one of the main causes of the deterioration of many existing RC structures [Sistonen et al. 2008]. Corrosion causes high costs in developed countries; as an example, the average annual cost to repair and replace conventional reinforced and prestressed concrete highway bridges specifically owing to corrosion damage was already fifteen years ago in the US more than $ 6.3 billion [Koch et al. 2002]. Corrosion may affect the structural performance and integrity of reinforced concrete components to a considerable degree over the long run [CEB-fib, 2000]. The corrosion of steel bars embedded in concrete may lead to several undesirable consequences, such as potentially severe damage resulting in the loss of a cross-sectional area of steel, which would reduce both the capacity and ductility of the reinforcement [Fernandez et al. 2015]. Furthermore, by occupying a higher volume than the original steel, the corrosion products affect the surrounding concrete, thereby increasing the mechanical pressure around the reinforcement. Crack propagation and cover delamination are the two most common physical signs of this phenomenon according to [Dang et al. 2013]. The volume expansion of rust not only causes splitting stresses but also affects steel-concrete bond properties, for an overview [Sæther, 2010]. These effects must be consider in structural assessments when corrosion takes place in anchorage zones [Imbsen et al, 1987]. Over the past few decades, many research studies have been conduct focusing on tests of damaged reinforced concrete specimens subjected to artificial corrosion attack. The loss of stiffness during the service life [Cairns et al, 2005], and the decrease of load-carrying capacity and ductility in the ultimate limit state [Zhu et al. 2015], were the main findings of these studies. Saifullah et al. (1994) showed that the current density applied to accelerated corrosion tests might notably influence bond strength. The comparisons of test results with low and high corrosion rates showed deviant behaviour of the local bond [Sæther, 2010], differences attributed to the chemistry of corrosion products, their ability to escape through cracks or penetrate the cement matrix, as well as concrete creep [CEB-fib, 2000]. While much effort has been devoted to testing artificially corroded reinforced concrete, relatively little attention has been devoted to the problem of assessing the residual strength of corroded structures in natural environments. Accordingly, there was a strong need for experiments involving naturally corroded specimens in order to gain an understanding of the true behaviour of corroded structures, as well as valuing the validity of different assessment methods developed and calibrated based upon the test results of accelerated-corrosion tests. Most of the above-mentioned research studies have been mainly focusing on the relationship between the degree of corrosion of steel reinforcement bars and the load carrying capacity of corresponding RC elements. Several empirical, analytical and numerical models have been develop to correlate corrosion level to load-carrying capacity [Bhargava et al. 2008]. However, since corrosion levels cannot be easily measure in existing structures, these models do not yet have any direct practical application. Given the fact that cracking, as the first sign of deterioration in RC structures, is mostly detect through visual inspection, simplified models are need to correlate cracking to structural strength. A few studies have investigated the correlation between corrosion attack and splitting crack opening on artificially corroded specimens [Andrade et al. 2016].

2.5.3.1 Concrete carbonation

The carbonation is consider the main cause of reinforcement corrosion in the UK [Beckett, D, 1986]. It is a chemical process in which atmospheric carbon dioxide (CO_2), dissolved in water(H_20), reacts with the calcium hydroxide ($Ca(OH)_2$) produced by the cement hydration to form calcium carbonate ($CaCO_3$). In a simple form, this is as shown in equation (15):

$$CO_2 + H_2O + Ca\,(OH)_2 \rightarrow CaCO_3 + 2H_2O \qquad (15)$$

This process in itself is not harmful to concrete or steel and it may in some instance to be beneficial. In impermeable concrete, the carbonation actually improves the surface properties, increasing the strength and forming a protective layer on the concrete surface [Currie, R. J, 1983]. This can help to reduce sulphate and corrosive attacks, and reduces leaching. In concrete that is more permeable, the carbonation can move a long way into the concrete. This creates a problem when steel reinforcement is present. Under normal circumstances, steel in concrete is protect by the alkaline environment, with pH values in excess of 13 frequently being observe in Portland cement paste [Dawson, J. L, 1983]. Concrete deterioration can take place due to a reaction between hydrated cement paste products and atmospheric CO_2, which can occur in all environments, but mainly in dense urban cities where pollution and certain climatic conditions favour such process. This reaction reduces the pH of the concrete pore solution, leading to the corrosion of the embedded reinforcement steel bars and subsequent formation of cracks in the concrete, which, in the end, results in a decrease in the residual service life of the structure. Carbonation rates vary depending on factors such as type and amount of cement used, concrete porosity, curing time, and type and quantity of minerals added [Moreno, E. and Sagüés, A, 1998]. Additionally, carbonation rates in concrete structures can also be influence by macro and microclimatic conditions, architectural design, environmental conditions such as humidity and insulation [Castro-Borges, P et al 1997], and the structure’s position relative to sea level [Castro-Borges, P, et al, 2000]. Because of carbonation, concrete structures may exhibit changes in concrete properties such as compressive strength, superficial hardness and resistance to aggressive agents such as sulphates and AAR [Verbeck, G, 1958].

2.5.3.2 Chlorides

The chlorides have three effects, which influence reinforcement corrosion: i) chlorides attack the steel by breaking down the passive layer [Beckett, D, 1986]; ii) presence of chloride concentrations results in the formation of electrical differentials within the steel [Arup, H, 1983]; and, iii) chlorides affect the cement hydrates leading to micro cracking. It has been report that corrosion resulting from externally applied chlorides is much worse than that resulting from chlorides added at the mixing stage [Mehta, P. K, 1977]. The corrosion of metals, especially steel, in concrete has always received increasing attention because of its widespread occurrence in certain types of structures and the high cost of repairs. The corrosion of steel reinforcement was first observe in marine structures and chemical manufacturing plants. More recently, numerous reports of its occurrence in bridge decks, parking structures, and other structures exposed to chlorides have made the problem particularly prominent [ACI 222R-01, 2004].

2.5.3.3 Other causes

The Reinforcement corrosion may occur as a direct result of another form of concrete deterioration, which exposes the steel directly to water and oxygen, or weakens the concrete sufficiently. In addition poor design and site practice can result in poor concrete in the cover zone which is then unable to provide protection to the steel [Beckett, D, 1986]. This may be caused by: 1) inadequate cover, due to poor design, or bad steel fixing; ii) plastic cracking, or settlement cracking, due to inadequate compaction; iii) honeycombing, or permeable cover due to poor mix design, or poor concrete handling on site; or, iv) permeable cover due to inadequate curing.

2.5.4 Discussion of deterioration

The deterioration is a subject, which is very easy to consider in purely academic terms. However, the implications of deterioration go deeper than the processes that cause it. What is its extent, what attitudes are there to concrete at design, construction, during its lifetime, will the problem of deterioration get worse. Will it be reduce by current knowledge? What options are available in the light of the knowledge we already have?

2.5.4.1 Extent of deterioration

Deterioration in one or more forms is likely to occur whenever anything is build, no matter what materials are used. The geographical extent of the deterioration is not important; of real importance is whether this is a crisis that is growing to epidemic proportions, or whether it is merely an overreaction to a problem which until recently received very little publicity. Major deterioration could be attribute to a particular set of circumstances. In the past, these have been such things as [Somerville, G, 1986]: i) introduction of salt as a de-icing agent on roads, ii) boom in construction in middle east during the 1970s, without enough thought being given to the aggressive conditions, and material, iii) use of high alumina cement without enough knowledge of its stability in certain service conditions.

2.5.4.2 Attitudes to deterioration

The concrete should not deteriorate, but in a real world, the factors controlling whether it does or not are frequently nothing to do with the material properties. Deterioration is unavoidable, recognises that ageing of concrete is a natural process, which cannot be stop. Problem then is to define the design life or service life that we can expect/want from the concrete [Barry, D. L, 1983], should it be acceptable, either now, or in the future, and what if anything can be done to change the situation?

2.5.4.3 Effects of deterioration

What are the effects of concrete deterioration? The physicochemical effects were well understand and easily analysed, but what about the socio-economic effects. A structure does not have to collapse and fall down to be a failure [Tuthill, L. H, 1980]. The main rival to concrete in the construction industry is steel, even though it is recognise that unprotected steel deteriorates under normal exposure conditions, whereas good concrete does not [Lawrence, C. D, 1985].

2.6 Corrosion mechanisms

The concrete structure that is in close proximity with water faces a myriad of life shortening processes. Reinforced concrete infrastructure, found in marine environments, commonly face reduced life spans due to exposure to extreme environmental conditions, which allow water and waterborne chlorides to penetrate through the concrete to the reinforcing steel. This contact results in corrosion and expansive cracking, which leads to premature deterioration. In order to ensure concrete structure do not face a reduced life span due to water, steps must taken to protect them. The first step understands how water damages concrete in the first place. There are three essential components necessary for corrosion to take place in reinforced concrete: electrolyte for ion transfer (water), conductor for electron transfer (steel reinforcement), and oxygen. Eliminating one of the above will mitigate the damages due to corrosion. This is why there is no corrosion in dry concrete; furthermore, this is also, why it is important to have low permeability concrete to prevent the movement of water and the harmful chemicals in solution from reaching the steel reinforcements. Overall, Concrete is a great host for the rebar. Due to the high-alkalinity of concrete, the steel reinforcing bars develop a passive layer that provides a protective barrier to the steel. In this state, concrete normally provides reinforcing steel with excellent corrosion protection. However, the passive layer can be broken down over time due to atmospheric carbon dioxide, causing carbonation, which lowers the pH of the concrete and destabilizes the passive layer. However, carbonation is a slow process and the overall rate depends on the density of concrete and humidity of the exposed environment. Durable concrete with low permeability can reduce the rate of carbonation, in addition to slowing down the rate of water penetration necessary for corrosion to occur.

Poor quality concrete has more connected pores and larger capillaries, which increase the potential for the ingress of detrimental substances into the concrete. Substances such as chlorides can enter into the concrete through the pore network, leading to the breakdown of the passive protection layer around the rebar. Without the passive iron oxide film protecting the steel, corrosion is able to commence at a much higher rate. The most common type of sulphate attack is through external means, whereby water containing dissolved sulphate penetrates the concrete. This is usually the result of high-sulphate soils and ground waters, but can also be cause by atmospheric or industrial water pollution, bacteria in sewers, or even just regular seawater. A sulphate attack will typically change the composition and microstructure of the concrete and lead to extensive cracking, Expansion, and Loss of bond between the cement paste and the aggregate. Occasionally, certain aggregates can react with the alkali hydroxides in concrete, causing slow deterioration of the concrete through expansion and cracking. These hairline cracks, which develop, are an invitation for water to cause corrosion of the rebar even in above-grade structures. There are two forms of alkali-aggregate reaction, Alkali-Silica reaction (ASR) and Alkali-carbonate reaction (ACR). ASR is the more concerning type of reaction, as it is more common to find aggregates that contain reactive silica materials, and the latter, ACR, is relatively rare. With ASR, the silica in these aggregates react with alkali hydroxide in concrete and forms a gel that swells by absorbing the water in the surrounding cement paste, or any water that finds its way into the concrete. As the gel absorbs more moisture, the swelling effect can cause long-term damage to the concrete by inducing expansive pressure. Cracking is often an indicator that ASR is present, with the cracking often located in areas with a frequent supply of water or moisture. Freeze/thaw actions will likely cause deterioration to non-air entrained concrete. When water freezes to ice, it occupies 9% more volume then that of water. With no available space for this increase in volume, freezing can cause distress to concrete leading to hairline cracks. Thawing will then allow water to penetrate through the cracks and with each freeze/thaw cycle increase the number and size of hairline cracks, resulting in greater damage to the concrete. Some noticeable signs of freeze/thaw damage are spalling and scaling of the concrete surface, surface parallel cracking, or exposed aggregate.

The concrete normally provides a high degree of protection to the reinforcing steel against corrosion due largely to the high alkalinity (p^H 12-13) of the pore solution. Under these conditions, a microscopically thin oxide layer of gamma ferric oxide (γ_Fe_2O_3), called the passive film is form on the steel surface. The passive film is a dense and protective layer, which if fully established and maintained prevents further corrosion of the steel. Normally this passivity is stable during the whole service life of a reinforced concrete structure but there are two mechanisms, which can destroy the passive film. These mechanisms are carbonation and chloride intrusion. [Ahmad. S, 2003]. Carbonation is a process in which atmospheric CO_2 diffuses through the porous concrete and reacts with the alkaline substances of the pore solution of the concrete according to the generalized reaction as indicate in equation (16):

$$Ca\,(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (16)$$

This reaction consumes alkalinity, $Ca\,(OH)_2$, and reduces the pH of the pore water in hardened Portland cement paste. The pH of pore water is reduce from between 12.6-13.5 to a value of about 8.3 when all the quantity of dissolved $Ca\,(OH)_2$ in the pore solution and of solid $Ca\,(OH)_2$ in the cement gel is converted to $CaCO_3$. When the pH around the surface of the reinforcing steel reaches this value, the protective oxide film is no longer maintained and corrosion can take place, provided sufficient oxygen and moisture necessary for the corrosion reactions are present [Neville, 2003]. In the case of chloride intrusion, chloride ions have only a small influence on the pH of the pore solution. However, they can destroy the passive layer when the chloride content in the pore solution exceeds a critical value (chloride threshold). However, it has proved rather difficult to establish a threshold chloride concentration below which there is no risk of corrosion as it depends on numerous factors including [Bertolini et al, 2004]: 1- pH of concrete. 2- Presence of voids at the steel/concrete interface, which depends on the workability of fresh concrete and the compacting procedure. An analysis of the data obtained on bridge structures in the U.K. suggested that chloride levels below 0.2% (by weight of cement) represent minima1 corrosion risk, while levels above 1.5% represent a very high corrosion risk. The results of similar work on the U.S. bridges suggested a range between 0.17 and 1.4% (by weight of cement), on Danish bridges 0.3 and 0.7% (by weight of cement), and while notably high threshold levels (from 1.8 to 2.2% by weight of cement) were reported in one survey of Austrian bridges. [Glass and Buenfeld, 1997]. In which Figure 2-1 shows the risk of corrosion determined on U.K. bridges plotted as a function of chloride content [Glass and Buenfeld, 1997].

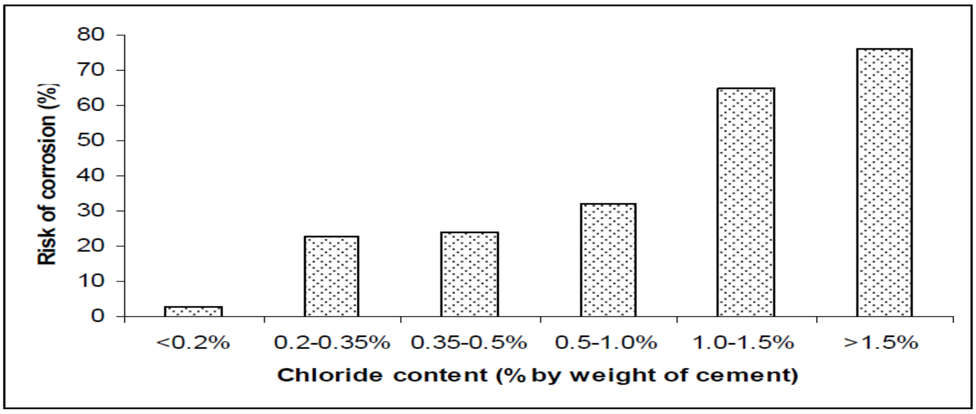


Figure 2-1 Risk of corrosion on U.K. bridges v/s chloride content

Although, generally, the chloride threshold value for structures exposed to the atmosphere is assume to be in the range of 0.4-1% by mass of cement, such values may significantly change, depending on the above parameters. When the chloride content in the pore solution exceeds the threshold level, chloride ions activate the surface of the steel to form an anode, the passivated surface being the cathode. The reactions involved are as the following [Neville, 2003] as shown in equations (17 and 18).

$$Fe^{2+} + 2Cl^{-} \rightarrow FeCl \qquad (17)$$

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl \qquad (18)$$

Once the passive layer breaks down then areas of rust will start appearing on the steel surface in the presence of oxygen and water. The chemical reactions are the same whether corrosion occurs by chloride attack or carbonation. A brief description of the corrosion phenomena is as follows [Broomfield, 2007]. When steel in concrete corrode it dissolves in the pore water and gives up electrons as noted in equation (19):

$$\text{The anodic reaction: } Fe \rightarrow Fe^{2+} + 2e^{-} \qquad (19)$$

The electrons pass through the steel into the cathode where they combine with water and oxygen as represent by equation (20) to form hydroxyl ions $(OH)^-$.

The cathodic reaction: $2e^- + H_2O + ½O_2 \rightarrow 2OH^-$ (20)

The anodic and cathodic reactions are the first steps in the process of creating rust. In the next stage, hydroxyl ions travel through the electrolyte and combine with ferrous ions to form ferrous hydroxide, which is in turn, converted by further oxidation to rust (Figure 2-2) as represent by equations (21, 22, and 23).

$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$ Ferrous hydroxide (21)

$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$ Ferric hydroxide (22)

$2Fe(OH)_3 \rightarrow Fe_2O3.H_2O + 2H_2O$ Hydrated oxide (rust) (23)

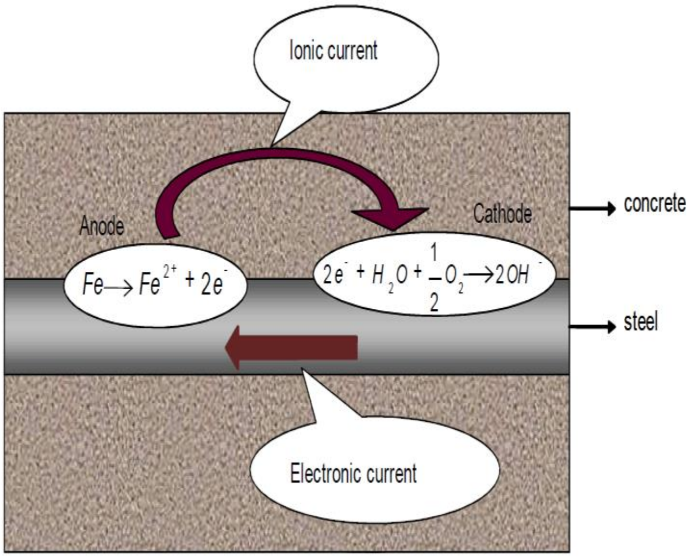


Figure 2-2 Anodic, cathodic, oxidation and hydration reactions for corroding steel

Unhydrated ferric oxide Fe_2O_3 has a volume of about twice that of the steel it replaces. When it became hydrate, it swells even more and becomes porous and thus the volume increase at the steel/concrete interface is between six and ten times. This leads to cracking, spalling and delamination of concrete. This inevitably makes it easier for aggressive agents to ingress toward the steel, with a consequent increase in the rate of corrosion. Progress of corrosion at the anode reduces the cross-sectional area of the steel, thus reducing its load-carrying capacity [Broomfield, 2007]. When the supply of oxygen is severely limited, corrosion can occur at a slow rate. The products of corrosion, which are less voluminous than under normal circumstances, may travel into voids in the concrete without progressive development of cracking and spalling [Neville, 2003].

2.7 Corrosion prevention and protection methods

There are a number of methods for prevent corrosion of reinforcement in concrete structures. The cost of prevention carried out during the design and execution stages are minimal compared to the cost of repair and rehabilitation, which might be required later. Corrosion prevention methods for reinforced concrete structures include such as: (1) specification of minimum concrete grade and cover (2) concrete surface treatment (3) barriers and deflection systems (4) corrosion inhibitors (5) corrosion-resistance reinforcement (6) cathodic protection.

2.7.1 Design for durability-concrete grade and cover

There are two major factors which influence the durability of reinforced concrete are (1) the resistance of concrete against penetration of aggressive agents (concrete grade) and (2) the thickness of the concrete cover. The quality of concrete depends on a wide range of factors such as w/c ratio, cement type and cement content, mixing, compaction and curing. These factors influence the pore structure of the concrete. A dense pore structure reduces the penetrability of concrete and enhances its permeation properties. Concretes made with lower w/c ratio have shown a better resistance to the penetration of aggressive agents. The thickness of concrete cover can be typically in the range of 10-70 mm. An increase in the thickness of concrete cover increases the barrier to the various aggressive agents moving towards the reinforcement and increases the time for corrosion initiation. Therefore, as the environmental aggressiveness increases it is theoretically possible to maintain a constant level of durability by increasing the thickness of concrete cover. However, the cover thickness cannot exceed certain limits. A thick layer of concrete cover may form cracks due to tensile forces exerted by drying shrinkage of the outer layer, while the wetter core does not shrink.

Following the standard's recommendations as per [BS EN: 206-1:2000] should prevent corrosion of reinforcement in many cases. However, the recommended value of concrete grade and cover depth are not adequate in some conditions of environmental exposure and unacceptable levels of corrosion have occurred in a relatively short period. In fact, recommendations by standards and codes have not provided adequate protection for severe environments.

2.7.2 Surface treatment of concrete

The surface treatments are apply to new structures as a preventative method, to existing structures where the need for future protection is anticipated and to repaired structures in order to improve the service life of the repairs as well as to mask the visible effect of repair [Bertolini et al 2004]. Surface treatments are a wide range of materials, which either make the concrete cover zone less permeable to aggressive substances or reduce the moisture content of concrete and thus increase its resistivity. Organic surface coatings are use to block the penetration of chloride ions by forming a continuous polymeric film on the surface of the concrete. Acrylic dispersions paints, epoxy resin paints, polyurethane, chlorinated rubber or acrylic rubber paints are some example of surface coatings [Bertolini et al 2004]. Surface coatings vary from very dense to rather open structures. Epoxy resins and chlorinated rubber polymers are dense coatings, which block the ingress of aggressive agents. However, they also prevent evaporation of the moisture that is present in the concrete at the time of treatment. This situation may lead to loss of adhesion to the concrete and thus a loss of effectiveness of the coating [Bertolini et al 2004]. On the other hand, acrylics are relatively open. Therefore, they are more permeable than the other coatings. However, this openness also makes them more durable as they allow evaporation of water vapour from inside the concrete. Therefore, their durability, which may extend beyond 10 years and the fact that they are very effective at reducing water ingress from the environment make them very popular [Bertolini et al 2004].

Penetrating sealers (hydrophobic treatment) have been recommend as a way of stopping chlorides getting into concrete by reducing capillary absorption of water and dissolved chloride ions. Silanes, siloxanes and siloxysilanes are some examples of these materials. The chemistry of the process is that silanes, siloxysilanes and similar chemicals penetrate the pores of the concrete and react with the water in the pores to form a hydrophobic layer that stops water getting in but does not affect the ingress of gaseous species and thus allows water vapour in and out of concrete [Broomfield, 2007]. Since the penetrating sealer is within the concrete, it is protect from physical damage and degradation by ultraviolet light. However, the problem is on the depth of penetration of the sealer into concrete. It is more difficult to obtain sufficient penetration of sealers in concrete with a dense pore structure and thus they are less effective in high-density concrete [Broomfield, 2007].

An extension of bridge working service life that surface treatments can provide clearly depends on the exposure conditions, concrete quality, cover depths and the reduction in water/chloride ingress achieved by the treatment. It also depends on the treatment being maintain effectively. Nevertheless, without maintenance the treatment may be sufficient to maintain serviceability for a finite period while, for example, a new structure or alternative route is plan. Concrete bridge structures most often experience different forms of deterioration, due to environmental and chemical attacks as inferred by [Md. Safiuddin and K. A. Soudki, 2011]. Sealers and coatings were use to reduce these forms of concrete deterioration by limiting penetration of water and water-borne deleterious agents, such as chlorides and sulphates. Moreover, sealers and coatings are use to resist chemical attack and corrosion damage due to de-icer and anti-ice chemicals. They also facilitate moisture vapour transmission, and thus aid rapid drying and mitigate effects of corrosion.

The experimental results showed [Cui Gong, et al, 2012] that the two silanes can penetrate to the depth of about 2∼6mm. Compared with untreated samples, the reduction of water absorption and chloride absorption of treated concrete was higher than 90%. The chloride diffusion coefficient and electric flux decreased obviously. The protection effect of silanes on concrete both improves with the increase of painting amount. The protection of silane gel on concrete was better than that of silane solution. Surface treatments either are use as part of a maintenance programme or repair work, which was report by [P. A. M. Basheer, and Long, 1997]. In both cases, they provide additional protection to the concrete by either arresting or reducing the penetration of aggressive substances from the environment. Numerous materials are available for this purpose and their inherent generic properties differ considerably. Quite often, this poses difficulties to practising engineers when selecting a surface treatment for a specific situation. In this review, it is possible to explain the protective aspects of various surface treatments so that their selection should be easier. Calder and McKenzie (2009) measured the weight gain (‘sorptivity’) of treated and untreated concrete cubes (w/c ratio 0.45) exposed to water on one surface for up to seven days. Silane/siloxane treatments all significantly reduced the uptake of water. Silicate and siliconate treatments resulted in similar, or slightly higher, water uptake than untreated controls, even though these products complied with the requirements of BD 43/03.

Hydrophobic impregnation is the most widely employed method to combat chloride attack for concrete structures. In this study, a silane-based material and a water-based material were evaluate, each applied on concrete cubes subjected to moisture pre-conditioning for up to 48 h. The test cubes were all surface dried prior to the application of the impregnate, and then submerged in sodium chloride solution for 60 d, before collecting dust samples at various depths, by dry drilling. When applied in dry conditions, the silane-based impregnate was more effective than the water-based one. The performance of both impregnates was significantly reduced when the concrete was subject to wet conditions for long periods. Internal moisture thus has a significant effect on the performance of the impregnate. A practical interpretation is that the specified 24 h drying period may not be sufficient to secure the benefit from hydrophobic impregnation [M.M.Rahman, et al, 2015].

Until recently, solvent-based forms of monomeric alkyl (isobutyl) trialkoxy silane, produced under various trade names, were exclusively use in the United Kingdom for concrete protection of transportation structures and other structures subject to surface salt contamination. This investigation evaluated the performance of an impregnation material and three water-based materials with respect to their resistance to water and salt solution absorption and chloride ion penetration. A comparative investigation assessed the possibility of using convenient concrete cubes rather than larger-scale slabs for chloride contamination testing by the salt-ponding method. The results of the study are particularly relevant to older reinforced concrete structures, which frequently suffer low concrete cover to their steel-reinforcing bars [M. M. Rahman, et al, 2013].

To establish an optimum surface protection system with silane type water repellents, experimental investigations were conducted for 2 kinds of water repellents that had shown good water absorption controlling effect in a previous exposure test in an actual structure carried out by an authors. The effects of the age of application of water repellents and the effects of the curing conditions before and after the application on the penetration depth of water repellents and the water absorption controlling effect were investigate for concretes of different mix proportions with four different w/c, of 35%, 42%, 50%, and 65%. Furthermore, the specimens used for the water absorption tests were subject to a weathering test to examine the durability of the water absorption controlling effect. In dry concrete, both water repellents showed a good water absorption controlling effect. While it is generally consider desirable that the water repellents be apply at an early age to obtain a better water absorption controlling effect, the authors propose that water repellents should be apply not too early for low w/c concrete, in order to ensure a penetration depth of at least 1-2 mm. The penetration depth and water absorption controlling effect are affect by the curing conditions before and after application of the water repellents. When the specimens with water repellents were subjected to a weathering test using a Xenon arc lamp for 98 days (equivalent to 2.8 years of weathering in Tokyo), no degradation of the water repellent layer was observed. An optimum surface protection for newly constructed structures is propose in this experimental work [A. Hosoda, Y. Matsuda and K. Kobayashi, 2010].

Strength and durability are the main properties that are affected by water ingress and moisture attack in concrete bridges and pavement. Protecting concrete from such attacks is solve by applying protective treatments on matured concrete. However, on-site moisture at the time of application concern over the penetration depth, and subsequent traffic actions reduce their performance. To eliminate these effects, there is growing interest to add hydrophobic material during the time of concrete production or even apply them at a very early stage of curing. The results demonstrated considerable reducing consequence of absorption of water, despite high slump and marginal reduction of strength at high percentage of admixture; although neither segregation nor thermal cracking was, observe in the matured concrete. The optimum performance was confirm in mixtures with 2% admixture. Additionally, mixture with 2% aqueous hydrophobic admixture revealed marginal strength gain compared to 2% crystalline cementitious hydrophobic admixture, although water protection appears to be better in cementitious crystalline mixture [Mazen Al-Kheetan, Mujib Rahman, and Denis Chamberlain, 2017].

Silages can act as hydrophobic pore liners for reinforced concrete (RC) structures. They can significantly reduce the depth of chloride penetration, a major cause of steel reinforcement corrosion. However, there is little published information on their long-term performance. Thirty-two concrete cores were extract from eight full-scale RC bridge supporting crossbeams that were treat with silane 20 years ago. Water absorption by capillarity was measure, and compared with sixteen control cores. Which is extract from four non-silane treated RC crossbeams constructed at the same time. Results show that silanes may provide a residual protective effect against water even after 20 years of service [C. Christodoulou et al, 2013].

2.8 Importance of moisture content

The fresh concrete consists of three parts such as cement, aggregate and water. When the cement grains and water are mix together, a reaction starts called cement hydration [H.F.W. Taylor, 1997]. Water is consume during the hydration and a fine pore system forms during the process. The size and quantity of the pores depend on several factors such as the original mixture, access of water, temperature, and additives. The pore system plays a central role in most processes taking place inside the concrete including transport and fixation of moisture [L.O. Nilsson, 1997]**.**

The porous materials will always contain a certain amount of water in their natural environment. For concrete, which is a porous material, several durability problems are relate to the moisture content inside the pores. The expansion of water, when it turns to ice, can cause severe frost damages in concrete if the pores are saturated [A.M. Neville, 1995]. The alkali silica reaction (ASR) depends on the access of water [R. N. Swamy, 1992] and the corrosion of reinforcement bars is affected [K. Tuutti, 1982]. These are all problems that are link to the degree of saturation in the pores. The corrosion rate is highly dependent on the moisture content inside the pore system. As it has confirmed from the results that, the corrosion rate reaches its maximum at around 97 % RH. A higher humidity increases the rate below this value while the access of oxygen sets the limit above. The initiation time until corrosion is affect by carbonation and/or chloride transport [K. Tuutti, 1982]. The diffusion rate of carbon dioxide and thus the carbonation rate are low when the moisture content is high. Transport of chloride ions into the concrete requires on the other hand a continuous water phase in the pore system. The maximum rate for chloride diffusion is reach at saturation and below 50 % RH; it is close to zero according to [E.P. Nielsen and M. Geiker, 2003].

2.9 Impregnation of concrete structures

The surface treatments are apply to new structures as a preventative method, to existing structures where the need for future protection is anticipated and to repaired structures in order to improve the duration of the repairs as well as to mask the visible effect of repair [Bertolini et al, 2004]. Surface treatments are a wide range of materials, which either make the concrete cover zone less permeable to aggressive substances or reduce the moisture content of concrete. The independent references indicate that, surface treatments based on silane/siloxane in turn may significantly reduce the ingress of moisture and chloride ions in concrete exposed to seawater splash, spray and ponding. In turn, which depends on the concrete moisture content, depth of impregnation, and cover depth. Whether the concrete cracked before or after treatment, range in effectiveness depends on the concentration of active ingredient, depth, and uniformity of impregnation achieve. Which is determine by the uniformity, and rate of application, concrete quality, concrete moisture content, and surface quality at the time of application, achieve better penetration when applied as creams or gels, because the treatment does not evaporate or drain from the surface during application. It’s not permanent, need to be reapplied at regular intervals of 10–20 years, depends on exposure conditions, and depth of impregnation may increase carbonation rates, but may reduce the rate of subsequent corrosion. Which depends on the concrete’s moisture content, if properly maintained, significantly extend the service life of a structure. In fact, depending on quality of application, exposure conditions, level of chloride ion contamination at the time of treatment, and cover depths, may be less beneficial to high-quality concrete or well-cured new concrete. Because it cannot penetrate as deeply. It may reduce the ultimate quality of concrete when apply to poor-quality/poorly cured new concrete, by preventing the ingress of water that would otherwise assist ongoing curing.

2.10 Chemistry of Alkylalkoxysilanes

The silanes or more correctly named alkylalkoxysilanes are use today as water repellent agents on concrete were develop in the 1940s as a way to create a covalent bond between organic and inorganic substances. However, it was not until the military in USA started to show interest in glass fibres as reinforcement in organic resins as the need for strong and sustainable bonding arose [E.P. Plueddemann, 1991]. A thorough description of the polymerization from silane, via siloxane to silicon resin or polymersiloxane and the bonding to the inorganic surface is present in [B. Arkles, 1977]. As when the water repellent agent is apply on concrete, it is transport into the concrete by capillary suction. The polymerisation starts inside the concrete. The alkoxygroups of the silanes react with the concrete and other alkoxygroups to form a fine network of polymer siloxane on the walls of the pores or a silicon resin. The degree to which the network is chemically link to the pore walls of the concrete is difficult to determine. In a study on Water repellent treated limestone, brick and sandstone the chemically linked mass of polymerized material to the substrate corresponded to 0-48 % depending on the choice of silane and substrate [H. De Clercq, 2008]. The stages in the reaction will be the same if the product is base on a siloxane.

When hydrophobic surface treatments were first introduce several different silanes and siloxanes existed at the market, but after experiences of practical use and laboratory experiments, the amount has decreased. Summarising between [H. De Clercq and E. De Witte, 2001] where the influence of the size of the alkyl group and the alkoxygroup on the reaction kinetics is studied, one can see that silanes with methoxygroups react significantly faster than those with ethoxygroups and that a big alkyl group slows down the reaction as well. Old concrete is often carbonate in the surface layer, meaning that the pH-value is lower. For carbonated concrete, with a lowering of the pH-value from 13-9 this would, according to [F.D. Osterholtz and E R. Pohl, 1992], mean a decrease in polymerization rate with a factor around 50. The conclusions are that a high temperature 50-55^{o}C results in a high polymerization rate and a lower 0.5^{o}C in a low state of evaporation for the volatile silanes. Which silane or siloxane that is most suitable varies with the conditions (type of concrete, humidity, pH-value etc.) but today almost all Water repellents on the market consist of alkyltriethoxysilanes with three to eight carbon atoms in the alkyl group.

2.11 Mechanisms of water repellent agents

The most frequently used way of illustrating the function of water repellent agents is illustrate in Figure 2-3 sometimes referred to as the lotus effect. For a hydrophilic material such as concrete, the contact angle is often consider zero. This means that when water is apply on the surface, fine system of pores will generate a force, which causes a capillary rise. This of course means that particles and ions in the water also are transport into the concrete. Transport of chloride ions is an example of this. When the concrete is, treat with a water repellent agent the surface properties of the concrete turns from hydrophilic to hydrophobic. The absence of a continuous water phase is an effective way of stopping chloride ions from entering. The effect of a water repellent treatment depends on the source of the moisture content inside the concrete structure. The treated surface is open to gaseous diffusion but the breathability is not as high as for untreated concrete [A. Johansson, M. Janz, J. Silfwerbrand, and J. Trägårdh, 2005].

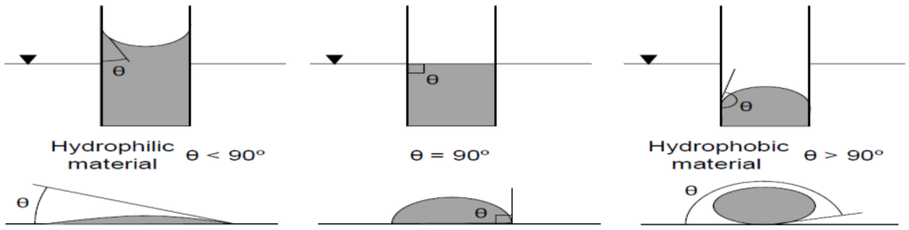


Figure 2-3 Difference between a hydrophilic and a hydrophobic material.

2.12 Marine environment chloride transport mechanisms

The steel embedded in concrete can develop a protective passivity layer on its surface soon after the hydration of cement has started, which mainly consists of γ-Fe_2O_3. As long as this oxide film is present, steel remains intact with concrete. However, chloride ions can destroy the film and, in the presence of water and oxygen, corrosion can occur. The chloride can be present in concrete either at the time of mixing, or during concrete lifetime due to the ingress from outside via various mechanisms. The predominant source of chlorides in concrete is the surrounding environment, which is mainly de-icing salts or seawater. Chloride ions can penetrate into concrete by permeation, capillary suction and diffusion. However, diffusion is the predominant mechanism that transports chlorides to the location of the reinforcing steel. Therefore, diffusion theory is generally use to quantify the multiple transport phenomena [Kropp and Hilsdorf, 1995]. The resistance of concrete to the chloride ingress is evaluate by a diffusion coefficient. However, the diffusion can be either steady or non-steady. Thus, the effective diffusion coefficient or apparent diffusion coefficient is use for steady state and non-steady state, respectively.

In the U.K., a maximum of 0.4% by weight of cement is chloride threshold level in concrete with embedded reinforcing steel [BS5328: Part 1: 1990]. In saturated concrete, which is continuously immerse in an aqueous solution, chloride transport occurs by diffusion through the pore solution. Movement into and through unsaturated concrete, a common state for concrete with surfaces exposed to the atmosphere, is largely controlled by absorption through the capillary pore system and diffusion of chlorides through pore solution. Absorption and diffusion are important transport mechanisms associated with chloride ingress in highway structures and bridges [Hong & Hooton, 1999].

2.12.1 Permeability

The Permeability is the movement of a liquid under hydrostatic pressure. Permeability can be describe by Darcy's law, which states that the steady-state rate of flow as represent by equation (24) is directly proportional to hydraulic gradient [Basheer et al, 2001].

$$v = \frac{Q}{A} = \frac{k\rho g}{\eta}\frac{\Delta h}{L} \qquad (24)$$

Where,

$\boldsymbol{v}$ = Apparent velocity of flow or volume of water per unit time per unit area (m/s)

$\boldsymbol{Q}$ = Flow rate (m^3/s)

$\boldsymbol{A}$ = Cross-sectional area of the sample (m^2)

$\Delta \boldsymbol{h}$ = Drop in hydraulic head through the sample (m)

$\boldsymbol{L}$ = Thickness of the sample (m)

$\boldsymbol{\eta}$ = Dynamic viscosity of the fluid ($kg/m.s$)

$\boldsymbol{\rho}$ = Density of the fluid (kg/m^3)

$\boldsymbol{g}$ = Acceleration due to gravity (m/s^2)

$\boldsymbol{k}$ = Intrinsic permeability of materials (m^2)

The intrinsic permeability coefficient "***k***" is independent of the fluid involved.

$$K = \frac{k\rho g}{\eta}\left(\frac{m}{s}\right) \tag{25}$$

Thus

$$v = \frac{Q}{A} = K\frac{\Delta h}{L} \tag{26}$$

Where ***K*** is the coefficient of permeability or hydraulic conductivity (m/s). When the flow is of an unsteady state, the hydraulic head may not decrease linearly along the direction of flow and in which case, the flow velocity is represent by expression.

$$v = -K\Delta h \tag{27}$$

In an one-dimensional system

$$v = -K\frac{dh}{dx} \tag{28}$$

The permeability of concrete depends on its porosity as well as the size, distribution, shape, tortuosity and continuity of pores. Therefore, it depends on all factors that influence the pore structure of concrete (w/c ratio, type of cement, cement replacement materials and the progress of hydration). Historically, permeability was use as the criteria to characterise the penetrability of concrete regardless of the situation. There are situations when permeability is relevant such as in permanently submerged concrete where water is force through concrete by hydraulic pressure (head of water). However, in concrete structures which are not in contact with water under pressure, like a bridge exposed to the environment, permeability is generally not one of the most important mechanisms [Emerson, 1990].

2.12.2 Diffusion

When transport of a substance through concrete is the result of a concentration gradient, diffusion takes place. Fick's laws can express the diffusion equation, and most models for predicting chloride ingress through saturated cement-based materials are base on this law [Khatib et al, 2005]. This methodology is base on papers from the early 1970's [Collepardi et al, 1972] and assumes chloride penetration occurs due to diffusion. Stationary diffusion (uni-directional and constant mass transfer) is usually describe by Fick’s first law of diffusion. It states that the rate of transfer of mass through unit area of a section, J (*mol/m*^{2}*.s*), is proportional to the concentration gradient, $\frac{dc}{dx}$ ($\frac{mol/m^3}{m}$), and the diffusion coefficient, D (*m*^{2} */s*) [Basheer et al, 2001].

$$J = -D\frac{dc}{dx} \qquad (29)$$

For in case of Non-stationary diffusion, when concentration c at a location changes with time, Fick’s second law characterizes it as noted in equation (30):

$$\frac{dc}{dt} = \frac{d}{dx}\frac{Ddc}{dx} \qquad (30)$$

There are many solutions to Fick's second law depending on the boundary and initial conditions as well as the diffusion coefficient. The diffusion coefficient, D may be assumed constant or a function of different variables such as time/age, porosity, degree of hydration (maturity), aggregate size, temperature, humidity and local chloride concentration [Oh, and Jang, 2007]. The fact that the diffusion coefficient changes with age of specimen is difficult to model in practice. Some studies simply assume that the diffusion coefficient remains constant with time whereas others have tried to incorporate this feature into their model [Nilsson, 2002]. In case of Constant diffusion coefficient $C_{0 = C}$ (0, t) which is constant surface chloride concentration and the initial condition C = 0 for x>0 and t = 0 was as notified by equation (31):

$$C = C_0 (1\text{- erf}\frac{x}{2\sqrt{Dt}}) \qquad (31)$$

Where erf is the standard error function [Crank, 1956]. Even though the above equation is only valid, if both the diffusion coefficient and surface concentration remain constant, it has been extensively use in cases where both parameters vary with time. Whereas in Time dependent diffusion coefficient [Tang and Nilsson, 1992] found that the diffusion coefficient of young concrete dramatically decreases with age using their rapid diffusivity test and proposed the following mathematical expression (32) for a time dependent chloride diffusion coefficient [Tang and Gulikers, 2007].

$$D(t') = a.(t')^{-n} \qquad (32)$$

Where, $D\ (t')$ is the time-dependent diffusion coefficient, t' is the concrete age, a and n are constants, with n being referred to as the age factor. For the given values of the diffusion coefficient and age, represented by D_0 and t'_0, in turn the above Equation (33) is re-write as:

$$\mathrm{D(t') = \ D_0.\,(t'_0)^n.\,(t')^{-n} \ = D_0\,.\,(\frac{t'}{t'^0})^{\ -n}} \qquad (33)$$

Alternatively, more commonly denoted as equation (34):

$$\mathrm{D(t) = \ D_{re}f(\frac{t_{re}f}{t})^{\ m}} \qquad (34)$$

Where $D_{\mathrm{re}}f$ is the diffusion coefficient at some time, $t_{\mathrm{re}}f$ (usually 28 days), and m is a variable which describes the rate of change of the diffusion coefficient and is constant for a specific concrete (depending on mix proportion). This is the most common form of equation used to predict the change in values of diffusion coefficient with age of concrete [Nokken et al, 2006]. Values of m for different concretes are yet not well established, but some preliminary values have been publish. Values in the range of (0.2-0.3) are common for normal Portland cement mixtures; while higher values (0.5-0.7) are attributed to fly ash and slag concrete [Bamforth, 2004].

2.12.2.1 Time-dependent surface chloride concentration

The surface chloride concentration is also report to change with time by some authors. However, the increase in surface concentration is mainly relate to concrete exposed to wet/dry cycles rather than those continuously immersed in salt solution. This is because surface concentration of concrete exposed to infinite seawater remains constant due to chemical equilibrium, whereas in the tidal zone the chloride content at the concrete surface may increase due to wet/dry cycles. As with the case of a variable diffusion coefficient, in order to use a time-dependent surface chloride concentration it is necessary to first, integrate the error function with respect to time.

2.12.2.2 Diffusion test methods

The Diffusion tests can be divide into three categories as steady state, non-steady state and electrical tests. The electrical tests can be subdivide into two groups of steady state or non-steady state electrical tests. Each method has strengths and weaknesses and therefore depending on the situation, suitable tests should be apply. As far as electrical tests are concerned, they have the advantage that they can be carry out rapidly, but the disadvantage is that they measure the conductivity of concrete not its diffusivity. Although, some attempts at correlating the measurements obtained from electrical tests and diffusivity tests, there is still a lack of understanding of fundamental processes involved. That makes interpretation of the results complicated and doubtful. Therefore, it is better to avoid using electrical testing if there is sufficient time to perform diffusivity testing. All steady state and non-steady-state diffusion tests are time consuming and therefore not suitable for use in quality control. However, they can be use in laboratory experiments and they have the advantage of yielding a meaningful value of chloride ion diffusivity. Of the long-term diffusion tests (Diffusion Cell, Ponding Test and Bulk Diffusion Test), the Bulk diffusion test is claimed to be the most accurate as it measures pure diffusion.

2.12.3 Factors influencing chloride diffusion in concrete

The Chloride diffusivity is a function of several variables such as maturity, time, temperature, w-c ratio, and cement type, curing regime, source and concentration of salt solution. The chloride diffusion coefficient decreases with time due to several issues such as continued hydration and chloride binding. The following factors, which influences the chloride diffusion in concrete, are highlight as mentioned below:

2.12.3.1 W/cm ratio

Water-to-cementitious material ratio influences the capillary pores and interfacial zones of concrete. Increasing w/cm ratio will also increase the volume of capillary pores content and creates a weaker interfacial zone between the coarse aggregate and the paste. This creates a path for the chloride ions and increases its penetration rate. Permeability is an experimentally found to be directly related to the w/cm ratio. Concretes with w/cm ratio of less than 0.30 were describe as virtually impermeable to water and chloride ions, especially when supplementary cementitious materials such as silica fume were added [Yeih, W. D., et al, 1994].

2.12.3.2 Curing regimes

Longer moist curing period will result in higher chloride resistance of concrete. It is believe that the continued hydration during moist curing will cause a decrease in porosity and pore size. Air-dried cover concrete would be extremely heterogeneous with small shrinkage cracks, interconnected voids, and open capillaries. This would allow chloride ion to penetrate faster into the concrete [Snyder, et al, 1995]. High curing temperatures in precast plants have also shown to reduce the resistance of plain Portland cement concrete to chloride ingress. Under hot weather conditions, the high temperatures are likely to result in excessive moisture loss. Maintaining mixing water in the concrete is the major concern. Continuous moist curing should be carry out for the entire curing period. If this is not possible, the concrete surfaces should be protect from drying out using any of the previously mentioned methods and the surfaces kept damp. Surfaces should dry out slowly after curing to reduce possibility of surface cracking. Curing in cold weather will be different as in this case the biggest concern will be the maintaining of an adequate and conducive temperature for hydration. For massive members, the heat generated by the concrete during hydration will be adequate to provide a satisfactory curing temperature. For non-massive members, a good alternative is steam curing, which provides both moisture and heat. In any case, a minimum favourable temperature in the range of 10-21° C must be maintain in the concrete for the minimum required curing period. Where moist curing is not conduct, very low temperatures may be avoid by insulating the member appropriately.

The curing period depends upon the type of cement used, mixture proportions, required strength, size and shape of member, ambient weather, future exposure conditions, and method of curing. Since all desirable properties are improve with curing, the period should be as long as practical. For most concrete structures, the curing period at temperatures above 5° C (40° F) should be a minimum of 7 days or until 70% of the specified compressive or flexural strength is attained. The period can be reduce to 3 days if high early strength concrete is used and the temperature is above 10° C (50° F).

2.12.3.3 Age and moisture condition of concrete

The continuing hydration process of concrete improves its chloride resistance. This is especially true for concrete, which are moist cured continuously. Meanwhile hydration of air-dried concrete may stop near the surface soon after moisture is remove. The dry surface will assist in drawing chloride ions into the concrete through capillary action [Bentz, D. P, 2008].

2.12.3.4 Others

2.12.3.4.1 Temperature

Diffusion rate and ion exchange increases with increasing temperature. This will allow the chloride ion to penetrate to a greater depth. An effective diffusion coefficient is temperature dependent. An increase of 10^0 C in temperature would double the effective diffusion coefficient value and reduces concrete resistance to chloride ingress [Tang, L, and Sorensen, H. E, 2001].

2.12.3.4.2 Type of chloride solution

Due to the different binding capacity of different cations, it was discover that the type of chloride solution also affects the chloride diffusion that the concrete structure is expose to [Snyder, K. A, 2001].

2.12.3.4.3 Construction defects

The Construction defect in the form of cracks will shorten the distance needed for chloride ion to reach the embedded steel. Therefore, the quality of construction is paramount in producing a chloride resistant concrete since no matter the quality of the mix, a defective construction would not protect the reinforcement from corrosion [Snyder, K. A, 2001].

2.12.3.5 Effect of chloride binding on diffusion

The chloride in concrete can be either dissolved in the pore solution (free chlorides), or chemically and physically bound to the cement hydrates and their surfaces (bound chloride). The aluminate (C_3A) and aluminoferrite (C_4AF) phases in cement have been consider responsible for the chemical binding of chloride. Physical binding depends upon the volume of hydration products, particularly the amount of C-S-H gel produced [Sumranwanich and Tangtermsirikul, 2004]. The Chloride binding in concrete is affected by many factors, such as type of cement, type and proportion of cement replacement material, w/c ratio, curing time prior to chloride attack, temperature, chloride concentration [Sumranwanich and Tangtermsirikul, 2004]. The chloride binding can affect the rate of chloride ingress through concrete for two reasons: (1) Removal of chloride ions from the pore solution of cement paste and concrete as the result of chloride binding reduces the free chloride concentration and therefore the quantity of mobile chloride at all locations within the concrete. (2) Chloride binding may change the pore structure of concrete by formation of Friedel's salt, which results in a less porous structure and slows down the transport of chloride ions [Yuan et al, 2008].

2.13 Absorption (capillary suction)

The transport of liquids in unsaturated porous concrete due to surface tension acting in capillaries was define as absorption. Absorption in concrete is relate not only to the pore structure, but also to the moisture content of the concrete [Basheer et al. 2001]. A linear or a near-linear relationship has been observe between the square root of time and the total volume or mass of liquid absorbed or the depth of penetration (distance of wetting front from surface). The slope of the line is define as the sorptivity of concrete as indicate in equation (35).

$$A = b + S\sqrt{t} \qquad (35)$$

Where A is the mass or volume of liquid absorbed per unit of surface or the depth of liquid penetration, S is sorptivity, t is elapsed time and b is initial absorption. In practice, it is often observe that there is a rapid initial absorption on the surface and therefore b is the correction factor added to account for this effect. The relationship between absorption and square root of time can be explain via either theory of capillarity or unsaturated flow.

2.13.1 Theory of capillarity

Capillary pressure in a tube is express by equation as (36):

$$P_{\mathrm{e}} = \frac{2\Upsilon Cos\Theta}{r} \qquad (36)$$

$\boldsymbol{P}_{\mathrm{e}}$ = Capillary pressure *(Pa)*

$\boldsymbol{\Upsilon}$ **=** Surface tension *(Pa.m)*

Θ **=** Wetting angle (Θ for water = 0)

$\boldsymbol{r}$ **=** Effective radius of capillary tube *(m)*

According to Poiseuille's equation (37) for the flow of liquid in a tube

$$Q = \frac{dV}{dt} = \frac{\pi p r^4}{8l\eta} \qquad (37)$$

$\boldsymbol{Q}$ = Flow rate (m^3/s)

$\boldsymbol{V}$ = Volume of liquid (m^3)

$\boldsymbol{p}$ = pressure gradient (Pa)

$\boldsymbol{l}$ = length of tube (m)

Substituting dV ($dV = \pi\ r^2$) in above Equation yields

$$\frac{ldl}{dt} = \frac{pr^2}{8\eta}$$

Assuming the capillary pressure to be the only driving force and substituting for p using Equation, which gives

$$\frac{ldl}{dt} = \frac{\Upsilon r}{4\eta}$$

Whereas, $\text{Cos}\Theta = 1$, Thus $l = S\sqrt{t}$, where S is Sorptivity

$$S = \sqrt{\frac{\Upsilon r}{2\eta}}$$

Since sorptivity is proportional to $\sqrt{\frac{\Upsilon r}{\eta}}$ it would seem that absorption is affect by the surface tension, viscosity of the absorbing liquid and by the pore radius.

2.13.2 Theory of unsaturated flow

The One-dimensional capillary absorption can also be modelled using Richard's equation for unsaturated flow. This equation is a combination of Darcy's equation and the law of conservation mass. As previously noted, Darcy's law for saturated flow (38),

$$\nu = \frac{Q}{A} = K\frac{\Delta h}{L} \qquad (38)$$

Which states that the steady-state rate of flow is directly proportional to hydraulic gradient and the equation changes to $\nu = -K\Delta h$ or $\nu = -K\ \frac{dh}{dx}$ for unsteady-state flow. Darcy's law is only sufficient to describe steady-state flow. To model unsteady-state flow, the law of conservation of matter is also required:

$$\frac{\delta\Theta}{\delta t} = -\ \frac{\delta\nu}{dx}$$

Θ = Volumetric water content and substituting ν value in equation, which yields:

$$\frac{\delta \Theta}{\delta t} = \frac{\delta}{dx}\left(K\frac{dh}{dx}\right)$$

In saturated porous medium with an incompressible matrix, , $\delta\Theta/\delta t = 0$ the conductivity is usually assume to remain constant hence above Equation (39) becomes:

$$Ks\frac{\delta^2 h}{\delta x^2} = 0 \qquad (39)$$

Where**,** Ks is the hydraulic conductivity of the saturated medium Darcy's law for saturated flow can be extend using Richard's equation to model flow in an unsaturated porous medium. The important differences between saturated and unsaturated flow are the moving force and hydraulic conductivity. In a saturated porous medium, the gradient of a positive pressure potential is the moving force and conductivity is constant and maximal. On the other hand, water in an unsaturated porous medium is subject to suction, and conductivity decreases with decreasing water content and flow is a function of suction or wetness.

$$\frac{\delta \Theta}{\delta t} = \frac{\delta}{dx}\left[K(\Psi)\Delta h\right]$$

Where $\boldsymbol{\Psi}$ suction head and $\Delta \boldsymbol{h}$ is the hydraulic head gradient, which may include both suction and a gravitational component. In one-dimensional flow with negligible gravitational head:

$$\frac{\delta \Theta}{\delta t} = \frac{\delta}{dx}\left[K(\Psi)\frac{\delta \Psi}{\delta x}\right]$$

The relationship between conductivity and suction is affect by hysteresis. However, the relationship between conductivity and volumetric water content (Θ) is much less affected by hysteresis. Hence,

$$\frac{\delta \Theta}{\delta t} = \frac{\delta}{dx}\left[K(\Theta)\frac{\delta \Psi}{\delta x}\right]$$

In order to simplify the mathematical and experimental treatment of unsaturated flow processes, the flow equation is change to the form of the diffusion equation (40)

$$\frac{\delta \Theta}{\delta t} = \frac{\delta}{dx}\left[\frac{K(\Theta)}{C(\Theta)}\frac{\delta \Theta}{\delta x}\right] \qquad (40)$$

$$C(\Theta) = \frac{d\Theta}{d\Psi}$$

$\boldsymbol{C}(\Theta)$ = Specific water capacity (m^{-1})

Therefore

$$\frac{\delta\Theta}{\delta t} = \frac{\delta}{\delta x}\left[D(\Theta)\frac{\delta\Theta}{\delta x}\right]$$

$$D(\Theta) = \frac{K(\Theta)}{C(\Theta)} = K(\Theta)\frac{d\Psi}{d\Theta} \qquad (41)$$

Where

$\boldsymbol{x}$ = depth (m)

$\boldsymbol{t}$ = time (s)

Θ = volumetric water content (L^3/L^3)

$\boldsymbol{D}(\Theta)$ = Capillary diffusivity (water diffusivity/unsaturated hydraulic diffusivity) (m^3/s)

$\boldsymbol{K}(\Theta)$ = Unsaturated hydraulic conductivity (*m/s*)

$\boldsymbol{\Psi}$ = Capillary potential (*m*)

It is important to note that although this equation is similar to the non-linear diffusion equation, it is base on an entirely different concept. The equation describes the flow of water under capillary suction in unsaturated porous solids [Pachepsky, 2003]. The above equation (42) has a solution of the form [Hall, 2007].

$$x(\Theta, t) = \phi(\Theta)\sqrt{t} \qquad (42)$$

Where $\phi(m/\sqrt{s})$ is the Boltzmann variable xt.$^{-1/2}$ Total volume or mass of water absorbed (43) can be estimate from [Wilson, 2003]

$$i(t) = \sqrt{t}\int_{\Theta^0}^{\Theta s} \phi d\Theta \qquad (43)$$

The integral in this expression (44) is termed Sorptivity (S) [Philip, 1957]

$$S = \int_{\Theta_0}^{\Theta s} \phi d\Theta \qquad (44)$$

Generally, the mathematical expressions in the literature derive from these two theories namely, capillarity and unsaturated flow.

2.13.3 Sorptivity test methods

There are several approaches have been used to measure sorptivity/absorption of concrete and a number of methods are recommended in codes and standards. These methods can be divide into three groups depending on the test sorption mode where concrete specimens are: (1) immersed in absorbing solution (2) subject to a head of absorbing solution (3) in contact with absorbing solution with suction surface facing down. The following discuss different sorptivity test methods. BS 1881-122 describes a water absorption test for concrete cylinders. BS 1881-208 describes a test for determination of the initial surface absorption of concrete, known as ISAT (Initial Surface Absorption Test). A sorptivity test was developed by (Fagerlund, 1982) in which the water mainly penetrates into the concrete by absorption. The specimens are place on wet sponges rather than immersing them under water or placing under a head of water, which had been use in the previous test methods. The samples thicknesses used were 20-30 mm, the suction surface could be cutted, and the samples were in moisture equilibrium with the surroundings before testing was start.

In 1997, Emerson, and Butler developed a sorptivity test procedure, which consisted of a numbers of wetting and drying cycles instead of only one wetting phase to reproduce the site condition. In fact, they preconditioned the concrete specimens by exposing them to wet/dry cycles to obtain a sorptivity value, which is representative of absorption properties of concrete on site. The Specimens had higher sorptivity at the first wetting phases and then sorptivity became more stable in subsequent cycles. The procedure for the sorptivity test developed by Emerson & Butler showed the importance of using a pre-conditioning regime of cyclic wetting and drying in order to achieve a repeatable moisture state in samples prior to a test.

2.13.4 Factors influencing sorptivity of concrete

The Sorptivity is a complex process, a function of both the pore structure of concrete and its moisture state. Pore structure of concrete depends on a variety of factors such as concrete mix design, curing regime and compaction. The moisture content of concrete depends on the environmental conditions and concrete pore structure.

2.13.4.1 Water-cement ratio

Water-cement ratio has a very important effect on the pore structure and quality of concrete. It has been observed that the sorptivity of concrete decreases with a decrease in water-cement ratio due to refinement of the pore structure [Kolias & Geargio, 2005]. The investigation on the effect of w-c ratio on the chloride penetration under cyclic wetting and drying showed that the chloride penetration decreases as the w-c ratio decreases [Polder and Peelen, 2002]. No results were confirm on the effect of w-c ratio on sorptivity when concretes are precondition by a wet/dry cyclic regime and the significance of its effect on sorptivity and chloride penetration as compared to other variables.

2.13.4.2 Cement content

The variation in cement content influences the quantity of cement paste to aggregate and the characteristics of the aggregate/cement paste interface depending on the mix design. Dhir et al (2004) found that sorptivity reduces as the cement content reduces using the initial surface absorption test (ISAT). Specimens were oven-dried at 105ºC prior to the test. Differences in sorptivity with changing cement content were slightly higher with increasing w-c ratio.

2.14 Effect of chloride binding on absorption

The effect of chloride binding on absorption does not appear to have been investigate to date. However, experimental studies on absorption of chloride contaminated water by concrete [McCarter et al, 1992] have shown that the chloride front moves into the concrete at a slightly slower rate than the water in which the chlorides were dissolved, suggesting that chloride binding affects the amount of chloride ions being transported by moisture flow.

2.14.1 Modelling chloride penetration into concrete

The most frequently refer service life model for reinforced concrete exposed to a corrosive environment is the model proposed by Tuutti (1992). The model represents the service life of concrete structures subjected to carbonation or chloride attack, and assumes corrosion occurs in two stages: 1) the initial stage in which Co_2 or chloride penetrates the concrete cover and reaches the surface of the outermost layer of steel reinforcing bars and cause depassivation, 2) the propagation stage during which active corrosion occurs.

The initiation stage covers the time from construction until the chloride content at the depth of the reinforcement is high enough (threshold chloride concentration) to initiate corrosion. The chloride threshold concentration is confirm to be affect by a number of factors such as cement content, type of binder and concentration of hydroxyl ions [Oh et al, 2007]. The initiation time also depends on several factors including degree of exposure to chlorides, w-c ratio, curing time, moisture state, P^h of the pore solution, carbonation, binder type, temperature and depth of concrete cover [Hobbs and Mattews, 1997]. During the propagation stage, the depassivated steel corrodes at a rate that eventually results in an unacceptable level of visual cracking. The rate of corrosion propagation is a function of oxygen availability, temperature and relative humidity. During the last 10 to 15 years, numerous models have been present for predicting the initiation time. These models can be group in two main categories: scientific models based on physical and chemical processes, and engineering or empirical models based on actual data. [Nilsson, 2006].

2.14.2 Scientific models

The scientific models describe the different physical and chemical processes that are involved during ingress of chloride. The models are the solution of the transport and mass balance equations considering the interaction between the ions in the pore solution and the cementitious matrix (chloride binding) and the interactions between water vapour, moisture and ions [Nilsson, 2006]. Scientific models are mathematically complex. The boundary conditions are usually very complicated, particularly for concrete exposed to wetting and drying cycles [Nilsson, 2006]. These models need quantification of a very large number of material parameters for a new concrete composition. The transport and binding properties of the various species, including moisture, must be available as functions of the material composition and age, temperature and moisture conditions [Nilsson, 2006]. Therefore, it has been necessary in many cases, to combine scientific and empirical models with respect to the time-dependency of chloride binding and diffusion coefficient. In addition to their complexity, scientific models have generally not been successful in predicting the penetration of chloride in concrete structures and therefore empirical models are more widely used in practice. Research carried by [L Tang, and L-O Nilsson, 2002] on prediction model for chloride penetration into concrete exposed to various exposure environments including alternative wet-and dry environment. A few years ago, a scientific model called ClinConc was develop from their previous work. The model is essentially base on the current knowledge of physical and chemical processes involved in the chloride transport and binding in concrete and has been verify by using the field data from one to five years exposure under seawater. In this study, the model is further develop for the application to alternative wet-and-dry environment, such as splash zone and road environment. The predicted results are in general fairly well in agreement with the field data, especially the shapes of chloride profiles from alternative wet-and-dry environments.

The numerical model ClinConc for prediction of chloride penetration into concrete was first present in the middle of 1990's [Tang 1995]. Not like other models, a unique character of the model ClinConc is that the chloride diffusivity, which can be determined by, e.g. the Nordtest method NT BUILD 492 (Nordtest 1999), is considered as a material property. It changes only when concrete is young, like many other material properties, such as porosity and strength. After an age of a half of year, this diffusivity becomes more or less constant according to the experiments [Tang 1996]. Another unique character of the model ClinConc is that the climatic parameters, such as chloride concentration and temperature, are use in both the flux and the mass balance equations. Therefore, the model can well describe the effects of exposure conditions on chloride penetration. The original version of ClinConc was develop based on the field data up to two years exposure under seawater. Due to the difficulties in combining moisture transport, the application of the original ClinConc was limited to submerged zone only. When five-year field exposure data were available [Andersen et al 1998], it was confirm that the original ClinConc underestimated the chloride content in the zone closer to the exposure surface, even though it predicted the penetration depth fairly well. In other words, the surface chloride content tends to increase with exposure time even under submerged conditions. This increased chloride content cannot be explain by drying-and-wetting effect, like in the splash zone. Time-dependent chloride binding might be a potential reason, since the chloride binding isotherms used in the original ClinConc were those obtained in the laboratory after about two weeks equilibrium [Tang and Nillson 1993]. The effect of alkalinity on chloride binding was also base on a limited investigation [Sandberg and Larsson 1993]. In reality, the pore solution compositions may change due to leaching and penetration of different substances, resulting in different characteristics of chloride binding. Another possible reason is an increased saturation degree of the air voids near the surface. The saturation degree of the air voids will increase after such a long period of immersion, especially in contact with a salt solution. It is difficult, however, to model the saturation degree of the air voids. Therefore, the time-dependent chloride binding was assume as a dominant reason for the increased chloride contents in the surface zone [Tang & Nillson 2000]. After this modification, the agreement between modelled and measured chloride profiles becomes better [Tang & Nillson 2000b]. Very recently, the model ClinConc was modified again in order to make it applicable to various exposure environments including alternative wet-and-dry ones. In fact, nothing except for the exposure conditions has been modify in the latest modification. This paper present this latest modification and the verification of the model using chloride profiles measured from the fields under various exposure environments.

2.14.3 Empirical models

The empirical models generally utilize a solution to Fick’s second law. This methodology which is the most widely used to predict chloride ingress is based on papers from the early 1970's [Collepardi et al, 1972] and assumes chloride penetration occurs due to diffusion. A solution to Fick's second law is fitted either to a chloride profile of laboratory concrete specimens after subjecting to a fixed period of exposure to salt solution or to chloride values measured in samples taken from the field with a known history of exposure to chloride. By means of this curve fitting approach, the diffusivity values is calculated and used as the main parameter to account for the rate of chloride penetration. This methodology has been employ in different exposure conditions such as total immersion of concrete samples in salt solution or exposure to wet/dry cycles in the laboratory, exposure to atmospheric, tidal, splash and submerged zone in coastal environments and exposure to de-icing salt in highway structures. Despite the fact that the diffusion equation is only applicable to saturated concrete, Fick’s second law has been apply to evaluate the rate of chloride ingress in all these exposure conditions and/or predict the penetration of chloride in long-term exposure. In these cases, D_C and C_S are usually refer to as apparent diffusion coefficient and surface chloride concentration respectively. Chloride penetration into concrete often depends on a combination of transport mechanisms in which diffusion may not be the principle mechanism, unless the concrete is saturated. However, Fickian models do not consider the effect of other mechanisms on chloride penetration as they assume that chloride penetrates solely by diffusion. Even in the case of saturated concrete, simplistic models based on the Fick’s law are applied which require several assumptions including constant surface chloride concentration and diffusion coefficient independent of position within the concrete and time of exposure. Moreover, they generally do not take into account the effect of chloride binding and electrical double layer formation on the cement hydration products (ionic interaction). Nevertheless, models based on the Fick’s 2nd law have been widely used to evaluate and predict chloride profiles in concretes exposed to any environment due to their relative simplicity and the fact that they generally provide a relatively good fit to chloride profiles from various conditions. An initial and boundary conditions must be consider in order to solve the Fick's second law of diffusion. The most common solution of the Fick's second law, namely the error function, is base on the assumptions of constant diffusion coefficient and constant surface chloride concentration. Many different assumptions had been consider on the time dependency of D_C and C_S and several equations have been propose. In addition to the time and age, D_C and C_S are confirm to be a function of concrete type, w-c ratio and exposure condition (temperature and RH).

An extensive research [J. Kim, et al, 2016] was carry out on full-scale, concrete pier-stems under long-term exposure to a marine environment with work focussing on XS2 (below mid-tide level) in which the concrete is regarded as fully saturated and XS3 (tidal, splash and spray) in which the concrete is in an unsaturated condition. These exposures represent zones where concrete structures are most susceptible to ionic ingress and deterioration. Chloride profiles and chloride transport behaviour are study using both an empirical model (erfc function) and a physical model (ClinConc). The time dependency of surface chloride concentration (Cs) and apparent diffusivity (Da) were established for the empirical model whereas, in the ClinConc model (originally based on saturated concrete), two new environmental factors were introduced for the XS3 environmental exposure zone and considered as one environmental exposure zone according to BS EN 206-1: 2013. The work has highlighted that even within this zone; significant changes in chloride ingress are evident. This study aims to update the parameters of both models for predicting the long-term transport behaviour of concrete subjected to environmental exposure classes XS2 and XS3.

The level of knowledge of the ambient and local microclimate is thus critical in establishing the reliability of performance-related design methods. Although BS EN 206:2013 still defines prescriptive design methods for durability. This code allows for performance-related methods and defines concrete based on an equivalent durability procedure (EDP); further detail on the EDP is present in PD CEN/TR 16563. Performance-based approach requires to fully implementing, (i) long-term experience of local materials, practices, and on detailed knowledge of the local environment; (ii) test methods based on approved and proven tests that are representative of actual conditions and have approved performance criteria; and, (iii) analytical models that have been calibrate against test-data representative of actual conditions in practice. Regarding (iii) above, a number of predictive models have been developed and have become increasingly more refined owing to our improved understanding the chloride transport mechanisms in concrete. These models range from simple, empirical models based on Fick's 2nd law to determine the propagation of chloride within concrete to more complex, physically based models using the flux-balance system of equations. Regarding the latter, the ClinConc model focusses on the mechanisms occurring within the concrete, namely diffusion and chemical interactions; the STADIUM® model [J. Marchand, 2001] which is a multi-ionic transport model and, in addition to diffusion and chemical interactions, considers electrical coupling of ions in the pore solution. The more sophisticated service-life prediction models become, most, if not all, cannot accurately predict the performance of a concrete in different environments without previously carrying out extensive calibration measurements [E.P. Nielsen, 2004] to evaluate, surface chloride concentrations, capillary porosity, chloride binding etc. It is evident that an additional refinement is required to both the physically based model and empirical model to cover local conditions as these, ultimately, influence the long-term movement of chloride into concrete. This refinement enhances both models for predicting chloride transport in the target structure. To this end, this paper uses data obtained from an extensive chloride-profiling programme undertaken over an 8-year period, together with a more limited study at 20-years, to evaluate both empirically based and physically based models. The testing was undertaken on full-scale, concrete bridge pier-stems exposed to a marine environment represented by the following environmental classifications defined in BS EN 206:2013, and BS 8500-1:2015.

2.14.4 Apparent diffusion coefficient

2.14.4.1 Effect of time and age on apparent D_C

The diffusion coefficients for concrete exposed to cyclic wet/dry environments including marine and highway structures was time-dependent [Costa, and Appleton, 1999]. Value of *m* was to be dependent on a number of factors, notably, concrete composition and exposure environment. Despite universal agreement on the time-dependency of diffusion coefficients, it has been assume to be constant in many cases.

2.14.4.2 Effect of cement type on apparent D_C

The Blended cements (PFA, GGBS and SF) generally cause a reduction in the rate of chloride diffusion through concrete [Bamforth, 2004] and proposed an equation (45) to show the effect of cement replacement on apparent D_c. [p is proportion of cement replacement in percentage by weight of binder].

$$\mathrm{Dc} = \mathrm{Dc(PC)x(Ap^2 + Bp + C)} \qquad (45)$$

The rate of change of D_c with time also varies for different mix types. It could be observe that, the change in D_c is relatively small for PC concrete. The values of m vary in the range of 0.2-0.6 based on the level of fly ash (% FA) and slag (%SG) in the mix. The effect of silica fume is accounted for by a reduction factor based on the level of silica fume in the concrete (%SF).

2.14.4.3 Effect of w-c ratio on apparent D_C

Several authors Bamforth, 2004 have reported the increase in the apparent DC as the w-c ratio increases]. In which Bamforth (2004) the obtained data were, normalize to 20-year equivalent values.

2.14.4.4 Effect of exposure condition and environment on apparent D_C

Costa and Appleton (1999) investigated the effect of environment on apparent D_C of concrete exposed to marine environment. It has concluded from the results that, the durability requirement for different marine environment should be different as the aggressiveness varies considerably with the exposure conditions. In the case of the time-dependent diffusion coefficient, $D(t) = D_1 t^{-m}$, the value of D_1 increases for the most severe exposure conditions and the value of m is higher, which means that the reduction of the diffusion coefficients will also be greater. This means that the higher the penetration is the greater the reduction of D_C over time will be.

2.14.5 Apparent surface chloride concentration

Apparent surface chloride concentration is normally estimated via a best fit curve to the chloride profile based on the error function equation and therefore, may not be in fact the true value of the surface chloride content. In fact, for lower surface content but higher values some distance from the surface have been observe in many cases when concrete is expose to wet/dry cycles [Alisa, 2000]. A number of possible theories have been suggested to explain the observed departure from Fick's law such as the existence of a wet/dry boundary where deposition of penetrating salt occurs, and redistribution and leaching of chlorides due to wetting by exposure to rain. Another explanation is that chlorides that are an initially bound within the concrete matrix are release as the concrete carbonates. The released chlorides can then move deeper into the concrete if it is sufficiently wet or may leach out of the concrete [Alisa, 2000].

2.14.5.1 Effect of Time/age on apparent C_S

An increasing number of inspections of marine RC structures, especially in Japan have found that the surface chloride content C_S is also a function of exposure time. Uji et al (1990) suggests that the apparent C_S is proportional to the square root of time ($C_0 = k\sqrt{t}$).

2.14.5.2 Effect of exposure condition on apparent C_s

An Environmental condition significantly influence apparent surface chloride concentration. According to a report by [Bamforth, 1992], surface chloride concentration is determined to a large degree by the location of the structure, the orientation of the surface, the degree of exposure to salt and by the general exposure conditions with regard to prevailing winds and rainfall. Concrete exposed to de-icing salts have a greater surface chloride level during winter as compared to summer when there is no chloride exposure. Summer/winter temperature variations leads to differences in the chloride binding capacity.

2.14.5.3 Effect of mix design and curing on apparent C_s

The influence of mix design on the value of apparent C_s is very complex. The level of C_s, which will ultimately establish appears to depend on both the physical and chemical nature of the concrete, At the most simplistic level, it may be assumed that concrete, which is more porous, will attract a higher surface chloride content.

Despite of the fundamental differences between Fick's law and the mechanisms by which chloride ions penetrate through concrete, particularly for concrete exposed to wet/dry cycles, Fickian models are widely used to model chloride penetration in different exposure conditions. The biggest obstacle in the Fickian models is the need to determine the apparent D_C and C_S as they depend on a number of factors including time of exposure, concrete mix and exposure condition. Although many studies have been carry out on the effect of these variables on apparent D_C and C_S, there is still no universal agreement on the effect these variables have on apparent D_C and C_S. The effect of concrete mix (cement type and w-c ratio) on apparent D_C has been investigate in a number of studies. Although there is a general agreement about the effect of these variables on the diffusion coefficient, there is no universal equation to define the correlation between them. There are few studies on the effect of exposure condition and environment on apparent D_C, particularly for concrete structures exposed to wet/dry cycles and to de-icing salts. In the case of apparent surface chloride concentration, it has been assume that apparent C_S, increases as the time of exposure increases. Increases linearly as the time of exposure increases, and remains constant after a period of time; is constant; builds up initially ($C_S = C_0$ at $t = 0$) and then increases as the time of exposure increases; and is constant in winter and zero in summer.

Thus, numerous prediction models have been propose to model chloride ingress into concrete. Physical models are base on actual penetration mechanisms but they are complicated and not practical. The Empirical models based on Fick's second law of diffusion are widely use due to their relative simplicity and provide a good fit to the field data. However, these models are not realistic and ignore the effect of absorption in chloride penetration. In addition, there is complication in terms of the apparent diffusion coefficient and surface chloride concentration. In fact, there is no universal agreement on the variation of apparent D_C and C_S with different variables such as time of exposure and concrete composition. Nevertheless, the effect of time of exposure and concrete composition on apparent D_C and C_S has been included in prediction of chloride penetration model. The effect of exposure conditions had taken into account to some extent.

Therefore, the gaps in the current understanding may be identify as: [1] Complications on measuring sorptivity. Different methods have been applied which makes it difficult to interpret the results and compare them with one another. In addition, the majority of test methods including those suggested in codes and standards are not representative of absorption properties of concrete in the field as they consist of only one wetting event; [2] Sorptivity test which reproduces the sorptivity of concrete in the field is developed by Emerson and Butler (1997). They introduced a cyclic wet/dry preconditioning to obtain representative sorptivity values. However, their method has not been used widely by other researchers so far; [3] Relatively few studies on chloride penetration in concrete exposed to wet/dry cycles and [4] Majority of studies on chloride penetration in concrete subjected to wet/dry cycles do not measure the sorptivity of concrete. As mentioned above, the majority of sorptivity tests do not apply wet/dry cycles. Therefore, there is no connection between studies on chloride penetration due to sorptivity and wet/dry cycles. There is no comprehensive study on the effect of sorptivity on depth of chloride penetration in concrete exposed to wet/dry cycles. The relationship between sorptivity, and chloride penetration is not yet established; [5] Limited work has been carried out on the effect of variables on sorptivity of concrete determined by cyclic regime, and chloride penetration due to wet/dry cycles; [6] Fickian models are widely used to model chloride penetration and an effect of absorption in chloride penetration has been ignored. There is a need for a simple and accurate model to predict chloride ingress in concrete exposed to wet/dry environments, which takes into account the effect of absorption.

2.14.6 Summary

- The concrete is an extremely versatile construction material, which was, seems to be considerable use in construction worldwide. The concrete deterioration is not a new problem, but it has become more prevalent in recent years.

- In turn an extensive use of concrete, changes in material properties, construction techniques, and design approaches have resulted in a large amount of concrete uncertain durability.

- In this chapter, the literature reviewed about the deterioration of concrete, background to deterioration of concrete, causes of concrete deterioration, corrosion prevention and protection technique, chloride transport mechanisms, and effect of chloride binding absorption.

- Thus, there is a need to protect the concrete infrastructures from the deterioration under different exposures condition.

CHAPTER 3 EXPERIMENTAL PROGRAMME

3.1 Introduction

It is an undeniable fact that concrete is the most widely used manufactured construction material in the world today, and will remain so for decades to come. The popularity of concrete is largely due to the abundance of raw material, low manufacturing and maintenance cost, excellence in compression, durability to weathering and fire hazards, versatility in forming various shapes and its unlimited structural applications in combination with steel reinforcement. There has also been an increase in the number of incidents where concrete structures experienced severe deterioration in extreme environmental conditions. All these factors have contributed pressures from various quarters to reduce deterioration of concrete structures, and to intensify research in exploring the possibilities of enhancing working service life and durability of concrete structures with protective impregnation materials under various exposure conditions.

The present experimental work was carry out, firstly, to evaluate compressive strength gain by means of non-destructive tests of concrete cubes after curing stage by Rebound hammer test (RHT) as per [BS 1881-202:1986] and Ultrasonic pulse velocity test (UPVT) as per [BS EN 12504-4, 2004]. Second case; interpret the rate of water absorption (sorptivity) in concrete cubes with wetting/drying cycle by sorptivity test [ASTM C1585]. Thirdly, evaluate the Sorptivity values in matured concrete cubes by an initial surface absorption test (ISAT) as per [BS 1881: Part 208:1996] on dry/differential moisture content (Mc =2.5%, and Mc =5%) concrete cube specimens and assess moisture content in concrete cubes as per [BS 812-109, 1990]. Fourth case, to produce Sorptivity values for in case of fully saturated, partially saturated, and drying condition. In turn to investigate the effect of different variables on sorptivity and chloride ingress in concrete exposed to wetting and drying cycles for in case of concrete cubes and slabs, identify the most critical factors influencing these concrete properties and establish the relationship between Sorptivity and chloride ingress. Fifth case to produce sorptivity values for in case of concrete cubes with differential moisture content (Mc =2%, and Mc =3%) which was fully submerged in salt solution with/without impregnation. In the following sections, the methodology, mix design and sample preparation and test procedure are present. The tests were carry out to evaluate the performance of protective treatment materials, and in turn were divide into two phases as shown in (Figure 3-1). In the present research work, two types of impregnation materials such as solvent based (SB) and water based (WB) impregnation materials were use respectively. It is apparent that very little is confirm regarding the durability of silane impregnations and their long-term residual protection. Their performance is assess by measuring chloride contamination at various depths over time. However, this is only an indirect method and does not provide information on the residual hydrophobic effect against water uptake. The SB product is a colourless liquid with an active content greater than 80%. According to the manufacturer's technical data sheet, a penetration depth >10 mm can be achieved. It is a Class II hydrophobic complying with [BSI EN 1504-2, 2004]. The WB product is a water-borne acrylic co-polymer with 0% VOC content, thus friendly to the environment and with a low-hazard nature. It is silicone and solvent free and achieves a penetration >1 mm. It is a Class I hydrophobic complying with [BSI EN 1504-2, 2004]. The objective of the present study was also to address the current gap in knowledge, improve our understanding of the efficacy and long-term service life of solvent-based (SB) and water based (WB) impregnations by undertaking testing of full-scale concrete cube/slabs under different exposure conditions respectively.

- **Phase 1:** Interpretation of non-destructive characterization of concrete cubes was assess by Rebound hammer test (RHT) and Ultrasonic pulse velocity test (UPVT). Evaluate the Sorptivity values in concrete cubes by Initial surface absorption test (ISAT) on dry/differential moisture content concrete specimens (Mc = 2.5% and Mc = 5%), to produce Sorptivity values for in case of fully saturated (Mc = 5%), partially saturated (Mc = 2.5%), and drying condition (Mc = 0%) by inducing moisture content in concrete specimens. In turn, investigate an effectiveness of different variables on Sorptivity and chloride ingress in concrete exposed to wetting and drying cycles for in case of concrete cubes and slabs, Generate data necessary for analysing chloride ingress due to wet/dry cycles including the effect of absorption with/without impregnation.

- **Phase 2**: to produce Sorptivity values for in case of concrete cubes with differential moisture content (Mc = 2.5% and Mc = 3%) which was fully submerge in salt solution with/without impregnation. In this research work, an attempt was made to investigate an effectiveness of moisture content on (chloride absorption) such as partially saturated condition (Mc = 2.5%) and fully saturated condition (Mc = 3%) in which moisture content was partially induced in concrete cubes by considering short-term duration as well as long-term duration and moisture content is calculate on weight basis method respectively.

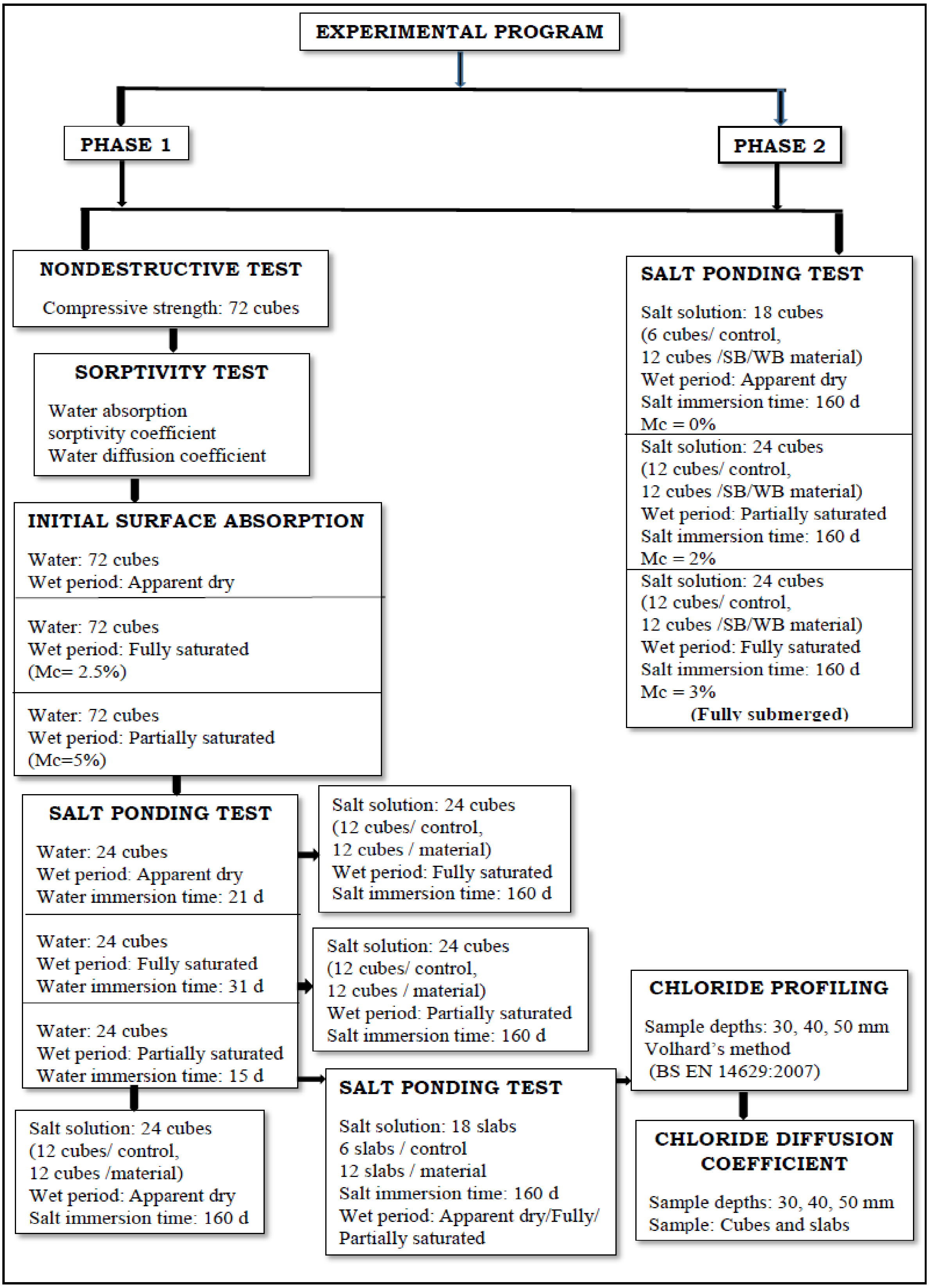


Figure 3-1 Flow chart of Experimental work

For Phase 1, Interpretation of non-destructive characterization of 72 concrete cubes was assess by Rebound hammer test (RHT) and Ultrasonic pulse velocity test (UPVT). In addition to that, evaluate the rate of flow values in 72 concrete cubes by Initial surface absorption test (ISAT) on dry/differential moisture content concrete cubes specimen. For absorption test, 72 concrete cubes were utilised, among those, 24 specimens were apparent dry, remaining 24 specimens were fully saturated, and rest of 24 specimens were partially saturated concrete specimens. In which, 48 concrete specimens were used for water absorption testing by imposing one surface of concrete specimens with water level in ordered to achieve fully as well as partially saturated pre-condition and 24 concrete specimens were used for drying cycle. Furthermore, in Phase 1, 72 pre-conditioned (fully, partially, and drying) cubes were utilised for chloride ponding test which was fully submerged. Out of which, 12 cubes were used for each protection material and the remaining 12 cubes as untreated control specimens. The performance of the protection materials was determined by comparing chloride ion penetrations in the various protected specimens such as solvent based (SB) as well as water based (WB) impregnation materials and the untreated controls.

Furthermore, 18 slabs were casted in Phase 1, among those, 6 specimens were apparent dry, remaining 6 specimens were fully saturated, and rest of 6 specimens were partially saturated. In which 12 concrete specimens were use for water absorption testing by completely submerged in water in ordered to achieve fully as well as partially saturated pre-condition and 6 concrete specimens were use for drying cycle. Furthermore, in Phase 1, 18 pre-conditioned (fully, partially, and drying) slabs were utilised for chloride ponding test. Out of which, 12 slabs were used for each protection material and the remaining 6 slabs as untreated control specimens. The performance of the protection materials was determined by comparing chloride ion penetrations in the various protected specimens such as solvent based (SB) as well as water based (WB) impregnation materials and the untreated controls.

For in case of Phase 2, 18 cubes were casted and pre-dry conditioned after initial 28-day curing in which among those, 6 specimens were use as untreated control, and remaining 12 specimens were impregnate. In which 18 pre-dry conditioned concrete cubes specimen were completely submerge in chloride solution in ordered to achieve chloride concentration. Also produce Sorptivity salt solution values for in case of 48 concrete cubes (24 untreated control, and 24 impregnated) with differential moisture content (Mc = 2%, and Mc = 3%) which was fully submerged in salt solution with/without impregnation.

3.2 Preparation of concrete specimens

This chapter explains details about the raw materials used, the production of concrete mixtures, type of mixture design used, and assessment of fresh and hardened concrete properties.

3.2.1 Materials

3.2.1.1 Cement

The Portland cement used for the test specimens is Portland-limestone cement, which was produce by the Hanson cement company; it is manufacture to comply with the requirements of BS EN 197-1-2011 CEM II/A-LL (Portland-limestone cement) strength class 42.5N.

3.2.1.2 Fine and coarse aggregate

Jonson Ltd. purchased the coarse and fine aggregates used in this experiment from Attenborough Quarry. Domestic concrete components company with its quarry and plant in Nottinghamshire. The coarse aggregate consisted of two grading of (5 and10/20) mm, with partial density (2600-2640 kg/m^3).

3.2.1.3 Impregnation materials

In this research work, two types of impregnation materials were use with their materials detail as represented in Table 3-1.

Table 3-1 Details of impregnation materials

Impregnation material	Base	Colour	Amount used	Drying time	General information
Material A	Solvent based	White	150 g/m^2	24 hr	Higher solids silane (40%) water repellent. It is mainly use for treatment of porous surfaces.
Material B	Water based	Colourless	165 g/m^2	1-2 hr	Aqueous crystallisation solution. Treat concrete surfaces, resistance to ion penetration.

3.2.1.4 Chemical agents used in experimental program

Chemical agents used during the experiment includes, sodium chloride (NaCl), distilled water, nitric acid, silver nitrate solution, ammonium thiocyanate solution, ammonium ferric sulphate indicator solution and diluted nitric acid, 3,5,5-trimethylhexanol.The uses of these agents are shown in Table 3-2. It is an indirect titration process (Volhards) used for determination of the anions that precipitate with silver. In which, the titration must perform in acidic medium to prevent precipitation of iron as hydrated oxide. The indicator concentration should be more than 0.2 M. The titration (Volhards) is useful where the process have to be perform at low P^h value. The limitations of Volhards method is that, it cannot be use where the solution has to be neutral. Also sometimes, adsorption of Ag may give false result. Whereas the chemical agents used for this experimental work in which, Nitric acid is a highly corrosive mineral acid. Nitric acid is the primary reagent used for nitration, the addition of a nitro group, typically to an organic molecule. While some resulting nitro compounds are shock and thermally-sensitive explosives, a few are stable enough to be used in munitions and demolition, while others are still more stable and used as pigments in inks and dyes. Nitric acid is also commonly use as a strong oxidizing agent. The problems found concern with the Volhard titration can be partly be solve by using more dilute solutions of $AgNO_{3,}$ and NH_4SCN. As concern to sodium chloride (rock salt) which has P^h value (5-8), vapour pressure (1mmHg865), and melting point (801^0 C). Silver nitrate ($AgNO_3$), which was use for this research work, has specifications such as boiling point (444^0 C), melting point (212^0 C), and P^h value (5.4-6.8). In addition to that, Ammonium thiocyanate (0.1 M, NH_4SCN) has specification such as P^h value (4.5-6) respectively. Thus, the employed chemical agents were suitable for the present chemical analysis.

Table 3-2 Chemical agents used in the experiment program

Chemical name	Chemical	Uses
Sodium chloride	NaCl	Salt ponding
Nitric acid	HNO_3	Chemical analysis
Silver nitrate solution	$AgNO_3$	Chemical analysis
Ammonium thiocyanate	NH_4SCN	Chemical analysis
Ammonium ferric sulphate	$NH_4Fe(So_4)_2$	Chemical analysis
3,5,5-trimethylhexanol	$C_9H_{20}O$	Chemical analysis

3.2.1.5 Concrete mixture design

In the present research work, six different mixtures type were prepared in total as per BRE (Teychenné, D.C, et al, 1997) code standards with a concrete cubes of size (100 x 100 x 100) mm, and concrete slabs of size (450 x 450 x 100) mm and cured for about 28 days as per (BS EN1766 BSI, 2000). Three of the mixtures type were concrete cubes and concrete slabs with a constant compressive strength 40 N/mm^2, different slump (0-10, 10-30, and 60-180 mm) and w/c (0.45, 0.44, and 0.43). These mixtures type were designate as M1, M2, and M3. Another Three of the mixtures type were concrete cubes and concrete slabs with a different compressive strength (25 N/mm^2, 30 N/mm^2, and 40 N/mm^2), w/c (0.5, 0.45, and 0.44), and constant slump (10-30 mm). These mixtures type were designate as M4, M5, and M6. The overall details of the mixtures proportion were to be represent in (Table 3-3, Table 3-4, Table 3-5, Table 3-6*)*. Twelve concrete cubes and three concrete slabs could be casted for each mixtures type.

Table 3-3 Concrete cubes mixture proportion (M1-M3)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mixture Proportions
M1	40	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M2	40	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M3	40	60-180	0.43	5.43	2.34	6.42	14.30	1:1.18:2.63

Table 3-4 Concrete cubes mixture proportion (M4-M6)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mixture Proportions
M4	25	10-30	0.50	3.84	1.92	5.98	17.04	1:1.55:4.44
M5	30	10-30	0.45	4.27	1.92	6.09	16.50	1:1.42:3.86
M6	40	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87

Table 3-5 Concrete slabs mixture proportion (M1-M3)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mixture Proportions
M1	40	0-10	0.45	18.23	8.20	29.70	94.16	1:1.63:5.17
M2	40	10-30	0.44	22.05	9.72	28.49	85.47	1:1.29:3.88
M3	40	60-180	0.43	27.51	11.85	32.50	72.41	1:1.18:2.63

Table 3-6 Concrete slabs mixture proportion (M4-M6)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mixture Proportions
M4	25	10-30	0.50	19.44	9.72	30.31	86.27	1:1.55:4.44
M5	30	10-30	0.45	21.63	9.72	30.86	83.55	1:1.42:3.86
M6	40	10-30	0.44	22.05	9.72	28.49	85.47	1:1.29:3.87

3.2.2 Properties of concrete

3.2.2.1 Workability of concrete

The slump test is a means of assessing the consistency of fresh concrete. It is use, indirectly, as a means of checking that the correct amount of water has been add to the mix. The slump measured should be record in mm of subsidence of the specimen during the test. Any slump specimen, which collapses or shears off laterally, gives incorrect result and if this occurs, the test should be repeat with another sample. If, in the repeat test also, the specimen shears, the slump should be measured and the fact that the specimen sheared, should be recorded. Slump depends on many factors like properties of concrete ingredients and aggregates. Temperature has its effect on slump value. So consider all these parameters in mind when deciding the ideal slump. In case of a dry sample, slump will be in the range of 25-50 mm. However, in case of a wet concrete, the slump may vary from 150-175 mm. Consistency refers to the ease with which concrete flows. It is use to indicate degree of wetness. The slump test is influence by several factors such as material properties like chemistry, fineness, particle size distribution, moisture content and temperature of cementitious materials, size, texture, combined grading, cleanliness and moisture content of the aggregates. Another factor namely chemical admixtures dosage and type. In addition to that, this test also affected by air content of concrete, concrete batching, mixing, transport methods and equipment, concrete temperature, sampling of concrete, slump testing technique and condition of equipment as well as amount of free water in concrete.

The mould and base plate (Figure 3-2*)* were dampen and the mould was place on the horizontal base plate. The mould was filled in three layers, each approximately one-third of the height of the mould when compacted (BS 1881, Part 102, 1991). Each layer was compacted with 25 strokes of the tamping rod. After the top layer has been compacted, the surface of the concrete was stroke off by means of rolling motion of the compacting rod. The mould was remove from the concrete by raising it carefully in a vertical direction. Immediately after removal of the mould, the slump was measure and record by determining the difference between the height of the mould and that of the highest point of the slumped test specimen.

Figure 3-2: Slump test

Table 3-7 Variation of slump in concrete cubes for different mixtures proportion (M1-M3)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	Slump, expt (mm)	Mixture Proportions
M1	40	0-10	0.45	7.50	1:1.63:5.16
M2	40	10-30	0.44	25	1:1.29:3.87
M3	40	60-180	0.43	120	1:1.18:2.63

In case of mixtures proportion (M1-M3) as observed from Table 3-7, even though the compressive strength is same, the obtained slump (7.5, 25, and 120 mm) was vary in different mixtures proportion. This variation may be due to variations in w/c ratio (0.45, 0.44, and 0.43), cement content (3.60, 4.35, 5.43 kg/m^3, water (1.62, 1.92, 2.34 kg/m^3), fine (5.86, 5.62, 6.42 kg/m^3) as well as coarse aggregate (18.60, 16.88. and 14.30 kg/m^3).

Table 3-8 Variation of slump in concrete cubes for different mixtures proportion (M4-M6)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	Slump, expt (mm)	Mix Proportions
M4	25	10-30	0.50	27	1:1.55:4.44
M5	30	10-30	0.45	20	1:1.42:3.86
M6	40	10-30	0.44	18	1:1.29:3.87

Whereas in case of mixtures proportion (M4-M6) as observed from Table 3-8, in fact for same slump value with different compressive strength, the obtained slump (27, 20, and 18 mm) was varied in different mixtures proportion. This variation may be due to variations in w/c ratio (0.50, 0.45, and 0.44), cement content (3.84, 4.27, 4.35 kg/m^3, water (1.92, 1.92, 1.92 kg/m^3), fine (5.98, 6.09, 5.62 kg/m^3) as well as coarse aggregate (17.04, 16.50. and 16.88 kg/m^3).

Table 3-9 Variation of slump in concrete slabs for different mixtures proportion (M1-M3)

Mix ID	Comp stg (N/m^2)	Slump (mm)	w/c	Slump, expt (mm)	Mix Proportions
M1	40	0-10	0.45	8.1	1:1.63:5.17
M2	40	10-30	0.44	28	1:1.29:3.88
M3	40	60-180	0.43	126	1:1.18:2.63

In case of mixtures proportion (M1-M3) as observed from Table 3-9, for the same compressive strength with different slump values (0-10, 10-30, and 60-180 mm), the obtained slump (8.1, 28, and 126 mm) was varied in different mixtures proportion. This variation may be due to variations in w/c ratio (0.45, 0.44, and 0.43), cement content (18.23, 22.05, 27.51 kg/m^3), water (8.20, 9.72, 11.85 kg/m^3), fine (29.70, 28.49, 32.50 kg/m^3) as well as coarse aggregate (94.16, 85.47. and 72.41 kg/m^3).

Table 3-10 Variation of slump in concrete slabs for different mixtures proportion (M4-M6)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	Slump, expt (mm)	Mixture Proportions
M4	25	10-30	0.50	26	1:1.55:4.44
M5	30	10-30	0.45	24	1:1.42:3.86
M6	40	10-30	0.44	19	1:1.29:3.87

In case of mixtures proportion (M4-M6) as observed from Table 3-10, for the different compressive strength with same slump values (10-30, 10-30, and 10-30 mm), the obtained slump (26, 24, and 19 mm) was varied in different mixtures proportion. This variation may be due to variations in w/c ratio (0.50, 0.45, and 0.44), cement content (19.44, 21.63, and 22.05 kg/m^3), water (9.72, 9.72, and 9.72 kg/m^3), fine (30.31, 30.86, and 28.49 kg/m^3) as well as coarse aggregate (86.27, 83.55. and 85.47 kg/m^3).

3.2.3 Summary

- In this chapter, the methodology, mix design and sample preparation and test procedure are present. The tests were carry out to evaluate the performance of protective treatment materials.
- Furthermore, details about an impregnation material, chemical agents, and mixtures proportion used for this study. Also, characterized the concrete mix properties by workability test in ordered to assess the slump values in different concrete mixtures type.

- An experimental flow chart was being highlighted in which, the present experimental work was carried out in the following sequences, to evaluate compressive strength gain by means of NDT of concrete cubes after curing stage by RHT and UPVT.

- An interpretation of the rate of water absorption (sorptivity) in concrete cubes with wetting/drying cycle by sorptivity test, evaluate the sorptivity values in matured concrete cubes by ISAT on dry/differential moisture content (Mc =2.5%, and Mc =5%) concrete cube specimens.

- Furthermore, to produce sorptivity values for in the case of DCC/PSC/FSC, in turn to investigate the effect of different variables on sorptivity and chloride ingress in concrete exposed to wetting and drying cycles for in case of concrete cubes/slabs.

- For an extensive research work, produce sorptivity values for in case of concrete cubes with differential moisture content (Mc =2%, and Mc =3%) which was fully submerged in salt solution with/without impregnation materials (SB/WB).

3.3 Non-destructive evaluation of concrete cubes

3.3.1 Introduction

The standard method of determining strength of hardened concrete consists of testing concrete cubes in compression (BS 1881: Part 116, 1983). The quality of an entire concrete of a structure cannot be fully assess by testing a few concrete cubes. The results obtained in testing cubes do not always reflect the actual strength of concrete in construction. In a whole day, concreting work cubes were casted in a few batches, the differences (unintentional and intentional) in the composition are uncommon, and their compaction and their hardening conditions always differ more or less from those of the structure. In addition, the number of test cubes is generally so small that they can only be consider as random tests. Sometimes, in case of failure of cubes, doubtful concrete, cracks, and deterioration of concrete. It becomes necessary to assess the quality and strength of concrete of the structure. In that, various non-destructive methods of testing concrete have been develop such as Ball indentation hammer, rebound hammer, pull out techniques, Windsor probe, ultrasonic pulse velocity methods, radioactive and nuclear methods, magnetic and electrical methods.

In order to assess an in-situ concrete strength in a faster manner, non-destructive testing (NDT) techniques have been develop and adopt. These techniques estimate the strength of existing structures by measuring some concrete properties other than its strength, and then relate these properties to strength or other mechanical properties of concrete [H. S. Shang, 2012]. Among the many available NDT techniques, the most widely employed is the one by using a device called as the rebound hammer, also known as the Schmidt Hammer. In turn that the device is portable, less expensive and easy to use. It was develop in 1948 by Swiss engineer Ernst Schmidt. The device uses a spring and measures the hardness of concrete surface using the rebound principle [Cemex USA, 2008]. The aim of rebound hammer tests of concrete is usually to find a relationship between surface hardness and compressive strength within an acceptable error [K. Szilảgyi, 2010]. However, studies have shown that rebound readings are sensitive to near-surface properties, thereby casting doubts on the accuracy of the test in estimating compressive strength. Factors that were found to influence the surface hardness include surface smoothness, age of concrete, moisture content, carbonation, presence of aggregates, presence of air voids and steel reinforcement, temperature, and calibration of the rebound hammer [Cemex USA, 2008]. Because of these factors, it has proven that the rebound hammer measurements are not unique and test result is dependent upon the characteristics of the concrete tested, which in turn varies with the different parameters of construction. A great number of research works have been conduct in order to verify whether the hammer test is a reliable tool for estimating concrete compressive strength. Some of the recent scientific works reveal that the hammer test can actually provide useful information about the quality of concrete, for as long as that the device has been calibrate for the type of concrete. According to the American Concrete Institute (ACI), the use of non-destructive tests in the field should be precede by the development of rebound correlation curves (Schmidt curves) from laboratory tests done on standard concrete specimens made with the same materials used in the concrete structure that is under evaluation. These findings, however, are still not being generally consider in estimating strength using rebound hammer test [A. Brencich, 2013]. The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. There is little apparent theoretical correlation between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been establish between strength properties and the rebound number [International atomic energy agency, 2002].

The crushing of the specimens is the usual destructive test to assess the strength of concrete. Non-destructive methods like rebound hammer test and ultrasonic test do not damage buildings and allow to have an inventory of structures and conditions. Non-destructive tests are widely applied to study mechanical properties and integrity of concrete structures [Proverbio and Venturi, 2005]. They are simple to use and often economically advantageous. They are suitable for taking measurements on site and taking continuous measurements. These non-destructive methods are usually associated with each other to improve diagnosis and reduce the number of tests [Breysse, 2012]. Ultrasound measurements provide a simple non-destructive and inexpensive method to evaluate the elastic modulus of concrete. The formulae proposed by different standards to estimate the dynamic modulus of elasticity from the resistance are very approximate [Baalbak et al., 1992]. The dynamic modulus of elasticity is strongly influenced by the aggregates, it cannot be determined accurately based on the strength, which depends mainly on the cement paste and the particle size [Giaccio et al., 1992]. For temperatures between - 10° C and + 30° C, there is an increase in the dynamic modulus of elasticity of the concrete with temperature [Gardner, 1990]. The estimation of mechanical properties of concrete were assess by several methods (destructive and non-destructive). In this context, the crushing of the samples is the usual destructive test to determine the concrete strength. The rebound hammer test and the ultrasonic device are used in the field of non-destructive tests to determine respectively the compression strength and the ultrasonic pulse velocity (UPV) in the concrete. In this work, eight concrete compositions were used to prepare cylindrical specimens (16 cm x 32 cm) by varying the water/ cement ratio and the cement dosage. An experimental study was conducted to determine the compressive strength of concrete by destructive (compression) and non-destructive (rebound hammer) tests at different ages (7, 14 and 28 days). In addition, the influence of several factors on the modulus of elasticity determined by pulse velocity test was investigated. These factors mainly included the age of concrete and the water/ cement ratio. The results showed that the difference between the resistance values obtained by destructive and non-destructive methods decreases with increasing age of concrete. The dynamic modulus of elasticity increases with the curing time of the concrete until the age of three months. In addition, a simplified expression has been proposed to estimate the rebound number from the value of the dynamic modulus of elasticity determined by pulse velocity test [Jedidi Malek, and Machta Kaouther, 2014]. In this paper, a series of compressive strength of core specimen has to correlate the rebound hammer indices and UPSV results obtained from member of existing buildings. The combined method (SONREB) was used to quality control and strength estimation of the concrete. This combined method requires short time to obtain the results, it is a non-invasive method and it does not affect the resistance of structural elements. The best-fit equation of SONREB method for the determination of concrete compressive strength is obtain through processing correlation among the data sets. Finally, the investigation and comparison of experimental results of non-destructive tests and core strength with the help of statistical data obtained by testing of specimen as per recommended procedures by IS 13311:1992 and IS 516:1959 respectively. The use of the combined methods (SONREB) increases the accuracy of the estimation of the in situ concrete compressive strength [Hemraj R Kumavat. et al, 2017].

Among the available methods of NDT, the UPV methods can be consider as one of most promising methods for evaluation the concrete structures, once it makes possible an examination of the material homogeneity. It is possible to obtain a total control of a structure, using the properties variations with the time. Analysis of the propagation variations of ultrasonic velocity wave, it is possible to verify the compactness or detect heterogeneous regions in the concrete [Lorenzi, Tisbierek, Carlos, & Filho, 2007]. These methods allow the examination of material homogeneity and turn easier the diagnosis of defects. The UPV methods make possible the continuous evaluation of concrete conditions during the entire structure service life. The UPV results can be use for diagnosis, prognosis and quality control. The method is base on the propagation of a high frequency sound wave, which passes through the material. The speed of the wave varies in function of the density of the material, allowing the estimation of the porosity and the detection of discontinuities. The idea is to project the sound inside a material and measure the time necessary for the wave to propagate through it. Once the known distance, it is possible to determine the average pulse velocity, which will depend on several factors such as the nature of the material and the presence of water in the pores, among others [Lorenzi et al., 2011]. The test is sensitive to changes in concrete density, constitution and soundness. Once there are various intervenient parameters, the results tend to be use in comparative terms. It is use to check the homogeneity, and to find spots that have different properties than the surrounding areas. It may also be use to measure the thicknesses of the several layers of a composite material. The UPV can also be use to explore the relation between the concrete qualities with the compressive strength. The main idea is to explore the fact that ultrasonic velocity waves are function of the density of the material and that they are correlate with the compressive strength. The relation is not always trustworthy once there are many variables that affect the concrete strength, such as the water/cement ratio, the size and type of aggregate, the moulding procedure, the sample size and the cement type. UPV method is effectively apply to monitoring some procedures of concrete curing. It allows controlling important parameters such as strength, elasticity module and shrinkage of concrete (in both laboratory and in-situ). The use of UPV methods is quite useful to investigate concrete structures once it allows the monitoring of the material characteristics along its service life. [Lorenzi et al., 2011]. Using ultrasonic data, it is possible to determine the concrete uniformity, to control its quality, to accompany its deterioration and, by using a comparison with control specimens, to estimate its strength. One limitation of the technique, however, is that the relationship between ultrasonic and compressive strength values is affect by several factors, such as the concrete age, the aggregate type and proportion, the carbonated depth, etc. Furthermore, the evaluation of ultrasonic is a highly specialized and complex activity, which requires careful data collection and expert analysis. The possibility of 51 estimating the compressive strength, which is the main structural parameter, from an NDT test, is very alluring. Therefore, there is a steady interest in establishing useful correlations between UT and compressive test results.

In present research work, the non-destructive tests were conduct on 72 concrete cubes of size (100x100x100 mm) by RHT and UPVT in order to evaluate the different designed mixtures type (M1-M6). In turn to study an effectiveness of compressive strength on rebound hammer number (hardness of concrete) as well interpret the concrete matrix formation in different mixtures type. An effectiveness of compressive strength on rebound hammer number as well ultrasonic pulse velocity was interpret and assessed their characteristics in all mixtures type (M1-M6). In which case that, the first mixtures type (M1-M3) was designed as higher compressive strength (40 N/mm^2) with varied slump value (0-10, 10-30, and 60-180) mm, and in second mixtures type (M4-M6), considered different compressive strength (25, 30, 40 N/mm^2) with constant slump value (10-30) mm. In fact, when slump value is constant, clearly water content is same in all designed concrete mixes (M4, M5, and M6). It’s possible to study an effectives of mix proportioning on different designed concrete mixes for in case of lower and higher characteristic compressive strength, fine, w/c ratio, and coarse aggregate respectively.

3.3.2 Rebound hammer test on concrete cubes (RHT)

The Schmidt rebound hammer [BS 1881-202:1986] is a surface hardness test with little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. Rebound hammer tests the surface hardness of concrete, which cannot be convert directly to compressive strength. The method measures the modulus of elasticity of the near surface concrete. The distance travelled by the mass, expressed as a percentage of the initial extension of the spring, is consider as Rebound number. There is a considerable amount of scatter in rebound numbers because of the heterogeneous nature of near surface properties (principally due to near-surface aggregate particles). In the present research work, the original Schmidt® hammer, type N, is designed for non-destructive testing of concrete items 100 mm or more in thickness, or concrete with a maximum particle size less than or equal to (32mm) was used for testing concrete cubes. It is design for testing concrete within a compressive strength range of (10 to 70 N/mm^2) and impact energy of the test is (2.207 Nm). The (type N) Schmidt hammer is pressed against the concrete structure and the rebound values are displayed on a mechanical sliding scale and which was used in the present research work as shown in Figure 3-3.

Figure 3-3 Rebound hammer test on concrete cube

This method can be use with greater confidence for differentiating between the questionable and acceptable parts of a structure or for relative comparison between two different structures. The test is classify as a hardness test and is base on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The energy absorbed by the concrete is relate to its strength. There is no unique relation between hardness and strength of concrete but experimental data relationships can be obtain from a given concrete. However, this relationship is dependent upon factors affecting the concrete surface such as degree of saturation, carbonation, temperature, surface preparation and location, and type of surface finish. The result is also affect by type of aggregate, mix proportions, hammer type, and hammer inclination. Areas exhibiting honeycombing, scaling, rough texture, or high porosity must be avoid.

There are several factors other than concrete strength that influence rebound hammer test results, including surface smoothness and finish, moisture content, coarse aggregate type, and the presence of carbonation. The rebound hammer method could be use for the following purposes such as assessing the compressive strength of concrete with the help of suitable co-rrelations between rebound index and compressive strength, uniformity of concrete, quality of concrete in relation to standard requirements, and quality of one element of concrete in relation to another. In general, the rebound number increases as the strength increases and is also affected by a number of parameters i.e. type of cement, type of aggregate, surface condition and moisture content of the concrete, curing and age of concrete, and carbonation of concrete surface. Moreover, the rebound index is indicative of compressive strength of concrete up to a limited depth from the surface.

Rebound numbers will not indicate the internal cracks, flaws or heterogeneity across the cross section.

In this present research work, the variation of non-destructive hardness value in 72 dry concrete cubes (100x100x100 mm), with their average compressive strength values obtained from the rebound hammer test were highlight for six different mixtures type. Its consider constant compressive strength and varied slump as in first case (M1-M3) and varied compressive strength with constant slump for second case (M4-M6) as shown in Table 3-11. The following points should be observe during testing: (a) Concrete surface should be smooth, clean and dry. (b) Any loose particles should be remove from the concrete surface with a grinding wheel or stone, before hammer testing. (c) Rebound hammer test should not be conduct on rough surfaces because of incomplete compaction, loss of grout, and spalled concrete surface. (d) The point of impact of rebound hammer on concrete surface should be at least 20 mm away from edge or shape discontinuity. Concrete cube specimens were remove from the water after 28 days curing and rub with a dry cloth to obtain a surface dry sample. The specimens were place in the testing machine and slight load was apply. Afterwards, a fixed amount of energy is apply by pushing the hammer against the test surface according to the ASTM C 805 (1993). The test method starts by the careful selection and preparation of the concrete surface to be tested and plunger must be allow to strike perpendicularly to the surface, as the angle of inclination of the hammer affects the results. Four opposite faces of the cubes were prepared before for the Schmidt hammer test when drying was complete and reading were record on all the four faces of concrete cubes. In which 12 concrete cubes was casted for each mixture type and each mixture type represented as (M1, M2, M3, M4, M5, and M6).

Table 3-11 Non-destructive hardness value in concrete cubes for different mixtures type

MIX ID	Comp stg, N/mm^2	Min, value	Max, value	STD	RHN	Min, value	Max, value	STD
M1	31.34	18.7	37.5	5.01	51.10	40.58	55.08	3.75
M2	32.43	27.7	39.0	3.58	51.95	48.90	55.60	2.71
M3	34.48	28.8	39.0	3.17	53.35	49.50	56.00	1.85
M4	25.48	20.5	29.2	2.58	47.14	42.40	50.10	2.20
M5	31.90	27.4	35.9	2.42	51.85	48.70	54.20	1.55
M6	32.12	22.9	35.2	3.69	51.83	45.30	54.00	2.63

The compressive strength of concrete cubes was increase in the mixture type (M2) as when compare to the mixture type (M1) which was vary in the range 2.68%. Whereas in case of mixture type (M3), the compressive strength was still more increased which was in the range 7.92% as compared to mixture type (M1). The compressive strength of concrete cubes was decrease for about 48.43% in the mixture type (M5) as when compare to the mixture type (M4). Whereas in case of mixture type (M6), the compressive strength was still more decreased which was in the range 49.06% as compared to mixture type (M4). The rebound hammer number of concrete cubes was increase in the mixture type (M2) as when compare to the mixture type (M1) which was vary in the range 1.55%. Whereas in case of mixture type (M3), the rebound hammer number was still more increased which was in the range 4% as compared to mixture type (M1). The rebound hammer number of concrete cubes was increase for about 50.84% in the mixture type (M5) as when compare to the mixture type (M4). Whereas in case of mixture type (M6), the rebound hammer number was somewhat increased which was in the range 50.65% as compared to mixture type (M4).

Actually the rebound hammer number was influenced by so many factors in which the concrete made of high alumina cement can give strengths up to 100% higher, whereas super-sulphated cement concrete can give 50% lower strength compared to a calibration obtained on Portland cement cubes. Similarly, the gravel and most crushed rocks give similar correlations, but lightweight aggregates and aggregates with unusual properties required special calibration. Surface and internal moisture condition of the concrete. This method of testing is apply only on close textured concrete. Open texture concrete typical of masonry blocks, `honeycombed’ concrete, or no fines concrete cannot be tested using this method. Troweled and floated surfaces as in floors, are harder than moulded surfaces and in most cases will tend to overestimate the strength. A wet surface will give rise to under-estimated of the strength of concrete calibrated under dry conditions. This influence can be considerable and in structural concrete, it is about 10% lower on wet surfaces than on an equivalent dry surface. In very old and dry concrete, the surface will be harder than the interior, giving rebound values somewhat higher than normal. New concrete with moist surface generally has a relatively softer surface, resulting in lower than normal rebound. Surface carbonation of concrete significantly affect the RHT result. The concrete test hammer is an excellent tool in the hands of experts. The operation of the hammer is very simple, yet it is not so simple as to entrust this tool to a raw hand for taking readings of a structure. Specialists trained for this purpose must always carry out its operation, calibration, taking readings of a concrete structure, analysis and interpretation of the test data. The variation of average compressive strength with rebound hammer number, standard deviation, and co-relation equation as well as R^2 value are represented in Table 3-12.

Table 3-12 Variation of Rebound hammer number with compressive strength

MIX ID	Comp stg, N/mm²	STD	RHN	STD	Co-relation Equation	R^2
M1	31.34	5.01	51.10	3.75	$Y = 2.6723e^{0'0479x}$	0.9477
M2	32.43	3.58	51.95	2.71	$Y = 2.8649e^{0'0466x}$	0.8700
M3	34.48	3.17	53.35	1.85	$Y = 2.4599e^{0'0494x}$	0.9691
M4	25.48	2.58	47.14	2.20	$Y = 2.6803e^{0'0477x}$	0.9896
M5	31.90	2.42	51.85	1.55	$Y = 2.5253e^{0'0489x}$	0.9876
M6	32.12	3.69	51.83	2.63	$Y = 2.6381e^{0'0481x}$	0.9884

It is observe from results that, the rebound hammer number was increase with higher compressive strength with different slump value for in case of mixtures type (M1-M3). Whereas in mixtures type (M4-M6), the rebound hammer number was decrease with lower compressive strength, increases with higher compressive strength for constant slump value. The correlation coefficient (R^2) as observed from results that its varied from each other in all mixtures type (M1-M6) which was ranges from 94.77%, 87%, 96.91, 98.96%, 98.76%, and 98.84%. This means that there is an excellent relationship between compressive strength and the rebound number. This also implies that the independent variable (rebound number) is a useful predictor of the dependent variable (Compressive strength).

3.3.3 Ultrasonic pulse velocity test on concrete cubes (UPVT)

The Ultrasonic pulse velocity test (BS EN 12504-4, 2004) is a non-destructive test, which is perform by sending high-frequency wave (over 20 kHz) through the media. By following the principle that a wave travels faster in denser media than in the looser one, an engineer can determine the quality of material from the velocity of the wave this can be apply to several types of materials such as concrete, and wood. Concrete is a material with a heterogeneous composition. This heterogeneousness is link up both to the nature of its constituents (cement, sand, gravel, reinforcement) and their dimensions, geometry/distribution. Portable ultrasonic non-destructive digital indicating test (PUNDIT) is use for this purpose. Two transducers, one as transmitter and the other one as receiver, are use to send and receive 55 kHz frequency. The velocity of the wave is measure by placing two transducers, one on each side of concrete element. Then a thin grease layer is apply to the surface of transducer in order to ensure effective transfer of the wave between concrete and transducer. Operation of UPV test equipment is relatively straightforward but requires great care about surface treatment of concrete cubes at an initial stage if reliable results are to be obtain in the present research work. The surfaces of concrete cubes were clean of materials such as grit, pebbles, oil, and mud particles. One essential factor is good acoustical coupling between the concrete surface and transducer face, this is provide by a medium such as petroleum jelly, liquid soap or grease. Air pockets must be eliminate, and it is an important that only a thin separating layer exists any surplus must be squeeze out. A light medium, such as petroleum jelly or liquid soap, has been consider to be the best for smooth surfaces, but a thicker grease is recommended for rougher surfaces, which have not been cast against smooth shutters. If the surface is very rough or uneven, grinding or preparation with plaster of Paris or quick-setting mortar may be necessary to provide a smooth surface for transducer application. It is also important that readings be repeat by complete removal and reapplication of transducers to obtain a minimum value for the transit time. There are many factors relating to measurements made on in-situ concrete, which may further influence results. The operating temperature ranges to be expect in temperate climates are unlikely to have an important influence on pulse velocities, which is to be maintain at laboratory site. Which in turn reflect possible internal micro cracking at high temperatures and the effects of water freezing within the concrete at very low temperatures. The time that the wave takes to travel is record from PUNDIT display. The velocity of the wave can be calculate as given by the (equation 49) respectively.

$$\mathrm{V} = \frac{\mathrm{L}}{\mathrm{T}} \qquad (49)$$

Where

$\boldsymbol{V} = \text{Velocity of the wave, Km}/sec$
$\boldsymbol{L} = \text{Distance between transducers, mm}$
$\boldsymbol{T} = \text{Travelling time, μ}$

Thus in the present research work, mount the transducers to the concrete element can be done in the formats (direct transducers), as shown in Figure 3-4. This arrangement is the most preferred arrangement in which transducers were keep directly opposite to each other on opposite faces of the concrete. The transfer of energy between transducers is maximum in this arrangement. The accuracy of velocity determination is govern by the accuracy of the path length measurement. The couplant used should be spread as thinly as possible to avoid any end effects resulting from the different velocities of pulse in couplant and concrete. If the concrete is not compact thoroughly and having segregation, cracks or flaws, the pulse velocity will be lower as compare to good concrete, although the same materials and mix proportions are used.

Figure 3-4 Ultrasonic pulse test on concrete cube

Pulse velocity tests can be carry out on both laboratory-sized specimens and existing concrete structures, but some factors affect measurement. There must be a smooth contact with the surface under test. It is desirable for path-lengths to be at least (30 cm) in order to avoid any errors introduced by heterogeneity. The method is base on the principle that the velocity of an ultrasonic pulse through any material depends upon the density, modulus of elasticity and Poisson's ratio of the material. Comparatively higher velocity is obtain when concrete quality is good in terms of density, uniformity, and homogeneity. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affects the pulse velocity. The pulse velocity depends on the properties of the concrete under test. Various factors which can influence pulse velocity and its correlation with various physical properties of concrete such as moisture content, temperature of concrete, path length, effect of reinforcing bars, as well as shape and size of specimens. The variation of Ultrasonic pulse velocity with compressive strength for different mixtures type (M1-M6) as represented in Table 3-13.

Table 3-13 Ultrasonic pulse velocity (m/sec) in concrete cubes for different mixtures type

MIX ID	Comp stg, N/mm²	Min, value	Max, value	STD	UPV,m/s	Min, value	Max, value	STD
M1	32.50	29.7	36.9	2.09	4347.25	3600	4900	333.3
M2	33.59	30.2	37.6	2.59	4371.91	4174	4700	184.2
M3	35.29	32.8	40.0	2.22	4446.33	4150	4974	268.1
M4	27.16	23.9	29.3	1.61	3528.33	3000	3950	364.9
M5	32.43	31.4	34.9	1.29	3645.91	3100	4500	556.1
M6	33.40	30.4	36.5	1.71	4080.16	3200	4584	483.9

The compressive strength of concrete cubes was increase in the mixture type (M2) as when compare to the mixture type (M1) which was vary in the range 2.88%. Whereas in case of mixture type (M3), the compressive strength was still more increased which was in the range 7.54% as compared to mixture type (M1). The ultrasonic pulse velocity was increase in mixtures type (M1:0-10 mm-M2-10-30 mm-M3:60-180 mm) with increased varied slump value and higher constant compressive strength (M1-M2-M3:40 N/mm²) respectively. Large slump of concrete is one of the factors that make differences in compressive strength and pulse velocity of concrete. With high concrete slump, the aggregates with different density separate easily, cause heterogeneity in the sample, and consequently affect the concrete compression strength and ultrasonic pulse rates. The results of ultrasonic pulse velocity of concrete cubes was also increase with higher the cement content value for in case of mixtures type (M1:3.60 Kg/m^3-M2:4.35 Kg/m^3-M3:5.43 Kg/m^3). The ultrasonic pulse velocity was decrease in mixtures type (M4:M5:M6:10-30 mm) with constant slump value and increased compressive strength (M4:25 N/mm²-M5:30 N/mm²-M6:40 N/mm²) respectively. The results of ultrasonic pulse velocity of concrete cubes was increase with higher the cement content value and compressive strength for in case of mixtures type (M4:3.84 Kg/m^3-M5:4.27 Kg/m^3-M6:4.35 Kg/m^3).

The compressive strength of concrete cubes was increase for about 16.03% in the mixture type (M5) as when compare to the mixture type (M4). Whereas in case of mixture type (M6), the compressive strength was still more increased which was in the range 18.58% as compared to mixture type (M4). The ultrasonic pulse velocity of concrete cubes was increase in the mixture type (M2) as when compare to the mixture type (M1) which was vary in the range 0.536%. Whereas in case of mixture type (M3), the ultrasonic pulse velocity was still more increased which was in the range 1.77% as compared to mixture type (M1). The ultrasonic pulse velocity of concrete cubes was increase for about 1.064% in the mixture type (M5) as when compare to the mixture type (M4). Whereas in case of mixture type (M6), the ultrasonic pulse velocity was more increased which was in the range 18.58% as compared to mixture type (M4). The variation of average compressive strength with ultrasonic pulse velocity, standard deviation, and co-relation equation as well as R^2 value are represent in Table 3-14.

Table 3-14 Variation of Ultrasonic pulse velocity with Compressive strength

MIXID	Comp stg,N/mm²	STD	UPV,m/s	STD	Co-relation Equation	R²
M1	32.50	2.09	4347.25	333.31	Y =0.0046x+12.709	0.5233
M2	33.59	2.59	4371.91	184.22	Y =0.0108x-13.807	0.5915
M3	35.29	2.22	4446.33	268.11	Y =0.0079x+0.1879	0.9063
M4	27.16	1.61	3528.33	364.93	Y =0.0031x+16.195	0.4927
M5	32.43	1.29	3645.91	556.17	Y =0.002x+25.09	0.7515
M6	33.40	1.71	4080.16	483.94	Y =0.0033x+19.93	0.8638

It is observe from results that, the ultrasonic pulse velocity was increase with higher compressive strength as well as different slump value for in case of mixtures type (M1-M3). Whereas in mixtures type (M4-M6), the ultrasonic pulse velocity was somewhat decreased with lower compressive strength, and increases with higher compressive strength for constant slump value. The correlation coefficient (i.e. R^2) as observed from results that its varied from each other in all mixtures type (M1-M6) which was ranges from 52.33%, 59.15%, 90.63%, 49.27%, 75.15%, and 86.38%. This means that there is an excellent relationship between compressive strength and ultrasonic pulse velocity. This in implies that the independent variable (ultrasonic pulse velocity) is a useful predictor of the dependent variable (Compressive strength).

3.3.4 Summary

- The non-destructive testing method is a worldwide group of analysis techniques used in science and technological industry to evaluate the properties of a concrete without causing damage.

- In present research work, the non-destructive test were conduct on concrete cubes by RHT and UPVT in order to evaluate the different designed mixtures type. In turn to study the effectiveness of compressive strength on rebound hammer number (hardness of concrete) and ultrasonic pulse velocity as well as interpret the concrete matrix formation in different mixtures type.

- It is observe from results that, the rebound hammer number, and ultrasonic pulse velocity was increase with higher compressive strength, and different slump value. Whereas the rebound hammer number as well as ultrasonic pulse, velocity was decrease with lower compressive strength, increases with higher compressive strength for constant slump value.

- There is an excellent relationship between compressive strength and the rebound number and ultrasonic pulse velocity. This also implies that the independent variable (rebound number and ultrasonic pulse velocity) is a useful predictor of the dependent variable (compressive strength).

3.4 Sorptivity test on concrete cubes

3.4.1 Introduction

The concrete durability can be evaluate by a number of properties such as water absorption and chloride diffusion. Each of these properties can be measured using standardized methods. Water absorption can be linked to porosity and therefore to eventual deterioration. Tests based on absorption have the potential to be simple. However, it is impossible to provide the standard conditions for in-situ measurements. Water absorption is strongly affect by environmental temperature and concrete moisture content. These different conditions may cause incorrect evaluation of concrete performance. Many building materials used in the construction industry are porous. The ingress of moisture and the transport properties of these materials have become the underlying source for many engineering problems such as corrosion of reinforcing steel, and damage due to freeze-thaw cycling or wetting and drying cycles. In the 1970’s, Hall suggested the importance of studying the unsaturated flow of water in porous medium. Sorptivity was introduce as a testing method that consisted of a uni-directional water absorption front within a specimen. In short, sorptivity is base on the rate of absorption, which is proportional to the surface area exposed to moisture and time [Hall, 1981]. The permeability was use as a surrogate to durability but this is not entirely accurate. Permeability relates movement of moisture through a saturated porous medium under a pressure gradient. The existence of a concrete structure under such conditions is consider highly unlikely and so sorptivity becomes a more accurate characteristic to describe the durability of a concrete structure. Sorptivity testing on concrete was confirm to be sensitive to compaction. Prolonged ramming of specimens increased bulk density and decreased porosity. With prolonged ramming, sorptivity plots exhibited a curvature. This finding brought forward the concept that elimination or reduction of large pores created this non-linearity [Hall and Raymond Yau, 1987].

Application of the sorptivity test to concrete became more important as there was a worldwide concern about the poor durability of concrete structures, the most dominant form of deterioration being the corrosion of steel reinforcement due to the ingress of moisture through the surface skin of concrete. Sorptivity could be sensitive to the quality of the cover skin of concrete members. It has proven an effective in revealing poor placing as well as finishing techniques in the field [McCarter, 1993]. Further support could be consider to sorptivity testing as it was discovered that testing was also sensitive to the depth of concrete. Specimens that were test at different depths for sorptivity gave different results, which could be indicative of signs of segregation or bleeding due to poor construction practices [Khatib and Mangat, 1995]. By the mid 1990's, it was generally accepted that good quality concrete was represented by low sorptivity values and extensive work had been done on the influence of various factors on water sorptivity. It was confirm that the quality of concrete increased with curing time, and that it varied based on the source and type of material used. The use of admixtures and the source of Portland cement also had a large influence on the quality of concrete described by sorptivity testing [Ho and Chirgwin, 1996].Further acceptance of sorptivity led to the development of sorptivity-based service life models such as Conclife [Bentz et al. 2001]. In combination with work done by Hooton and Desouza [Desouza et al. 1998] this led to the standardization of the Sorptivity Test as ASTM C 1585. Literature has suggested that the specimens be coated on their curved sides and be moderately preconditioned for 3 days at 50^0 C [Dias, 2004]. The following section derived from the Portland Cement Association (PCA) Research and Development Journal details the development of the ASTM C 1585 test method [Ferraris and Stutzman, 2006]. The test setup for sorptivity has been consider sensitive to boundary conditions. Sorptivity testing based on ASTM C 158504 consists of subjecting a disc-shaped concrete specimen (100 mm in diameter and 50 mm in thickness) to one-sided exposure to water. In order to ensure a unidirectional flow, the remaining surfaces of the specimen that are not immerse must be seal appropriately with a suitable material. After scanning the literature, it became evident that a wide variability of sorptivity values exists, depending on the choice of sealant. These include electrical insulation tape, grease, bituminous paint, and paraffin wax [Gonen and Yazicioglu, 2007]. The acceptance of sorptivity as an important durability index, because, it is testing methodology reflects the way in which most concretes are penetrate by water and that it is thus a good measure of the quality of the near surface concrete, has broadened the application of the standardized test. For example, sorptivity has been use to determine the presence of carbonation in concrete [Dias, 2000]. The onset of carbonation reduces the porosity of near-surface concrete. Therefore, sorptivity is reduce. Measuring the sorptivity at various depths can give an indication of the severity of carbonation. Bai (2002) confirmed that there exists a strong correlation between carbonation depth and sorptivity [Bai et al, 2002]. The ASTM C 1585 has also been extended to determine the effects of compaction on the durability of the concrete [Gonen and Yazicioglu, 2007]. Various applications of the standard have also included determining water absorption at 28 and 56 days to study the continuation of cement hydration in concrete [El-Dieb, 2007]. As well, the standard has been apply to evaluate the effectiveness of fly ash and slag in lowering the transport properties in concretes [Radlinski et al, 2007]. It has been confirm that the dominant characteristics in concrete degradation are its near-surface properties [Basheer et al. 2001], thus tests methods characterizing the surface zone of concrete, such as the ASTM C 1585, become very important.

Water is generally involved in every form of deterioration, and in porous solid permeability of the material to water usually determines the rate of deterioration. This paper focuses on designing structure the durability characteristics should be evaluate as carefully as the other mechanical properties and the initial cost. A South African approach is use to measure the sorptivity index testing and concluded that, the method is applicable to actual project also and is sorptivity index is a parameter to evaluate the durability of RPC and cover zone concrete. RPC shows a good resistance to permeability indicating impermeable concrete [M. K. Maroliya, 2012]. When excess water in concrete evaporates, it leaves voids inside the concrete element creating capillaries, which are directly relate to the concrete porosity and permeability. An impervious concrete can be obtain by proper selection of ingredients and mix proportioning and following the good construction practices. The flow of water through concrete is similar to flow through any porous body. The pores in cement paste consist of gel pores and capillary pores. The pores in concrete because of incomplete compaction. The voids of larger size, which give a honeycomb structure leading to concrete of low strength. Due to problems, associated with the absorption test and permeability tests, measures the response of concrete to pressure, which is rarely the driving force of fluids entering concrete, there is a need for another type of test. This test should measure the rate of absorption of water by capillary suction, “sorptivity” of unsaturated concrete and attempt was made to study the properties of fly ash concrete [Jayeshkumar Pitroda and F. S. Umrigar, 2013].

During this study, the water absorption and sorptivity properties of fly-ash based geopolymer concrete were study in detail. Geopolymer concrete is one among the steps taken towards sustainable construction. It has a lower greenhouse footprint than traditional concrete. The effect of accelerated corrosion on geopolymer concrete was also study and the results were compare with control concrete. It was conclude through the study that geopolymer concrete is less porous and has a lesser linear curve as compared to control concrete [Salmabanu Luhar, and Urvashi Khandelwal, 2015]. The purpose of this paper is an investigation of porosity and sorptivity of aerated concrete with varying percentage additions of aluminium powder between 0.25% and 0.75%. The bulk density, porosity and sorptivity were determined after 28 days of water curing. The results show that the highest density of aerated concrete was with 0.25% aluminium powder. The porosity values obtained by vacuum saturation were consistently form to be higher than those obtained by soaking which suggests that the soaking method does not access all the pore space. In addition, the capillary suction of aerated concrete as assessed by sorptivity was significantly higher than that measured by coefficient of water absorption method [Rana Shabbar, et al, 2016]. Increasing amounts of recycled materials are being investigate worldwide to supplement natural components of typical building mixes, like concretes and mortars, due to environmental reasons. Because of wide range of possible alternative materials and their parameters, research activities involve detailed analysis of all aspects of their influence on the new materials parameters. Durability can be consider as one of the most significant parameters of building materials, having direct impact on the lifetime of material itself as well as the lifetime of whole building. Durability of cement-based mortars/concretes is dependent mainly on the amount of a fluid to penetrate the material. Low permeability can improve resistance to the penetration of water, sulphate ions, chloride ions, Co_2, and other harmful substances, which cause chemical attack. Sorptivity expressed by water absorption coefficient is a characteristic of moisture transport into material, and recently it has been establish as an important performance characteristic of durability. Mortar/concrete sorptivity has a close relationship with the characteristics of its pore structure, which can be modify by application of very small particles. In the paper, the set of mortar samples, as well as set of concrete samples with portions of brick, glass and concrete powders as a partial substitution of natural aggregate have been investigate. Long-time water absorption coefficient was tested; positive effect of fine-grain additive was demonstrate only in case of concretes, while the concrete powder gave the best results and the glass powder gave the worst one. Effect of time was consider beneficial in all cases [Alena Sicakovaa, 2017]. In this research work, six mixtures type were design and evaluated 72 concrete cube specimens for their effectiveness on water absorption characteristics.

3.4.2 Water absorption test

The 100 mm x 100 mm x 100 mm size concrete cube after casting were immerse in water for 28 days curing. These specimens were then oven dried at 50±2ºC for 3 days until the mass became constant and again weighed. This weight was note as the dry weight (W1) of the concrete cube. After that, specimens were keep in contact with water from one bottom surface and water level not more than 5 mm above the base of specimen. The flow from the peripheral surface is prevent by sealing it properly with non-absorbent coating for a specified time interval as per [ASTM C 1585] with their arrangement as shown in Figure 3-5. Then this weight was note as the wet weight (W2) of the concrete cube.

$$\text{water absorption (\%)} = \left[\frac{\mathrm{W2} - \mathrm{W1}}{\mathrm{W1}}\right] X100 \qquad (50)$$

Where,

$\boldsymbol{W1} = \text{Oven dry weight of concrete cubes in grams}$
$\boldsymbol{W2} = \text{Wet weight of concrete cubes after specified time in grams}$

The water absorption in concrete cubes was vary between 0.43-0.59% at initial time duration to 4-4.64% at longer time duration as noted from different mixtures type (M1-M6). The moisture content varied linearly with initial time duration, deviates afterwards at later time duration, and reaches equilibrium state for longer time duration.

Figure 3-5 Water absorption test on concrete cubes

The water absorption test was carry out on 72 concrete cubes with size (100x100x100) mm in all six mixtures type (M1-M6). In which ASTM C1585 is commonly use to determine the absorption and rate of absorption of water in unsaturated hydraulic cement concretes. The results confirm that water absorption testing is considerably influence by sample preparation. The absorption is also influence by the volume of paste in the samples. The experiments show that a lack of control on moisture content or lack of consideration of the material composition may lead to a misunderstanding of the actual absorption behaviour. The water absorption was increased (49.76%) at time duration 5 min as when compared to initial time duration 0 min in all mixtures type (M1-M6). Whereas the water absorption (87.98%) was predominantly increased at longer time duration (28 day). The water absorption (48.91-50.57%) at 0 min as well as (87.82-88.13%) at 28 days was little bit varied as compared to different mixtures type (M1-M3) and (M4-M6). Similarly, the water absorption was more increase in mixture type (M4) for lower compressive strength with constant slump value. Also the water absorption was going on decreased with increased compressive strength in case of mixture type (M5), but increased with compressive strength in mixture type (M6) at initial stage as well as at longer time duration at 28 day. The water absorption was vary with absorption rate (sorptivity coefficient) as represent in (Table 3-15*)*.

Table 3-15 Relationship between water absorption-sorptivity coefficient

MIX ID	Co-rrelation Equation	R^2
M1	$Y = 4.0402e^{-1937X}$	0.8852
M2	$Y = 4.7562e^{-1591X}$	0.8462
M3	$Y = 3.7738e^{-1988X}$	0.8319
M4	$Y = 5.6996e^{-1194X}$	0.7885
M5	$Y = 3.9850e^{-1843X}$	0.8819
M6	$Y = 4.2476e^{-1950X}$	0.8721

The water diffusion coefficient was vary with logarithmic (negative) value of water absorption (Table 3-16). The water diffusion coefficient was increase in all concrete mix designs (M1-M6) for lower water absorption value and goes on reduces with increased water absorption and compressive strength.

Table 3-16 Relationship between water diffusion coefficient-water absorption

MIX ID	Co-rrelation Equation	R^2
M1	$y=- 1.76\ln(x)+2.1493$	0.9659
M2	$y = -2.17\ln(x)+2.7686$	0.9814
M3	$y = -2.24\ln(x)+2.1922$	0.9960
M4	$y = -1.88\ln(x)+2.9940$	0.9921
M5	$y = -1.54\ln(x)+2.1632$	0.9960
M6	$y = -1.42\ln(x)+2.0595$	0.9978

3.4.3 Sorptivity test

It is define as a measure of the capacity of the medium to absorb or desorb liquid by capillarity. The Sorptivity is widely used in chacterizing soils and porous construction materials such as brick, stone, and concrete.

$$\text{Sorptivity coefficient } (S) = \frac{\mathrm{i}}{\sqrt{\mathrm{t}}} \tag{51}$$

$\boldsymbol{S}$ = Sorptivity in mm,

$\boldsymbol{i}$ = cumulative absorption at time (t), m/s

$\sqrt{\boldsymbol{t}}$ = square root of elapsed time in min,

The Sorptivity coefficient (rate of water absorption) was increase at initial time duration (0.0009-0.0011 m/min$^{0.5}$) as when compare to longer time duration (4.2E-05-5.4E-05 m/min$^{0.5}$). The Sorptivity coefficient increases at initial time duration, this may be due to unsaturated pore structure, and in turn, the rate of absorption is more at that time. As time increases, the rate of absorption goes on decreases with increased time duration in turn indicates that, pore structure may be reach fully saturated condition. Sorptivity test is a very simple technique that measures the capillary suction of concrete when it is expose to water. The sorptivity test was perform in accordance with the ASTM C 1585. This test is use to determine the rate of absorption (Sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one bottom surface of the specimen is exposed to water ingress of unsaturated concrete by capillary suction during an initial contact with water. The rate of sorption is the slope of the best-fit line to the plot of absorption against square root of time. The concrete cubes (100 mm x 100 mm x 100 mm) after casting were immerse in water for 28 days curing. Prior the test, specimens were placed in a desiccator oven at temp.50 ±2ºC for 3 days. After that, specimens were keep in contact with water from one bottom surface with water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevent by sealing it properly with non-absorbent coating. The quantity of water absorbed in specified time was measure by weighting the specimen on a top pan balance weighting up to 0.1 mg.

The surface water on the specimen was wipe off with a dampened tissue and each weighting operation. Weights of the concrete cube specimens after sealing were record as an initial weight (W1). The initial mass of the sample was consider and at time 0 min, it was immerse to a depth of 5 mm in the water. At selected times (typically 0, 5, 10, 15, 20, 25, 30, 60, and 200 minutes) the sample was removed from the water, the stop watch stopped, excess water blotted off with a damp paper towel or cloth and the sample weighed (W2). It was then replaced in water and stopwatch was started again was complete within 30 seconds. Finally, it is possible to calculate the sorptivity by knowing the difference in saturated weight to dry weight of concrete cube specimens, surface area of the concrete cube specimens through which water penetrated, and density of water. Sorptivity (S) is a material property, which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t).

$$i = S\sqrt{t} \tag{52}$$

$$\mathrm{S} = \frac{\mathrm{i}}{\sqrt{\mathrm{t}}} \tag{53}$$

Where

S = sorptivity in mm,

T = elapsed time in mint. i = Δ w/Ad

Δ ***w*** = change in weight = W2-W1

W1 = Oven dry weight of cube in grams

W2 = Weight of cube after specified time minute capillary suction of water in grams

A = surface area of the specimen through which water penetrated

d = density of water

As observed from the results that, the Sorptivity coefficient was increases at initial time duration with decreased cumulative water absorption in all mixtures type as when compared to longer time duration. The Sorptivity coefficient at an initial time duration was confirm to be in the range (0.0009-0.0014 m/min$^{0.5}$) and (4.5E-05-5.5E-05 m/min$^{0.5}$) at final time duration. Whereas the cumulative absorption varied at initial stage between (0.002-0.003 m) at early time duration and (0.008-0.013 m) at longer time duration. Finally, the Sorptivity coefficient was decreases with decreased rate of cumulative absorption at longer time duration in turn it indicates that, the pore structure reaches fully saturated condition in all mixtures type.

3.4.4 Moisture content

The total amount of moisture contained within the concrete, as either water or water vapour, is call as the moisture content. It is generally express as a percentage of the mass of the concrete (BS 812-109, 1990). Moisture in concrete is present in the capillary pores and smaller gel pores within the concrete matrix. Moisture may exist as either water (when the concrete is wet and the pores are saturated) or as water vapour, which provides a level of relative humidity within the concrete material. The amount of water vapour and hence relative humidity within the concrete may vary significantly over time as water vapour moves in or out of the concrete in order to establish an equilibrium with the changing ambient conditions. The initial source of moisture in concrete is the mixing water that is use at the time of manufacture. Once the concrete is place, there are numerous other sources of moisture. These include wet curing, exposure to the weather, wet subgrades (in slab-on-ground construction), condensation (either within the concrete or on the surface) and application of mortar tile bedding and other water-based adhesives.

$$\text{Moisture content} = \frac{Wet\ weight - Dry\ weight}{Wet\ weight} \times 100\% \qquad (54)$$

The moisture content ranges between (0.45-0.60%) at initial time duration to (4-4.5%) at longer time duration as confirmed from different mixtures type (M1-M6). The moisture content varied linearly with initial time duration, deviates afterwards at later time duration, and reaches equilibrium state for longer time duration.

The difference in moisture content was higher (50.05%) at time duration 5 min as when compare to an initial time duration 0 min in all mixtures type (M1-M6). Whereas the difference in moisture content (76.86%) was predominantly higher at longer time duration (28 day). The moisture content (48.22-50.87%) at 0 min as well as (76.75-76.97%) at 28 days was little bit varied as compared to different mixtures type (M1-M3) and (M4-M6). Similarly, the moisture content was increase in mixture type (M4) for lower compressive strength and constant slump value at 5 min. Moisture content was going on decreased with increased compressive strength in case of mixture type (M5). Similarly, still more increased compressive strength in mixture type (M6), moisture content was somewhat increased at 5 min. However, at longer time duration at 28 days, moisture content slightly increased in all mixtures type (M4-M6) for in all grade of concrete.

3.4.5 Cumulative absorption

The cumulative absorption coefficient was confirm to be decrease at an initial time duration (0.00097-0.00107 m) for in case of mixtures type (M1-M3) as when compared to (0.00097-0.00134 m) mixtures type (M4-M6). The cumulative absorption coefficient was increases (0.0087-0.00899m) at longer time duration for in case of mixtures type (M1-M3) with same grade of concrete, and cumulative absorption coefficient was varied (0.00877-0.01323 m) in mixtures type (M4-M6) with different grade of concrete at constant slump value. In turn, the rate of absorption is more at longer time duration and this rate of absorption decreases with increased grade of concrete. In fact, the cumulative absorption coefficient increases with increased rate of absorption (sorptivity coefficient) and lower grade of concrete.

$$i = S.\sqrt{t} \tag{55}$$

$\boldsymbol{i}$ = cumulative absorption at time (t), m/s
$\boldsymbol{S}$ = Sorptivity in mm,
$\boldsymbol{t}$ = elapsed time in min,

The cumulative water absorption was interpret for about 28 days in concrete cubes for designed six mixtures type (M1-M6). The cumulative absorption was increase initial time duration at 10 min as when compare to 5 min, which was vary as 11.53%. Similarly, the cumulative absorption was increase at final time duration (28 day) as when compared to 5 min, which was, vary as 77%.

The cumulative absorption curve reaches first phase of equilibrium level at time duration 65.72 min. Cumulative absorption of the concrete mixtures decreases with the decrease in water-cementitious material ratio for in case of all designed mixtures type (M1-M6) and as result of that, less amount of water availability in the mixture which results in dense concrete.

3.4.6 Sorptivity coefficient

The sorptivity coefficient was decrease when compared to initial time duration (5-10) min. In fact, there was decrease in Sorptivity coefficient (21.89%) at 10 min as when compared to initial time duration (5 min) for in case of all mixtures type (M1-M6). Similarly, sorptivity coefficient was goes on decreases gradually at certain point, it reaches parabolic pattern, and afterwards it reaches equilibrium (28 day) in turn sorptivity coefficient was decreased (95.18%). Whereas at 1 day, the increase in sorptivity coefficient was confirm to be 82.07% for in case of all mixtures type (M1-M6). The variation of sorptivity coefficient with square root of time for in case of designed mixtures type with their correlation equation as well as R^2 values was represent in (Table 3-17). The sorptivity coefficient for in case of mixtures type (M1-M3) at initial time duration (10 min) was found to be increased (21.32%) as when compared to time duration (5 min). Similarly, at 10 min, there is increase in sorptivity coefficient (22.46%) as when compare to time duration (5 min) for in case all mixtures type (M4-M6). The rate of absorption was always more at initial time duration because of differential gradient exists between higher to lower concentration gradient section, there was a variation in the rate of absorption up to certain time duration after that, it reaches parabolic pattern which is very smooth flow of rate of absorption. Once it reaches that, pore structure, cement paste, and concrete matrix reaches fully saturated in turn finally the sorptivity coefficient reaches equilibrium state.

Table 3-17 Relationship between Sorptivity coefficient and Square root of time

MIX ID	Co-rrelation Equation	R^2
M1	$Y = 0.0016x^{-0‘647}$	0.9921
M2	$Y = 0.0019x^{-0‘64}$	0.9911
M3	$Y = 0.0015x^{-0‘64}$	0.9930
M4	$Y = 0.0023x^{-0‘644}$	0.9906
M5	$Y = 0.0016x^{-0‘636}$	0.9917
M6	$Y = 0.0016x^{-0‘657}$	0.9919

3.4.7 Sorptivity coefficient-cumulative absorption

The sorptivity coefficient was observe to be higher/lower for in case of all mixtures type (M1-M6) at an initial time duration. But it goes on gradually decreased and reached equilibrium state as when pore structure was reached fully saturated condition. Logically at an initial time duration, the sorptivity coefficient was more but the cumulative absorption was lesser. Because the cumulative or net absorption was not achieved once for all, this may in turn depends on cement paste matrix, concrete matrix, aggregate volume fraction, w-c ratio, compressive strength, and slump. At inetermedaite time duration, the sorptivity coefficient was gradually decreased with increased cumulative absorption for in case of all mixtures type (M1-M6). But once equilibrium reached, the sorptivity coefficient was still goes on reduced slightly in turn net cumulative absorption was found to be increased up to cetain time duration, after that both sorptivity coefficient and cumulative absorption was reversed in nature in turn both tries to decreases which indicates that pore structure was reached fully saturated state and finally there is no more increased rate of absorption for in case of longer time duration. The variation of sorptivity coefficient with cumulative absorption at different time interval was correlate by a power type of equation for in case of various concrete mixtures type with correlation equations as represent in Table 3-18 .

Table 3-18 Relationship between sorptivity coefficient-cumulative absorption

MIX ID	Co-rrelation Equation	R^2
M1	$Y = 2E\text{-}08x^{-1.757}$	0.9383
M2	$Y = 4E\text{-}08x^{-1.708}$	0.9328
M3	$Y = 2E\text{-}08x^{-1.716}$	0.9474
M4	$Y = 1E\text{-}08x^{-1.831}$	0.9335
M5	$Y = 3E\text{-}08x^{-1.681}$	0.9390
M6	$Y = 6E\text{-}08x^{-1.725}$	0.9283

3.4.8 Water diffusion coefficient

The ratio of difference in wet weight-dry weight to wet weight of concrete cubes is known as moisture content. Similarly in the present research work from water absorption test, calculate moisture content (Mt) of concrete cubes at different time intervals (5, 10, 15, 20, 30, 60 and 40320 min) and continues water absorption test unit it reaches an equilibrium state in moisture content (M_∞) of concrete cubes at an infinite time duration (40320 min) respectively. The diffusion coefficient is calculate from the solution of one-dimensional Fickian theory for unsteady diffusion process. The percent of moisture gain at any time t, (M_t) can obtain from the solution of the one-dimensional Fickian model with constant boundary conditions as:

$$Mt = M_{\infty}\{1 - \frac{8}{\pi^2}\sum_{n=0}^{\infty}(2n+1)^{-2}\exp[\frac{-D(2n+1)^2\pi^2 t}{L^2}]\} \qquad (56)$$

Where M_{∞} is the moisture gain at saturation equilibrium (%), n is a known integer, which varies from material to material, L, is the thickness of the material, and D is the diffusivity of the material. At an initial stage of diffusion, the solution for Fick's law at minor reduces to as:

$$\frac{Mt}{M_{\infty}} = 4\sqrt{\left(\frac{D}{\pi L^2}\right)}\sqrt{t} \qquad (57)$$

The water diffusion coefficient was gradually increased which follows linearity of proportion at initial time duration, afterwards deviates with square root of time duration and reaches equilibrium in turn indicates that, pore structure was attained fully saturated condition. The water diffusion coefficient was vary approximately in between 0.5-2.2 mm^2/min in all mixtures type (M1-M6). The water diffusion coefficient was initially increase in all mixtures type (M1-M6). The diffusion coefficient was increase at shorter time duration (5 min) which was about 9.70% in mixtures type (M1-M3) as when compare to time duration at 10 min. Also The diffusion coefficient was increase at shorter time duration (5 min) which was about 10.32% in mixtures type (M4-M6) as when compare to time duration at 10 min. Similarly, water diffusion was more vary at initial time duration 5 min that was in the range of about 57.21% as when compared to 1 day (1440 min). Furthermore, it was still increase at initial time (5 min) duration of about 76.50% as when compare to 185.90 min in all mixtures type. However, at initial stage (5 min), the observed diffusion coefficient was increase in case of mixtures type (M1-M3) as about 76.92% as well as (76.02%) for in mixtures type (M4-M6) as when compared to longer time duration (185.90 min). The variation of water diffusion coefficient with square root of time for in case of designed mixtures type with their correlation equation as well as R^2 values was represent in

Table 3-19.

Table 3-19 Interpretation of water diffusion coefficient-square root of time

MIX ID	Co-rrelation Equation	R^2
M1	$Dw = -0.669\ln(\sqrt{t})+2.50$	0.9525
M2	$Dw = -0.378\ln(\sqrt{t})+2.43$	0.9661
M3	$Dw = -0.345\ln(\sqrt{t})+2.29$	0.9652
M4	$Dw = -0.35\ln(\sqrt{t})+2.37$	0.9475
M5	$Dw = -0.341\ln(\sqrt{t})+2.26$	0.9648
M6	$Dw = -0.335\ln(\sqrt{t})+2.16$	0.9708

The diffusion coefficient was initially increased, may be due to concentration gradient. Actually the concentration gradient was more at initial time duration, due to that the rate of absorption was also more, once the pore structure was fully saturated, the rate of diffusion coefficient goes on decreases with time duration. Thus, the concentration gradient was more at initial stage, goes on decreases as time passes and thus diffusion coefficient was reduce gradually as time in turn reaches equilibrium state.

3.4.9 Water diffusion coefficient-moisture content

The water diffusion coefficient was increases at initial time duration in all mixtures type (M1-M6) in which its ranged about 2.25 mm^2/min at 5 min time duration with moisture content (Mc = 1.07%). The diffusion coefficient-moisture content curve deviates nearer point at moisture content (Mc = 1.9-2%) in almost all mixtures type at which the diffusion coefficient was about at least 1.072 mm^2/min. After time passes, the water diffusion coefficient was reach equilibrium state with increase in moisture content. The variation of water diffusion coefficient at different time interval with moisture content was correlate by quadratic equation for in case of mix designs (M1-M3) and power type of equation for in cases of mix designs (M4-M6) as represent in Table 3-20 respectively.

Table 3-20 Interpretation of water diffusion coefficient-moisture content

MIX ID	Co-rrelation Equation	R^2
M1	$Dw = 0.215Mc^2-1.54x+3.33$	0.954
M2	$Dw = 0.170Mc^2-1.46x+3.66$	0.948
M3	$Dw = 0.226Mc^2-1.58x+3.34$	0.935
M4	$Dw = 2.945Mc^{-0.791}$	0.888
M5	$Dw = 2.098Mc^{-0.819}$	0.929
M6	$Dw = 2.06Mc^{-0.924}$	0.939

The diffusion coefficient was very higher at higher concentration gradient with lesser moisture content at an initial stage. Once if moisture content was increase in concrete matrix, pore structure may become fully filled water, in turn thus diffusion coefficient was goes on reduced as time passes with increase in moisture content for in case of all mixtures type (M1-M6).

3.4.10 Moisture content ratio-time duration

The moisture content ratio coefficient depends on factors such as square root of material thickness, diffusion coefficient, and time. As observed from the research work that, the moisture content ratio varies linearly at initial time duration, afterwards the curve follows non-linear trend, and finally reaches equilibrium conditions in all mixtures type. In addition to that, the moisture content ratio varies between 1-1.2 for in case of mixtures type (M1-M3). Whereas the moisture content ratio varies more 1.6 for in case of mixture type M4 as when compared to mixtures type (M5-M6). This may be due to Grade of concrete in turn it is indicate that, higher the grade of concrete, lesser the moisture content ratio. In fact, the moisture content ratio depends up on the mixture proportion, compactness of concrete matrix, quantity of fine and coarse aggregate, slump value, and fineness of cement.

The moisture content (Mt) depends on time, lesser/more the time, lesser/more moisture content availability in concrete matrix, which depends on the pore structure formation, aggregates volume fraction, w-c ratio, slump, and compressive strength. From this ratio, it is possible to predict the time duration for that ratio and in turn able to predict diffusion coefficient at that ratio. As observed from the results that, the moisture content ratio varied at different time duration, the ratio variation was lesser in case of mixtures type (M1-M3) as well as (M4-M6) at initial time duration (5 min) in as 0.255, and 0.284. Similarly, it is vary in mixtures type such as (M1-M3) with (M4-M6) as 1.107 and 1.23 at time duration (185.90 min).

3.4.11 Water diffusion coefficient-sorptivity coefficient

The water diffusion coefficient depends on factors such as square root of moisture content ratio, material thickness, and time. Whereas Sorptivity coefficient depends on factors such as cumulative water absorption, and square root of time. It has interpreted from experimental results that, the diffusion coefficient was very lesser at initial stages with decreased Sorptivity coefficient, and the diffusion coefficient was increase gradually with increased rate of Sorptivity coefficient in all mixtures type (M1-M6). The water diffusion coefficient was lesser at initial stage with decreased Sorptivity coefficient, this may be due to variation in aggregates to cement paste matrix, mixtures proportion, slump value, grade of concrete, and rate of absorption. In fact, the diffusion coefficient was vary between 2-0.5 mm^2/min at short and long time duration. Whereas the Sorptivity coefficient was varied between 0.0005-0.0015$m/min^{0.5}$. The variation of average water diffusion coefficient and sorptivity coefficient at different time interval was correlate by a power type of equation for in case of various concrete mixtures type with correlation equation $Dw = 67.168s^{0'4943}$ and ($R^2 = 0.9989$) respectively. The variation of water diffusion coefficient with sorptivity coefficient at different time interval for in case of designed mixtures types with their correlation equation as well as R^2 values was represent in Table 3-21 respectively.

Table 3-21 Variation of water diffusion coefficient-sorptivity coefficient

MIX ID	Co-rrelation Equation	R^2
M1	$Dw = 73.018s^{0'5035}$	0.9995
M2	$Dw = 83.558s^{0'5221}$	0.9993
M3	$Dw = 68.385s^{0'4848}$	0.9963
M4	$Dw = 49.991s^{0'4661}$	0.9901
M5	$Dw = 66.652s^{0'4893}$	0.9979
M6	$Dw = 70.452s^{0'5039}$	0.9994

Actually, the diffusion coefficient was lesser at initial stage when the rate of absorption was lesser at initial stage for in case of all mixtures type (M1-M6). The concentration gradient increases in turn the flow of water was starts moving towards lower concentration. Thus, clearly the rate of absorption goes on increases as time passes and reaches equilibrium and there was no further increase in diffusion coefficient in all designed mixtures type (M1-M6). The variation in diffusion coefficient and Sorptivity coefficient was found to be varied in between ($D_{5\ min} = 2.25\ mm^2/min$, and $S_{5\ min} = 0.001\ m/min^{0.5}$) as well as ($D_{185.90\ min} = 2.25\ mm^2/min$, and $S_{185.90\ min} = 0.001\ m/min^{0.5}$).

3.4.12 De-sorptivity coefficient

It is a phenomenon whereby a substance is release from or through a surface and in fact, the process is the opposite of sorption. Desorption involves the liberation of both absorbed and adsorbed water molecules. As the term, sorption in concrete technology is use to describe both absorption and adsorption so desorption should be considered the opposite process where water is released from a concrete surface. Therefore, de-sorptivity is define as a measure of the rate at which concrete releases water into a drying environment. The drying of a saturated concrete surface will develop menisci within the pore structure creating capillary tension will influence water transport. Therefore, a de-sorptivity coefficient can be obtain from measuring uniaxial drying from a concrete surface in a constant temperature and humidity environment. In the present research work, concrete cubes (100 mm x 100 mm x 100 mm) after casting were immerse in water for 28 days curing. Prior to the desorption test after curing age, an initial weight of concrete cube specimens were note for in case of all concrete mixtures type. After that, specimens with one bottom face were expose to natural room temperature (25^0 C). At pre-determined times (typically 5, 10, 15, 20, 25, 30, 60, and 200 minutes), the concrete sample were weigh at particular time interval by using stopwatch. Finally, it is possible to calculate the desorptivity coefficient by knowing the ratio of difference in an initial weight-final weight, which is expose to natural room temperature to square root of time.

$$i = D_s.t^{1/2} \tag{58}$$

$\boldsymbol{D_s}$ = Coefficient of desorptivity ($\mathrm{g/m^2/min^{0.5}}$)
$\boldsymbol{i}$ = Mass loss/exposed surface area (g/m^2)
t = time of exposure (hr)

The de-sorption coefficient was found to be increased (40 g/$\mathrm{m^2/min^{0.5}}$) at initial time duration as when compared to longer time duration (0.3 g/$\mathrm{m^2/min^{0.5}}$) in all mixtures type (M1-M6). The de-sorptivity coefficient was investigate in all mixtures type (M1-M6) at different time interval for up to 28 days. The desorption coefficient was the rate of decrease of water absorption at each and every time interval which was depends on environmental conditions such as temperature, humidity, pore structure, compactness of concrete, and mixture proportion. The desorption coefficient was carried out by simply exposed the concrete cubes to room temperature and noted their reduced weight at each time until it reaches equilibrium state.

3.4.13 De-sorptivity-sorptivity coefficient

The sorptivity and de-sorptivity coefficient increases gradually at three stages which follows square root of time and linearly proportional to each other. It is observe from results that, the linearity proportional ranges between 0-50 min, 50-100 min, and 100-200 min. The ratio of sorptivity to de-sorptivity coefficient values range between 0.0023-0.15 at short and long time duration in all mixtures type (M1-M6). The sorptivity and de-sorptivity coefficient follows linearity of proportional, this may be due the fact that, both the coefficients directly proportional to cumulative water absorption (mass gain), mass loss, and inversely proportional to square root of time. Therefore, the sorptivity coefficient is equal to de-sorptivity coefficient, which follows linearity of proportion.

3.4.14 Summary

- It is possible to characterize the sorptivity fundamental parameters in order to evaluate different designed concrete mix. In turn to establish relationship between sorptivity coefficient-cumulative absorption, water diffusion coefficient-moisture content, moisture content ratio-time duration, water diffusion coefficient-sorptivity coefficient, and sorptivity-de-sorptivity coefficient.

- The sorptivity coefficient was very lesser with higher compressive strength and varied slump value in first three set of mixtures type. An average sorptivity coefficient was higher for lower compressive strength and constant slump and reduced with higher compressive strength value for in second set of three mixtures type. It is possible to established power type equation between sorptivity coefficient-square root of time for six different mixtures type.

- The sorptivity coefficient was higher at lower cumulative absorption for in the case of higher compressive strength and varied slump value in first three set of mixtures type. It is higher as against cumulative absorption for lower compressive strength and constant slump and reduced with higher compressive strength value for in second set of three mixtures type. It is possible to established power type equation between sorptivity coefficient-cumulative absorption for desired different mixtures type.

- The water diffusion coefficient was co-rrelated with square root of time, in turn, an average variation of water diffusion coefficient was more for in case of higher compressive strength and varied slump for in first three set of mixtures type. For in the case of lower compressive strength and constant slump, the water diffusion coefficient was slightly higher in case of second three set of mixture type. It is possible to establish logarithmic relationship between water diffusion coefficient-square root of time. The water diffusion coefficient was lesser at an initial stage when the rate of absorption was lesser at initial stage for in case of all mixtures type. From this research work, there is power type equation relationship exists between water diffusion coefficient-sorptivity coefficient.

- The sorptivity/de-sorptivity coefficient ratio was co-rrelated with square root of time by a polynomial of second-degree and varied linearly up to certain time duration.

3.5 Initial surface absorption test on concrete cubes (ISAT)

3.5.1 Introduction

An information about water permeability of the surface layer of concrete can be obtain through ISAT. In which the moisture content or water content of test specimens can have negative influence on measured results and test results of various types of concrete are then not comparable (Reiterman et al, 2012). Water content reduces water valve absorbing capacity and therefore it is advisable to dry test specimens prior to the test in a drying furnace at the temperature 105 °C for 48 hours. After drying, test specimens are cool down for another 24 hours in laboratory environment (temperature 20 ± 2 °C). In fact, the results reflect the variability, which may be considerable of the condition of the surface and concrete properties in the surface zone. In fact, the concrete subjected to site/laboratory condition is likely to yield more variable results than oven dried concrete. An investigation by researchers [H. Abdul Razak, et al, 2004] on the use of metakaolin and silica fume as supplementary cementing materials in enhancing the near surface properties of concrete. Metakaolin and silica fume were confirm to enhance the overall near surface characteristics of the concrete. The inclusion of metakaolin and silica fume greatly reduced an initial surface absorption, water absorption and sorptivity of concrete in varying magnitudes. Concrete is one of the most common building materials and its durability has been observed with increased attention. The concrete durability is closely connect with permeability and, generally speaking, the quality of its surface layer. Evaluating the quality of the surface layer of concrete is a rather difficult issue that can be address in different ways and focus on three internationally used methods (TPT, GWT and ISAT) in order to investigate the influence of concrete composition on the outputs of the methods [Petr Misák, et al, 2017]. For the purposes of an experiment, specimens were casted by using nine mixtures, which differed only in the amount of cement and plasticiser (water/cement ratio). The experiment was designed and evaluated using the statistical methodology DOE (Design of Experiment).

The concrete structure is expose to high temperature, which results in the degradation of inner structure of concrete. Level of permeability of the surface layer is important for evaporation of water vapour from an entire bulk of the structure. If permeability of the surface layer is low, explosive spilling can occur and steel reinforcement can be uncovered. One of methods of measuring permeability of the surface layer of concrete is the ISAT. Results of the measurements showed that structure of surface layer in case of concrete with lightweight expanded clay aggregate is less porous than the structure of concrete with basalt aggregates. Damages caused by exposed to high temperature were record on both tested mixtures but concrete with lightweight expanded clay aggregate resists better [Iveta Nováková, et al, 2015]. The intrinsic permeability test provides an easy and fast method of evaluating permeability, the BRE test is appropriate to measure bulk properties and the on surface test measures the surface layer properties of the concrete. The importance and influence of curing and conditioning of test specimens is establish in the test results. Further research is required in this field since the link between permeability and durability is significant [O. M. AI-Otaibi, and B Barr, 2002].

Oven drying may cause changes in the cement paste structure in turn give different results from naturally dry concretes. Initial surface absorption was affect by so many factors such as moisture condition, concrete mixture, and aggregate, surface finish type, curing, age of concrete, cracking, water type, and temperature. In fact, the results reflect the variability, which may be considerable of the condition of the surface and of concrete properties in the surface zone. The concrete subjected to site/laboratory condition is likely to yield more varied results than oven dried concrete. Oven drying may cause changes in the cement paste structure in turn give different results from naturally dry concretes. Thus in the present research work, an effectiveness of 72 preconditioned concrete cubes of size (100x100x100) mm such as dry/partially saturated/fully saturated was evaluated for in the case of six designed mixtures type (M1-M6). In which first mixtures type (M1-M3) was design as constant compressive strength (40 N/mm^2) with varied slump value (0-10, 10-30, and 60-180) mm and whereas second mixtures type (M4-M6) was design as constant slump value (10-30) mm with different compressive strength.

3.6 Initial surface absorption test on concrete cubes

An initial surface absorption test (ISAT) measures the rate of flow of water into a sample per unit area. This test was carried out in accordance with BS 1881: Part 208 (1996) and the apparatus is shown in Figure 3-6. The flow of water into the sample is measure at 10, 30, and 60 minutes from the start of the test under a constant head of water of 200 mm ± 20 mm.

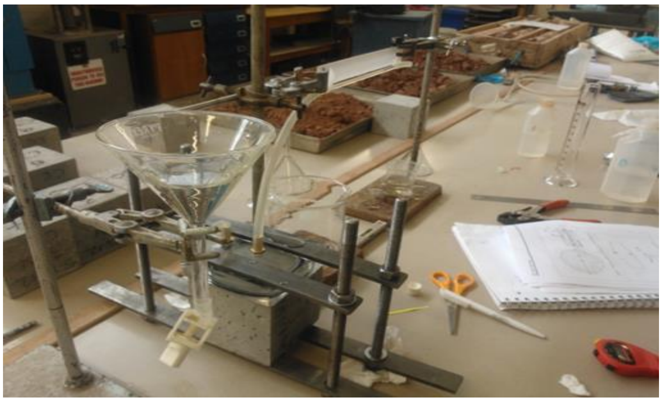


Figure 3-6 ISAT on concrete cubes

The ISAT provides a measure of surface properties that is of interest in relation to performance criteria such as durability. Oven-dried samples were use in this study. The samples were dry in a well- ventilated oven at 105±5 °C until constant weight, not more than 0.1 % weight change over any 24 h drying period, is achieve. When the sample had reached constant weight, it was place in a suitable airtight cooling cabinet until the temperature in the cabinet falls to a temperature within 2 °C of that of the room. The equipment used consists of a cap, reservoir, glass and capillary tubing. In this study, a glass cap was use. An inlet and an outlet tube were fix into the cap, the former connecting to the reservoir and the latter to the capillary tube. The outlet was position so that it was at the highest part of the cap to allow all trapped air to escape. The cap was clamp into position using two screw clamps on either side of the cap. If any leakage was detect, the joint was properly fix by tightening the clamps or using more sealant material round the edges of the cap. The reservoir was fill so that a head of 200 ± 20 mm of water was apply to the surface of the concrete. The capillary tube was support horizontally at the same level as the surface of the water in the reservoir so that the open end of the capillary tube can be raise to avoid overflow of the water between taking readings.

The tap from the reservoir was close and the reservoir filled with water. The time of the start of the test was record and the tap opened to allow the water to run into the cap and out of the outlet tubing until no more air escaped. At all times, care was take that the reservoir does not empty itself. The outlet tubing was connected to the capillary tube and any additional trapped air was flushed out by allowing the capillary to overflow and, if necessary, by sharply pinching the flexible tubing. The reservoir was replenish to maintain the specified head of water. Readings were record after specified interval from the start of the test. Just before the specified intervals, the position of the capillary tube was adjust so that it is completely fill with water. It was then fix in a horizontal position at the same level as the surface of the water in the reservoir. At each of the specified test intervals, the tap was close and when water started to flow along the capillary tube, the stopwatch was start. After 5s the number of scale units the water has moved was note and, the period during which movement is noted was determined. Readings were record over a 2 min or 30 s period, the measurement was multiply by 0.5 or 2 respectively, and the number of scale units the water travels in one minute was record. Between test intervals, the tap was open and the level of the water in the reservoir was maintain at the specified head. The capillary tube was title to prevent overflow of the water.

$$f = \frac{T}{t} \times D \times 0.01 \tag{55}$$

f = Rate of flow (ml/m^2/sec)

T = Total test time in Seconds

t = test point time period in Seconds

D = Number of scale divisions during period t

The variation of standard deviation, minimum and maximum value of ISAT in dry 72 concrete cubes as represented in Table 3-22 .

Table 3-22 Standard deviation in Dry concrete cubes

ISAT on DCC cubes [Mc = 0%]				
	ISAT, ml/m^2/s, av, 10 min			
Mix ID	STD	Min,$_{value}$	Max, $_{value}$	ISAT,$_{value}$
M1	0.32	1.80	2.85	2.26
M2	0.55	1.60	3.15	2.52
M3	0.58	1.90	3.50	2.67
M4	0.58	1.90	3.50	2.90
M5	0.22	2.50	3.20	2.83
M6	0.13	3.00	3.45	2.70
	ISAT, ml/m^2/s, av, 30 min			
Mix ID	STD	Min,$_{value}$	Max,$_{value}$	ISAT,$_{value}$
M1	0.11	1.35	1.75	1.49
M2	0.35	0.90	1.95	1.53
M3	0.56	1.25	3.00	2.14
M4	0.56	1.25	3.00	2.27
M5	0.09	1.95	2.25	2.13
M6	0.24	2.00	2.90	2.50
	ISAT, ml/m^2/s, av, 60 min			
Mix ID	STD	Min,$_{value}$	Max,$_{value}$	ISAT, $_{value}$

M1	0.17	1.00	1.45	1.17
M2	0.47	0.60	1.85	1.19
M3	0.62	1.10	2.65	1.71
M4	0.62	1.10	2.65	1.90
M5	0.12	1.55	1.95	1.76
M6	0.09	1.95	2.25	2.08

The ISAT was carry out on 72 partially saturated pre-conditioned concrete cubes (100x100x100) mm. Before conducting ISAT on partially saturated concrete cubes, samples were dry in a well-ventilated oven at 105±5 °C until constant weight, not more than 0.1 % weight change over any 24 h drying period, is achieve. When the sample had reached constant weight, it was place in a suitable airtight cooling cabinet until the temperature in the cabinet falls to a temperature within 2 °C of that of the room. Each sample was remained in the cabinet until testing and their dry weight was record before ISAT on concrete sample. Then the concrete cubes were fully submerge in water and note down their wet weight at subsequent time interval until it reaches required moisture content (Mc = 2.5%). Thus, the ratio of difference between wet weight-dry weights to wet weight of concrete cubes is consider as moisture content of desired concrete specimens. The variation of standard deviation, minimum, and maximum values of an initial surface absorption in partially saturated concrete cubes were represent as in Table 3-23 .

Table 3-23 Standard deviation variation in ISAT on PSC cubes

ISAT on PSC cubes [Mc = 2.5%]				
	ISAT, ml/m^2/s, av, 10 min			
Mix ID	STD	Min,$_{\text{value}}$	Max, $_{\text{value}}$	ISAT,$_{\text{value}}$
M1	0.06	0.30	0.45	0.36
M2	0.02	0.30	0.35	0.30
M3	0.02	0.30	0.35	0.33
M4	0.03	0.25	0.35	0.29
M5	0.04	0.20	0.30	0.25
M6	0.02	0.20	0.25	0.21
	ISAT, ml/m^2/s, av, 30 min			
Mix ID	STD	Min,$_{\text{value}}$	Max,$_{\text{value}}$	ISAT,$_{\text{value}}$
M1	0.06	0.225	0.400	0.29
M2	0.03	0.225	0.300	0.27
M3	0.03	0.225	0.300	0.26
M4	0.02	0.225	0.300	0.24
M5	0.03	0.150	0.225	0.20
M6	0.04	0.120	0.225	0.20
	ISAT, ml/m^2/s, av, 60 min			

Mix ID	STD	Min,$_{\text{value}}$	Max,$_{\text{value}}$	ISAT, $_{\text{value}}$
M1	0.05	0.15	0.30	0.21
M2	0.01	0.20	0.24	0.23
M3	0.02	0.20	0.24	0.22
M4	0.01	0.20	0.24	0.20
M5	0.02	0.12	0.20	0.15
M6	0.03	0.10	0.20	0.14

The initial surface absorption test was carry out on 72 fully saturated pre-conditioned concrete cubes (100x100x100) mm with moisture content (Mc = 5%). Similarly, the variation of standard deviation, minimum, and maximum values of an initial surface absorption in fully saturated concrete cubes as represented in Table 3-24.

Table 3-24 Interpretation of standard deviation in ISAT on FSC cubes

ISAT on FSC cubes [Mc = 5%]				
	ISAT, ml/m^2/s, av, 10 min			
Mix ID	STD	Min,$_{\text{value}}$	Max, $_{\text{value}}$	ISAT,$_{\text{value}}$
M1	0.05	0.20	0.30	0.23
M2	0.05	0.20	0.35	0.28
M3	0.03	0.20	0.30	0.24
M4	0.04	0.20	0.30	0.23
M5	0.02	0.20	0.25	0.23
M6	0.03	0.13	0.20	0.17
	ISAT, ml/m^2/s, av, 30 min			
Mix ID	STD	Min,$_{\text{value}}$	Max,$_{\text{value}}$	ISAT,$_{\text{value}}$
M1	0.03	0.15	0.22	0.18
M2	0.04	0.15	0.30	0.23
M3	0.03	0.15	0.24	0.19
M4	0.03	0.15	0.22	0.21
M5	0.02	0.15	0.22	0.21
M6	0.01	0.12	0.15	0.13
	ISAT, ml/m^2/s, av, 60 min			
Mix ID	STD	Min,$_{\text{value}}$	Max,$_{\text{value}}$	ISAT, $_{\text{value}}$
M1	0.02	0.10	0.15	0.14
M2	0.03	0.12	0.20	0.16
M3	0.03	0.10	0.20	0.17
M4	0.05	0.10	0.24	0.19
M5	0.02	0.10	0.15	0.15
M6	0.01	0.10	0.12	0.11

3.6.1 Effect of compressive strength on Initial surface absorption

The absorption of the surface near zone is of great interest, because this zone which protects the steel reinforcement, and the porosity of the inner body are also important, which affect the other properties of the concrete. Surface absorption is measure directly using the Initial surface absorption technique, while, strength is measure as an indirect indication about the inner porosity of the concrete body and, it is the most important property, which must be investigate. Thus in the present research work, the effectiveness of compressive strength on initial surface absorption in 72 concrete cubes (100 mm) was investigated under pre-conditioned concrete cubes such as dry/partially saturated/fully saturated condition and in turn evaluate the designed six mixtures type (M1-M6). The ISAT value reduced with constant higher compressive strength and varied slump at initial time duration (10 min) in all mixtures type (M1-M3). In addition, it is confirm from present results that, the ISAT values decreases for different time intervals (10-60) min. However, ISAT value increases at longer time duration even though the compressive strength is higher in turn it may be due to different slump as well as w/c ratio.

Whereas, ISAT values was increase in mixtures type (M4-M6) at initial stage (10 min) with different compressive strength and constant slump as compared to mixtures type (M1-M3). In fact, it is observe from the results that, the ISAT values was clearly decrease for longer time duration at 30 min and 60 min with higher compressive strength. Furthermore, the ISAT values was vary in dry conditioned concrete cubes even though the mixtures proportion was designed with constant slump and compressive strength as well as varied compressive strength and slump. Thus in turn depends on the pre-drying condition, temperature, mixture proportion, and pore structure. The overall effectiveness of compressive strength on ISAT in dry conditioned concrete cubes as represented in Table 3-25.

Table 3-25 ISAT in Dry-conditioned concrete cubes

ISAT, ml/m^2/s, aver on DCC [Mc = 0%] cubes in different mix types						
Mix ID/ Time	M1	M2	M3	M4	M5	M6
Com Stg (N/mm^2)	31.34	32.43	34.48	25.48	31.91	32.13
10 min	2.26	2.52	2.67	2.90	2.83	2.70
30 min	1.49	1.53	2.14	2.27	2.13	2.50
60 min	1.17	1.19	1.71	1.90	1.76	2.08

The ISAT values was predominately decrease as when compared to dry conditioned concrete cubes in all mixtures type (M1-M6). In partially saturated conditioned concrete cubes, the ISAT values was increased at time duration (30 min and 60 min) for lower compressive strength and decreases for higher compressive strength in all mixtures type (M1-M3). Whereas in case of mixture type (M4-M6), the ISAT values was slightly decreases with different compressive strength as when compared to mixtures type (M1-M3). In addition to that, the ISAT values was reduce predominantly with increased compressive strength. The overall effectiveness of compressive strength on ISAT in partially saturated conditioned concrete cubes as represented in Table 3-26.

Table 3-26 ISAT in partially saturated-conditioned concrete cubes

ISAT, ml/m²/s, aver on PSC cubes [Mc = 2.5%] in different mix types						
Mix ID/Time	M1	M2	M3	M4	M5	M6
Com Stg (N/mm²)	31.34	32.43	34.48	25.48	31.91	32.13
10 min	0.36	0.30	0.33	0.29	0.25	0.21
30 min	0.29	0.27	0.26	0.24	0.20	0.20
60 min	0.21	0.23	0.22	0.20	0.15	0.14

In case of fully saturated conditioned concrete cubes, the ISAT values was found to be more as when compared to dry conditioned concrete cubes and partially saturated conditioned concrete cubes in all mixtures type (M1-M6). However, the ISAT value was reduce in accordance within stipulated time duration (10-60) min for higher compressive strength. In fact, at intermediate compressive strength level, the ISAT value was slightly increase with increased compressive strength, afterwards it is more reduced with higher compressive strength in all mixtures type (M1-M3).

It is true that for lower compressive strength, the ISAT was predominantly increase at time duration (10-60) min in all mixtures type (M4-M6). Whereas it is also clear that, the ISAT values was extremely reduce at time durations (10-60) min as when compared to mixtures type (M1-M3). Thus, it is conclude that, the ISAT value was extremely reduce in all mixtures type (M1-M6) as when compare to dry conditioned concrete cubes and partially saturated conditioned concrete cubes. This in turn indicates that, the ISAT values was affect by moisture content. The higher the moisture content, the lesser the pore voids in turn the pore structure was completely reach fully saturated condition in fully saturated conditioned concrete cubes. The overall effectiveness of compressive strength on ISAT in fully saturated conditioned concrete cubes as represented in Table 3-27.

Table 3-27 ISAT in fully saturated-conditioned concrete cubes

ISAT, ml/m²/s, aver on FSC cubes [Mc = 5%] in different mix types						
Mix ID/Time	M1	M2	M3	M4	M5	M6
Com Stg (N/mm²)	31.34	32.43	34.48	25.48	31.91	32.13
10 min	0.23	0.28	0.24	0.23	0.23	0.17
30 min	0.18	0.23	0.19	0.21	0.21	0.13
60 min	0.14	0.16	0.17	0.19	0.15	0.11

3.6.2 Initial surface absorption test on dry conditioned concrete cubes

The ISAT was carry out on 72 pre-dry conditioned concrete cubes with six designed mixtures type (M1-M6). The pre-dry conditioning of concrete cubes was archived by drying the specimens in the oven at 105±5^0 C until constant mass is reached in turn it's not more than 0.1% weight change over any 24 hr drying period. When the specimens has reached constant mass, place it in the cooling cabinet and allow temperature in the cabinet to fall to within 2^0 C of that of room. As observed from results that, ISAT was increase in all mixtures type (M1-M6) at 10 min. Actually ISAT was increase at early stage (10 min) as compared to 30 min and 60 min, which was, varied about 24.51% as well as 38.70% respectively.

Similarly, the ISAT was observe to increase at early time duration (10 min) as compared to longer time duration at 30 min and 60 min in which it is varied as 31.06% as well as 45.65% for in mixtures type (M1-M3). Whereas in case of mixtures type (M4-M6), the ISAT was slightly decreased at early stage (10 min) as when compared to longer time duration at 30 min and 60 min which was varied about 17.95% as well as 31.75% respectively. Furthermore, the ISAT values was more as when compared to PSC and FSC concrete cubes in all mixtures type (M1-M6).

3.6.3 Initial surface absorption test on partially saturated concrete cubes

The ISAT was carry out on 72 pre-partially saturated conditioned concrete cubes with six designed mixtures type (M1-M6). The pre-partially saturated conditioning of concrete cubes was archived by fully submerged specimens in the water until its reached partially saturated condition (Mc =2.5%). As observed from results that, ISAT was increase in all mixtures type (M1-M6) at 10 min. Actually ISAT was increase at early stage (10 min) as compared to 30 min and 60 min, which was, varied about 15.44% as well as 33.78% in ISAT value respectively. Similarly, the ISAT was observe to increase at early time duration (10 min) as compared to longer time duration at 30 min and 60 min in which it is varied as 16.88% as well as 32.77% for in mixtures type (M1-M3).

Whereas in case of mixtures type (M4-M6), the ISAT was slightly decreased at early stage (10 min) as when compared to longer time duration at 30 min and 60 min which was varied about 14% as well as 34.78% respectively. Furthermore, the ISAT values was more decreased as when compared to DCC concrete cubes in all mixtures type (M1-M6).

3.6.4 Initial surface absorption test on fully saturated concrete cubes

The 72 concrete cubes were oven-dried at 105±5 °C until constant weight, not more than 0.1 % weight change over 24 hr drying period is achieve. Moisture content is define, as the ratio of difference between (wet weight-dry weights) to wet weight and it is express as percentage. Then conditioned concrete cubes were fully submerged in water until it attains moisture content (Mc = 5%) as per the requirement of the present research work. This attainment of moisture content (Mc = 5%) in the present research work is designate as fully saturated conditioned concrete cubes. The ISAT was carry out on 72 pre-fully saturated conditioned concrete cubes with six designed mixtures type (M1-M6). The pre-fully saturated conditioning of concrete cubes was archived by fully submerged specimens in the water until its reached fully saturated condition (Mc = 5%). As observed from results that, ISAT was increase in all mixtures type (M1-M6) at 10 min. Actually ISAT was increase at early stage (10 min) as compared to 30 min and 60 min, which was, varied about 16.89% as well as 33.10% respectively. Similarly, the ISAT was observe to increase at early time duration (10 min) as compared to longer time duration at 30 min and 60 min in which it is varied as 20.14% as well as 37.05% for in mixtures type (M1-M3). Whereas in case of mixtures type (M4-M6), the ISAT was slightly increased at early stage (10 min) as when compared to longer time duration at 30 min and 60 min which was varied about 13.64% as well as 29.15% respectively. Furthermore the ISAT values was more decreased as when compared to DCC and PSC concrete cubes in all mixtures type (M1-M6).

3.6.5 Summary

- In the present research work, the designed mixtures type was characterized in 72 concrete cubes of size (100x100x100 mm) by ISAT in dry/wet condition (Mc = 0%, Mc =2.5%, and Mc =5%) with water in order to evaluate near surface characteristics of concrete. In turn to study an effectiveness of compressive strength on ISAT in different mixtures type. In which, the first mixtures type (M1-M3) was designed as higher compressive strength (40 N/mm^2) with varied slump value (0-10, 10-30, and 60-180) mm, and in second mixtures type (M4-M6), its comprised of different compressive strength (25, 30, 40 N/mm^2) with constant slump value (10-30) mm.

- An extensive information about water permeability of the near surface layer of concrete could be obtain through ISAT. Moisture content can have negative influence on measured results of various types of concrete. The moisture content was reduced water absorption capacity and thus it is advisable to dry test specimens prior to testing in the ISAT. ISAT value in DCC concrete cubes was to be more as when compared to PSC and FSC concrete cubes.

- Similarly, ISAT value was more in PSC as when compared to FSC concrete cubes. ISAT value was more at an initial time duration for higher compressive strength and goes on decreases with an increased time duration. Similarly, ISAT value was more at initial time duration for lower compressive strength, goes on reduces with increased time duration and compressive strength in all pre-conditioned concrete cubes.

- It is determined from the results that, ISAT value with moisture content (Mc =5%) was found to be predominantly decreased as when compared to DCC and PSC (Mc =2.5%) concrete cubes in all designed mixtures type.

3.7 Salt ponding test on concrete cubes

3.7.1 Introduction

In worldwide the use of de-icing salts has been common since 1960 in areas where snow and ice is a seasonal roadway safety hazard, automobile, and highway bridge corrosion, and ecosystem changes caused by deicing salt is well documented and focus of considerable study until now in recent years. The salts are necessary to provide safe winter driving conditions and save lives by preventing the freezing of a layer of ice on roads and bridge decks. However, the safety and sense of comfort provided by the salts is not without a price, as these salts can greatly contribute to the degradation and decay of reinforced concrete transportation systems. Most salts are chloride-based and when the applied salts diffuse into the concrete and reach the level of the steel reinforcement, the chloride ions can quickly de-passivate the steel and activate corrosion reactions that can ultimately result in the loss of functionality of the concrete structure. Furthermore, research has indicated that these same salts attack the concrete itself, through reactions and phase changes, producing dimensional changes and cracking of the concrete. The further penetration of the salts into these cracks sets up a vicious cycle of concrete spalling and degradation.

Actually, the total amount of moisture contained within the concrete, as either water or water vapour, is call as the moisture content. Moisture in concrete is present in the capillary pores and smaller gel pores within the concrete matrix. Moisture may exist as either water (when the concrete is wet and the pores are saturated) or as water vapour, which provides a level of relative humidity within the concrete material. The initial source of moisture in concrete is the mixing water that is use at the time of manufacture. Water is add to the concrete during batching to allow hydration of the cement and provide the workability required to place and finish the concrete. Some water will be lost through bleeding and evaporation and some amount will be consume by the hydration process. Either a small quantity of water will remain following hydration of the cement in the minute spaces (capillary pores) within the concrete, or within the hydration product, themselves (gel pores). Almost all forms of deterioration in reinforced concrete involve ingress of deleterious fluids through the pore structure of the concrete. In particular, the ingress of chlorides is a major cause of early deterioration of reinforced concrete structures due to subsequent corrosion. In saturated concretes, fluids will enter through diffusion whereas partially saturated concretes, fluids will be absorb by capillary suction. In reality most concrete are in a continual flux between saturated and partially saturated states, as they undergo continuous cycles of wetting and drying. The corrosion of reinforcement bars due to chloride ingress is a well-known problem in reinforced concrete. Several methods have been adopt to protect reinforced concrete, and one of them is to provide added protection to the concrete surface in the form of surface treatments. They react with the cement matrix and form a hydrophobic layer on the walls of the pores within the concrete. This protects the concrete from the ingress of water and water-born salts. However, too much water in the pores of concrete will prevent the treatments from penetrating deeper into the pores. Actually, the depth of penetration and therefore the durability of the treatment is adversely affect when the concrete is near saturation. In fact, billions of dollars could be spend annually to replace defective infrastructure that needs replacement only because of concrete failing to attain its expected service life. The cost is due to the effects of chloride ingress into the concrete removing protective sheaths from steel reinforcement leading to destructive corrosion of the infrastructure. Thus accurate prediction of the rate of chloride ingress into concrete would lead to the establishment of proper specification in turn achieve designed service life. There are currently many types of protective materials for reinforced concrete structures and the influence of these materials in the chloride diffusion coefficient still needs more research.

The primary focus of this present study is to examine an effects of wetting and drying with 10% sodium chloride solution in concrete cubes with/without impregnation material (solvent based and water based) for about 160 days. In fact that, the chloride concentration stability was maintain over entire salt ponding, test period by covering the concrete specimens with plastic cover in order to avoid evaporation of chloride concentration. Chloride profiles of samples exposed to wetting and drying cycles were determined. From these profiles, the rate and depths of chloride ingress were calculated and compared for six different mixtures type of concrete. There have been a number of studies in which, the chloride penetration profile of concrete exposed to a chloride solution for different defined periods. But in this present research work, chloride concentration at different drill depths such as 30-40-50 mm was interpreted in order to evaluate chloride diffusion coefficient by using Fick's second law for in case of concrete cubes with/without impregnation material for six different mixtures type.

3.7.2 Assessment of chloride absorption in concrete cubes

The objective of the work is to investigate an effect on the distribution of chloride at different depths of some factors concerning concrete pore structure, namely water/cement ratio, cement type, grade of concrete, and slump. For that, concrete cubes are pre-condition such as drying, fully saturated, and partially saturated condition with water, after that the pre-conditioned concrete cubes were fully submerge in sodium chloride solution for about 160 days, and during which their mass is monitored for long-term duration. In turn, the chloride profile was measure after salt ponding test, and the diffusion coefficient was calculate from the Fick's second law. In ponding test, transport mechanism of chloride ions in concrete during wetting and drying cycles of varying duration is evaluate in this research work. An experimental test results were used to in order to assess the influence of diffusion coefficient, surface chloride ion concentration and dry/ wet cycle durations on the transport mechanism of chloride ions in concrete. The dry-wet cycles accelerate the transport process of chloride ions within a certain distance from the surface, beyond this distance, chloride ions in the complete immersion specimen migrate more rapidly than those under dry-wet cycles do. The smaller the diffusion coefficient, the higher the surface chloride concentration.

Thus, totally seventy-two concrete cubes of size (100x100x100) mm were fabricate with different six mixtures type. Out of which three mixtures type (constant compressive strength, varied slump) were design as one group (M1-M3). In second group (M4-M6), rest of three mixtures type designed as with different compressive strength, and constant slump. After 28 days of an initial curing in water, the concrete cubes were subject to different exposure conditions such as drying, fully and partially saturated conditions for a specified time duration. Hence, it is possible to develop a better understanding of the long-term tests to assess the resistance of concrete to chloride penetration under different pre-conditions such as drying, partially saturated, and fully saturated conditions with/without impregnation. The results show that the most significant effect of sorptivity on long-term chloride ingress to concrete is its effect on surface chloride content. The value of this parameter is a way of taking account of absorption when modelling chloride ingress under cyclic wetting and drying conditions.

3.7.3 Pre-conditioning of concrete cubes

In this research work, seventy-two concrete cubes of size (100x100x100) mm with six mixtures type were design and pre-conditioned the concrete cube specimens to investigate their effect on chloride diffusion in Dry, fully saturated, and partially saturated conditioned concrete specimens with/without impregnation. In which 48 concrete cubes with different mixtures type were partially submerge in water to achieve fully saturated (31 days) condition. In order to ensure that, the concrete specimens were fully saturated as well as to study their effectiveness on chloride absorption in turn the specimens were submerge for such a long time in the present research work. Partially saturated condition (21 days) as well as 24 concrete cubes with different mixtures type were dry to achieve dry conditioned concrete cubes condition for about 28 days. Thus, the research was carry out to evaluate the performance of impregnation material such as solvent based and water based on concrete cubes/slabs under pre-determined conditions such as dry/fully saturated/partially saturated condition. In turn analysed the chloride concentrations at different drill depths.

3.7.4 Pre-conditioned dry concrete cubes

The pre-conditioning was induced in order achieve desired dry condition in specified 24 concrete cubes. In which all 24 concrete cubes were expose to natural room temperature for about 28 days. In turn recorded their dry weight at subsequent time duration from 0-3880 min. The weight loss versus time duration values were interpreted in six all mixtures type (M1-M6). The weight loss was gradually increased with linearly proportional to time duration at an initial stage and varied at later stage, depends on environmental conditions such as room temperature, mixture proportions, compressive strength, slump, and w-c ratio in all mixtures type. The variation in weight loss were found to be in the range between (0.022-1.44%), (0.018-1.85%), (0.017-1.35%), (0.026-2.62%), (0.017-1.4%), and (0.023-1.69%) for in case of six mixtures type (M1-M6).

3.7.5 Pre-conditioned Fully saturated concrete cubes in water

The pre-conditioned fully saturated condition was achieve in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 31 days. Similarly recorded their saturated weight at subsequent time duration from 0-43200 min. The weight gain versus time duration values were analysed in six all mixtures type (M1-M6). The weight gain was gradually increased with time duration at an initial stage and varied at later stage depends environmental conditions in all mixtures type. The variation in weight gain were found to be in the range between (0.048-2.93%), (0.054-4.09%), (0.049-4.42%), (0.051-5.06%), (0.058-4.38%), and (0.049-2.92%) for in case of six mixtures type (M1-M6).

3.7.6 Pre-conditioned Partially saturated concrete cubes in water

The pre-conditioned partially saturated condition was assess in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 21 days. Similarly recorded their saturated weight at subsequent time duration from 0-30240 min. The weight gain versus time duration values were establish in six all mixtures type (M1-M6). The weight gain was suddenly increase with time duration at initial stage and reached equilibrium at later stage depends environmental conditions such as mixture proportions, compressive strength, slump, and w-c ratio, moisture content in all mixtures type. The variation in weight gain were found to be in the range between (0.048-1.81%), (0.049-1.44%), (0.005-1.39%), (0.051-1.85%), (0.049-0.33%), and (0.049-0.23%) for in case of six mixtures type (M1-M6). In PSC case, the weight gain was more or less same or decreased in all mixtures type (M1-M6) at an initial time duration as when compared to longer time duration. Whereas in case of longer time duration, the weight gain was predominantly higher in mixtures type (M1-M3) with constant compressive strength and varied slump. But the weight gain was more in lower compressive strength, goes on decreased slightly more with increased different compressive strength and constant slump for in case of mixtures type (M4-M6).

3.7.7 Chloride profile analysis in Pre-conditioned concrete cubes

The corrosion of reinforcement has been establish as the predominant factor causing widespread deterioration of concrete worldwide. The most important reason of this kind of corrosion attack on concrete is chloride ingress. It causes corrosion in the steel reinforcements embedded in the concrete. The hydration products of cement provide a high alkaline environment in concrete, which will activate a passivating film of iron oxide on the embedded steel bars. The passivating film can keep its chemical stability on the steel surface and protect the steel from being corrode. However, when the chloride concentration in concrete reaches a threshold value, the protective film on the steel bars is destroyed (at pH level below 11), and the reinforcement corrosion starts. As a result, effective cross sectional area of reinforcements gets reduce and it is replace with corrosion products. Hence, the ultimate strength of reinforcing bars is reduce. Later due to over accumulation of corrosion product on the reinforcement surface tensile stress is generated in concrete, which causes cracking and premature loss of service life of concrete. Chloride ion ingression and thereby induced reinforcement corrosion in steel-reinforced concretes have attracted much research interest. Now, to prevent this kind of loss in serviceability of concrete and also to predict the life time of a concrete structure in a marine environment, a detailed knowledge of the of the whole procedure, starting right from the chloride penetration to the occurring of corrosion damage in concrete is to be understood.

The concretes are in a state of flux between saturated and partially saturated conditions as they undergo continuous cycles of wetting and drying. In saturated concrete, dissolved ions enter through diffusion, whereas in partially saturated concrete, ion-containing fluids are absorb by capillary suction and concentrated by evaporation of water. The wetting and drying causes continuous moisture movement through concrete pores. The wetting and drying action accelerates durability problems, for it subjects the concrete to the movement and accumulation of harmful materials, such as sulphates, alkalies, acids, and chlorides. Thus the wetting and drying is a problem for reinforced concrete structures exposed to chlorides, such as marine structures, parking garages (de-icer salts), and highway structures (bridges and other elevated roadways). In fact, mechanisms govern chloride ingress into concrete such as absorption, diffusion, chloride binding, permeation, wicking, and dispersion. For structures exposed to cyclic wetting and drying, absorption and diffusion are two of the most significant mechanisms.

There are several factors can affect the extent that, chlorides penetrate concrete through cyclic wetting and drying. Chloride ingress is strongly influence by the sequence and duration of wetting and drying. Specifically, the degree of dryness and therefore the ambient drying conditions are very important. If the concrete remains wet, some salts may migrate inward from the concrete surface by diffusion. However, if the wetting period is short, the entry of salt water is mainly by absorption. The salts are carry into the interior of the concrete and further concentrated during the following drying cycle. Below the outer “convection zone” of the cover, the concrete remains moist and chlorides penetrate further by diffusion regardless of the external moisture conditions. The wetting and drying can increase the rate of corrosion in reinforced concrete structures because of two actions. First, wetting and drying concentrates ions, such as chlorides, can increase the rate of corrosion by the evaporation of water during the drying phase. Second, once chloride thresholds have been reach at the depth of cover, drying of the concrete increases the availability of oxygen required for steel corrosion, because oxygen has a substantially lower diffusion coefficient in saturated concrete. For higher quality concrete, longer drying times have a reduced effect. This illustrates that concretes of higher quality, which have a finer pore structure, require longer drying times to obtain a particular moisture content. In addition to that, the results indicate that concretes with respectively lower moisture content will result in an increase rate of chloride ingress, when experiencing cyclic chloride exposure. As the moisture content of the concrete decreased, the amount of capillary sorption should increase, likely causing the chlorides to be pull further into the concrete.

To obtain a better understanding of the mechanisms controlling this increase in chloride ingress due to longer drying periods, a more thorough analysis was need. The chlorides that have entered the concrete during the wetting phase will likely continue inward, due to diffusion during the drying phase. Diffusion will stop when saturation is no longer maintain at a given depth. However, it is difficult to know when this will occur. For both cases, the wet/dry-cycled chloride concentrations were higher near the surface, but lower deeper into the concrete. However, at deeper levels where concretes tend to remain saturated, diffusion is the dominant mechanism. This also confirms that the increase in chloride ingress is likely due to the dryer moisture conditions, rather than diffusion during a longer drying period. Wetting and drying cycles with longer drying periods accelerate chloride penetration more than shorter drying cycles due to the increased drying resulting in deeper sorption. The diffusion of chlorides in saturated pores at greater depths continues to occur during the drying phase. Extending the drying period appears to increase the chloride ingress by capillary sorption in subsequent wetting cycles, rather than by continued diffusion during the drying phase. The rate of drying is dependent on the pore structure of the concrete and as a result higher quality concretes dry at a slower rate.

The primary focus of this research was to examine effects of wetting and drying pre-conditioned concrete specimens with sodium chloride solution. In turn chloride profiles of samples exposed to different pre-determined conditions such as dry/fully saturated/partially was evaluate in control/impregnation concrete cubes/slabs for about 160 days in all six mixtures type (M1-M6).

The chloride profiles were analysed by drilling the concrete cubes. The drilling was done with a diameter of 20 mm (max aggregate size) and drill depths of (30, 40, and 50) mm. The dust sample collected weighted between 1-5 grams as specified by (BS EN 15629:2007) for the determination of the chloride penetration. The chloride concentration for each of the dust samples, including from the control specimens was determined in accordance with BS EN 15629:2007 in hardened concrete. The chloride content was calculate as a percentage of chloride ion by mass of the sample of concrete. Volhards Method was use for the determination of the total chloride content in the concrete. Samples of dust powder drilled from the concrete specimens at depths of 30 mm, 40 mm, and 50 mm were use for the determination of the chloride penetration in the concrete samples. The concrete cubes was drill for chloride profile analysis at different drill depths, which was as shown in Figure 3-7.

Figure 3-7 Concrete cubes drilled for chloride profile analysis

In dissolving chlorides, between 1-5 gm of concrete powder was weight, and placed in a 250 ml beaker. The powder was wetted with 50 ml of distilled water; 10ml of 5 mole/l nitric acid was add followed by 50 ml of hot distilled water. The mixture was heat until boiling, boiled for at least 3 minutes with continuously stir. The mixture was filter using a medium-textured paper. Distilled water was use for dissolving chlorides. Tape water was not use as it already contains salts and it was therefore going to produce unreliable results.

Volhard’s Method: 5 ml of silver nitrate solution was add by pipette into the test solution and was stir to precipitate the chloride. 5 drops of indicator solution was add to the test solution. The solution was titrated with ammonium thiocyanate solution one drop at a time, while continually agitating the solution until the faint reddish-brown coloration no longer disappeared. The volume (V_1) of the solution used in titration was record. The same procedure was carry out with no dust samples (blank sample) test portion to determine the value for (V_2), which was used as a constant to calculate the chloride ion penetration as a percentage. The titration test procedure was as shown in Figure 3-8.

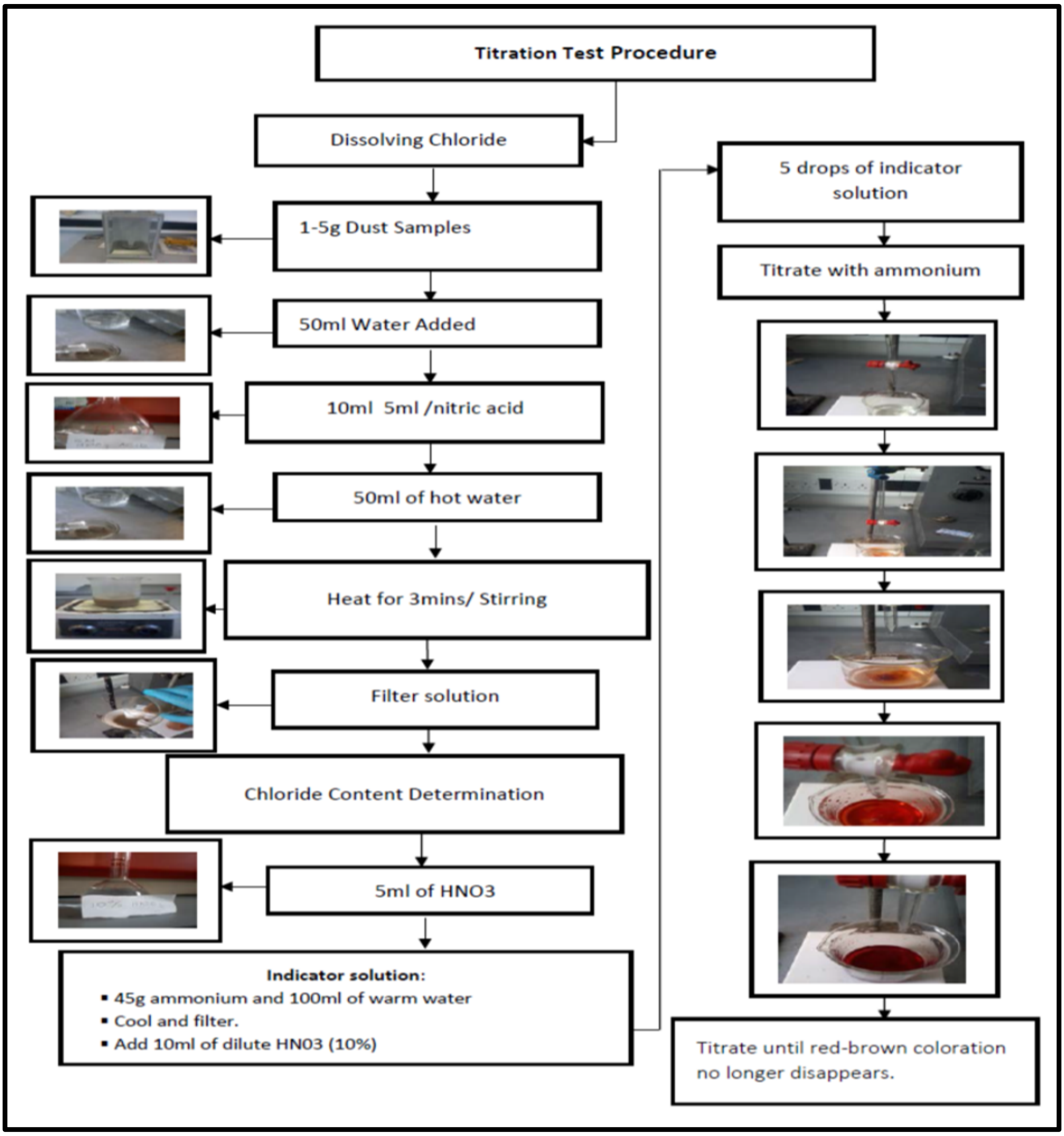


Figure 3-8 Chloride profile analysis

The chloride content as a percent of the chloride ion by mass of the sample was calculate using the formula:

$$CC= 3.545 *f *(V_2-V_1)/ m \qquad (57)$$

Where

V_1 = volume of the ammonium thiocyanate solution used in the titration (ml)

V_2 = volume of the ammonium thiocyanate solution used in the blank titration (ml)

m = mass of the concrete sample (g)

f = molarity of the silver nitrate solution (0.02M)

This test method follows the one outlined in the British Standard (BS EN 15629:2007), Products and systems for the protection and repair of concrete structures-test methods-determination of chloride content in hardened concrete. The chloride concentration in 24 DCC concrete cubes was analysed in control/impregnation concrete cubes. The chloride concentration was to be increase when one-one for in case of drill depths (30-40) mm in control/impregnation concrete cubes as interpreted from the present research work. Whereas when compared with drill depth (30-50) mm, the chloride concentration was more increased in all mixtures type (M1-M6). The chloride concentration in 24 PSC concrete cubes was interpret in control/impregnation concrete cubes. The chloride concentration was observe to be lesser in drill depths (30-40) mm and (30-50) mm for in all mixtures type (M1-M6). Similarly, the chloride concentration in 24 FSC concrete cubes was interpret in control/impregnation concrete cubes. The chloride concentration was observe to be lesser in drill depths (30-40) mm and (30-50) mm for in all mixtures type (M1-M6). Chloride concentration in case of FSC concrete cubes could be very lesser in all mixtures type (M1-M6), as when compare to DCC and PSC concrete cubes. This may be due to increase moisture content, mix proportion, pore structure, concrete matrix-cement paste structure formation, compressive strength, slump, w-c ratio, aggregate volume fraction and cement content and type. The variation of chloride concentration in PCC concrete cubes in control/impregnation was represent as in Table 3-28 .

Table 3-28 Chloride concentration in pre-conditioned control/impregnation concrete cubes

Final CC, % Results for DCC cubes				Final CC, % Results for PSC cubes				Final CC, % Results for FSC cubes			
CUBE ID	30 mm	40 mm	50 mm	CUBE ID	30 mm	40 mm	50 mm	CUBE ID	30 mm	40 mm	50 mm
M1CC	0.070	0.066	0.064	M1CC	0.066	0.064	0.061	M1CC	0.059	0.056	0.054
M1SB	0.060	0.053	0.053	M1SB	0.059	0.059	0.056	M1SB	0.054	0.052	0.049
M1WB	0.064	0.064	0.061	M1WB	0.061	0.061	0.059	M1WB	0.056	0.055	0.053
M2CC	0.066	0.064	0.063	M2CC	0.064	0.061	0.061	M2CC	0.059	0.056	0.054
M2SB	0.061	0.058	0.056	M2SB	0.059	0.059	0.056	M2SB	0.054	0.052	0.049
M2WB	0.063	0.061	0.059	M2WB	0.061	0.061	0.059	M2WB	0.056	0.054	0.052
M3CC	0.074	0.072	0.072	M3CC	0.073	0.071	0.071	M3CC	0.068	0.066	0.063
M3SB	0.071	0.068	0.066	M3SB	0.068	0.066	0.064	M3SB	0.061	0.056	0.054
M3WB	0.072	0.071	0.068	M3WB	0.071	0.068	0.066	M3WB	0.063	0.061	0.059
M4CC	0.075	0.067	0.064	M4CC	0.061	0.056	0.061	M4CC	0.060	0.054	0.052
M4SB	0.061	0.059	0.057	M4SB	0.059	0.056	0.056	M4SB	0.054	0.052	0.049
M4WB	0.061	0.061	0.059	M4WB	0.061	0.059	0.059	M4WB	0.056	0.052	0.051
M5CC	0.071	0.068	0.067	M5CC	0.068	0.067	0.066	M5CC	0.063	0.062	0.061
M5SB	0.064	0.061	0.059	M5SB	0.061	0.058	0.057	M5SB	0.054	0.051	0.052
M5WB	0.068	0.066	0.066	M5WB	0.066	0.064	0.059	M5WB	0.056	0.054	0.054
M6CC	0.068	0.066	0.064	M6CC	0.066	0.065	0.062	M6CC	0.061	0.059	0.056
M6SB	0.064	0.061	0.061	M6SB	0.061	0.058	0.057	M6SB	0.056	0.052	0.049
M6WB	0.066	0.064	0.062	M6WB	0.064	0.063	0.061	M6WB	0.059	0.056	0.054

The chloride concentration could found to be increase at drill depth 30 mm as when compare to drill depth 50 mm in control/impregnation concrete cubes. In fact, the chloride concentration was lesser with pre-conditioned concrete cubes for in case of PSC and FSC cubes as when compare to DCC cubes. This may be due to degree of saturation in turn higher the presence of moisture content, lesser the chloride concentration ingress into the concrete cubes. The chloride concentration in control/impregnation concrete cubes at different drill depths (30-40-50) mm was interpret by chemical analysis. Compare the chloride concentration results at different drill depths (30-40) mm and (30-50) mm in control/solvent/water based concrete cubes. For in case of constant compressive strength and varied slump with mixtures type (M1-M3) as well as different compressive strength and constant slump for in case of mixtures type (M4-M6) under dry/partially/fully saturated conditioned concrete cubes, which was, represent as in Table 3-29 respectively.

Table 3-29 Comparison of chloride concentration in control/impregnation concrete cubes

Final CC, % Results for DCC cubes			Final CC, % Results for PSC cubes			Final CC, % Results for FSC cubes		
CUBE ID	(30-40)mm	(30-50) mm	CUBE ID	(30-40)mm	(30-50) mm	CUBE ID	(30-40)mm	(30-50) mm
M1CC	5.74	8.99	M1CC	3.61	7.27	M1CC	4.38	8.89
M1SB	11.48	11.85	M1SB	0.15	3.87	M1SB	4.29	8.67
M1WB	1.18	5.35	M1WB	0.15	4.33	M1WB	1.88	6.14
M2CC	3.16	3.56	M2CC	3.81	4.14	M2CC	4.25	8.07
M2SB	5.76	7.66	M2SB	0.34	4.10	M2SB	4.18	8.64
M2WB	3.41	6.80	M2WB	0.52	4.26	M2WB	4.59	8.75
M3CC	1.97	2.37	M3CC	2.89	3.34	M3CC	3.86	7.16
M3SB	3.83	6.99	M3SB	3.51	6.94	M3SB	7.60	11.54
M3WB	1.98	5.59	M3WB	3.71	6.91	M3WB	3.73	6.65
M4CC	10.99	15.27	M4CC	7.95	0.29	M4CC	10.47	12.71
M4SB	3.16	7.14	M4SB	4.21	4.26	M4SB	4.08	8.79
M4WB	0.09	3.84	M4WB	3.83	3.88	M4WB	8.30	10.19
M5CC	3.4	4.93	M5CC	1.73	3.38	M5CC	1.80	4.05
M5SB	3.7	7.43	M5SB	5.82	7.53	M5SB	4.79	4.45
M5WB	3.3	3.76	M5WB	3.46	11.06	M5WB	4.28	4.32
M6CC	3.19	6.89	M6CC	1.40	5.78	M6CC	3.84	7.75
M6SB	3.32	3.68	M6SB	5.12	6.77	M6SB	8.38	12.54
M6WB	3.52	5.28	M6WB	1.82	4.25	M6WB	3.86	8.04

The chloride concentration was observe to be more in control concrete cubes (M1CC-M3CC) as when compared to impregnation concrete cubes (M1SB-M3SB and M1WB-M3WB) with constant compressive strength and varied slump. In addition to that, the chloride concentration in control concrete cubes (M4CC-M6CC) and impregnation concrete cubes (M4SB-M6SB and M4WB-M6WB) was more with lower compressive strength and it goes on decrease with increased in compressive strength with constant slump for in case of dry conditioned concrete cubes. The variation of chloride concentration in DCC control/impregnation cubes was as represent in Table 3-30. The chloride concentration was increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M1CC-M1SB:14.23%, M2CC-M2SB:7.09%, M3CC-M3SB:2.18%, M1CC-M1WB:7.87%, M2CC-M2WB:3.95%, M3CC-M3WB:2.18%) for in case of constant compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M4CC-M4SB:18.73%, M5CC-M2SB:10.02%, M6CC-M3SB:6.87%, M4CC-M4WB:18.38%, M5CC-M5WB:3.45%, M6CC-M6WB:3.47%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride concentration was increase in water-based (WB) impregnation concrete cubes as compared to solvent based impregnation concrete cubes (M1WB-M1SB:6.90%, M2WB-M2SB:3.37%, M3WB-M3SB:1.95%) for in case of constant compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in water-based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:0.42%, M5WB-M5SB:6.81%, M6WB-M6SB:3.52%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Similarly, the chloride concentration in control concrete cubes was compare to solvent-based (SB)/water based (WB) impregnation concrete cubes at drill depths 40 mm and 50 mm respectively.

Table 3-30 Comparison of chloride concentration in DCC control/impregnation concrete cubes

Comparison of final CC, % Results for DCC cubes at different drill depths									
CUBE ID	30 mm	Incr (%)	Incr (%)	40 mm	Incr (%)	Incr (%)	50 mm	Incr (%)	Incr (%)
M1CC	0.07	0		0.066	0		0.064	0	
M1SB	0.06	14.23		0.053	19.46		0.053	16.93	
M1WB	0.064	7.87	6.90	0.064	3.42	16.61	0.061	4.18	13.30
M2CC	0.066	0.00		0.064	0.00		0.063	0.00	
M2SB	0.061	7.09		0.058	9.58		0.056	11.04	
M2WB	0.063	3.85	3.37	0.061	4.10	5.72	0.059	7.08	4.26
M3CC	0.074	0.00		0.072	0.00		0.072	0.00	
M3SB	0.071	2.18		0.068	5.91		0.066	8.63	
M3WB	0.072	2.18	1.95	0.071	2.19	3.80	0.068	5.40	3.41
M4CC	0.075	0.00		0.067	0.00		0.064	0.00	
M4SB	0.061	18.73		0.059	11.59		0.057	10.93	
M4WB	0.061	18.38	0.42	0.061	8.39	3.48	0.059	7.37	3.84
M5CC	0.071	0.00		0.068	0		0.067	0.00	
M5SB	0.064	10.02		0.061	10.3		0.059	12.38	
M5WB	0.068	3.45	6.81	0.066	3.35	7.19	0.066	2.26	10.36
M6CC	0.068	0.00		0.066	0.00		0.064	0.00	
M6SB	0.064	6.87		0.061	7.00		0.061	3.67	
M6WB	0.066	3.47	3.52	0.064	3.80	3.32	0.062	1.81	1.89

However, the chloride concentration was different for in case of PSC and FSC concrete cubes due to saturated condition. For in case of PSC concrete cubes, the chloride concentration in control concrete cubes was not increase with lower compressive strength and constant slump, instead of that, increased more with increased compressive strength in fact this might be due to variation of moisture content. The variation of chloride concentration was analysed and compared in impregnation concrete cubes as when compared to control concrete cubes at different drill depths in all mixture type (M1-M6). Similarly, the variation and comparison of chloride concentration in control/impregnation concrete was indicate in Table 3-31 .

The chloride concentration was increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M1CC-M1SB:11.23%, M2CC-M2SB:7.84%, M3CC-M3SB:6.58%, M1CC-M1WB:7.18%, M2CC-M2WB:3.89%, M3CC-M3WB:3.06%) for in case of constant compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M4CC-M4SB:3.84%, M5CC-M2SB:10.42%, M6CC-M3SB:7.18%, M4CC-M4WB:0.21%, M5CC-M5WB:3.44%, M6CC-M6WB:3.28%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. The chloride concentration was increase in water-based (WB) impregnation concrete cubes as compared to solvent based impregnation concrete cubes (M1WB-M1SB:4.36%, M2WB-M2SB:4.11%, M3WB-M3SB:3.63%) for in case of constant compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in water-based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:3.63%, M5WB-M5SB:7.23%, M6WB-M6SB:4.03%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Similarly, the chloride concentration in control concrete cubes was compare to solvent-based (SB)/water based (WB) impregnation concrete cubes at drill depths 40 mm and 50 mm respectively.

Table 3-31 Comparison of chloride concentration in PSC control/impregnation concrete cubes

Comparison of final CC, % Results for PSC cubes at different drill depths									
CUBE ID	30 mm	Incr (%)	Incr (%)	40 mm	Incr (%)	Incr (%)	50 mm	Incr (%)	Incr (%)
M1CC	0.066	0		0.064	0		0.061	0	
M1SB	0.059	11.23		0.059	8.05		0.056	8.0	
M1WB	0.061	7.18	4.36	0.061	3.85	4.36	0.059	4.2	3.91
M2CC	0.064	0.00		0.061	0.00		0.061	0.0	
M2SB	0.059	7.84		0.059	4.52		0.056	7.8	
M2WB	0.061	3.89	4.11	0.061	0.60	3.94	0.059	4.0	3.95
M3CC	0.073	0.00		0.071	0.00		0.071	0.0	
M3SB	0.068	6.58		0.066	7.18		0.064	10.1	
M3WB	0.071	3.06	3.63	0.068	3.89	3.43	0.066	6.7	3.65
M4CC	0.061	0.00		0.056	0.00		0.061	0.0	
M4SB	0.059	3.84		0.056	-0.07		0.056	7.7	
M4WB	0.061	0.21	3.63	0.059	-4.26	4.01	0.059	3.8	4.02
M5CC	0.068	0.00		0.067	0.00		0.066	0.0	
M5SB	0.061	10.42		0.058	14.15		0.057	14.3	
M5WB	0.066	3.44	7.23	0.064	5.14	9.50	0.059	11.1	3.54
M6CC	0.066	0.00		0.065	0.00		0.062	0.0	
M6SB	0.061	7.18		0.058	10.68		0.057	8.2	
M6WB	0.064	3.28	4.03	0.063	3.69	7.26	0.061	1.7	6.56

In case of FSC concrete cubes, the increase in chloride concentration was not more for in control/impregnation concrete cubes with constant compressive strength and varied slump. However, the chloride concentration was reduce as when compared to PSC concrete cubes at lesser drill depth with different compressive strength and constant slump. The comparison of chloride concentration in FSC control/impregnation concrete cubes was record as shown in Table 3-32.

The chloride concentration was increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M1CC-M1SB:8.49%, M2CC-M2SB:8.27%, M3CC-M3SB:10.69%, M1CC-M1WB:4.33%, M2CC-M2WB:3.83%, M3CC-M3WB:7.19%) for in case of constant compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M4CC-M4SB:9.87%, M5CC-M2SB:15.02%, M6CC-M6SB:7.75%, M4CC-M4WB:5.94%, M5CC-M5WB:11.27%, M6CC-M6WB:3.84%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride concentration was increase in water-based (WB) impregnation concrete cubes as compared to solvent based impregnation concrete cubes (M1WB-M1SB:4.35%, M2WB-M2SB:4.62%, M3WB-M3SB:3.78%) for in case of constant compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in water-based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:4.18%, M5WB-M5SB:4.23%, M6WB-M6SB:4.06%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Furthermore, the chloride concentration in control concrete cubes were compare to solvent-based (SB)/water based (WB) impregnation concrete cubes at drill depths 40 mm and 50 mm respectively.

Table 3-32 Comparison of Chloride concentration in FSC control/impregnation concrete cubes

Comparison of final CC, % Results for FSC cubes at different drill depths										
CUBE ID	30 mm	Incr (%)	Incr (%)	40 mm	Incr (%)	Incr (%)	50 mm	Incr (%)	Incr (%)
M1CC	0.059	0		0.056	0		0.054	0	
M1SB	0.054	8.49		0.052	8.41		0.049	8.28	
M1WB	0.056	4.33	4.35	0.055	1.83	6.70	0.053	1.45	6.93
M2CC	0.059	0.00		0.056	0.00		0.054	0.00	
M2SB	0.054	8.27		0.052	8.20		0.049	8.84	
M2WB	0.056	3.83	4.62	0.054	4.16	4.21	0.052	4.54	4.50
M3CC	0.068	0.00		0.066	0.00		0.063	0.00	
M3SB	0.061	10.69		0.056	14.17		0.054	14.91	
M3WB	0.063	7.19	3.78	0.061	7.06	7.65	0.059	6.68	8.82
M4CC	0.060	0.00		0.054	0.00		0.052	0.00	
M4SB	0.054	9.87		0.052	3.44		0.049	5.82	
M4WB	0.056	5.94	4.18	0.052	3.66	-0.23	0.051	3.22	2.69
M5CC	0.063	0.00		0.062	0.00		0.061	0.00	
M5SB	0.054	15.02		0.051	17.61		0.052	15.38	
M5WB	0.056	11.27	4.23	0.054	13.52	4.73	0.054	11.52	4.36
M6CC	0.061	0.00		0.059	0.00		0.056	0	
M6SB	0.056	7.75		0.052	12.10		0.049	12.54	
M6WB	0.059	3.84	4.06	0.056	3.86	8.57	0.054	4.14	8.76

3.7.8 Interpretation of pre-conditioned concrete cubes with water

In this research work, seventy-two concrete cubes of size (100x100x100) mm with six mixtures type (M1-M6) were design and pre-conditioned the concrete cube specimens to investigate their effect on chloride diffusion in Dry, fully saturated, and partially saturated conditioned concrete cubes with/without impregnation. In which 48 concrete cubes with different mixtures type were partially submerge in water to achieve fully saturated (31 days) and partially saturated condition (21 days) as well as 24 concrete cubes with different mixtures type were dried in ordered to achieve dry conditioned concrete cubes condition for about 28 days. Thus, the research is conduct to evaluate the performance of impregnation material such as solvent based and water based on concrete cubes under pre-determined conditions such as dry/fully saturated/partially saturated condition. In turn analysed the chloride concentrations at different drill depths (30, 40, and 50) mm for different mixtures type (M1-M6) after salt ponding test for about 160 days.

It’s observed from the results the weight loss (0.019%) and (0.022%) was found to be varied at initial time (5 min) for in case of mixtures type (M1-M3) as well as for in case of mixtures type (M4-M6). Similarly, the weight loss (1.55%) and (1.91%) was found to be varied at longer time duration (28 day) for in case of mixtures type (M1-M3) as well as for in case of mixtures type (M4-M6). Its confirmed from the results that, the weight loss in mixture type (M1) was slightly lesser as when compared to mixture type (M2) as well as the weight loss was also lesser in the mixture type (M3). Similarly, the weight loss was extremely more due lower compressive strength and constant slump for in case of mixture type (M4). Furthermore, the weight loss was predominantly lesser for in case of mixture type (M5) as well the weight loss was more for in case of mixture type (M6) as when compared to mixture type (M5). From this lesser/more weight loss, it has confirmed that for higher compressive strength and varied slump value, the weight loss was lesser in magnitude. Also its observed from the results that, for lower compressive strength and constant slump value, the weight loss was found to be more as when compared to higher compressive strength for in case of mixtures type (M5-M6). An effectiveness of the different mixtures type (M1-M6) was interpret for about 28 days and its average value such as weight loss as well as their standard deviation was varied in all mixtures type as represented in Table 3-33.

Table 3-33 Interpretation of weight loss/gain in pre-conditioned concrete cubes

Variation of weight loss/gain in pre-conditioned concrete cubes with water								
Weight loss (%) in DCC			Weight gain (%) water PSC			Weight gain (%) in FSC		
Cube ID	Aver	STD	Cube ID	Aver	STD	Cube ID	Aver	STD
M1CC	0.56	0.57	M1CC	0.62	0.71	M1CC	0.96	1.14
M2CC	0.70	0.74	M2CC	0.57	0.63	M2CC	1.01	1.36
M3CC	0.52	0.53	M3CC	0.57	0.62	M3CC	1.10	1.55
M4CC	0.99	1.06	M4CC	0.66	0.75	M4CC	1.24	1.76
M5CC	0.54	0.55	M5CC	0.14	0.10	M5CC	0.85	1.39
M6CC	0.66	0.67	M6CC	0.11	0.06	M6CC	0.59	0.93

The variation of average weight loss/weight gain as well as standard deviation values was represent in all mixture type (M1-M6) for in case of DCC/PSC/FSC cubes.

It's clear from the results the weight gain (0.051%) and (0.050%) was found to be varied at initial time (5 min) for in case of mixtures type (M1-M3) as well as for in case of mixtures type (M4-M6). Similarly, the weight gain (3.81%) and (4.12%) was found to be varied at longer time duration (31 day) for in case of mixtures type (M1-M3) as well as for in case of mixtures type (M4-M6). It is confirm from the results that, the weight gain in mixture type (M1) was lesser (2.75%) as when compared to mixture type (M2) with their weight gain was (4%) and the weight gain (4.25%) was more in the mixture type (M3). Similarly, the weight gain (5%) was extremely more due lower compressive strength and constant slump for in case of mixture type (M4). Furthermore, the weight gain (4.25%) was lesser for in case of mixture type (M5) as well the weight gain (2.75%) was lesser for in case of mixture type (M6) as when compared to mixture type (M5) and mixture type (M4). From this lesser/more weight gain, it's confirmed that for lower compressive strength and varied slump value, the weight gain was found to be higher in magnitude (5%) for in case of mixture type (M4). it's observed from the results that, its goes on decreases slightly with increase in compressive strength and constant slump value. In turn the weight gain values was found to be varied in the range 4.25% and 2.75% for in case of mixture type (M5) and mixture type (M6) respectively. The effectiveness of the different mixtures type (M1-M6) was interpret for about 31 days and its average value such as weight gain as well as their standard deviation was varied in all mixtures type.

It's confirmed from the results the weight gain (0.049%) and (0.051%) was found to be varied at initial time (5 min) for in case of mixtures type (M1-M3) as well as for in case of mixtures type (M4-M6). Similarly, the weight gain (1.55%), and (0.81%) was found to be varied at longer time duration (21 day) for in case of mixtures type (M1-M3) as well as for in case of mixtures type (M4-M6). The weight gains in mixture type (M1) was higher (1.81%) as when compared to mixture type (M2) with their weight gain was (1.44%) and the weight gain (1.39%) was more in the mixture type (M3). Similarly, the weight gain (1.85%) was extremely more due lower compressive strength and constant slump for in case of mixture type (M4). Furthermore, the weight gain (0.33%) was lesser for in case of mixture type (M5) as well the weight gain (0.24%) was lesser for in case of mixture type (M6) as when compared to mixture type (M5) and mixture type (M4). From this lesser/more weight gain, it has confirmed that for lower compressive strength and varied slump value, the weight gain was confirm to be higher in magnitude (1.85%) for in case of mixture type (M4). In addition, it is observe from the results that, its goes on decreases slightly with increase in compressive strength and constant slump value. In turn the weight gain values was found to be varied in the range 0.33% and 0.24% for in case of mixture type (M5) and mixture type (M6) respectively. An effectiveness of the different mixtures type (M1-M6) was interpret for about 21 days and its average value such as weight gain as well as their standard deviation was varied in all mixtures type.

3.7.9 Analysis of salt ponding test in pre-conditioned concrete cubes

In the present research work, Seventy-two concrete cubes of size (100x100x100) mm with six mixtures type (M1-M6) were designed and pre-conditioned the concrete cube in order to investigate their effectiveness (10% Nacl solution) on the chloride diffusion in Dry, fully saturated, and partially saturated conditioned concrete cubes with/without impregnation such as solvent based and water based impregnation material. Penetration of chloride in concrete to wet/dry environment occurs by diffusion and absorption. The drying temperature was the most critical factors influencing rate of absorption (Sorptivity) and depth of chloride penetration. In fact, the salt solution concentration also had a significant effect on chloride penetration through the apparent surface chloride content. The drying temperature had the most significant effect on weight Sorptivity, depth of chloride penetration, and, apparent chloride diffusion coefficient. This is due to the fact that, drying temperature influences the effective porosity of concrete. Furthermore, in the drying period, the water is evaporating from the concrete, leaving the chloride ions in the concrete. An increasing amount of chloride ions at the penetration depth by capillary suction is creating a high concentration gradient over the remaining concrete. In turn analysed the chloride concentrations at different drill depths (30, 40, and 50) mm and chloride diffusion coefficient for different mixtures type (M1-M6) after salt ponding test for about 160 days. The variation of chloride absorption in dry control conditioned /impregnation concrete cubes as represented in

Table 3-34.

Table 3-34 Variation of chloride solution absorption in DCC/IC cubes

Chloride solution absorption (%) in DCC/IC concrete cubes											
Cube ID	31 day	61 day	91 day	121 day	160 day	Cube ID	31 day	61 day	91 day	121 day	160 day
M1CC	1.13	1.65	2.27	2.68	2.89	M4CC	2.47	2.90	3.36	3.81	4.04
M1SB	1.04	1.35	1.75	2.16	2.38	M4SB	1.94	2.36	2.78	3.23	3.42
M1WB	1.10	1.49	1.92	2.31	2.50	M4WB	2.04	2.55	3.01	3.47	3.71
M2CC	1.86	2.36	2.94	3.37	3.55	M5CC	1.57	2.17	2.61	3.06	3.27
M2SB	1.12	1.46	1.89	2.35	2.56	M5SB	0.99	1.37	1.82	2.26	2.48
M2WB	1.21	1.62	2.05	2.49	2.72	M5WB	1.22	1.65	2.09	2.50	2.68
M3CC	1.62	2.25	2.72	3.13	3.37	M6CC	1.53	1.93	2.38	2.79	3.02
M3SB	1.26	1.71	2.09	2.54	2.78	M6SB	1.11	1.47	1.78	2.24	2.50
M3WB	1.27	1.81	2.28	2.69	2.92	M6WB	1.28	1.82	2.22	2.61	2.84

Thus the effectiveness of the different mixtures type (M1-M6) for in the case of control concrete cube as well as impregnation concrete cubes was interpreted for about 160 days and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average chloride absorption and standard deviation in dry condition control/impregnation concrete cubes as represented in Table 3-35.

Table 3-35 Variation of average chloride solution absorption in DCC/IC cubes

Chloride solution absorption (%) in DCC/IC concrete cubes									
Cube ID	Average	STD	Min,value	Max,value	Cube ID	Average	STD	Min,value	Max,value
M1CC	1.97	0.75	0.31	2.89	M4CC	3.17	0.68	1.61	4.04
M1SB	1.59	0.61	0.21	2.38	M4SB	2.62	0.63	1.24	3.42
M1WB	1.72	0.62	0.25	2.50	M4WB	2.82	0.68	1.45	3.71
M2CC	2.66	0.75	0.67	3.55	M5CC	2.38	0.72	0.71	3.27
M2SB	1.75	0.62	0.41	2.56	M5SB	1.63	0.66	0.31	2.48
M2WB	1.88	0.64	0.51	2.72	M5WB	1.89	0.63	0.46	2.68
M3CC	2.45	0.75	0.43	3.37	M6CC	2.19	0.66	0.48	3.02
M3SB	1.94	0.64	0.33	2.78	M6SB	1.66	0.64	0.34	2.50
M3WB	2.06	0.69	0.34	2.92	M6WB	2.00	0.67	0.40	2.84

The variation of chloride solution absorption in partially saturated control conditioned /impregnation concrete cubes as represented in

Table 3-36.

Table 3-36 Variation of chloride absorption in PSC/IC cubes

Chloride solution absorption (%) in PSC/IC concrete cubes											
Cube ID	31 day	61 day	91 day	121 day	160 day	Cube ID	31 day	61 day	91 day	121 day	160 day
M1CC	0.31	0.52	0.87	1.06	1.40	M4CC	0.29	0.70	0.98	1.11	1.63
M1SB	0.19	0.46	0.74	0.93	1.20	M4SB	0.21	0.52	0.76	0.90	1.25
M1WB	0.24	0.50	0.75	0.93	1.24	M4WB	0.26	0.58	0.76	0.92	1.36
M2CC	0.26	0.56	0.87	1.10	1.46	M5CC	0.26	0.56	0.88	0.99	1.52
M2SB	0.20	0.42	0.73	0.83	1.25	M5SB	0.19	0.50	0.72	0.87	1.22
M2WB	0.24	0.42	0.74	0.92	1.33	M5WB	0.21	0.48	0.74	0.87	1.33
M3CC	0.21	0.53	0.94	1.11	1.62	M6CC	0.23	0.50	0.77	0.93	1.32
M3SB	0.17	0.47	0.74	0.84	1.21	M6SB	0.20	0.43	0.69	0.89	1.24
M3WB	0.18	0.48	0.74	0.88	1.23	M6WB	0.21	0.47	0.74	0.89	1.25

Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted for about 160 days and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average chloride absorption and standard deviation in partially saturated conditioned control/impregnation concrete cubes as represented in Table 3-37

Table 3-37 Interpretation of average weight gain and standard deviation in PSC/IC cubes

Chloride solution absorption (%) in PSC/IC concrete cubes									
Cube ID	Average	STD	Min,value	Max,value	Cube ID	Average	STD	Min,value	Max,value
M1CC	0.75	0.39	0.23	1.40	M4CC	0.82	0.42	0.24	1.63
M1SB	0.63	0.35	0.15	1.21	M4SB	0.63	0.35	0.16	1.25
M1WB	0.65	0.34	0.19	1.24	M4WB	0.67	0.35	0.21	1.36
M2CC	0.76	0.41	0.21	1.46	M5CC	0.73	0.40	0.21	1.52
M2SB	0.61	0.35	0.16	1.25	M5SB	0.62	0.35	0.15	1.23
M2WB	0.64	0.36	0.20	1.33	M5WB	0.64	0.36	0.16	1.33
M3CC	0.77	0.46	0.17	1.62	M6CC	0.66	0.35	0.18	1.32
M3SB	0.60	0.35	0.12	1.22	M6SB	0.61	0.34	0.15	1.24
M3WB	0.62	0.35	0.14	1.23	M6WB	0.63	0.35	0.16	1.25

The variation of chloride absorption in fully saturated control conditioned /impregnation cubes as represented in

Table 3-38.

Table 3-38 Variation of weight gain in FSC/IC cubes

Chloride solution absorption (%) in FSC/IC concrete cubes											
Cube ID	31 day	61 day	91 day	121 day	160 day	Cube ID	31 day	61 day	91 day	121 day	160 day
M1CC	0.13	0.14	0.30	0.54	1.16	M4CC	0.25	0.26	0.39	0.45	1.31
M1SB	0.07	0.08	0.10	0.13	0.22	M4SB	0.14	0.16	0.21	0.25	0.44
M1WB	0.09	0.09	0.12	0.14	0.28	M4WB	0.15	0.16	0.23	0.29	0.53
M2CC	0.17	0.18	0.27	0.41	1.10	M5CC	0.14	0.16	0.30	0.35	1.03
M2SB	0.07	0.09	0.11	0.24	0.31	M5SB	0.10	0.11	0.19	0.22	0.45
M2WB	0.08	0.10	0.23	0.28	0.59	M5WB	0.10	0.11	0.19	0.23	0.64
M3CC	0.11	0.13	0.23	0.28	0.78	M6CC	0.12	0.14	0.22	0.29	0.74
M3SB	0.08	0.09	0.12	0.14	0.36	M6SB	0.08	0.10	0.18	0.22	0.40
M3WB	0.10	0.12	0.20	0.24	0.43	M6WB	0.10	0.11	0.18	0.23	0.53

Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted for about 160 days and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average chloride absorption and standard deviation in fully saturated conditioned control/impregnation concrete cubes as represented in Table 3-39.

Table 3-39 Variation of average weight gain and standard deviation in FSC/IC cubes

Chloride solution absorption (%) in FSC/IC concrete cubes									
Cube ID	Average	STD	Min,value	Max,value	Cube ID	Average	STD	Min,value	Max,value
M1CC	0.37	0.32	0.10	1.16	M4CC	0.43	0.29	0.21	1.31
M1SB	0.11	0.04	0.06	0.22	M4SB	0.22	0.10	0.12	0.44
M1WB	0.13	0.05	0.07	0.28	M4WB	0.25	0.12	0.14	0.53
M2CC	0.34	0.29	0.07	1.10	M5CC	0.31	0.25	0.12	1.03
M2SB	0.16	0.09	0.06	0.31	M5SB	0.19	0.12	0.09	0.45
M2WB	0.21	0.16	0.07	0.59	M5WB	0.21	0.16	0.10	0.64
M3CC	0.25	0.20	0.10	0.78	M6CC	0.24	0.17	0.10	0.74
M3SB	0.14	0.09	0.08	0.36	M6SB	0.17	0.10	0.05	0.40
M3WB	0.19	0.11	0.09	0.43	M6WB	0.20	0.13	0.09	0.53

3.7.10 Chloride profile analysis in pre-conditioned concrete cubes

In fact, if there are no chlorides in the environment, there is of course no chloride-induced corrosion. As a known fact that, in cold countries region, de-icing salts are applied to the concrete infrastructure in turn the chloride ions, migrate into structures through joints exposed, caps, girders, and through defected parts of the structure. Actually the wetting-drying of the concrete increases the rate of accumulation of chlorides inside the concrete and can lead to chloride concentrations in concrete that are higher than in the external environment because evaporation increases the chloride concentrations on the surface of the concrete. In real concrete structure, the chloride ions from the service environment can penetrate into concrete and deposit in the surface layer to form the boundary conditioning for further diffusion towards the interior and in fact, the w-c ratio influences the surface chloride concentration in concrete matrix. Thus in the present research work, Seventy-two concrete cubes of size (100x100x100) mm with six mixtures type (M1-M6) were designed. In which the first three set of mixtures type were designed as with higher compressive strength (40 N/mm^2) and different slump values (0-10, 10-30, and 60-180) mm as well second three set of mixtures type were designed as varied compressive strength (25, 30, and 40 N/mm^2) with constant slump value (10-30) mm. Pre-conditioned the concrete cube in order to investigate their effectiveness (10% Nacl solution) on the chloride diffusion in Dry, fully saturated, and partially saturated conditioned concrete cubes with/without impregnation such as solvent based and water based impregnation material.

3.7.11 Chloride profile analysis in dry conditioned concrete cubes

It's confirmed that for higher compressive strength and varied slump value, the chloride concentration was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride concentration was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days and its average value such as chloride concentration as well as their standard deviation was varied in all mixtures type as represented in Table 3-40.

Table 3-40 Variation of average chloride concentration and standard deviation in DCC cubes

Final CC, % Results for DCC cubes				Average	STD					Average	STD
CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm	CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm
M1CC	0.070	0.066	0.064	0.066	0.003	M4CC	0.075	0.067	0.064	0.068	0.006
M1SB	0.060	0.053	0.053	0.055	0.004	M4SB	0.061	0.059	0.057	0.059	0.002
M1WB	0.064	0.064	0.061	0.063	0.002	M4WB	0.061	0.061	0.059	0.060	0.001
M2CC	0.066	0.064	0.063	0.064	0.001	M5CC	0.071	0.068	0.067	0.069	0.002
M2SB	0.061	0.058	0.056	0.058	0.002	M5SB	0.064	0.061	0.059	0.061	0.002
M2WB	0.063	0.061	0.059	0.061	0.002	M5WB	0.068	0.066	0.066	0.067	0.001
M3CC	0.074	0.072	0.072	0.073	0.001	M6CC	0.068	0.066	0.064	0.066	0.002
M3SB	0.071	0.068	0.066	0.068	0.002	M6SB	0.064	0.061	0.061	0.062	0.001
M3WB	0.072	0.071	0.068	0.070	0.002	M6WB	0.066	0.064	0.062	0.064	0.002

The average chloride concentration at different drill depths from (30-50) mm was found to be slightly lesser in all control concrete cubes for in case of mixtures type (M1-M3). Similarly, the average chloride concentration at different drill depths from (30-50) mm was increased with lower compressive strength and constant slump value for in case of mixture type (M4) and goes on reduced with increased compressive strength for in case of mixtures type (M5-M6).

The chloride concentration in solvent-based impregnation concrete cubes was reduce as when compared to control concrete cubes for in case of all mixtures type (M1-M6). Furthermore, the chloride concentration in water based impregnation concrete cubes was slightly increase as when compared to solvent-based impregnation concrete cubes in all mixtures type (M1-M6). The chloride concentration was also increase at drill depth 30 mm as when compare to drill depths (40-50) mm. The variation of chloride concentration in dry conditioned/impregnation concrete cubes at different drill depths as shown in Table 3-41.

Table 3-41 Interpretation of chloride concentration in DCC cubes at different drill depths

Comparison of final CC, % Results for DCC cubes at different drill depths															
CUBE ID	30 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	40 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	50 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)
M1CC	0.070	0		0	0	0.066	0		0	0	0.064	0			
M1SB	0.060	14.23		85.77		0.053	19.45		80.55		0.053	16.93		83.07	
M1WB	0.064	7.87	6.89	92.13	93.11	0.064	3.41	16.61	96.59	83.39	0.061	4.18	13.30	95.82	86.70
M2CC	0.066	0		0	0	0.064	0		0		0.063	0.00			
M2SB	0.061	7.08		92.92		0.058	9.58		90.42		0.056	11.04		88.96	
M2WB	0.063	3.84	3.36	96.64	96.64	0.061	4.10	5.72	95.90	94.28	0.059	7.08	4.26	92.92	95.74
M3CC	0.074	0		0	0	0.072	0.00		0		0.072	0.00			
M3SB	0.071	2.18		97.82		0.068	5.91		94.09		0.066	8.63		91.37	
M3WB	0.072	2.18	1.95	97.82	98.05	0.071	2.19	3.80	97.81	96.20	0.068	5.40	3.41	94.60	96.59
M4CC	0.075	0		0	0	0.067	0.00		0		0.064	0.00			
M4SB	0.061	18.72		81.28		0.059	11.59		88.41		0.057	10.93		89.07	
M4WB	0.061	18.38	0.42	81.62	99.58	0.061	8.39	3.48	91.61	96.52	0.059	7.37	3.84	92.63	96.16
M5CC	0.071	0		0	0	0.068	0.00		0		0.067	0.00			
M5SB	0.064	10.01		89.99		0.061	10.30		89.70		0.059	12.38		87.62	
M5WB	0.068	3.44	6.80	96.56	93.20	0.066	3.35	7.19	96.65	92.81	0.066	2.26	10.36	97.74	89.64
M6CC	0.068	0		0	0	0.066	0.00		0		0.064	0.00			
M6SB	0.064	6.87		93.13		0.061	7.00		93.00		0.061	3.67		96.33	
M6WB	0.066	3.47	3.52	96.53	96.48	0.064	3.80	3.32	96.20	96.68	0.062	1.81	1.89	98.19	98.11

The chloride concentration in solvent-based impregnation concrete cubes was decreased/increased as when compared to control concrete cubes at different drill depths (30-50) mm. Whereas the chloride concentration in water based impregnation concrete cubes was reduced at different drill depths (30-50) mm as when compared to control concrete cubes for in case of all mixtures type (M1-M6). The chloride concentration in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes at drill depth (30 mm). Furthermore the chloride concentration at 50 mm drill depth in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes.

3.7.12 Chloride profile analysis in partially saturated concrete cubes

It’s confirmed that for higher compressive strength and varied slump value, the chloride concentration for in case control concrete cubes was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride concentration was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days and its average value such as chloride concentration as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride concentration as well as standard deviation values in partially saturated conditioned/impregnation concrete cubes at different drill depths (30-50) mm was represent in all mixture type (M1-M6) as presented in Table 3-42.

Table 3-42 Variation of average chloride absorption in PSC cubes

Final CC, % Results for PSC cube				Average	STD					Average	STD
CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm	CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm
M1CC	0.066	0.064	0.061	0.064	0.002	M4CC	0.061	0.056	0.061	0.060	0.003
M1SB	0.059	0.059	0.056	0.058	0.001	M4SB	0.059	0.056	0.056	0.057	0.001
M1WB	0.061	0.061	0.059	0.060	0.002	M4WB	0.061	0.059	0.059	0.060	0.001
M2CC	0.064	0.061	0.061	0.062	0.001	M5CC	0.068	0.067	0.066	0.067	0.001
M2SB	0.059	0.059	0.056	0.058	0.001	M5SB	0.061	0.058	0.057	0.058	0.002
M2WB	0.061	0.061	0.059	0.060	0.001	M5WB	0.066	0.064	0.059	0.063	0.004
M3CC	0.073	0.071	0.071	0.072	0.001	M6CC	0.066	0.065	0.062	0.064	0.002
M3SB	0.068	0.066	0.064	0.066	0.002	M6SB	0.061	0.058	0.057	0.059	0.002
M3WB	0.071	0.068	0.066	0.068	0.002	M6WB	0.064	0.063	0.061	0.062	0.001

The average chloride concentration at different drill depths from (30-50) mm was found to be slightly lesser in all control concrete cubes for in case of mixtures type (M1-M3) such that their varied valued were interpreted as M1CC (0.066%, 0.063%, 0.061%), M2CC (0.063%, 0.061%, 0.061%), and M3CC(0.073%, 0.071%, 0.070%). Similarly, the average chloride concentration at different drill depths from (30-50) mm was somewhat decreased with lower compressive strength and constant slump value for in case of mixture type (M4) and goes on reduced with increased compressive strength for in case of mixtures type (M5-M6). Thus the interpreted average values of chloride concentration at different drill depth from (30-50) mm was represented as M4CC (0.061%, 0.056%, 0.061%), M5CC (0.068%, 0.067%, 0.066%), and M6CC (0.065%, 0.065%, 0.062%) respectively.

The chloride concentration in solvent based impregnation concrete cubes was reduced as when compared to control concrete cubes for in case of all mixtures type (M1-M6) in which the variation of average chloride concentration at different drill depths from (30-50) mm in different mixtures type. Furthermore, the chloride concentration in water based impregnation concrete cubes was slightly increase as when compared to solvent-based impregnation concrete cubes in all mixtures type (M1-M6). The chloride concentration was also increase at drill depth 30 mm as when compare to drill depths (40-50) mm. The variation of chloride concentration in partially saturated conditioned/impregnation concrete cubes at different drill depths as shown in

Table 3-43.

The chloride concentration was increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M1CC-M1SB:11.23%, M2CC-M2SB:7.84%, M3CC-M3SB:6.58%, M1CC-M1WB:7.18%, M2CC-M2WB:3.89%, M3CC-M3WB:3.06%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M4CC-M4SB:3.84%, M5CC-M2SB:10.42%, M6CC-M6SB:7.18%, M4CC-M4WB:0.21%, M5CC-M5WB:3.44%, M6CC-M6WB:3.28%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride concentration was decrease in solvent-based (SB)/water based (WB) impregnation cubes as compared to control concrete cubes (M1SB-M1CC:88.77%, M2SB-M2CC:92.16%, M3SB- M3CC:93.42%, M1WB-M1CC:92.82%, M2WB-M2CC:96.11%, M3WB-M3CC:96.94%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also decrease in solvent-based (SB)/water based (WB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4CC:96.16%, M5SB-M5CC:89.58%, M6SB-M6CC:92.82%, M4WB-M4CC:99.79%, M5WB -M5CC:96.56%, M6WB-M6CC:96.72%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Furthermore, the chloride concentration was also decrease in solvent-based (SB) impregnation cubes as compared to water based (WB) impregnation cubes (M1SB-M1WB:95.64%, M2SB-M2WB:95.89%, M3SB-M3WB:96.37%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also decrease in solvent-based (SB) impregnation concrete cubes as compared to water based (WB) impregnation concrete cubes (M4SB-M4WB:96.37%, M5SB-M5WB:92.77%, M6SB-M6WB:95.97%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride concentration was increase in water-based (WB) impregnation concrete cubes as compared to solvent based impregnation concrete cubes (M1WB-M1SB:4.36%, M2WB-M2SB:4.11%, M3WB-M3SB:3.63%) for in case of constant higher compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in water-based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:3.63%, M5WB-M5SB:7.23%, M6WB-M6SB:4.03%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Furthermore, the chloride concentration in control concrete cubes were compare to solvent-based (SB)/water based (WB) impregnation concrete cubes at drill depths 40 mm and 50 mm respectively.

Table 3-43 Interpretation of chloride concentration in PSC cubes at different drill depths

Comparison of final CC, % Results for PSC cubes at different drill depths															
CUBE ID	30 mm	%, incr	%, incr	%,decr	%,decr	40 mm	%, incr	%, incr	%,decr	%,decr	50 mm	%, incr	%, incr	%,decr	%,decr
M1CC	0.066	0		0		0.06362	0				0.0612	0			
M1SB	0.05859	11.23		88.77		0.0585	8.05		91.95		0.05632	7.97		92.03	
M1WB	0.06126	7.18	4.36	92.82	95.64	0.06117	3.85	4.36	96.15	95.64	0.05861	4.23	3.91	95.77	96.09
M2CC	0.06376	0.00				0.06133	0.00				0.06112	0.00			
M2SB	0.05876	7.84		92.16		0.05856	4.52		95.48		0.05635	7.80		92.20	
M2WB	0.06128	3.89	4.11	96.11	95.89	0.06096	0.60	3.94	99.40	96.06	0.05867	4.01	3.95	95.99	96.05
M3CC	0.07311	0.00				0.071	0.00				0.07067	0.00			
M3SB	0.0683	6.58		93.42		0.0659	7.18		92.82		0.06356	10.06		89.94	
M3WB	0.07087	3.06	3.63	96.94	96.37	0.06824	3.89	3.43	96.11	96.57	0.06597	6.65	3.65	93.35	96.35
M4CC	0.06126	0.00				0.05639	0.00				0.06108	0.00			
M4SB	0.05891	3.84		96.16		0.05643	-0.07		100.07		0.0564	7.66		92.34	
M4WB	0.06113	0.21	3.63	99.79	96.37	0.05879	-4.26	4.01	104.26	95.99	0.05876	3.80	4.02	96.20	95.98
M5CC	0.06834	0.00				0.06716	0.00				0.06603	0.00			
M5SB	0.06122	10.42		89.58		0.05766	14.15		85.85		0.05661	14.27		85.73	
M5WB	0.06599	3.44	7.23	96.56	92.77	0.06371	5.14	9.50	94.86	90.50	0.05869	11.12	3.54	88.88	96.46
M6CC	0.06588	0.00				0.06496	0.00				0.06207	0.00			
M6SB	0.06115	7.18		92.82		0.05802	10.68		89.32		0.05701	8.15		91.85	
M6WB	0.06372	3.28	4.03	96.72	95.97	0.06256	3.69	7.26	96.31	92.74	0.06101	1.71	6.56	98.29	93.44

The chloride concentration in solvent base/water base impregnation concrete cubes was decrease as when compare to control concrete cubes at different drill depths (30-50) mm as when compared to control concrete cubes for in case of all mixtures type (M1-M6) at different drill depths (30, 40, and 50) mm. The chloride concentration in solvent-based impregnation concrete cubes was decrease as when compared to water based impregnation concrete cubes at drill depth (30 mm). Similarly, the chloride concentration at drill depth 40 mm in solvent-based impregnation concrete cubes was decrease as when compared to water based impregnation concrete cubes. Furthermore, the chloride concentration at 50 mm drill depth in solvent-based impregnation concrete cubes was decrease as when compared to water based impregnation concrete cubes.

3.7.13 Chloride profile analysis in fully saturated concrete cubes

It's confirmed from results that for higher compressive strength and varied slump value, the chloride concentration for in case of control concrete cubes was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride concentration was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days and its average value such as chloride concentration as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride concentration as well as standard deviation values at different drill depths (30-50) mm was represent in all mixture type (M1-M6) as presented in Table 3-44.

Table 3-44 Variation of average chloride concentration in FSC cubes

Final CC, % Results for FSC cubes				Average	STD					Average	STD
CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm	CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm
M1CC	0.059	0.056	0.054	0.056	0.003	M4CC	0.060	0.054	0.052	0.055	0.004
M1SB	0.054	0.052	0.049	0.052	0.002	M4SB	0.054	0.052	0.049	0.052	0.002
M1WB	0.056	0.055	0.053	0.055	0.002	M4WB	0.056	0.052	0.051	0.053	0.003
M2CC	0.059	0.056	0.054	0.056	0.002	M5CC	0.063	0.062	0.061	0.062	0.001
M2SB	0.054	0.052	0.049	0.052	0.002	M5SB	0.054	0.051	0.052	0.052	0.001
M2WB	0.056	0.054	0.052	0.054	0.002	M5WB	0.056	0.054	0.054	0.055	0.001
M3CC	0.068	0.066	0.063	0.066	0.002	M6CC	0.061	0.059	0.056	0.059	0.002
M3SB	0.061	0.056	0.054	0.057	0.004	M6SB	0.056	0.052	0.049	0.052	0.004
M3WB	0.063	0.061	0.059	0.061	0.002	M6WB	0.059	0.056	0.054	0.056	0.002

The average chloride concentration at different drill depths from (30-50) mm was found to be slightly lesser in all control concrete cubes for in case of mixtures type (M1-M3). Similarly, the average chloride concentration at different drill depths from (30-50) mm was somewhat increased with lower compressive strength and constant slump value for in case of mixture type (M4) and goes on reduced with increased compressive strength for in case of mixtures type (M5-M6). Thus the interpreted average values of chloride concentration at different drill depth from (30-50) mm.

The chloride concentration in solvent based impregnation concrete cubes was reduced as when compared to control concrete cubes for in case of all mixtures type (M1-M6) in which the variation of average chloride concentration at different drill depths from (30-50) mm in different mixtures type. The interpretation of chloride concentration in fully saturated conditioned/impregnation concrete cubes as represented in Table 3-45.

The chloride concentration was increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M1CC-M1SB:8.49%, M2CC-M2SB:8.27%, M3CC-M3SB:10.69%, M1CC-M1WB:4.33%, M2CC-M2WB:3.83%, M3CC-M3WB:7.19%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M4CC-M4SB:9.87%, M5CC-M2SB:15.02%, M6CC-M6SB:7.75%, M4CC-M4WB:5.94%, M5CC-M5WB:11.27%, M6CC-M6WB:3.84%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride concentration was decrease in solvent-based (SB)/water based (WB) impregnation cubes as compared to control concrete cubes (M1SB-M1CC:91.51%, M2SB-M2CC:91.73%, M3SB- M3CC:89.31%, M1WB-M1CC:92.82%, M2WB-M2CC:96.11%, M3WB-M3CC:96.94%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also decrease in solvent-based (SB)/water based (WB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4CC:90.13%, M5SB-M5CC:84.98%, M6SB-M6CC:92.52%, M4WB-M4CC:94.06%, M5WB -M5CC:88.73%, M6WB-M6CC:96.16%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Furthermore, the chloride concentration was also decrease in solvent-based (SB) impregnation cubes as compared to water based (WB) impregnation cubes (M1SB-M1WB:95.65%, M2SB-M2WB:95.38%, M3SB-M3WB:96.22%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also decrease in solvent-based (SB) impregnation concrete cubes as compared to water based (WB) impregnation concrete cubes (M4SB-M4WB:95.82%, M5SB-M5WB:95.77%, M6SB-M6WB:95.94%) for lower compressive strength

(25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride concentration was increase in water-based (WB) impregnation concrete cubes as compared to solvent based impregnation concrete cubes (M1WB-M1SB:4.35%, M2WB-M2SB:4.62%, M3WB-M3SB:3.78%) for in case of constant higher compressive strength and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride concentration was also increase in water-based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:4.18%, M5WB-M5SB:4.23%, M6WB-M6SB:4.06%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Chloride concentration in control concrete cubes was compare to solvent-based (SB)/water based (WB) impregnation concrete cubes at drill depths 40 mm and 50 mm respectively.

Table 3-45 Interpretation chloride concentration in FSC cubes at different drill depths

Comparison of final CC, % Results for FSC cubes at different drill depths															
CUBE ID	30 mm	%, incr	%, incr	%,decr	%,decr	40 mm	%, incr	%, incr	%,decr	%,decr	50 mm	%, incr	%, incr	%,decr	%,decr
M1CC	0.05886	0				0.05628	0				0.05363	0			
M1SB	0.05386	8.49		91.51		0.05155	8.41		91.59		0.04919	8.28		91.72	
M1WB	0.05631	4.33	4.35	95.67	95.65	0.05525	1.83	6.70	98.17	93.30	0.05285	1.45	6.93	98.55	93.07
M2CC	0.05871	0.00				0.05621	0.00				0.05397	0.00			
M2SB	0.05385	8.27		91.73		0.0516	8.20		91.80		0.0492	8.84		91.16	
M2WB	0.05646	3.83	4.62	96.17	95.38	0.05387	4.16	4.21	95.84	95.79	0.05152	4.54	4.50	95.46	95.50
M3CC	0.06821	0.00				0.06558	0.00				0.06333	0.00			
M3SB	0.06092	10.69		89.31		0.05629	14.17		85.83		0.05389	14.91		85.09	
M3WB	0.06331	7.19	3.78	92.81	96.22	0.06095	7.06	7.65	92.94	92.35	0.0591	6.68	8.82	93.32	91.18
M4CC	0.0598	0.00				0.05354	0.00				0.0522	0.00			
M4SB	0.0539	9.87		90.13		0.0517	3.44		96.56		0.04916	5.82		94.18	
M4WB	0.05625	5.94	4.18	94.06	95.82	0.05158	3.66	-0.23	96.34	100.23	0.05052	3.22	2.69	96.78	97.31
M5CC	0.06344	0.00				0.0623	0.00				0.06087	0.00			
M5SB	0.05391	15.02		84.98		0.05133	17.61		82.39		0.05151	15.38		84.62	
M5WB	0.05629	11.27	4.23	88.73	95.77	0.05388	13.52	4.73	86.48	95.27	0.05386	11.52	4.36	88.48	95.64
M6CC	0.06094	0.00				0.0586	0.00				0.05622	0.00			
M6SB	0.05622	7.75		92.25		0.05151	12.10		87.90		0.04917	12.54		87.46	
M6WB	0.0586	3.84	4.06	96.16	95.94	0.05634	3.86	8.57	96.14	91.43	0.05389	4.14	8.76	95.86	91.24

Furthermore, the chloride concentration in water based impregnation concrete cubes was slightly increase as when compared to solvent-based impregnation concrete cubes in all mixtures type (M1-M6). The chloride concentration was also increase at drill depth 30 mm as when compare to drill depths (40-50) mm in concrete cubes. The chloride concentration in solvent-based impregnation concrete cubes was decreased/increased as when compared to control concrete cubes at different drill depths (30-50) mm. Chloride concentration in water based impregnation concrete cubes was reduced at different drill depths (30-50) mm as when compared to control concrete cubes for in case of all mixtures type (M1-M6). The chloride concentration in solvent-based impregnation concrete cubes was observe to be decrease as when compared to water based impregnation concrete cubes at drill depth (30 mm). Similarly, the chloride concentration at drill depth 40 mm in solvent-based impregnation concrete cubes was decrease as when compared to water based impregnation concrete cubes. Furthermore, the chloride concentration at 50 mm drill depth in solvent-based impregnation concrete cubes was decrease as when compared to water based impregnation concrete cubes.

3.7.14 Summary

- In worldwide a usage of de-icing salts has been common in areas where snow and ice is a seasonal roadway safety hazard, automobile, and highway bridge corrosion, and ecosystem changes caused by deicing salt are well document and focus of considerable study until now in recent years.

- In this research work, seventy-two concrete cubes of size (100x100x100) mm with six mixtures type were design and pre-conditioned the concrete cubes with water to investigate their effect on chloride diffusion in dry, fully saturated, and partially saturated conditioned concrete cubes with/without impregnation.

- The research was carry out to evaluate the performance of impregnation material such as solvent based and water based on concrete cubes under pre-determined conditions such as dry/fully saturated/partially saturated condition. In turn analysed the chloride concentrations at different drill depths (30, 40, and 50 mm).

- From this weight loss variation in water under pre-dry conditioned concrete cubes, it has confirmed that for higher compressive strength and varied slump value, the weight loss was to be lesser in magnitude. For lower compressive strength, and constant slump value, the weight loss was to be more as when compared to higher compressive strength and constant slump value.

- In addition, it has confirmed that for lower compressive strength and constant slump value, the weight gain in water under pre-fully/partially saturated concrete cubes was to be higher in magnitude. In fact, its goes on decreases slightly with increase in compressive strength and constant slump value. Weight gain in water was increase for higher compressive strength and varied slump.

- It has confirmed that for higher compressive strength and varied slump value, the average chloride concentration at drill depths (30-50) mm in control concrete cubes was to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes. It is observe from the results that, for lower compressive strength and constant slump value, the average chloride concentration at drill depths (30-50) mm in control concrete cubes was to be slightly more as when compared to higher compressive strength.

- For higher/lower compressive strength and varied/constant slump value, the average chloride concentration at drill depths (30-50) mm in control/solvent/water based impregnation pre-partially/fully saturated concrete cubes was found to be slightly lower in magnitude as when compared to dry conditioned control/solvent/water based impregnation concrete cubes.

- It’s also clear that for higher/lower compressive strength and varied/constant slump value, the average chloride concentration at drill depths (30-50) mm in pre-partially saturated control/solvent/water based impregnation concrete cubes was found to be slightly higher in magnitude as when compared to fully saturated conditioned control/solvent/water based impregnation concrete cubes.

3.8 Salt ponding test on concrete slabs

3.8.1 Introduction

In fact, the de-icing compounds is use to melt ice and snow on streets, roads, and motorways to improve public safety. Most de-icing agents are salts which melt ice by lowering the freezing point of water below 0^0 C. Among these compounds, sodium chloride (NaCl) is the cheapest and most commonly used de-icing agent. As much as 40-80 tons of salt per lane kilometre are apply to many roads for ice and snow control each year. In Britain and other European countries, several million tons of NaCl is use annually for de-icing purposes. In Canada and USA, 5 and 10 million tons of the salt is apply on roads each year [Transportation Research Board, 1991]. However, their widespread use over a long period has left the construction industry and the engineering community with a huge problem regarding the durability of highway reinforced concrete bridges and multi-storey parking structures, due mainly to the fact that they cause corrosion of the reinforcement and steel components.

3.8.2 Pre-conditioning of concrete slabs

An objective of the research work is to investigate the effect of the chloride penetration at different depths of some factors concerning concrete pore structure, namely water/cement ratio, cement type, grade of concrete, and slump. For that, concrete slabs are pre-conditioned such as drying, fully saturated, and partially saturated condition with water, after that the pre-conditioned concrete slabs were uni-directionally exposed to sodium chloride solution for about 160 days. An overall detail of the mixtures proportion were to be represent in (Table 3-46*)*. Twelve concrete cubes and three concrete slabs could be casted for each mixtures type.

In turn, the chloride profile was measure after salt ponding test, and the diffusion coefficient was calculate from the Fick's second law. The experimental result shows that, the diffusion coefficients obtained from salt ponding test. In ponding test, the diffusion coefficient obtained from the profile method. The transport mechanism of chloride ions in concrete during wetting and drying cycles of varying duration is evaluate in this research work. The dry-wet cycles accelerate the transport process of chloride ions within a certain distance from the surface, beyond this distance, chloride ions in the complete immersion specimen migrate more rapidly than those under dry-wet cycle do. The smaller the diffusion coefficient, the higher the surface chloride concentration.

Table 3-46 Concrete slabs mixture proportion (M1-M6)

Mix ID	Comp stg (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mixture Proportions
M1	40	0-10	0.45	18.23	8.20	29.70	94.16	1:1.63:5.17
M2	40	10-30	0.44	22.05	9.72	28.49	85.47	1:1.29:3.88
M3	40	60-180	0.43	27.51	11.85	32.50	72.41	1:1.18:2.63
M4	25	10-30	0.50	19.44	9.72	30.31	86.27	1:1.55:4.44
M5	30	10-30	0.45	21.63	9.72	30.86	83.55	1:1.42:3.86
M6	40	10-30	0.44	22.05	9.72	28.49	85.47	1:1.29:3.87

Thus totally 18 concrete slabs of size (450mm x 450mm x 100mm) mm were fabricated with different six mixtures type (M1-M6). Out of which three mixtures type (constant compressive strength, varied slump) were design as one group (M1-M3). In second group (M4-M6), rest of three mixtures type designed as with different compressive strength, and constant slump. The mixture ingredients quantity were found to be more or less same, so that, the mixture proportions were adopted in dry conditioned concrete slabs (DCC) as mixture type (M1=M2), (M3=M5), and (M4=M6) for in case of partially saturated (PSC) as well as fully saturated conditioned concrete (FSC) slabs. As concern to DCC concrete slabs, the control/impregnation concrete slabs were represent as (M1CS, M2CS) with solvent based/water based concrete slabs as (M1S1, M2S3) and (M1S2, M2S4). For in case of PSC concrete slabs, the control/impregnation concrete slabs were represent as (M3CS, M5CS) with solvent based/water based concrete slabs as (M3S5, M5S7) and (M3S6, M5S8). With reference to FSC concrete slabs, the control/impregnation concrete slabs were represent as (M4CS, M6CS) with solvent based/water based concrete slabs as (M4S9, M6S11) and (M4S10, M6S12). After 28 days of initial curing in water, the concrete slabs were subject to different exposure conditions such as drying, fully and partially saturated conditions for a specified time duration. Hence, it is possible to develop a better understanding of the long-term tests to assess the resistance of concrete to chloride penetration under different pre-conditions such as drying, partially saturated, and fully saturated conditions with/without impregnation. The results show that the most significant effect of sorptivity on long-term chloride ingress to concrete is its effect on surface chloride content. The value of this parameter is a way of taking account of absorption when modelling chloride ingress under cyclic wetting and drying conditions. The casting of concrete slabs was carry out based on their mixtures proportion as shown in Figure 3-9.

Figure 3-9 Casting of concrete slabs

Totally 12 concrete slabs were treated with two different impregnation materials such as Solvent based (M1S1, M2S3, M3S5, M5S7, M4S9, M6S11) and Water based (M1S2, M2S4, M3S6, M5S8, M4S10, M6S12). The other 6 concrete slabs were untreated as control concrete slabs (M1CS, M2CS, M3CS, M4CS, M5CS, M6CS and M6CS). Water based (WB) and Solvent based (SB), impregnate materials were use in this present research work. To avoid criticizing or promoting one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclose and they will be refer to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material, which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

The concrete slabs were casted as per their mixtures proportion in which the Fine aggregate of size 4.50 mm down 600 µ (micron), and coarse aggregate (10 mm) size, cement type (42.5 N/mm^2) was all mixed using the mixer for a minimum of 5 minutes, after that water was added and mixing continued for a further 3 minutes. The concrete was finally place in the wooden moulds in two layers. Each layer was vibrate to improve the compressive strength by removing the air voids in the concrete. The vibration was carry out to consolidate the concrete until it was fully compacted. The concrete specimens were cure under damp conditions for 24 hours. The hessian was clean off from the concrete slabs using compressed air. The specimen were cure for a minimum of 28 days before the application of the impregnation material. As per TRL method, it is recommend that the application of materials was carry out after 28 days curing, but because of a few logistics, this was not possible in this case. Actually, in this present research work, the impregnation materials was apply for all concrete slabs after at least 40 days.

The impregnation was apply after curing and cleaning the specimens. The specimens were all cleaned using compressed air in the laboratory. All the impregnation materials were apply by brush. The impregnation material were mixed and applied as per manufactures' recommendations as shown in Figure 3-10. Gloves were wear during the application, new gloves and a new brush was use for every different coating to avoid cross contamination. After the application of the impregnation materials and left the concrete slabs for 7-day curing after the application of impregnation materials as per the manufactures recommendation. In which 12 impregnation concrete slabs and 6 control slabs were ponded with sodium chloride solution. Sodium chloride solution ponding was repeat every two weeks for about 160 days. The sodium chloride solution contained 1 litre of water and 10% by weight (100 grams) of sodium chloride for each specimen. A one litre-measuring cylinder was use to mix the solution. The specimen was all cover in a black plastic cover to reduce the evaporation of water from the sodium chloride solution.

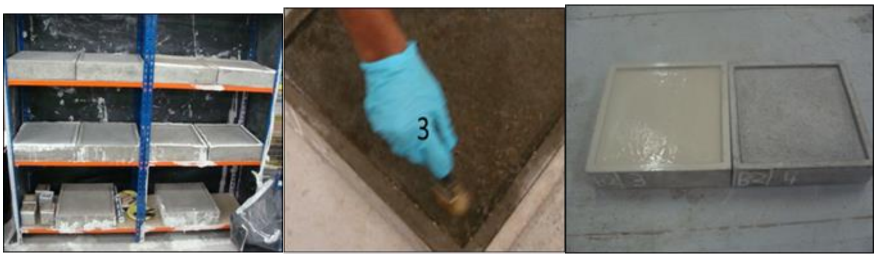


Figure 3-10 Application of impregnation material

3.8.3 Pre-conditioned dry concrete slabs

The six concrete slabs were pre-condition to achieve dry condition for about 28 days before salt ponding test. The initial and dry weights of concrete slabs was observe to be (42.55, 41.30, 41.55, 40.90, 42.33, 41.22 kg) as well as (41.25, 40.15, 39.55, 39.50, 41.23, 40.12 kg). After that, the concrete slabs are seal to prevent evaporation from those surfaces and impose directional control of the chloride penetration. The ponded slabs are stored to allow air circulation around the slabs in a room. A cover is place over the solution pond to prevent evaporation of water from the solution.

3.8.4 Pre-conditioned Fully saturated concrete slabs in water

The six concrete slabs were pre-condition to achieve fully saturated condition for about 60 days before salt ponding test. The initial and dry weights of concrete slabs was observe to be (41.75, 40.60, 42.20, 42.50, 41.25, 41.22 kg) as well as (42.50, 43.35, 43.75, 42.20, 42.23, 42.12 kg). Similarly, after pre-conditioning, the concrete slabs are seal to prevent evaporation from those surfaces and impose directional control of the chloride penetration. The ponded slabs are stored to allow air circulation around the slabs in a room. A cover is place over the solution pond to prevent evaporation of water from the solution.

3.8.5 Pre-conditioned Partially saturated concrete slabs in water

The six concrete slabs were pre-condition to achieve partially saturated condition for about 40 days before salt ponding test. The initial and dry weights of concrete slabs was observe to be (42.20, 41.20, 42.15, 41.30, 41.25, 41.50 kg) as well as (42.75, 43.50, 43.50, 42.75, 42.30, 42.22 kg). As usually, the concrete slabs are seal to prevent evaporation from those surfaces and impose directional control of the chloride penetration. The ponded slabs are stored to allow air circulation around the slabs in a room. A cover is place over the solution pond to prevent evaporation of water from the solution. In this present research work, the unidirectional salt ponding test was conduct out on totally 18 concrete slabs with 6 control concrete slabs and 12 impregnation concrete slabs, out of which 6 solvent based impregnated and 6 water based impregnated concrete slabs. The unidirectional salt ponding was adopt as per AASHTO T 259 method. In which the slabs are typically moist cured for a length of time followed by a period of drying at 50% relative humidity before ponding with a 10% sodium chloride solution. AASHTO T 259 calls for 14 days moist curing followed by 28 days of drying. The ponded slabs are stored to allow air circulation around the slabs in a room at 50% relative humidity. A cover is place over the solution pond to prevent evaporation of water from the solution. AASHTO T 259 calls for a ponding period of 90 days. For low-permeability concretes, this is confirm to be too short for significant penetration of chloride ions into the concrete, and ponding is often extend for longer periods. But in this present research work, certain concrete slabs were pre-conditioned such as fully/partially saturated conditioned in water for certain time duration and dry pre-conditioning for specified time duration before salt ponding test which was about 160 days. The variation of chloride concentration at different drill depths was interpret in all designed six mixtures type (M1-M6).

3.8.6 Chloride profile analysis in Pre-conditioned concrete slabs

The chloride profiles were analysed by drilling the slabs. The drilling was done with a diameter of 20 mm (max aggregate size) and drill depths of (30, 40, and 50) mm. The dust sample were collected, weighted between 1-5 grams as specified by (BS EN 15629:2007) for the determination of the chloride penetration. The chloride concentration for each of the dust samples, including from the control specimens was determined in accordance with BS EN 15629:2007 in hardened concrete. The chloride content was calculate as a percentage of chloride ion by mass of the sample of concrete. Volhard's Method was use for the determination of the total chloride content in the concrete. Samples of dust powder drilled from the concrete specimens at different drill depths of 30 mm, 40 mm, and 50 mm were used for the determination of the chloride penetration in the concrete samples for in case of six mixtures type (M1-M6). The chloride salt ponding with analysis in pre-conditioned concrete slabs as shown in Figure 3-11.

Figure 3-11 Chloride profile analysis in pre-conditioned concrete slabs

The chloride concentration in 6 dry conditioned concrete slabs was analysed in control/impregnation concrete slabs. The chloride concentration was increase in control slabs (M1CS and M2CS). Whereas the chloride concentration was comparatively lesser in solvent based impregnation concrete slabs (M1S1 and M2S3) as when compared to water based impregnation concrete slabs (M1S2 and M2S4) at drill depth 30 mm. Similarly, the chloride concentration for in case of 6 PSC concrete slabs was interpreted in which, the chloride concentration in control concrete slabs (M3CS, and M5CS) was more as when compared to FSC concrete slabs at drill depth 30 mm. Also the chloride concentration was observed to be slightly lesser in solvent based impregnation concrete slabs (M3S5 and M5S7) as when compared to water based impregnation concrete slabs (M3S6, and M5S6).

In case of 6 FSC concrete slabs, the chloride concentration was observe to be more reduced as when compared to DCC, and PSC concrete slabs for in case of control concrete slabs (M4CS, and M6CS) at drill depth 30 mm. Similarly, the chloride concentration was reduced in solvent based impregnation concrete slabs (M4S9, and M6S11) as when compared to water based impregnation concrete slabs (M4S10, and M6S12) at drill depth 30 mm. The chloride concentration in control/impregnation concrete slabs was found to be more in DCC concrete slabs as when compared to PSC and FSC concrete slabs and this may be due to mix proportion, pore structure, concrete matrix-cement paste structure formation, compressive strength, slump, w-c ratio, aggregate volume fraction and cement content and type. The variation of chloride concentration in pre-conditioned concrete slabs in control/impregnation was represent in Table 3-47.

Table 3-47 Chloride concentration in different pre-conditioned concrete slabs

Final CC (%) Results for DCC Slabs				Final CC (%) Results for PSC Slabs				Final CC (%) Results for FSC Slabs			
Mixture type [M1=M2]				Mixture type [M3=M5]				Mixture type [M4=M6]			
Slab ID	30 mm	40 mm	50 mm	Slab ID	30 mm	40 mm	50 mm	Slab ID	30 mm	40 mm	50 mm
M1CS	0.092	0.086	0.082	M3C5	0.079	0.073	0.069	M4CS	0.072	0.071	0.065
M1S1	0.089	0.084	0.075	M3S5	0.074	0.071	0.066	M4S9	0.069	0.067	0.062
M1S2	0.092	0.085	0.080	M3S6	0.075	0.072	0.067	M4S10	0.070	0.069	0.063
M2CS	0.082	0.078	0.065	M5CS	0.085	0.074	0.062	M6CS	0.065	0.060	0.056
M2S3	0.077	0.067	0.061	M5S7	0.080	0.061	0.058	M6S11	0.063	0.052	0.05
M2S4	0.078	0.068	0.063	M5S8	0.081	0.071	0.059	M6S12	0.064	0.055	0.054

The percentage variation of chloride concentration in different pre-conditioned concrete slabs at drill depth was represent as in Table 3-48.

Table 3-48 Comparison of chloride concentration at different drill depth in concrete slabs

Comparison of Final CC Results for DCC Slabs					
Mixture type [M1=M2]					
Slab ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)
M1CS	0.092	0.0864	6.42	0.082	11.67
M1S1	0.089	0.0835	6.66	0.075	15.78
M1S2	0.092	0.0854	6.68	0.08	12.83
M2CS	0.082	0.0782	4.85	0.065	20.47
M2S3	0.077	0.0672	13.21	0.061	20.74
M2S4	0.078	0.0683	12.80	0.063	20.01
Comparison of Final CC Results for PSC Slabs					
Mixture type [M3=M5]					
Slab ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)
M3C5	0.079	0.0731	7.13	0.069	12.70
M3S5	0.074	0.0711	3.54	0.066	10.85
M3S6	0.075	0.0722	3.46	0.067	10.30
M5CS	0.085	0.0736	12.94	0.062	27.11
M5S7	0.081	0.0613	23.90	0.058	28.44
M5S8	0.081	0.0706	13.25	0.059	27.21
Comparison of Final CC Results for FSC Slabs					
Mixture type [M4=M6]					
Slab ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)
M4CS	0.072	0.0716	0.80	0.065	9.88
M4S9	0.07	0.0672	3.48	0.062	10.29
M4S10	0.07	0.0685	2.62	0.063	9.88
M6CS	0.065	0.0599	8.38	0.056	14.61
M6S11	0.063	0.0524	17.33	0.05	20.80
M6S12	0.065	0.0547	15.34	0.054	16.91

The interpretation of Chloride concentration in control/impregnation concrete slabs as explained in Table 3-49.

Table 3-49 Interpretation of chloride concentration in control/impregnation concrete slabs

Comparison of Final CC Results for DCC Slabs at diiferent drill depths									
Mixture type [M1=M2]									
Slab ID	30 mm	Incr (%)	Incr (%)	40 mm	Incr (%)	Incr (%)	50 mm	Incr (%)	Incr (%)
M1CS	0.0923	0.00		0.086	0.00		0.082	0.00	
M1S1	0.0895	3.04		0.084	3.29		0.075	7.56	
M1S2	0.0915	0.83	2.23	0.085	1.10	2.21	0.08	2.13	5.54
M2CS	0.0821	0.00		0.078	0.00		0.065	0.00	
M2S3	0.0774	5.80		0.067	14.08		0.061	6.12	
M2S4	0.0784	4.58	1.28	0.068	12.55	1.74	0.063	4.03	2.19
Comparison of Final CC Results for PSC Slabs at diiferent drill depths									
Mixture type [M3=M5]									
Slab ID	30 mm	Incr (%)	Incr (%)	40 mm	Incr (%)	Incr (%)	50 mm	Incr (%)	Incr (%)
M3C5	0.0787	0		0.073	0		0.069	0	
M3S5	0.0737	6.35		0.071	2.74		0.066	4.37	
M3S6	0.0748	4.99	1.43	0.072	1.24	1.51	0.067	2.37	2.04
M5CS	0.0846	0.00		0.074	0.00		0.062	0.00	
M5S7	0.0806	4.75		0.061	16.75		0.058	6.49	
M5S8	0.0813	3.83	0.96	0.071	4.18	13.11	0.059	3.96	2.64
Comparison of Final CC Results for FSC Slabs at diiferent drill depths									
Mixture type [M4=M6]									
Slab ID	30 mm	Incr (%)	Incr (%)	40 mm	Incr (%)	Incr (%)	50 mm	Incr (%)	Incr (%)
M4CS	0.0722	0		0.072	0		0.065	0	
M4S9	0.0696	3.57		0.067	6.17		0.062	4.01	
M4S10	0.0704	2.55	1.05	0.069	4.33	1.93	0.063	2.55	1.50
M6CS	0.0654	0		0.06	0.00		0.056	0.00	
M6S11	0.0634	3.06		0.052	12.52		0.05	10.09	
M6S12	0.0646	1.15	1.93	0.055	8.65	4.24	0.054	3.81	6.53

3.8.7 Chloride profile analysis in pre-conditioned concrete slabs

In the present research work, eighteen concrete slabs of size (450x450x100) mm with six mixtures type (M1-M6) were design. First three set of mixtures type were design as with higher compressive strength (40 N/mm^2) and varied slump values (0-10, 10-30, and 60-180) mm. Second three set of mixtures type were design as with varied compressive strength (25-30-40 N/mm^2), and constant slump value (10-30) mm. Concrete slabs were pre-conditioned to investigate their effectiveness (10% Nacl solution) on the chloride diffusion in dry/fully saturated/partially saturated conditioned concrete slabs with/without impregnation such as solvent (SB)/water based (WB) impregnation material. Thus the overall average variation of chloride concentration at different drill depths (30-50) mm in pre-conditioned dry conditioned concrete slabs was increased as when compared to partially saturated as well as fully saturated concrete slabs such as in control (CS), solvent (SB) and water based (WB) concrete slabs.

Its varied average chloride concentration at different drill depths was increased for in case of DCC slabs as when compared to PSC concrete slabs and its varied values are represented as M1CS (15.23%), M1SB (15.23%), M1WB (16.61%), M2CS (2.55%), M2SB (3.08%), M2WB (0.8%) respectively. In addition to that, the chloride concentration was also increased in case of DCC concrete slabs as when compared to FSC concrete slabs and its varied average chloride concentration at drill depths are interpreted as M1CS (19.73%), M1SB (19.78%), M1WB (21.21%), M2CS (19.74%), M2SB (19.39%), M2WB (17.38%) respectively. Similarly the chloride concentration was increased in PSC concrete slabs as when compared to FSC concrete slabs in which its average variation of chloride concentration at different drill depths was represented as M3CS (5.30%), M3SB (5.36%), M3WB (5.52%), M5CS (17.64%), M5SB (16.82%), and M5WB (18.04) respectively.

3.8.8 Chloride profile analysis in dry conditioned concrete slabs

It's confirmed that for higher compressive strength (40 N/mm^2) and varied slump value (0-10, and 10-30 mm) the chloride concentration for in case of control concrete slabs (CS) was found to be slightly higher in magnitude as when compared to solvent based (SB) and water based (WB) impregnation concrete slabs as observed from mixtures type (M1-M2). An effectiveness of the different mixtures type (M1-M2) for in case of control concrete slab (CS) as well as impregnation (SB and WB) concrete slab was interpret from 160 days salt ponding test. Its averaged values at different drill depths (30-40-50) mm such as chloride concentration and standard deviation was vary in all mixtures type as represented in Table 3-50. An average variation of chloride concentration at different drill depths (30-50) mm in pre-conditioned dry conditioned concrete slabs (DCC) was increased as when compared to partially saturated (PSC) concrete slabs such as in control (CS), solvent (SB) and water based (WB) concrete slabs. Its varied average chloride concentration at different drill depths was increased for in case of DCC slabs as when compared to PSC concrete slabs and its varied values are represented as M1CS (15.24%), M1S1,SB (15.23%), M1S2,WB (16.62%), M2CS (2.55%), M2S3,SB (3.08%), M2S4,WB (0.8%) respectively.

Table 3-50 Variation of average chloride concentration in DCC slabs

Final CC Results for DCC Slabs				Average	STD	(DCC-PSC)
Mixture type [M1=M2]						Incr (%)
Slab ID	30 mm	40 mm	50 mm			
M1CS	0.09230	0.086	0.0815	0.087	0.005	15.24
M1S1	0.08949	0.084	0.0754	0.083	0.007	15.23
M1S2	0.09153	0.085	0.0798	0.086	0.006	16.62
M2CS	0.08213	0.078	0.0653	0.075	0.009	2.55
M2S3	0.07737	0.067	0.0613	0.069	0.008	3.08
M2S4	0.07837	0.068	0.0627	0.070	0.008	-0.8

The variation of average values of chloride concentration as well as standard deviation values at different drill depths (30-50) mm was represent in all mixture type (M1-M2). The average chloride concentration at different drill depths from (30-50) mm was found to be slightly increase in control concrete slabs for in case of mixtures type (M1-M2). Similarly, the average chloride concentration at different drill depths from (30-50) mm was reduced in solvent based impregnation concrete slabs (SB) as when compared to control concrete (CS). Furthermore, the chloride concentration in water based impregnation concrete slabs (WB) was slightly increase as when compared to solvent-based impregnation concrete slabs (SB) in all mixtures type (M1-M2). The chloride concentration was also increased at drill depth 30 mm for in case of control, solvent, and water based impregnation concrete cubes as when compared to drill depths (40-50) mm and its varied values were represented as M1CS (6.42%, 11.66%), M1SB (6.65%, 15.77%), M1WB (6.67%, 12.82%), M2CS (4.84%, 20.46%), M2SB (13.20%, 20.74%), M2WB (12.79%, 20%) respectively.

The chloride concentration in solvent based impregnation concrete slabs (SB) was decreased as when compared to control concrete slabs (CS) at different drill depths (30-50) mm and in which its varied values were determined as M1SB (96.95%, 96.71%, 92.44%), and M2SB(94.20%, 85.92%, 93.87%) respectively. Whereas the chloride concentration in water based impregnation concrete slabs (WB) was reduced at different drill depths (30-50) mm as when compared to control concrete slabs (CS) for in case of all mixtures type (M1-M2) and its varied values are at different drill depths (30, 40, and 50) mm as M1WB (99.16%, 98.90%, 97.86%), and M2WB (95.42%, 87.44%, 95.97%) respectively. Similarly, the chloride concentration in solvent based impregnation concrete slabs (SB) was decreased as when compared to water based impregnation concrete cubes (WB) in which its varied values at different drill depths (30-50) mm as M1SB (97.77%, 97.78%, 94.46%), M2SB (98.72%, 98.25%, 97.81%) respectively.

3.8.9 Chloride profile analysis in partially saturated concrete slabs

It is clear from results that for higher compressive strength (40 N/mm^2), and varied slump value (60-180 mm), lower compressive strength (25 N/mm^2), and constant slump value (10-30 mm). Chloride concentration for in case of control concrete slabs was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete slabs as observed from mixtures type (M3-M5). Thus the effectiveness of the different mixtures type (M3-M5) for in case of control concrete slab as well as impregnation concrete slab was interpreted from 160 days' salt ponding and its averaged value at different drill depths such as chloride concentration as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride concentration as well as standard deviation values at different drill depths (30-50) mm was represent in Table 3-51. An average variation of chloride concentration at different drill depths (30-50) mm in pre-conditioned partially saturated (PSC) concrete slabs was decrease as when compared to dry conditioned concrete slabs such as in control (CS), solvent (SB) and water based (WB) concrete slabs. Its varied average chloride concentration at different drill depths was decreased for in case of PSC slabs as when compared to DCC concrete slabs and its varied values are represented as M3CS (18.00%), M3S5,SB (17.97%), M3S6,WB (19.92%), M5CS (2.62%), M5S7,SB (3.18%), M5S8,WB (0.79%) respectively.

Table 3-51 Variation of average chloride concentration in PSC slabs

Final CC Results for PSC Slabs				Average	STD	(PSC-DCC)
Mixture type [M3=M5]						decr (%)
Slab ID	30 mm	40 mm	50 mm			
M3C5	0.0787	0.0731	0.0687	0.074	0.005	18
M3S5	0.0737	0.0711	0.0657	0.070	0.004	17.97
M3S6	0.0748	0.0722	0.0671	0.071	0.004	19.92
M5CS	0.0846	0.0736	0.0616	0.073	0.011	2.62
M5S7	0.0806	0.0613	0.0576	0.066	0.012	3.18
M5S8	0.0813	0.0706	0.0592	0.070	0.011	0.79

The average chloride concentration was increase in control concrete slabs for in case of mixtures type (M3-M5) at different drill depths (30, 40, 50 mm) as when compared to impregnation concrete slabs. Similarly, the average chloride concentration at different drill depths from (30-50) mm was reduced in solvent based impregnation concrete slabs as when compared to control concrete slabs for in case of mixture type (M3CC) and (M5CC). Thus the interpreted average values of chloride concentration at different drill depth from (30-50) mm. Furthermore, the chloride concentration in water based impregnation concrete slabs was slightly increase as when compared to solvent-based impregnation concrete slabs in all mixtures type (M3-M5). The chloride concentration was also increased at drill depth 30 mm for in case of control, solvent, and water based impregnation concrete slabs as when compared to drill depths (40-50) mm and its varied values were represented as M3CC (7.12%, 12.70%), M3SB (3.54%, 10.85%), M3WB (3.46%, 10.29%), M5CC (12.93%, 27.11%), M5SB (23.89%, 28.44%), M5WB (13.25%, 27.21%) respectively.

The chloride concentration in solvent based impregnation concrete slabs was decreased as when compared to control concrete slabs at different drill depths (30-50) mm and in which its varied values were determined as M3SB (93.64%, 97.26%, 95.63%), and M5SB (95.24%, 83.25%, 93.51%) respectively. Whereas the chloride concentration in water based impregnation concrete slabs was reduced at different drill depths (30-50) mm as when compared to control concrete slabs for in case of all mixtures type (M3-M5) in its varied values are at different drill depths (30, 40, and 50) mm as M3WB (95%, 98.75%, 97.62%), and M5WB (96.16%, 95.81%, 96.04%) respectively. Similarly the chloride concentration in solvent based impregnation concrete slabs was decreased as when compared to water based impregnation concrete cubes in which its varied values at different drill depths (30-50) mm as M3SB (98.56%, 98.49%, 97.95%), M5SB (99.04%, 86.88%, 97.36%) respectively.

3.8.10 Chloride profile analysis in fully saturated concrete slabs

It's confirmed from results that for higher compressive strength (30 N/mm^2) and constant slump value (10-30 mm), lower compressive strength (25 N/mm^2), the chloride concentration for in case of control concrete slabs was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete slabs as observed from mixtures type (M4-M6). Thus the effectiveness of the different mixtures type (M4-M6) for in case of control concrete slab as well as impregnation concrete slab was interpreted from 160 days salt ponding and its averaged value at different drill depths such as chloride concentration as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride concentration as well as standard deviation values at different drill depths (30-50) mm was represent in all mixture type (M4-M6) as represented in Table 3-52. An average variation of chloride concentration at different drill depths (30-50) mm in pre-conditioned partially saturated (PSC) concrete slabs was increase as when compared to Fully saturated conditioned concrete slabs such as in control (CS), solvent (SB) and water based (WB) concrete slabs. Its varied average chloride concentration at different drill depths was decreased for in case of FSC slabs as when compared to PSC concrete slabs and its varied values are represented as M4CS (5.30%), M4S9,SB (5.37%), M4S10,WB (5.52%), M6CS (17.64%), M6S11,SB (16.83%), M6S12,WB (18.04%) respectively.

Table 3-52 Variation of average chloride concentration FSC slabs

Final CC Results for FSC Slabs				Average	STD	(PSC-FSC)
Mixture type [M4=M6]						Incr (%)
Slab ID	30 mm	40 mm	50 mm			
M4CS	0.0722	0.0716	0.0651	0.070	0.004	5.30
M4S9	0.0696	0.0672	0.0625	0.066	0.004	5.37
M4S10	0.0704	0.0685	0.0634	0.067	0.004	5.52
M6CS	0.0654	0.0599	0.0558	0.060	0.005	17.64
M6S11	0.0634	0.0524	0.0502	0.055	0.007	16.83
M6S12	0.0646	0.0547	0.0537	0.058	0.006	18.04

The average chloride concentration was increased in control concrete slabs for in case of mixtures type (M4-M6) at different drill depths (30, 40, 50 mm) as when compared to impregnation concrete slabs and their varied valued were interpreted as M4CS (0.072%, 0.071%, 0.065%), M6CS (0.065%, 0.059%, 0.055%). Similarly, the average chloride concentration at different drill depths from (30-50) mm was reduced in solvent based impregnation concrete slabs as when compared to control concrete slabs for in case of mixture type (M4CS) and (M6CS). Thus the interpreted average values of chloride concentration at different drill depth from (30-50) mm was represented as M4SB (0.069%, 0.067%, 0.062%), M6SB (0.063%, 0.052%, 0.050%) respectively. Furthermore, the chloride concentration in water based impregnation concrete slabs was slightly increased as when compared to solvent based impregnation concrete slabs in all mixtures type (M4-M6) in which their varied values was observed to be as M4WB (0.070%, 0.068%, 0.063%), M6WB (0.064%, 0.054%, 0.053%) respectively. The chloride concentration was also increased at drill depth 30 mm for in case of control, solvent, and water based impregnation concrete slabs as when compared to drill depths (40-50) mm and its varied values were represented as M4CS (0.80%, 9.87%), M4SB (3.47%, 10.28%), M4WB (2.61%, 9.87%), M6CS (8.38%, 14.61%), M6SB (17.32%, 20.80%), M6WB (15.33%, 16.91%) respectively.

The chloride concentration in solvent based impregnation concrete slabs was decreased as when compared to control concrete slabs at different drill depths (30-50) mm and in which its varied values were determined as M4SB (96.42%, 93.82%, 95.98%), and M6SB (96.94%, 87.47%, 89.91%) respectively. Whereas the chloride concentration in water based impregnation concrete slabs was reduced at different drill depths (30-50) mm as when compared to control concrete slabs for in case of all mixtures type (M4-M6) in its varied values are at different drill depths (30, 40, and 50) mm as M4WB (97.45%, 95.67%, 97.44%), and M6WB (98.85%, 91.34%, 96.18%) respectively. Similarly, the chloride concentration in solvent based impregnation concrete slabs was decreased as when compared to water based impregnation concrete cubes in which its varied values at different drill depths (30-50) mm as M4SB (98.94%, 98.07%, 98.50%), M6SB (98.06%, 95.76%, 93.47%) respectively.

3.8.11 Chloride profile analysis in pre-conditioned concrete slabs

It's interpreted from results that for higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm and 30-60 mm), the chloride concentration and standard deviation for in case of dry conditioned control concrete slabs was found to be slightly higher in magnitude as when compared to partially saturated as well as fully saturated control concrete slabs. The varied average chloride concentration and standard deviation at different drill depths (30-50) mm in dry conditioned control concrete slabs was represented as M1CC (0.0053-0.086%), M2(0.0075%-0.0087). The varied average chloride concentration and standard deviation at different drill depths (30-50) mm in partially saturated conditioned control concrete slabs was represented as M3CC (0.0050-0.073%), M5CC (0.0073-0.011%) respectively. Similarly the varied average chloride concentration and standard deviation at different drill depths(30-50) mm in fully saturated conditioned control concrete slabs was represented as M4CC(0.0039-0.069%), M6CC(0.0047-0.0060%) respectively.

Thus the average chloride concentration in dry conditioned concrete slabs at different depth (30-50) mm was found be increased with its varied values are represented as M1CC (15.23%) and M2CC (2.55%) as when compared to partially saturated control concrete slabs. In addition, the average chloride concentration in dry conditioned concrete slabs at different depth (30-50) mm was found be increased as when compared to fully saturated control concrete slabs and its varied values are represented as M3CC (19.73%) and M5CC (19.74%) respectively. Furthermore, the average chloride concentration in partially saturated conditioned control concrete slabs at different depth (30-50) mm was found be increased as when compared to fully saturated control concrete slabs and its varied values are represented as M3CC 5.30%) and M5CC (17.64%) respectively.

3.8.12 Summary

- In this research work, eighteen concrete slabs (450x450x100) mm with six mixtures type (M1-M6) were design and pre-conditioned the specimens to investigate their effect on chloride diffusion in DCC/PSC/FSC concrete specimens with/without impregnation.

- The research was carry out to evaluate the performance of impregnation material such as solvent based and water based material on concrete slabs under pre-determined conditions such as dry/fully saturated/partially saturated condition. In turn analysed the chloride concentrations at different drill depths (30, 40, and 50) mm for different mixtures type (M1-M6) after salt ponding test for about 160 days.

- The chloride concentration could be increase in DCC control concrete slabs as when compare to PSC, and FSC concrete slabs. Similarly, the chloride concentration in control concrete slabs could be increase for in case of PSC concrete cubes as when compared to FSC concrete slabs.

- The chloride concentration could be increase in DCC control concrete slabs as when compared to PSC (SB), and FSC (SB) slabs. Similarly, the chloride concentration in PSC control concrete slabs could be increase as when compared to FSC (SB) slabs.

- In addition to that, the chloride concentration could be increase in DCC control concrete slabs as when compared to PSC (WB), and FSC (WB) slabs. Whereas the chloride concentration in PSC control concrete slabs was increase as when compared to FSC (WB) slabs.

3.9 Chloride diffusion coefficient in concrete cubes

3.9.1 Chloride diffusion coefficient in pre-conditioned concrete cubes

The chloride ingress into concrete is model by using Fick's second law of diffusion. The common form of Fick's second law was derive for the boundary condition of one surface being in contact with a reservoir of constant concentration. However, in structures exposed to cyclic wetting and drying, this constant concentration boundary condition is not satisfied. Essentially, in cyclic exposures the surface concentration is not constant, but increases as a function of time. Chloride ingress occurs through sorption and diffusion in such exposures, but solely through diffusion in saturated environments. There are mainly three driving forces of the diffusion of chloride ions in non-saturated concrete. The first driving force is the non-uniform distribution of chloride ions, which is important for both saturated and non-saturated concrete. The second driving force is the diffusion of moisture, which is important in the case of non-saturated concrete. The third driving force is the ionic migration driven by an electric potential gradient, which is important only in some special cases.

The chloride ingress in to the concrete can only take place if the concrete pores are totally/partly fill with water. The penetration occurs either through the capillary pores/through cracks by permeation, capillary suction, and diffusion. In the exposure conditions, the concrete moisture content, and the pore structure will determine the relative importance of those penetration mechanisms. The chloride ingress into the concrete due to the various transport mechanisms obeys different laws. However, Fick’s second law of diffusion is commonly apply to quantify the chloride penetration in marine environment due to the multiple transport mechanism. This law is represent by the following expression (58):

$$\frac{\partial C}{\partial t} = D\,\frac{\delta^2 C}{\delta x^2} \qquad (58)$$

Where C (*x*, *t*) is the chloride concentration at depth (*x*) at time (*t*) and *D* is the diffusion coefficient. For a semi-finite uni-directional diffusion, the solution of this equation (59) is as follows:

$$C\,(x,t) = C_s\,[1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)] \qquad (59)$$

Whereas C_s is the surface chloride concentration and *erf* is the error function. Actually equations (58) and (59) assumes that, concrete is homogenous in structure and that *D* is independent of the humidity of concrete, chloride concentration, and temperature, in turn assume that the binding isotherm is linear. In fact, for a certain time interval, this law is a good approximation for the chloride variation with depth in structure expose to either the atmosphere or submerged environmental condition. The primary aim of this research was to interpret the effects of wetting and drying pre-conditioned concrete cubes on chloride diffusion coefficient, which was exposed to different pre-determined conditions such as dry/fully saturated/partially saturated condition was evaluated in control/impregnation concrete cubes for about 160 days in all designed six mixtures type (M1-M6). AASHTO T 259 calls for a ponding period of 90 days for in case of concrete slabs. For low-permeability concretes, this is consider to be too short for significant penetration of chloride ions into the concrete, and ponding is often extended for longer periods. Thus in this present research work, certain concrete slabs/cubes were pre-conditioned such as fully/partially saturated conditioned in water for certain time duration and dry pre-conditioning for specified time duration before salt ponding test which was conduct for about 160 days. The variation of chloride concentration at different drill depths was interpret in all designed six mixtures type (M1-M6) for longer time duration.

3.9.2 Chloride diffusion coefficient in pre-DCC cubes

The chloride diffusion coefficient was increase in dry conditioned concrete cubes in all control concrete cubes as when compared to solvent and water based impregnation concrete cubes for in case of all mixtures type (M1-M6). In fact, the chloride diffusion coefficient was slightly higher in control concrete cubes with lower compressive strength and constant slump value as when compared to solvent based as well as water based impregnation concrete cubes, in turn chloride diffusion coefficient goes on reduces with increased compressive strength for in case of mixtures type (M4-M6). The chloride diffusion coefficient was found to be more at lesser drill depth (30 mm) and it goes on reduces as drill depth increases in turn it depends on concrete matrix and mix proportioning, concrete compressive strength, slump, w-c ratio, temperature as well as pore structure formation. The variation of chloride diffusion coefficient at different drill depths (30-40-50) mm, with their average chloride diffusion coefficient as well as standard deviation values for different drill depths in dry conditioned concrete cubes (DCC) as represented in Table 3-53.

Table 3-53 Variation of chloride diffusion coefficient (mm^2/sec) in DCC concrete cubes

Chloride diffusion coefficient for DCC cubes				Average	Std deviation
CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm
M1CC	0.002699	0.002359	0.002188097	0.0024	0.0002
M1SB	0.001936	0.001473	0.001358627	0.0016	0.0002
M1WB	0.00257	0.002153	0.001888528	0.0022	0.0003
M2CC	0.00257	0.00227	0.002120373	0.0023	0.0002
M2SB	0.002094	0.001736	0.001607328	0.0018	0.0002
M2WB	0.002189	0.001788	0.001652827	0.0019	0.0002
M3CC	0.002568	0.001989	0.001716518	0.0021	0.0004
M3SB	0.002089	0.001636	0.001505855	0.0017	0.0002
M3WB	0.001868	0.001553	0.001519429	0.0016	0.0002
M4CC	0.002827	0.002304	0.002273141	0.0025	0.0003
M4SB	0.002507	0.001853	0.001719429	0.0020	0.0003
M4WB	0.002698	0.002089	0.001803518	0.0022	0.0004
M5CC	0.002327	0.001804	0.001770373	0.0020	0.0003
M5SB	0.00197	0.001636	0.001515855	0.0017	0.0002
M5WB	0.002089	0.001753	0.001655283	0.0018	0.0002
M6CC	0.002259	0.001789	0.001670373	0.0019	0.0003
M6SB	0.001953	0.001553	0.001502855	0.0017	0.0002
M6WB	0.002016	0.001657	0.001651943	0.0018	0.0002

3.9.3 Chloride diffusion coefficient in PSC cubes

The chloride diffusion coefficient was reduce in PSC concrete cubes as when compared to DCC concrete cubes for in case of all mixtures type (M1-M6). Actually, the diffusion is depending on concentration gradient in turn it depends on the rate of absorption. In fact, the diffusion is more at initial stage rather than at the longer time duration. In this way the chloride diffusion coefficient was more at initial stage and goes on reduces and that to the chloride diffusion coefficient was lesser in magnitude for in case PSC concrete cubes as when compared to DCC concrete cubes. The variation of chloride diffusion coefficient at different drill depths (30-40-50) mm, with their average chloride diffusion coefficient as well as standard deviation values for different drill depths in partially saturated conditioned concrete cubes (PSC) as represented in Table 3-54.Table 3-54

Table 3-54 Variation of chloride diffusion coefficient (mm^2/sec) in PSC concrete cubes

Chloride diffusion coefficient for PSC cubes				Average	Std deviation
CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm
M1CC	0.002136	0.001936	0.001858627	0.00198	0.00014
M1SB	0.001619	0.001519	0.001510373	0.00155	0.00006
M1WB	0.001706	0.001688	0.001635855	0.00168	0.00004
M2CC	0.00227	0.001719	0.001619429	0.00187	0.00035
M2SB	0.00157	0.001504	0.001470373	0.00151	0.00005
M2WB	0.001553	0.001536	0.001552827	0.00155	0.00001
M3CC	0.002159	0.001707	0.001688528	0.00185	0.00027
M3SB	0.001756	0.00158	0.001552827	0.00163	0.00011
M3WB	0.001658	0.001636	0.001650943	0.00165	0.00001
M4CC	0.002314	0.002139	0.001930841	0.00213	0.00019
M4SB	0.001836	0.00177	0.001665855	0.00176	0.00009
M4WB	0.001831	0.001753	0.001719429	0.00177	0.00006
M5CC	0.002257	0.002016	0.002010194	0.00209	0.00014
M5SB	0.001953	0.001736	0.001673141	0.00179	0.00015
M5WB	0.002015	0.001862	0.001751753	0.00188	0.00013
M6CC	0.002161	0.001936	0.001835855	0.00198	0.00017
M6SB	0.001719	0.00158	0.001573141	0.00162	0.00008
M6WB	0.001888	0.001788	0.001588528	0.00175	0.00015

3.9.4 Chloride diffusion coefficient in FSC cubes

The chloride diffusion coefficient was more reduce in FSC concrete cubes as when compared to DCC and PSC concrete cubes for in case of all mixtures type (M1-M6). In fact, the diffusion is more at initial stage rather than at the longer time duration, which depends on pre-conditioning of concrete specimens. In this way the chloride diffusion coefficient was more at initial stage and goes on reduces and that to the chloride diffusion coefficient was still more lesser in magnitude for in case FSC concrete cubes as when compared to DCC and PSC concrete cubes. Thus the mixture proportion, exposure condition, micro-structural properties, slump, w-c ratio, and time duration has its effect on chloride diffusion coefficient in all pre-conditioned concrete cubes. The variation of chloride diffusion coefficient at different drill depths (30-50) mm, with their average chloride diffusion coefficient as well as standard deviation values for different drill depths in fully saturated conditioned concrete cubes (FSC) as represented in Table 3-55

Table 3-55 Variation of chloride diffusion coefficient (mm^2/sec) in FSC concrete cubes

Chloride diffusion coefficient for FSC cubes				Average	Std deviation
CUBE ID	30 mm	40 mm	50 mm	(30-50) mm	(30-50) mm
M1CC	0.001468	0.001412	0.001376136	0.00142	0.00005
M1SB	0.001443	0.00138	0.001361987	0.00140	0.00004
M1WB	0.001445	0.001404	0.001371353	0.00141	0.00004
M2CC	0.001536	0.001469	0.001430841	0.00148	0.00005
M2SB	0.001451	0.001415	0.001394046	0.00142	0.00003
M2WB	0.001509	0.001419	0.001404479	0.00144	0.00006
M3CC	0.001519	0.00148	0.001458627	0.00149	0.00003
M3SB	0.001418	0.001368	0.001381987	0.00139	0.00003
M3WB	0.001459	0.001431	0.00141753	0.00144	0.00002
M4CC	0.001458	0.001394	0.001344787	0.00140	0.00006
M4SB	0.001442	0.001373	0.001331987	0.00138	0.00006
M4WB	0.001453	0.001383	0.001364001	0.00140	0.00005
M5CC	0.001519	0.001429	0.001419429	0.00146	0.00006
M5SB	0.001422	0.001405	0.001364046	0.00140	0.00003
M5WB	0.001418	0.001378	0.001367777	0.00139	0.00003
M6CC	0.001504	0.001459	0.001430841	0.00146	0.00004
M6SB	0.001421	0.001368	0.001361987	0.00138	0.00003
M6WB	0.00143	0.001401	0.001390458	0.00141	0.00002

3.9.5 Interpretation of chloride diffusion coefficient in PCC cubes

In the present research work, Seventy-two concrete cubes of size (100x100x100) mm with six mixtures type (M1-M6) were design. First three set of mixtures type were design as with higher compressive strength (40 N/mm^2) with slump values (0-10, 10-30, and 60-180) mm. Second three set of mixtures type were design as varied compressive strength (25, 30, and 40 N/mm^2) with constant slump value (10-30) mm and pre-conditioned the concrete cube. In order to investigate their effectiveness (10% Nacl solution) on the chloride diffusion coefficient in dry, fully saturated, and partially saturated conditioned concrete cubes with/without impregnation such as solvent based and water based impregnation material.

3.9.6 Chloride diffusion coefficient in pre-dry conditioned concrete cubes

It is observe from the results that the chloride diffusion coefficient was vary at various drill depths (30-40-50) mm in different mixtures type (M1-M6). The variation of chloride diffusion coefficient in DCC control/impregnation concrete cubes at different depths was represent in Table 3-56. The chloride diffusion coefficient was increased at initial drill depth (30 mm), as when compared to higher drill depths (40-50) mm. its varied increased value at drill depth (30 mm) as when compared to drill depth (40 mm). Similarly, the chloride diffusion coefficient was increased drill depth (30 mm) as when compare to drill depth (50 mm). Furthermore, the chloride diffusion coefficient was increase at drill depth (40 mm) as when compare to drill depth (50 mm). For in case of control concrete cubes, the chloride diffusion coefficient was increase as when compared to solvent based and water based impregnation concrete cubes. The chloride diffusion coefficient in DCC concrete cubes was also increase in water based impregnation concrete cubes as when compared to solvent-based impregnation concrete cubes. The chloride diffusion coefficient in DCC concrete cubes was decrease in solvent based and water based impregnation concrete cubes as when compared to control concrete cubes and its varied values at different drill depths (30-50) mm.

Table 3-56 Interpretation of chloride diffusion coefficient (mm^2/sec) in DCC cubes

Variation of chloride diffusion coefficient in DCC cubes						Incr (%)
CUBE ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)	(40-50) mm
M1CC	0.002699	0.002359	12.60	0.0021881	18.92	7.23
M1SB	0.001936	0.001473	23.90	0.00135863	29.82	7.77
M1WB	0.00257	0.002153	16.24	0.00188853	26.53	12.28
M2CC	0.00257	0.00227	11.67	0.00212037	17.51	6.61
M2SB	0.002094	0.001736	17.10	0.00160733	23.23	7.40
M2WB	0.002189	0.001788	18.30	0.00165283	24.48	7.57
M3CC	0.002568	0.001989	22.57	0.00171652	33.16	13.68
M3SB	0.002089	0.001636	21.67	0.00150586	27.90	7.95
M3WB	0.001868	0.001553	16.87	0.00151943	18.66	2.15
M4CC	0.002827	0.002304	18.51	0.00227314	19.59	1.32
M4SB	0.002507	0.001853	26.10	0.00171943	31.42	7.20
M4WB	0.002698	0.002089	22.58	0.00180352	33.14	13.65
M5CC	0.002327	0.001804	22.49	0.00177037	23.91	1.84
M5SB	0.00197	0.001636	16.98	0.00151586	23.07	7.34
M5WB	0.002089	0.001753	16.07	0.00165528	20.74	5.56
M6CC	0.002259	0.001789	20.82	0.00167037	26.05	6.61
M6SB	0.001953	0.001553	20.48	0.00150286	23.04	3.22
M6WB	0.002016	0.001657	17.79	0.00165194	18.05	0.31

Similarly, variation (decrease) of the chloride diffusion coefficient in water based concrete cubes as when compared to control concrete cubes. Finally, the chloride diffusion coefficient was also decrease in solvent-based impregnation concrete cubes as when compared to water based concrete cubes. The comparison of chloride diffusion coefficient in DCC control/impregnation concrete cubes at different drill depths was represent as in Table 3-57.

Table 3-57 Comparison of chloride diffusion coefficient (mm^2/sec) in DCC control/IC cubes

Variation of Chloride diffusion coefficient in DCC control/impregnation concrete cubes															
CUBE ID	30 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	40 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	50 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)
M1CC	0.0026985	0		0	0	0.0023586	0		0		0.00219	0	0		
M1SB	0.0019359	28.26		71.74	0	0.0014731	37.54		62.46		0.00136	37.91	0.00	62.09	
M1WB	0.0025704	4.75	24.69	95.25	75.31	0.0021528	8.72	31.57	91.28	68.43	0.00189	13.69	28.06	86.31	71.94
M2CC	0.0025704	0.00				0.0022704	0.00		0.00		0.00212	0.00			
M2SB	0.0020938	18.54		81.46		0.0017359	23.54		76.46		0.00161	24.20		75.80	
M2WB	0.0021885	14.86	4.33	85.14	95.67	0.0017881	21.24	2.92	78.76	97.08	0.00165	22.05	2.75	77.95	97.25
M3CC	0.002568	0.00				0.0019885	0.00				0.00172	0.00			
M3SB	0.0020885	18.67		81.33		0.0016359	17.74		82.26		0.00151	12.27		87.73	
M3WB	0.001868	27.26	-11.81	72.74	111.81	0.0015528	21.91	-5.35	78.09	105.35	0.00152	11.48	0.89	88.52	99.11
M4CC	0.0028268	0.00	0.00		0.00	0.0023035	0.00	0.00	0.00	0.00	0.00227	0.00	0.00	0.00	0.00
M4SB	0.0025073	11.30	0.00	88.70	0.00	0.0018528	19.57	0.00	80.43	0.00	0.00172	24.36	0.00	75.64	0.00
M4WB	0.0026975	4.57	7.05	95.43	92.95	0.0020885	9.33	11.29	90.67	88.71	0.0018	20.66	4.66	79.34	95.34
M5CC	0.0023268	0.00	0.00	0.00	0.00	0.0018035	0.00	0.00	0.00	0.00	0.00177	0.00	0.00	0.00	0.00
M5SB	0.0019704	15.32	0.00	84.68	0.00	0.0016359	9.30	0.00	90.70	0.00	0.00152	14.38	0.00	85.62	0.00
M5WB	0.0020885	10.24	5.66	89.76	94.34	0.0017528	2.81	6.67	97.19	93.33	0.00166	6.50	8.42	93.50	91.58
M6CC	0.0022589	0.00	0.00	0.00	0.00	0.0017885	0.00	0.00	0.00	0.00	0.00167	0.00	0.00		0.00
M6SB	0.0019528	13.55	0.00	86.45	0.00	0.0015528	13.18	0.00	86.82	0.00	0.0015	10.03	0.00	89.97	0.00
M6WB	0.0020157	10.76	3.12	89.24	96.88	0.001657	7.35	6.29	92.65	93.71	0.00165	1.10	9.02	98.90	90.98

The chloride diffusion coefficient in DCC concrete cubes with their variation of R^2 values in all six mixtures type (M1-M6) were represent in Table 3-58.

Table 3-58 Interpretation of chloride diffusion coefficient equation in DCC concrete cubes

MIX ID	Co-relation Equation	R^2	MIX ID	Co-relation Equation	R^2
M1CC	$Dc = 0.0019x^{-0‘413}$	0.9919	M4CC	$Dc = 0.00123x^{-0‘44}$	0.8509
M1SB	$Dc = 0.0209x^{-0‘705}$	0.9476	M4SB	$Dc = 0.00317x^{-0‘753}$	0.9326
M1WB	$Dc = 0.02x^{-0‘604}$	0.9998	M4WB	$Dc = 0.0397x^{-0‘793}$	0.9932
M2CC	$Dc = 0.0093x^{-0‘379}$	0.9914	M5CC	$Dc = 0.0148x^{-0‘552}$	0.8554
M2SB	$Dc = 0.0123x^{-0‘524}$	0.9733	M5SB	$Dc = 0.0114x^{-0‘52}$	0.9732
M2WB	$Dc = 0.0144x^{-0‘557}$	0.9694	M5WB	$Dc = 0.0099x^{-0‘462}$	0.9557
M3CC	$Dc = 0.0378x^{-0‘793}$	0.9933	M6CC	$Dc = 0.0171x^{-0‘601}$	0.9466
M3SB	$Dc = 0.0187x^{-0‘65}$	0.9586	M6SB	$Dc = 0.0114x^{-0‘526}$	0.8913
M3WB	$Dc = 0.0075x^{-0‘416}$	0.8793	M6WB	$Dc = 0.0078x^{0‘403}$	0.8207

3.9.7 Chloride diffusion coefficient in PSC concrete cubes

It has interpreted from the research work that the chloride diffusion coefficient was vary at various drill depths (30-40-50) mm in different mixtures type (M1-M6). The variation of diffusion coefficient (mm^2/sec) at different drill depths (30-50) mm was interpreted in control, solvent based and water based impregnation concrete cubes as represented in Table 3-59.

Table 3-59 Variation of chloride diffusion coefficient (mm^2/sec) in PSC cubes

Variation of Chloride diffusion coefficient for PSC cubes						Incr (%)
CUBE ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)	(40-50) mm
M1CC	0.00213586	0.0019359	9.36	0.001858627	12.98	3.99
M1SB	0.00161943	0.0015194	6.18	0.001510373	6.73	0.60
M1WB	0.00170552	0.0016881	1.02	0.001635855	4.08	3.09
M2CC	0.00227037	0.0017194	24.27	0.001619429	28.67	5.82
M2SB	0.0015705	0.0015035	4.26	0.001470373	6.38	2.20
M2WB	0.00155383	0.0015359	1.16	0.001552827	0.06	-1.11
M3CC	0.00215885	0.0017073	20.92	0.001688528	21.79	1.10
M3SB	0.00175636	0.0015804	10.02	0.001552827	11.59	1.74
M3WB	0.00165828	0.0016359	1.35	0.001650943	0.44	-0.92
M4CC	0.00231431	0.0021392	7.57	0.001930841	16.57	9.74
M4SB	0.00183586	0.0017704	3.57	0.001665855	9.26	5.90
M4WB	0.00183073	0.0017528	4.26	0.001719429	6.08	1.91
M5CC	0.00225704	0.0020159	10.68	0.002010194	10.94	0.28
M5SB	0.00195283	0.0017359	11.11	0.001673141	14.32	3.61
M5WB	0.00201536	0.0018619	7.61	0.001751753	13.08	5.92
M6CC	0.00216073	0.0019359	10.41	0.001835855	15.04	5.17
M6SB	0.00171943	0.0015804	8.09	0.001573141	8.51	0.46
M6WB	0.0018881	0.0017881	5.30	0.001588528	15.87	11.16

The chloride diffusion coefficient was increased at initial drill depth (30 mm) as when compared to higher drill depths (40-50) mm and its varied increased value at drill depth (30 mm) as when compared to drill depth (40 mm). Similarly, the chloride diffusion coefficient was consider to be increased drill depth (30 mm) as when compared to drill depth (50 mm). Furthermore, the chloride diffusion coefficient was increase at drill depth (40 mm) as when compare to drill depth (50 mm). For in case of control concrete cubes, the chloride diffusion coefficient was increase as when compared to solvent based and water based impregnation concrete cubes. The chloride diffusion coefficient in DCC concrete cubes was also increase in water based impregnation concrete cubes as when compared to solvent-based impregnation concrete cubes. The chloride diffusion coefficient in PSC concrete cubes was decrease in solvent based and water based impregnation concrete cubes as when compared to control concrete cubes. Similarly, the interpreted variation (decrease) of the chloride diffusion coefficient was observe in water based concrete cubes as when compared to control concrete cubes. Finally, the chloride diffusion coefficient was also decrease in solvent-based impregnation concrete cubes as when compared to water based concrete cubes. The comparative study of chloride diffusion coefficient in PSC control/impregnation concrete cubes at different drill depths was represent in Table 3-60.

Table 3-60 Comparative study of chloride diffusion coefficient (mm^2/sec) in PSC cubes

Variation of Chloride diffusion coefficient for PSC cubes															
CUBE ID	30 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	40 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	50 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)
M1CC	0.0021	0				0.001935855					0.00186				
M1SB	0.0016	24.18		75.82		0.001519429	21.51		78.49		0.00151	18.74		81.26	
M1WB	0.0017	20.15	5.05	79.85	95.0	0.001688097	12.80	9.99	87.20	90.01	0.00164	11.99	7.671	88.01	92.33
M2CC	0.0023					0.001719429					0.00162				
M2SB	0.0016	30.83		69.17		0.001503518	12.56		87.44		0.00147	9.20		90.80	
M2WB	0.0016	31.60	-1.14	68.40	101.1	0.001535855	10.68	2.11	89.32	97.89	0.00155	4.11	5.310	95.89	94.69
M3CC	0.0022					0.001707328					0.00169				
M3SB	0.0018	18.64		81.36		0.001580373	7.44		92.56		0.00155	8.04		91.96	
M3WB	0.0017	23.19	-5.91	76.81	105.9	0.001635855	4.19	3.39	95.81	96.61	0.00165	2.23	5.943	97.77	94.06
M4CC	0.0023					0.002139199					0.00193				
M4SB	0.0018	20.67		79.33		0.001770373	17.24		82.76		0.00167	13.72		86.28	
M4WB	0.0018	20.90	-0.28	79.10	100.3	0.001752827	18.06	-1.00	81.94	101.00	0.00172	10.95	3.116	89.05	96.88
M5CC	0.0023					0.002015885					0.00201				
M5SB	0.002	13.48		86.52		0.001735855	13.89		86.11		0.00167	16.77		83.23	
M5WB	0.002	10.71	3.10	89.29	96.9	0.001861943	7.64	6.77	92.36	93.23	0.00175	12.86	4.488	87.14	95.51
M6CC	0.0022					0.001935855					0.00184				
M6SB	0.0017	20.42		79.58		0.001580352	18.36		81.64		0.00157	14.31		85.69	
M6WB	0.0019	12.62	8.93	87.38	91.1	0.001788097	7.63	11.62	92.37	88.38	0.00159	13.47	0.969	86.53	99.03

The chloride diffusion coefficient in PSC concrete cubes with their variation of R^2 values in all six mixtures type were represent in Table 3-61.

Table 3-61 Interpretation of chloride diffusion coefficient equation in PSC concrete cubes

MIX ID	Co-rrelation Equation	R^2	MIX ID	Co-rrelation Equation	R^2
M1CC	Dc = 0.0054$x^{-0‘275}$	0.974	M4CC	Dc = 0.007$x^{-0‘351}$	0.9781
M1SB	Dc = 0.0026$x^{-0‘14}$	0.867	M4SB	Dc = 0.0035$x^{-0‘187}$	0.9534
M1WB	Dc = 0.0022$x^{-0‘079}$	0.8773	M4WB	Dc = 0.0028$x^{-0‘124}$	0.9786
M2CC	Dc = 0.0022$x^{-0‘676}$	0.9216	M5CC	Dc = 0.0049$x^{-0‘235}$	0.8267
M2SB	Dc = 0.0024$x^{-0‘13}$	0.9876	M5SB	Dc = 0.0055$x^{-0‘308}$	0.952
M2WB	Dc = 0.0016$x^{-0‘002}$	0.0053	M5WB	Dc = 0.0051$x^{-0‘274}$	1.000
M3CC	Dc = 0.0114$x^{-0‘497}$	0.8405	M6CC	Dc = 0.0064$x^{-0‘322}$	0.9842
M3SB	Dc = 0.004$x^{-0‘247}$	0.902	M6SB	Dc = 0.0031$x^{-0‘18}$	0.8447
M3WB	Dc = 0.0017$x^{-0‘011}$	0.1501	M6WB	Dc = 0.0059$x^{-0‘331}$	0.9219

3.9.8 Chloride diffusion coefficient in pre-fully saturated concrete cubes

It has interpreted from the research work that the chloride diffusion coefficient was vary at various drill depths (30-40-50) mm in different mixtures type (M1-M6). Its varied average diffusion coefficient (mm^2/sec) and standard deviation from different drill depths (30-50) mm was represent in control, solvent based and water based impregnation concrete cubes. The variation of chloride diffusion coefficient in FSC control/impregnation concrete cubes at different drill depths is as shown in Table 3-62.

Table 3-62 Variation of chloride diffusion coefficient (mm^2/sec) in FSC cubes

Variation of Chloride diffusion coefficient for FSC cubes						Incr (%)
CUBE ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)	(40-50) mm
M1CC	0.001468	0.00141	3.77	0.00138	6.23	2.55
M1SB	0.001443	0.00138	4.37	0.00136	5.62	1.31
M1WB	0.001445	0.0014	2.84	0.00137	5.07	2.29
M2CC	0.001536	0.00147	4.38	0.00143	6.84	2.57
M2SB	0.001451	0.00141	2.50	0.00139	3.91	1.45
M2WB	0.001509	0.00142	5.96	0.0014	6.90	1.00
M3CC	0.001519	0.00148	2.57	0.00146	4.00	1.47
M3SB	0.001418	0.00137	3.51	0.00138	2.51	-1.04
M3WB	0.001459	0.00143	1.90	0.00142	2.82	0.93
M4CC	0.001458	0.00139	4.36	0.00134	7.74	3.53
M4SB	0.001442	0.00137	4.78	0.00133	7.63	2.99
M4WB	0.001453	0.00138	4.80	0.00136	6.11	1.38
M5CC	0.001519	0.00143	5.92	0.00142	6.58	0.70
M5SB	0.001422	0.0014	1.22	0.00136	4.07	2.89
M5WB	0.001418	0.00138	2.80	0.00137	3.51	0.73
M6CC	0.001504	0.00146	2.99	0.00143	4.83	1.90
M6SB	0.001421	0.00137	3.73	0.00136	4.14	0.42
M6WB	0.00143	0.0014	2.05	0.00139	2.77	0.74

The chloride diffusion coefficient was increased at initial drill depth (30 mm) as when compared to higher drill depths (40-50) mm and its varied increased value at drill depth (30 mm) as when compared to drill depth (40 mm). Similarly, the chloride diffusion coefficient was to be increase at drill depth (30 mm) as when compared to drill depth (50 mm). Furthermore, the chloride diffusion coefficient was increase at drill depth (40 mm) as when compare to drill depth (50 mm). For in case of control concrete cubes, the chloride diffusion coefficient was increase as when compared to solvent based and water based impregnation concrete cubes. The interpretation of chloride diffusion coefficient in FSC control/impregnation concrete cubes at different drill depths was represent as in Table 3-63.

Table 3-63 Chloride diffusion coefficient (mm^2/sec) in FSC cubes at different drill depths

Variation of Chloride diffusion coefficient for FSC cubes															
CUBE ID	30 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	40 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)	50 mm	Incr (%)	Incr (%)	Decr (%)	Decr (%)
M1CC	0.001468					0.00141					0.00138				
M1SB	0.001443	1.66		98.34		0.00138	2.27		97.73		0.00136	1.03		98.97	
M1WB	0.001445	1.57	0.10	98.43	99.90	0.00140	0.61	1.67	99.39	98.33	0.00137	0.35	0.68	99.65	99.32
M2CC	0.001536					0.00147					0.00143				
M2SB	0.001451	5.54		94.46		0.00141	3.68		96.32		0.00139	2.57		97.43	
M2WB	0.001509	1.78	3.82	98.22	96.18	0.00142	3.40	0.29	96.60	99.71	0.00140	1.84	0.74	98.16	99.26
M3CC	0.001519					0.00148					0.00146				
M3SB	0.001418	6.71		93.29		0.00137	7.60		92.40		0.00138	5.25		94.75	
M3WB	0.001459	4.00	2.82	96.00	97.18	0.00143	3.34	4.41	96.66	96.66	0.00142	2.82	2.51	97.18	97.49
M4CC	0.001458					0.00139					0.00134				
M4SB	0.001442	1.07		98.93		0.00137	1.50		98.50		0.00133	0.95		99.05	
M4WB	0.001453	0.32	0.74	99.68	99.26	0.00138	0.79	0.72	99.21	99.28	0.00136	-1.43	2.35	101.43	97.65
M5CC	0.001519					0.00143					0.00142				
M5SB	0.001422	6.41		93.59		0.00140	1.74		98.26		0.00136	3.90		96.10	
M5WB	0.001418	6.71	-0.31	93.29	100.31	0.00138	3.61	-1.95	96.39	101.95	0.00137	3.64	0.27	96.36	99.73
M6CC	0.001504					0.00146					0.00143				
M6SB	0.001421	5.50		94.50		0.00137	6.23		93.77		0.00136	4.81		95.19	
M6WB	0.00143	4.88	0.65	95.12	99.35	0.00140	3.96	2.36	96.04	97.6397	0.00139	2.82	2.05	97.18	97.95

The chloride diffusion coefficient in FSC concrete cubes was also increase in water based impregnation concrete cubes as when compared to solvent-based impregnation concrete cubes and its varied values at different drill depths (30-50) mm. The chloride diffusion coefficient in FSC concrete cubes was decrease in solvent based and water based impregnation concrete cubes as when compared to control concrete cubes and its varied values at different drill depths (30-50) mm. Similarly, the interpreted variation (decrease) of the chloride diffusion coefficient was observe in water based concrete cubes as when compared to control concrete cubes. Finally, the chloride diffusion coefficient was also decrease in solvent-based impregnation concrete cubes as when compared to water based concrete cubes. The chloride diffusion coefficient in FSC concrete cubes with their variation of R^2 values in all six mixtures type were represent in Table 3-64.

Table 3-64 Interpretation of chloride diffusion coefficient equation in FSC concrete cubes

MIX ID	Co-rrelation Equation	R^2	MIX ID	Co-rrelation Equation	R^2
M1CC	$Dc = 0.0023x^{-0‘126}$	0.9984	M4CC	$Dc = 0.0025x^{-0‘157}$	0.9999
M1SB	$Dc = 0.0021x^{-0‘115}$	0.9474	M4SB	$Dc = 0.0024x^{-0‘156}$	0.9962
M1WB	$Dc = 0.002x^{-0‘102}$	0.9989	M4WB	$Dc = 0.0022x^{-0‘126}$	0.9435
M2CC	$Dc = 0.0025x^{-0‘139}$	0.9939	M5CC	$Dc = 0.0024x^{-0‘137}$	0.8779
M2SB	$Dc = 0.0019x^{-0‘079}$	0.9934	M5SB	$Dc = 0.0019x^{-0‘08}$	0.9103

M2WB	$Dc = 0.0024x^{-0\text{‘}143}$	0.9005	M5WB	$Dc = 0.0018x^{-0\text{‘}071}$	0.9356
M3CC	$Dc = 0.002x^{-0\text{‘}08}$	0.9928	M6CC	$Dc = 0.0021x^{-0\text{‘}097}$	0.9969
M3SB	$Dc = 0.0017x^{-0\text{‘}053}$	0.5496	M6SB	$Dc = 0.0019x^{-0\text{‘}085}$	0.8762
M3WB	$Dc = 0.0018x^{-0\text{‘}056}$	0.9846	M6WB	$Dc = 0.0017x^{-0\text{‘}056}$	0.9633

3.9.9 Summary

- The corrosion of steel reinforcement is primarily control by the diffusion of chlorides. An effect of hydraulic pressure and capillary sorption is not considered in the model described as in most cases it can be ignored. Diffusion is thus the most common way in which, chloride ions ingress into the reinforced concrete bridge decks, and diffusion occurs because of concentration gradients.

- Thus in the present research work, an extensive research was carried out to evaluate the effectiveness of chloride diffusion coefficient in different exposure conditions for long-term duration. The chloride diffusion coefficient could be increase in DCC control cubes as when compare to PSC, and FSC cubes with varied slump and constant compressive strength as well as the chloride diffusion coefficient could be increase for in case of PSC concrete cubes as when compared to FSC.

- The chloride diffusion coefficient could be increase in DCC control concrete cubes as when compare to PSC (SB) and FSC (SB) with varied compressive strength and constant slump value and the chloride diffusion coefficient in PSC control concrete cubes could be increase as when compared to FSC (SB) with varied slump and constant compressive strength.

- In addition to that, the chloride diffusion coefficient could be increase in DCC control concrete cubes as when compared to PSC (WB) and FSC (WB) with varied slump and constant compressive strength. Whereas the chloride concentration in PSC control concrete cubes found to be increased as when compared to FSC (WB) in the first set of mixtures type.

- The chloride diffusion coefficient could be increase in DCC control cubes as when compare to PSC, and FSC with varied compressive strength and constant slump value as well as the chloride diffusion coefficient in control concrete cubes could be increase for in case of PSC concrete cubes as when compared to FSC.

- The chloride diffusion coefficient could be increase in dry conditioned control concrete cubes DCC as when compared to PSC (SB), and FSC (SB) varied compressive strength and constant slump value and the chloride diffusion coefficient in PSC control concrete cubes could be increase as when compared to FSC (SB).

- In addition to that, the chloride diffusion coefficient were increase in dry conditioned control concrete cubes DCC as when compared to PSC (WB) and FSC (WB) with varied compressive strength and constant slump value. Whereas the chloride concentration in PSC control concrete cubes found to be increased as when compared to FSC (WB) with varied compressive strength and constant slump.

3.10 Chloride diffusion coefficient in concrete slabs

3.10.1 Chloride diffusion coefficient in pre-conditioned concrete slabs

The focus of this research work was to interpret the effects of wetting and drying pre-conditioned concrete slabs on chloride diffusion coefficient, which was exposed to different pre-determined conditions such as dry/fully saturated/partially saturated condition was evaluated in control/impregnation concrete slabs for about 160 days in all designed six mixtures type (M1-M6). In which first three set of mixtures type (M1-M3) was designed as higher compressive strength (40 N/mm^2) with varied slump value (0-10, 10-30, and 60-180) mm and second set of mixtures type (M4-M6) was designed as varied compressive strength (25, 30, and 40 N/mm^2) with same slump value (10-30) mm respectively.

3.10.2 Chloride diffusion coefficient in pre-dry conditioned concrete slabs

The chloride diffusion coefficient was increase in dry conditioned concrete slabs in all control concrete slabs as when compared to solvent and water based impregnation concrete slabs for in case of all mixtures type (M1-M2). In fact, the chloride diffusion coefficient was slightly higher in control concrete slabs with lower compressive strength and constant slump value as when compared to solvent based as well as water based impregnation concrete slabs, in turn chloride diffusion coefficient goes on reduces with increased compressive strength for in case of mixtures type (M2). The varied average chloride diffusion coefficient values from different drill depths (30-50) mm are represented as M1CC (0.0023%), M1SB (0.0021%), M1WB (0.0022%), M2CC (0.0021%), M2SB (0.0019%), and M2WB (0.0020%) respectively. The chloride diffusion coefficient was found to be more at lesser drill depth (30 mm) and it goes on reduces as drill depth increases in turn it depends on concrete matrix and mix proportioning, concrete compressive strength, slump, w-c ratio, temperature as well as pore structure formation. The variation of chloride diffusion coefficient at different drill depths (30-50) mm, with their average chloride diffusion coefficient as well as standard deviation values for different drill depths in dry conditioned concrete slabs (DCC) as represented in Table 3-65.

Table 3-65 Variation of chloride diffusion coefficient in DCC concrete slabs

Chloride diffusion coefficient in DCC concrete Slabs					
Mixture type [M1=M2]					
Slab ID	30 mm	40 mm	50 mm	Average	STD
M1CS	0.002600	0.00223	0.00218	0.0023	0.00023
M1SB	0.002326	0.00211	0.00208	0.0022	0.00013
M1WB	0.002412	0.00216	0.00214	0.0022	0.00015
M2CS	0.002291	0.00210	0.00202	0.0021	0.00014
M2SB	0.002147	0.00195	0.00189	0.0020	0.00013
M2WB	0.002208	0.00198	0.00195	0.0020	0.00014

3.10.3 Chloride diffusion coefficient in PSC concrete slabs

The chloride diffusion coefficient was increase in partially saturated conditioned concrete slabs in all control concrete slabs as when compared to solvent and water based impregnation concrete slabs for in case of all mixtures type (M3-M5). In fact, the chloride diffusion coefficient was slightly higher in control concrete slabs with lower compressive strength and constant slump value as when compared to solvent based as well as water based impregnation concrete slabs, in turn chloride diffusion coefficient goes on reduces with increased compressive strength for in case of mixtures type (M5). The chloride diffusion coefficient was found to be more at lesser drill depth (30 mm) and it goes on reduces as drill depth increases in turn it depends on concrete matrix and mix proportioning, concrete compressive strength, slump, w-c ratio, temperature as well as pore structure formation. The variation of chloride diffusion coefficient at different drill depths (30-50) mm, with their average chloride diffusion coefficient as well as standard deviation values for different drill depths in partially saturated conditioned concrete slabs (PSC) as represented in Table 3-66.

Table 3-66 Variation of chloride diffusion coefficient (mm^2/sec) in PSC concrete slabs

Chloride diffusion coefficient in PSC concrete Slabs					
Mixture type [M3=M5]					
Slab ID	30 mm	40 mm	50 mm	Average	STD
M3CS	0.002191	0.00200	0.00191	0.00203	0.00014
M3SB	0.002079	0.00192	0.00182	0.00194	0.00013
M3WB	0.002144	0.00195	0.00191	0.00200	0.00013
M5CS	0.002105	0.00193	0.00184	0.00196	0.00013
M5SB	0.001934	0.00180	0.00183	0.00185	0.00007
M5WB	0.001969	0.00184	0.00190	0.00190	0.00006

3.10.4 Chloride diffusion coefficient in FSC concrete slabs

The chloride diffusion coefficient was increase in fully saturated conditioned concrete slabs in all control concrete cubes as when compared to solvent and water based impregnation concrete slabs for in case of all mixtures type (M4-M6). In fact, the chloride diffusion coefficient was slightly higher in control concrete slabs with lower compressive strength and constant slump value as when compared to solvent based as well as water based impregnation concrete slabs, in turn chloride diffusion coefficient goes on reduces with increased compressive strength for in case of mixtures type (M6). Similarly, the chloride diffusion coefficient was reduce as when compared to DCC and PSC concrete slabs for in case of both control, solvent based as well as water based impregnation concrete slabs. In observed from results that, the chloride diffusion coefficient was reduce as when compared to DCC and PSC concrete slabs. It's may be due to moisture content, concrete matrix and mix proportioning, concrete compressive strength, slump, w-c ratio, temperature as well as pore structure formation. The variation of chloride diffusion coefficient at different drill depths (30-50) mm, with their average chloride diffusion coefficient as well as standard deviation values for different drill depths in fully saturated conditioned concrete slabs (FSC) as represented in Table 3-67.

Table 3-67 Variation of chloride diffusion coefficient (mm^2/sec) in FSC concrete slabs

Chloride diffusion coefficient in FSC concrete Slabs					
Mixture type [M4=M6]					
Slab ID	30 mm	40 mm	50 mm	Average	STD
M4CS	0.002199	0.00203	0.00198	0.00207	0.00011
M4SB	0.002104	0.00171	0.00162	0.00181	0.00026
M4WB	0.002019	0.00180	0.00172	0.00185	0.00015
M6CS	0.002161	0.00190	0.00182	0.00196	0.00018
M6SB	0.001890	0.00174	0.00162	0.00175	0.00014
M6WB	0.001896	0.00177	0.00172	0.00180	0.00009

3.10.5 Evaluation of chloride diffusion coefficient in PCC slabs

In the present research work, eighteen concrete slabs of size (450x450x100) mm with six mixtures type (M1-M6) were design. First three set of mixtures type were design as with higher compressive strength (40 N/mm^2) with slump values (0-10, 10-30, and 60-180) mm. Second three set of mixtures type were design as varied compressive strength (25, 30, and 40 N/mm^2) with constant slump value (10-30) mm. Pre-conditioned the concrete slabs in order to investigate their effectiveness (10% Nacl solution) on the chloride diffusion coefficient in dry, fully saturated, and partially saturated conditioned concrete slabs with/without impregnation such as solvent based and water based impregnation material.

3.10.6 Chloride diffusion coefficient in pre-dry conditioned concrete slabs

It is confirm from the results that the chloride diffusion coefficient was vary at various drill depths (30-40-50) mm in different mixtures type (M1-M2). The chloride diffusion coefficient was increased at initial drill depth (30 mm) as when compared to higher drill depths (40-50) mm and its varied increased value at drill depth (30 mm) as when compared to drill depth (40 mm). Similarly, the chloride diffusion coefficient was observe to be increase at drill depth (30 mm) as when compared to drill depth (50 mm). Furthermore, the chloride diffusion coefficient was increase at drill depth (40 mm) as when compare to drill depth (50 mm). The comparative study of chloride diffusion coefficient in DCC control/impregnation concrete slabs at different drill depths is as shown in Table 3-68.

Table 3-68 Determination of chloride diffusion coefficient (mm^2/sec) in DCC slabs

Variation of chloride diffusion coefficient in DCC concrete Slabs						
Mixture type [M1=M2]			(30-40) mm		(30-50) mm	(40-50) mm
Slab ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)	Incr (%)
M1CS	0.002600	0.00223	14.23	0.00218	16.15	2.24
M1SB	0.002326	0.00211	9.29	0.00208	10.58	1.42
M1WB	0.002412	0.00216	10.45	0.00214	11.28	0.93
M2CS	0.002291	0.00210	8.34	0.00202	11.83	3.81
M2SB	0.002147	0.00195	9.18	0.00189	11.97	3.08
M2WB	0.002208	0.00198	10.33	0.00195	11.68	1.52

For in case of control concrete slabs, the chloride diffusion coefficient was increase as when compared to solvent based and water based impregnation concrete slabs. The chloride diffusion coefficient in DCC concrete slabs was also increase in water based impregnation concrete slabs as when compared to solvent-based impregnation concrete slabs. The chloride diffusion coefficient in DCC concrete slabs was decrease in solvent/water based impregnation concrete slabs as when compared to control concrete cubes and it has varied at different drill depths (30-50) mm. Finally, the chloride diffusion coefficient was also decrease in solvent-based impregnation concrete slabs as when compared to water based concrete slabs. The variation of chloride diffusion coefficient in DCC control/impregnation concrete slabs at different drill depths was represent in Table 3-69.

Table 3-69 Determination of chloride diffusion coefficient in (mm^2/sec) DCC slabs

Chloride diffusion coefficient in DCC concrete Slabs					
Mixture type [M1=M2]					
Slab ID	30 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M1CS	0.0026				
M1SB	0.0023	10.54		89.46	
M1WB	0.0024	7.24	3.56	92.76	96.44
M2CS	0.0023				
M2SB	0.0021	6.29		93.71	
M2WB	0.0022	3.62	2.76	96.38	97.24
Slab ID	40 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M1CS	0.0022				
M1SB	0.0021	5.32		94.68	
M1WB	0.0022	3.34	2.04	96.66	97.96
M2CS	0.0021				
M2SB	0.0020	7.10		92.90	
M2WB	0.0020	5.71	1.47	94.29	98.53
Slab ID	50 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M1CS	0.0022				
M1SB	0.0021	4.40		95.60	
M1WB	0.0021	1.67	2.78	98.33	97.22
M2CS	0.0020				
M2SB	0.0019	6.40		93.60	
M2WB	0.0020	3.35	3.15	96.65	96.85

The chloride diffusion coefficient in DCC concrete slabs with their variation of R² values in all six mixtures type were represent in Table 3-70.

Table 3-70 Interpretation of chloride diffusion coefficient equation in DCC concrete slabs

MIX ID	Co-rrelation Equation	R^2
M1CC	$Dc = 0.0086x^{-0'356}$	0.9026
M1SB	$Dc = 0.0049x^{-0'223}$	0.9019
M1WB	$Dc = 0.0054x^{-0'241}$	0.8568
M2CC	$Dc = 0.0053x^{-0'25}$	0.9808
M2SB	$Dc = 0.0050x^{-0'253}$	0.9580
M2WB	$Dc = 0.0051x^{-0'248}$	0.8886

3.10.7 Chloride diffusion coefficient in PSC concrete slabs

It has interpreted from the results that, the chloride diffusion coefficient was vary at various drill depths (30-40-50) mm in different mixtures type (M3-M5). Its varied average diffusion coefficient (mm^2/sec) and standard deviation from different drill depths (30-50) mm. The chloride diffusion coefficient was increased at initial drill depth (30 mm) as when compared to higher drill depths (40-50) mm and its varied increased value at drill depth (30 mm) as when compared to drill depth (40 mm). Similarly, the chloride diffusion coefficient was to be increase at drill depth (30 mm) as when compared to drill depth (50 mm). Furthermore, the chloride diffusion coefficient was increase at drill depth (40 mm) as when compare to drill depth (50 mm). The interpretation of chloride diffusion coefficient in PSC control/impregnation concrete slabs at different drill depths as represented in Table 3-71.

Table 3-71 Estimation of chloride diffusion coefficient (mm^2/sec) in PSC slabs

Variation of Chloride diffusion coefficient in PSC concrete Slabs						
Mixture type [M3=M5]			(30-40) mm		(30-50) mm	(40-50) mm
Slab ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)	Incr (%)
M3CS	0.0022	0.0020	8.72	0.00191	12.83	4.50
M3SB	0.0021	0.0019	7.65	0.00182	12.46	5.21
M3WB	0.0021	0.0020	9.05	0.00191	10.91	2.05
M5CS	0.0021	0.0019	8.31	0.00184	12.59	4.66
M5SB	0.0019	0.0018	6.93	0.00183	5.38	-1.67
M5WB	0.0020	0.0018	6.55	0.00190	3.50	-3.26

For in case of control concrete slabs, the chloride diffusion coefficient was increase as when compared to solvent based and water based impregnation concrete slabs and its varied values at different drill depths (30-40-50) mm. The chloride diffusion coefficient in PSC concrete slabs was also increase in water based impregnation concrete slabs as when compared to solvent-based impregnation concrete slabs and its varied values at different drill depths (30-50) mm. The chloride diffusion coefficient in PSC concrete slabs was decrease in solvent based and water based impregnation concrete slabs as when compared to control concrete slabs. It is vary at different drill depths (30-50) mm. Finally, the chloride diffusion coefficient was also decrease in solvent-based impregnation concrete slabs as when compared to water based concrete cubes and its varied values. The comparative study of chloride diffusion coefficient in PSC control/impregnation concrete slabs at different drill depths as shown in Table 3-72.

Table 3-72 Variation of chloride diffusion coefficient (mm^2/sec) in PSC slabs

Chloride diffusion coefficient in PSC concrete Slabs					
Mixture type [M3=M5]					
Slab ID	30 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M3CS	0.0022				
M3SB	0.0021	5.14		94.86	
M3WB	0.0021	2.18	3.03	97.82	96.97
M5CS	0.0021				
M5SB	0.0019	8.09		91.91	
M5WB	0.0020	6.47	1.74	93.53	98.26
Slab ID	40 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M3CS	0.0020				
M3SB	0.0019	4.14		95.86	
M3WB	0.0020	2.67	1.52	97.33	98.48
M5CS	0.0019				
M5SB	0.0018	6.39		93.61	
M5WB	0.0018	4.42	2.06	95.58	97.94
Slab ID	50 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M3CS	0.00191				
M3SB	0.00182	4.58		95.42	
M3WB	0.00191	0.09	4.66	100.09	95.34
M5CS	0.00184				
M5SB	0.00183	0.51		99.49	
M5WB	0.00190	-3.30	3.69	103.3	96.31

The chloride diffusion coefficient in PSC concrete slabs with their variation of R^2 values in all six mixtures type were represent in Table 3-73.

Table 3-73 Interpretation of chloride diffusion coefficient equation in PSC concrete slabs

MIX ID	Co-relation Equation	R^2
M3CC	$Dc = 0.0055x^{-0'271}$	0.991
M3SB	$Dc = 0.0050x^{-0'259}$	0.9986
M3WB	$Dc = 0.0046x^{-0'23}$	0.9235
M5CC	$Dc = 0.0051x^{-0'264}$	0.9873
M5SB	$Dc = 0.0028x^{-0'113}$	0.6191
M5WB	$Dc = 0.0025x^{-0'075}$	0.3313

3.10.8 Chloride diffusion coefficient in FSC concrete slabs

It has analysed from the results that, the chloride diffusion coefficient was vary at various drill depths (30-40-50) mm in different mixtures type (M4-M6). The chloride diffusion coefficient was increased at initial drill depth (30 mm) as when compared to higher drill depths (40-50) mm and its varied increased value at drill depth (30 mm) as when compared to drill depth (40 mm). Similarly, the chloride diffusion coefficient was to be increase at drill depth (30 mm) as when compared to drill depth (50 mm). The estimation of chloride diffusion coefficient in FSC control/impregnation concrete slabs at different drill depths was represent in Table 3-74.

Table 3-74 Estimation of chloride diffusion coefficient (mm^2/sec) in FSC slabs

Determination of Chloride diffusion coefficient in FSC concrete Slabs						
Mixture type [M4=M6]			(30-40) mm		(30-50) mm	(40-50) mm
Slab ID	30 mm	40 mm	Incr (%)	50 mm	Incr (%)	Incr (%)
M4CS	0.0022	0.00203	7.69	0.00198	9.96	2.46
M4SB	0.0021	0.00171	18.73	0.00162	23.00	5.26
M4WB	0.0020	0.0018	10.85	0.00172	14.81	4.44
M6CS	0.0022	0.0019	12.08	0.00182	15.78	4.21
M6SB	0.0019	0.00174	7.94	0.00162	14.29	6.90
M6WB	0.0019	0.00177	6.65	0.00172	9.28	2.82

Furthermore, the chloride diffusion coefficient was increase at drill depth (40 mm) as when compare to drill depth (50 mm). For in case of control concrete slabs, the chloride diffusion coefficient was increase as when compared to solvent/water based impregnation concrete slabs and it is vary at different drill depths (30-40-50) mm. The chloride diffusion coefficient in FSC concrete slabs was also increase in water based impregnation concrete slabs as when compared to solvent-based impregnation concrete slabs and it has varied at different drill depths (30-50) mm. The variation of chloride diffusion coefficient in FSC control/impregnation concrete slabs at different drill depths is as shown in Table 3-75.

Table 3-75 Variation of chloride diffusion coefficient (mm^2/sec) in FSC slabs

Chloride diffusion coefficient in FSC concrete Slabs					
	Mixture type [M4=M6]				
Slab ID	30 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M4CS	0.0022				
M4SB	0.0021	4.32		95.68	
M4WB	0.0020	8.20	-4.23	91.80	104.23
M6CS	0.0022				
M6SB	0.0019	12.51		87.49	
M6WB	0.0019	12.23	0.32	87.77	99.68
Slab ID	40 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M4CS	0.0020				
M4SB	0.0017	15.64		84.36	
M4WB	0.0018	11.07	5.14	88.93	94.86
M6CS	0.0019				
M6SB	0.0017	8.84		91.16	
M6WB	0.0018	6.88	2.11	93.12	97.89
Slab ID	50 mm	Incr (%)	Incr (%)	Dec (%)	Dec (%)
M4CS	0.00198				
M4SB	0.00162	18.14		81.86	
M4WB	0.00172	13.23	5.66	86.77	94.34
M6CS	0.00182				
M6SB	0.00162	11.00		89.00	
M6WB	0.00172	5.46	5.86	94.54	94.14

The chloride diffusion coefficient in FSC concrete slabs was decrease in solvent based and water based impregnation concrete slabs as when compared to control concrete slabs and its varied values at different drill depths (30-50) mm. Finally, the chloride diffusion coefficient was also decrease in solvent-based impregnation concrete slabs as when compared to water based concrete slabs. The interpretation of chloride diffusion coefficient in FSC concrete slabs with their variation of R² values in all six mixtures type were represent in Table 3-76.

Table 3-76 Interpretation of chloride diffusion coefficient equation in FSC concrete slabs

MIX ID	Co-relation Equation	R²
M4CC	$Dc = 0.0044x^{-0'207}$	0.9385
M4SB	$Dc = 0.012x^{-0'518}$	0.9334
M4WB	$Dc = 0.0059x^{-0'317}$	0.9730
M6CC	$Dc = 0.0068x^{-0'340}$	0.9628
M6SB	$Dc = 0.0053x^{-0'302}$	0.9998
M6WB	$Dc = 0.0036x^{-0'192}$	0.9793

3.10.9 Summary

- The concrete exposed to various environmental conditions can be penetrate by many aggressive ions. Chloride ions affect the durability of concrete subjected to the action of seawater, chloride-bearing air in marine areas and de-icing salts. The penetration of chloride ions can cause corrosion of concrete and rebar is embed in concrete. Thus in the present study, evaluate an effectiveness of chloride diffusion coefficient in concrete slabs under different exposure conditions for long-term duration wit/without impregnation.

- The chloride diffusion coefficient could be increase in DCC concrete slabs as when compared to PSC, and FSC concrete slabs. Similarly, the chloride diffusion coefficient in control concrete slabs could be increase for in case of PSC concrete slabs as when compared to FSC. The chloride diffusion coefficient could be increase in DCC concrete slabs as when compared to PSC (SB), and FSC (SB).

- In addition, the chloride diffusion coefficient in PSC control concrete slabs could be increase as when compared to FSC (SB). In addition to that, the chloride diffusion coefficient could be increase in DCC control concrete slabs as when compared to PSC (WB), and FSC (WB). Whereas the chloride concentration in PSC control concrete, slabs found to be increased as when compared to FSC (WB).

- Chloride concentration (average) from different drill depths could be increase in DCC control concrete slabs with higher compressive strength and varied slump value as when compare to control PSC, and FSC concrete cubes.

- An average chloride concentration from drill depths in DCC solvent-based impregnation/water based impregnation concrete slabs with higher compressive strength and varied slump value could be increase as when compared to solvent-based impregnation DCC/PSC/FSC concrete cubes and goes on reduces with higher compressive strength and constant slump value.

- Chloride concentration (average) from drill depths in DCC (SB) impregnation concrete cubes was more decreased as when compared to PSC/FSC water based impregnation concrete cubes with higher compressive strength and varied slump value.

- In addition to that, an average chloride concentration in PSC (SB) impregnation/water based impregnation concrete cubes was lesser decreased as when compared to FSC solvent based impregnation/water based impregnation with higher compressive strength and varied slump value.

- The chloride diffusion coefficient (average) in DCC control concrete slabs were decreased at different drill depths for in case of designed mixture type as when compared to PSC/FSC control concrete cubes average chloride diffusion coefficient.

- The average chloride diffusion coefficient in DCC (SB) impregnation concrete slabs were increased at different drill depths for in case of designed mixture type as when compared to PSC/FSC solvent based impregnation concrete cubes average chloride diffusion coefficient.

- In fact, chloride diffusion coefficient (average) in DCC (WB) impregnation concrete slabs were predominantly lesser increased at different drill depths for in case of designed mixture type as when compared to PSC/FSC water based impregnation concrete cubes average chloride diffusion coefficient.

- Furthermore, chloride diffusion coefficient (average) in DCC (SB) impregnation concrete cubes were predominantly decreased at different drill depths for in case of designed mixture type as when compared to PSC/FSC water based impregnation concrete cubes average chloride diffusion coefficient.

3.11 SPT on concrete cubes with differential moisture content

3.11.1 Pre-conditioning of concrete cubes with differential moisture contents

The chloride penetration and moisture diffusion are two important transport processes for studying the long-term durability of concrete. The chloride penetration and moisture transfer in concrete are consider as two coupled transport processes. The interaction between moisture diffusion and chloride penetration in concrete affects the durability of reinforced concrete structures. The corrosion of the reinforcement in concrete takes place when the chloride content of concrete near steel bar has reached a threshold value and the moisture content in concrete is sufficiently high.

Therefore, moisture and chloride ions are two necessary condition for the onset of corrosion of rebar in concrete. The diffusion of chloride and moisture in concrete can be study for two different situations such as fully and partially saturated condition. In fist instance, the concrete is fully saturated and dominant mechanisms for both chloride diffusion and moisture diffusion is the concentration gradient of chloride. In turn, the chloride concentration gradient drives not only the chloride penetration but also the moisture movement in the concrete. In another instance, the concrete is partially saturated, and the moisture concentration gradient (in addition to the chloride concentration gradient) results in the moisture penetration as well as the chloride diffusion. In this case, both concentration gradients are driving forces.

Thus in the present research work salt ponding test (SPT) was carried out for chloride solution absorption on pre-conditioned concrete cubes (100x100x100) mm such as dry/fully/partially saturated condition concrete cubes in order to evaluate an effectiveness of two impregnation materials namely solvent based and water based impregnation material respectively. In turn to interpret an effectiveness of impregnation concrete cubes with control cubes for six mixtures type under pre-conditioned concrete cubes with constant compressive strength, and varied slump in one case as well as varied compressive strength with constant slump in second case.

3.11.2 Pre-conditioned dry concrete cubes (Mc =0%)

The chloride absorption test is carry out on concrete cubes of size (100x100x100) mm, and tested as per code BS 1881-122. They were water cured before subjected to the test, at 160 days. Before testing, the concrete specimens were oven dried to constant mass at 105±5^{0}C for 72±2 hours and then stored in airtight containers before subjected to testing. The concrete specimens are weighing before immersion and after immersion for specified time duration. For chloride absorption test, totally 18 concrete cubes was casted, out of which 6 control concrete cubes, 6 solvent based concrete cubes, and 6 water based concrete cubes. The chloride absorption test was carry out with 10% sodium chloride solution for about 160 days.

The chloride absorption in case of mixtures type (M1-M3) was vary in between (0.12-0.13%) at 31th day. In case of mixtures type (M4-M6), the variation of chloride absorption was vary in between (0.11-0.12%). Similarly, the chloride absorption was goes on increase with time duration and finally it reaches with chloride absorption in the ranges between (2.13-2.43%) in the case of mixtures type (M1-M3). Whereas in case of mixtures type (M4-M6), it is varied in between (1.8-1.95%). The chloride absorption in dry conditioned concrete cubes was immerse in 10% chloride solution with one face exposed to chloride solution as shown in Figure 3-12.

Figure 3-12 Chloride solution absorption in DCC concrete cubes

The chloride absorption was varied in solvent based impregnation concrete cubes in the range between (0.1-0.103%) and (0.104-0.105%) in case of mixtures type (M1-M3) as well as mixtures type (M4-M6) at time duration 31th day. However, it has increased as time passes which was interpreted as (0.71-0.73%) and (0.723-.0741%) in mixtures type (M1-M3) as well as mixtures type (M4-M6) at longer time duration for about 160 days. The variation of chloride solution absorption in dry conditioned control, and solvent based as well as water based impregnation concrete cubes was represent in Table 3-77.

Table 3-77 Chloride solution absorption in dry conditioned concrete cubes

Chloride solution absorption (%) in DCC cubes					
Cube ID	31 day	61 day	91 day	121 day	160 day
M1-0%	0.134	0.269	0.968	1.892	2.431
M2-0%	0.122	0.335	1.072	1.902	2.126
M3-0%	0.119	0.283	1.026	1.886	2.136
M4-0%	0.118	0.226	0.967	1.909	1.958
M5-0%	0.111	0.251	1.041	1.873	1.937
M6-0%	0.124	0.295	0.964	1.829	1.787
M1SB	0.103	0.136	0.573	1.358	0.726
M2SB	0.102	0.136	0.565	1.376	0.735
M3SB	0.100	0.130	0.556	1.328	0.719
M4SB	0.105	0.139	0.594	1.331	0.727
M5SB	0.105	0.131	0.579	1.328	0.745
M6SB	0.104	0.153	0.576	1.325	0.723
M1WB	0.113	0.157	0.607	1.483	0.811
M2WB	0.107	0.142	0.565	1.398	0.757
M3WB	0.114	0.146	0.581	1.389	0.771
M4WB	0.109	0.156	0.598	1.347	0.788
M5WB	0.105	0.141	0.608	1.345	0.727
M6WB	0.114	0.139	0.604	1.331	0.734

Whereas in water based impregnation concrete cubes, the chloride absorption in mixtures type (M1-M3) was decreased in the range between (0.106-0.114) at early time duration 31th day as compared to longer time duration which was ranged between (0.75-.81%). Similarly, for in case of mixtures type (M4-M6), the chloride absorption were decrease in the range between (0.105-0.113%) at 31th day as compared to longer time duration, which was vary in between (0.72-0.78%). The chloride absorption was observe to be vary in different mixtures type (M1-M6), which in turn depends on compressive strength, slump, w/c ratio, and mixture proportions. As observed from results that, the chloride absorption was more or less same in mixture type (M1-M6) at 31th day salt ponding. Whereas the variation in the chloride absorption was more increased at 160 day salt ponding, but its varied little bit as compared to one another in all mixtures type (M1-M6) as compared to early time duration at 31th day.

3.11.3 Pre-conditioned Fully saturated concrete cubes in water (Mc =3%)

The chloride absorption test with 10% sodium chloride solution was carried out on pre-conditioned fully saturated concrete cubes (Mc = 3%) of size 100 mm which was fully submerged and noted their weights at each time duration for about 160 days. For chloride absorption test, totally 12 concrete cubes were casted, out of which 6 control concrete cubes, and 6 solvent based concrete cubes.

The chloride absorption in control concrete cubes was varied in between (0.004-0.0051%) and (0.223-0.685%) at 31th day as well as 160th day respectively for all mixtures type (M1-3%-M6-

3%). In case of mixtures type (M1SB-M6SB), the variation of chloride absorption was varied in between (0.002-0.0035%) and (0.11-0.393%) at 31th day as well as 160th day respectively. In both control and solvent based impregnation concrete cubes, the chloride absorption was found to be lesser at early age as when compared to longer time duration. Whether at early or longer time duration, the chloride absorption in solvent-based impregnation concrete cubes was predominately reduce as when compared to control concrete cubes. The chloride absorption in partially saturated conditioned concrete cubes was immersed in 10% chloride solution with one face exposed to chloride solution as shown in Figure 3-13, and the variation chloride solution absorption in control as well as solvent based impregnation concrete cubes was interpreted for moisture content (Mc = 3%) as represented in Table 3-78 .

Figure 3-13 Chloride solution absorption in FSC concrete cubes

Table 3-78 Chloride solution absorption in fully saturated conditioned concrete cubes

Chloride solution absorption (%) in FSC concrete cubes					
Cube ID	31 day	61 day	91 day	121 day	160 day
M1-3%	0.005	0.049	0.129	0.261	0.685
M2-3%	0.004	0.025	0.092	0.135	0.224
M3-3%	0.004	0.045	0.118	0.187	0.489
M4-3%	0.004	0.023	0.090	0.135	0.222
M5-3%	0.004	0.043	0.099	0.183	0.478
M6-3%	0.003	0.023	0.078	0.120	0.209
M1SB	0.004	0.038	0.091	0.127	0.394
M2SB	0.003	0.021	0.077	0.080	0.214
M3SB	0.003	0.025	0.066	0.124	0.337
M4SB	0.003	0.020	0.030	0.079	0.175
M5SB	0.002	0.023	0.031	0.040	0.123
M6SB	0.002	0.015	0.018	0.020	0.111

3.11.4 Pre-conditioned Partially saturated concrete cubes in water (Mc =2%)

The chloride absorption test with 10% sodium chloride solution was carried out on pre-conditioned partially saturated concrete cubes (Mc = 2%) of size 100 mm which was fully submerged and noted their weights at each time duration for about 160 days. For chloride absorption test, totally 12 concrete cubes was casted, out of which 6 control concrete cubes, and 6 solvent based concrete cubes.

The chloride absorption in control concrete cubes was varied in between (0.0102-0.0152%) and (0.28-1.001%) at 31th day as well as 160th day respectively for all mixtures type (M1-2%-M6-2%). In case of mixtures type (M1SB-M6SB), the variation of chloride absorption was varied in between (0.0102-0.0108%) and (0.209-0.566%) at 31th day as well as 160th day respectively. In both control and solvent based impregnation concrete cubes, the chloride absorption was found to be same/lesser at early age as when compared to longer time duration. However, at early, the chloride absorption was predominately increase in control/solvent based impregnation concrete cubes as when compared to FSC control/solvent impregnation concrete cubes but decreases at later stage in PSC concrete cubes. The chloride absorption in partially saturated conditioned concrete cubes was immersed in 10% chloride solution with one face exposed to chloride solution as shown in Figure 3-14, and the variation chloride solution absorption in control as well as solvent based impregnation concrete cubes was interpreted for moisture content (Mc = 2%) as represented in Table 3-79 .

Figure 3-14 Chloride solution absorption in PSC concrete cubes

Table 3-79 Sodium chloride solution absorption in PSC concrete cubes

Chloride solution absorption (%) in PSC concrete cubes					
Cube ID	31 day	61 day	91 day	121 day	160 day
M1-2%	0.015	0.123	0.374	0.506	1.002
M2-2%	0.011	0.096	0.195	0.205	0.387
M3-2%	0.012	0.115	0.298	0.301	0.690
M4-2%	0.010	0.094	0.187	0.204	0.283
M5-2%	0.013	0.125	0.202	0.212	0.664
M6-2%	0.011	0.093	0.159	0.170	0.258
M1SB	0.011	0.123	0.199	0.209	0.556
M2SB	0.010	0.093	0.142	0.147	0.227
M3SB	0.011	0.110	0.185	0.192	0.485
M4SB	0.010	0.081	0.141	0.143	0.215
M5SB	0.011	0.108	0.182	0.187	0.430
M6SB	0.010	0.036	0.129	0.136	0.210

Similarly the chloride absorption test with 10% sodium chloride solution was carried out on pre-conditioned partially saturated concrete cubes (Mc = 2%) of size 100 mm which was fully submerged and noted their weights at each time duration for about 160 days. For chloride absorption test, totally 12 concrete cubes was casted, out of which 6 control concrete cubes, and 6 water based concrete cubes. The chloride absorption in control concrete cubes was varied in between (0.0075-0.0085%) and (0.312-1.109%) at 31th day as well as 160th day respectively for all mixtures type (M1-2%-M6-2%). However, in case of mixtures type (M1WB-M6WB), the variation of chloride absorption was varied in between (0.0071-0.008%) and (0.232-0.572%) at 31th day as well as 160th day respectively. In both control and water based impregnation concrete cubes, the chloride absorption was found to be same/more at early age as when compared to longer time duration. However, at early, the chloride absorption was slightly lesser in control/water based impregnation concrete cubes as when compared to control/water based impregnation concrete cubes at later stage. The chloride absorption in partially saturated conditioned concrete cubes was immersed in 10% chloride solution with one face exposed to chloride solution and the variation of chloride solution absorption in control as well as water based impregnation concrete cubes was interpreted for moisture content (Mc = 2%) as represented in Table 3-80.

Table 3-80 Chloride solution absorption in partially saturated conditioned concrete cubes

Chloride solution absorption (%) in PSC concrete cubes					
Cube ID	31 day	61 day	91 day	121 day	160 day
M1-2%	0.0086	0.0092	0.0148	0.3317	1.1095
M2-2%	0.0076	0.0085	0.0101	0.0904	0.4304
M3-2%	0.0080	0.0087	0.0137	0.2089	0.7407
M4-2%	0.0076	0.0082	0.0091	0.0685	0.3127
M5-2%	0.0078	0.0081	0.0102	0.1778	0.6818
M6-2%	0.0076	0.0080	0.0086	0.0633	0.2707
M1WB	0.0087	0.0090	0.0097	0.1530	0.5723
M2WB	0.0076	0.0084	0.0092	0.0912	0.2527
M3WB	0.0080	0.0087	0.0095	0.1108	0.5206
M4WB	0.0073	0.0083	0.0088	0.0529	0.2415
M5WB	0.0076	0.0082	0.0093	0.0793	0.4655
M6WB	0.0071	0.0075	0.0080	0.0384	0.2324

Furthermore the chloride absorption test with 10% sodium chloride solution was also carried out on pre-conditioned fully saturated concrete cubes (Mc = 3%) of size 100 mm which was fully submerged and noted their weights at each time duration for about 160 days. For chloride absorption test, totally 12 concrete cubes was casted, out of which 6 control concrete cubes, and 6 water based concrete cubes. The chloride absorption in control concrete cubes was varied in between (0.00414-0.0066%) and (0.235-0.706%) at 31th day as well as 160th day respectively for all mixtures type (M1-3%-M6-3%). However, in case of mixtures type (M1WB-M6WB), the variation of chloride absorption was varied in between (0.0021-0.0047%) and (0.129-0.495%) at 31th day as well as 160th day respectively. In both control and water based impregnation concrete cubes, the chloride absorption was found to be little bit varied at early age as when compared to longer time duration. However, at early, the chloride absorption was more differentiate in control/water based impregnation concrete cubes as when compared to control/water based impregnation concrete cubes at later stage. The chloride absorption in fully saturated conditioned concrete cubes was immersed in 10% chloride solution with one face exposed to chloride solution and the variation chloride absorption in control as well as solvent based impregnation concrete cubes was interpreted for moisture content (Mc = 3%) as represented in Table 3-81 .

Table 3-81 Chloride solution absorption in fully saturated conditioned concrete cubes

Chloride solution absorption (%) in FSC concrete cubes					
Cube ID	31 day	61 day	91 day	121 day	160 day
M1-3%	0.007	0.012	0.230	0.332	0.706
M2-3%	0.005	0.010	0.076	0.128	0.238
M3-3%	0.005	0.012	0.222	0.310	0.502
M4-3%	0.004	0.006	0.103	0.129	0.236
M5-3%	0.005	0.012	0.127	0.249	0.495
M6-3%	0.003	0.008	0.078	0.173	0.211
M1WB	0.005	0.010	0.113	0.253	0.496
M2WB	0.003	0.008	0.036	0.123	0.219
M3WB	0.005	0.006	0.097	0.226	0.352
M4WB	0.002	0.003	0.036	0.114	0.179
M5WB	0.004	0.005	0.055	0.119	0.166
M6WB	0.002	0.003	0.049	0.086	0.129

3.11.5 Interpretation of chloride absosption in concrete cubes with moisture content

The chloride penetration and moisture diffusion are two important transport processes for studying the long-term durability of concrete. The chloride penetration and moisture transfer in concrete are consider as two coupled transport processes. The interaction between moisture diffusion and chloride penetration in concrete affects the durability of reinforced concrete structures. Thus in the present research work chloride absorption test was carried out on pre-conditioned concrete cubes (100x100x100) mm such as dry/fully/partially saturated conditioned concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent based and water based impregnation material respectively. In turn to interpret the effectiveness of impregnation concrete cubes with control cubes for six mixtures type under pre-conditioned concrete cubes with constant compressive strength (40 N/mm^2), and varied slump (0-10, 10-30, 60-180) mm in one case as well as varied compressive strength (25-30-40 N/mm^2) with constant slump (10-30) mm in second case.

3.11.6 Chloride solution absorption in dry conditioned concrete cubes

In this research work, for chloride absorption test, totally 18 concrete cubes of size (100 mm) was casted, out of which 6 control concrete cubes, 6 solvent based concrete cubes, and 6 water based concrete cubes. The chloride absorption test was carry out with 10% sodium chloride solution, which was fully submerge for about 160 days.

It's observed from results that for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days salt ponding and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride solution absorption as well as standard deviation values at different time duration (31th -160th day) was represented in all mixture type (M1-M6) in Table 3-82.

Table 3-82 Interpretation of chloride solution absorption in DCC cubes

Sodium chloride solution absorption in DCC concrete cubes							
Cube ID						Aver (31-160)	STD (31-160)
Time, days	31	61	91	121	160	Days	Days
M1-0%	0.134	0.269	0.968	1.892	2.431	1.139	1.004
M2-0%	0.122	0.335	1.072	1.902	2.126	1.111	0.900
M3-0%	0.119	0.283	1.026	1.886	2.136	1.090	0.912
M4-0%	0.118	0.226	0.967	1.909	1.958	1.035	0.883
M5-0%	0.111	0.251	1.041	1.873	1.937	1.043	0.864
M6-0%	0.124	0.295	0.964	1.829	1.787	1.000	0.802
M1SB	0.103	0.136	0.573	1.358	0.726	0.579	0.512
M2SB	0.102	0.136	0.565	1.376	0.735	0.583	0.520
M3SB	0.100	0.130	0.556	1.328	0.719	0.567	0.503
M4SB	0.105	0.139	0.594	1.331	0.727	0.579	0.502
M5SB	0.105	0.131	0.579	1.328	0.745	0.578	0.503
M6SB	0.104	0.153	0.576	1.325	0.723	0.576	0.496
M1WB	0.113	0.157	0.607	1.483	0.811	0.634	0.559
M2WB	0.107	0.142	0.565	1.398	0.757	0.594	0.528
M3WB	0.114	0.146	0.581	1.389	0.771	0.600	0.523
M4WB	0.109	0.156	0.598	1.347	0.788	0.599	0.508
M5WB	0.105	0.141	0.608	1.345	0.727	0.585	0.506
M6WB	0.114	0.139	0.604	1.331	0.734	0.584	0.500

The average chloride solution absorption was increased at 61th, 91th, 121th, and 160th days as when compared to 31th day which could in the range varied (60th-31th day) as in control concrete cubes, solvent based (SB) impregnation concrete cubes, and water based (WB) impregnation concrete cubes in mixtures type (M1-M6) respectively as represented in Table 3-83. The chloride solution absorption was increase in DCC concrete cubes at 60th day, as compared to an early age 31th day in control concrete cubes (M1-0%-50.44%, M2-0%-63.70%, M3-0%-57.90%) for in case of constant higher compressive strength, and varied slump value (0-10, 10-30, and 60-180 mm). It’s also increase in control DCC concrete cubes (M4-0%-47.97%, M5-0%-55.79%, and M6-0%-58.05%) for in the case of varied compressive strength (25-30-40 N/mm^2), and constant slump value (10-30 mm). Chloride solution absorption was decrease in solvent-based impregnation concrete cubes (M1SB-24.09%, M2SB-25.38%, M3SB-22.77%, M4SB-24.32%, M5SB-19.67%, MSB6-31.62%) and water based impregnation concrete cubes M1WB-28.15%, M2WB-24.84%, M3WB-21.40%, M4WB-30.36%, M5WB-25.47%, MWB6-17.98%) respectively. Similarly, the chloride solution concentration was goes on increase at 91th day, 121th day, and 160th day in control concrete cubes as against solvent based and water based impregnation concrete cubes respectively.

Table 3-83 Chloride absorption variation in DCC concrete cubes at different time duration

Chloride solution absorption in DCC concrete cubes									
Cube ID	31 day	61 day	Incr (%)	91 day	Incr (%)	121 day	Incr (%)	160 day	Incr (%)
M1-0%	0.134	0.269	50.44	0.968	86.21	1.892	92.94	2.43	94.51
M2-0%	0.122	0.335	63.70	1.072	88.65	1.902	93.61	2.13	94.28
M3-0%	0.119	0.283	57.90	1.026	88.40	1.886	93.69	2.14	94.43
M4-0%	0.118	0.226	47.97	0.967	87.85	1.909	93.84	1.96	94.00
M5-0%	0.111	0.251	55.79	1.041	89.33	1.873	94.07	1.94	94.27
M6-0%	0.124	0.295	58.05	0.964	87.16	1.829	93.23	1.79	93.07
M1SB	0.103	0.136	24.09	0.573	81.98	1.358	92.40	0.73	85.79
M2SB	0.102	0.136	25.38	0.565	82.01	1.376	92.62	0.73	86.18
M3SB	0.100	0.130	22.77	0.556	81.95	1.328	92.44	0.72	86.04
M4SB	0.105	0.139	24.32	0.594	82.33	1.331	92.12	0.73	85.57
M5SB	0.105	0.131	19.67	0.579	81.80	1.328	92.06	0.74	85.84
M6SB	0.104	0.153	31.62	0.576	81.87	1.325	92.12	0.72	85.57
M1WB	0.113	0.157	28.15	0.607	81.40	1.483	92.38	0.81	86.07
M2WB	0.107	0.142	24.84	0.565	81.08	1.398	92.35	0.76	85.86
M3WB	0.114	0.146	21.40	0.581	80.31	1.389	91.76	0.77	85.16
M4WB	0.109	0.156	30.36	0.598	81.82	1.347	91.93	0.79	86.21
M5WB	0.105	0.141	25.47	0.608	82.71	1.345	92.18	0.73	85.54
M6WB	0.114	0.139	17.98	0.604	81.15	1.331	91.45	0.73	84.50

The chloride solution absorption was increase in control concrete cubes as when compared to solvent-based impregnation as well as water based impregnation concrete cubes in mixtures type (M1-M6) respectively, which is as shown in

Table 3-84.

Table 3-84 Variation of chloride solution absorption in DCC/IC cubes

Sodium chloride absorption in DCC/IC cubes			
Cube ID	%,inc DCC-SB	%,inc DCC-WB	%,dec SB-WB
Time, days	Aver (31-160 day)	Aver (31-160 day)	Aver (31-160 day)
M1-0%	49.14	44.30	-9.52
M2-0%	47.58	46.57	-1.93
M3-0%	48.02	44.94	-5.93
M4-0%	44.08	42.10	-3.54
M5-0%	44.57	43.86	-1.29
M6-0%	42.35	41.55	-1.40

3.11.7 Chloride solution absorption in PSC cubes

In this research work, for chloride absorption test, totally 12 concrete cubes of size (100 mm) was casted as well as pre-conditioned to achieved moisture content (Mc = 2%), out of which 6 control concrete cubes, and 6 solvent based concrete cubes were used for this experimental work. The chloride absorption test was carry out with 10% sodium chloride solution, which was fully submerge for about 160 days.

It’s observed from results that for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days salt ponding and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride solution absorption as well as standard deviation values at different time duration (31^{th} -160^{th} day) was represented in all mixture type (M1-M6) as shown in

Table 3-85.

Table 3-85 Interpretation of chloride solution absorption in PSC cubes

Sodium chloride solution absorption in PSC concrete cubes							
Cube ID						Aver (31-160)	STD (31-160)
Time, days	31	61	91	121	160	Days	Days
M1-2%	0.015	0.123	0.374	0.506	1.002	0.404	0.387
M2-2%	0.011	0.096	0.195	0.205	0.387	0.179	0.141
M3-2%	0.012	0.115	0.298	0.301	0.690	0.283	0.259
M4-2%	0.010	0.094	0.187	0.204	0.283	0.156	0.106
M5-2%	0.013	0.125	0.202	0.212	0.664	0.243	0.248
M6-2%	0.011	0.093	0.159	0.17	0.258	0.138	0.092
M1SB	0.011	0.123	0.199	0.209	0.556	0.219	0.204
M2SB	0.010	0.093	0.142	0.147	0.227	0.124	0.080
M3SB	0.011	0.110	0.185	0.192	0.485	0.197	0.177
M4SB	0.010	0.081	0.141	0.143	0.215	0.118	0.077
M5SB	0.011	0.108	0.182	0.187	0.430	0.184	0.155
M6SB	0.010	0.036	0.129	0.136	0.210	0.104	0.081

The average chloride absorption was increased at 61th, 91th, 121th, and 160th days as when compared to 31th day which could in the range varied (60th -31th day) as in control concrete cubes, solvent based impregnation concrete cubes, and water based impregnation concrete cubes in (M1-M6) which was represented in Table 3-86.

The chloride solution absorption was increase in partially saturated conditioned concrete cubes at 60th day as compared to early 31th day in control concrete cubes (M1-2%-87.59%, M2-2%-88.74%, M3-2%-89.96%) for in case of constant higher compressive strength and varied slump value (0-10, 10-30, and 60-180 mm). Whereas chloride solution absorption were varied in the following range (M4-2%-89.06%, M5-2%-89.37%, and M6-2%-88.67%) for in case of varied, compressive strength (25-30-40 N/mm^2) and constant slump value (10-30 mm). Chloride solution absorption was decrease in solvent-based impregnation concrete cubes (M1SB-91.18%, M2SB-88.84%, M3SB-90.20%) and water based impregnation concrete cubes M1WB-87.24%, M2WB-90.10%, M3WB-71.26%) respectively. Similarly, the chloride solution concentration was goes on increase at 91th day, 121th day, and 160th day in control concrete cubes as against solvent based and water based impregnation concrete cubes respectively.

Table 3-86 Chloride solution absorption variation in PSC cubes

Chloride solution absorption in PSC concrete cubes									
Cube ID	31 day	61 day	Incr (%)	91 day	Incr (%)	121 day	Incr (%)	160 day	Incr (%)
M1-2%	0.015	0.123	87.59	0.374	95.91	0.506	96.98	1.002	98.47
M2-2%	0.011	0.096	88.74	0.195	94.46	0.205	94.73	0.387	97.21
M3-2%	0.012	0.115	89.96	0.298	96.12	0.301	96.15	0.690	98.32
M4-2%	0.010	0.094	89.06	0.187	94.54	0.204	94.99	0.283	96.39
M5-2%	0.013	0.125	89.37	0.202	93.44	0.212	93.72	0.664	98.00
M6-2%	0.011	0.093	88.67	0.159	93.39	0.170	93.82	0.258	95.92
M1SB	0.011	0.123	91.18	0.199	94.53	0.209	94.80	0.556	98.05
M2SB	0.010	0.093	88.84	0.142	92.68	0.147	92.97	0.227	95.44
M3SB	0.011	0.110	90.20	0.185	94.15	0.192	94.36	0.485	97.77
M4SB	0.010	0.081	87.24	0.141	92.68	0.143	92.77	0.215	95.19
M5SB	0.011	0.108	90.10	0.182	94.14	0.187	94.32	0.430	97.53
M6SB	0.010	0.036	71.26	0.129	92.02	0.136	92.44	0.210	95.10

The chloride solution absorption was increase in control concrete cubes as when compared to solvent-based impregnation concrete cubes as represented in Table 3-87.

Table 3-87 Determination of sodium chloride solution absorption in PSC/IC cubes

Sodium chloride absorption in PSC/IC cubes		
Cube ID	%,inc PSC-SB	%,decr SB-PSC
Time, days	Aver (31-160 day)	Aver (31-160 day)
M1-2%	45.67	54.33
M2-2%	30.77	69.23
M3-2%	30.54	69.46
M4-2%	24.06	75.94
M5-2%	24.56	75.44
M6-2%	24.61	75.39

3.11.8 Chloride solution absorption in FSC cubes

In this research work, for chloride absorption test, totally 12 concrete cubes of size (100 mm) was casted as well as pre-conditioned to achieved moisture content (Mc = 3%), out of which 6 control concrete cubes, and 6 solvent based concrete cubes were used for this experimental work. The chloride absorption test was carry out with 10% sodium chloride solution, which was fully submerge for about 160 days.

It’s clear from results that for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days’ salt ponding and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride absorption as well as standard deviation values at different time duration (31th -160th day) was represented in all mixture type (M1-M6) as explained in Table 3-88.

Table 3-88 Interpretation chloride absorption in FSC concrete cubes at different time duration

Sodium chloride solution absorption in FSC concrete cubes							
Cube ID						Aver (31-160)	STD (31-160)
Time, days	31	61	91	121	160	Days	Days
M1-3%	0.005	0.049	0.129	0.261	0.685	0.226	0.275
M2-3%	0.004	0.025	0.092	0.135	0.224	0.096	0.088
M3-3%	0.004	0.045	0.118	0.187	0.489	0.169	0.192
M4-3%	0.004	0.023	0.090	0.135	0.222	0.095	0.088
M5-3%	0.004	0.043	0.099	0.183	0.478	0.161	0.189
M6-3%	0.003	0.023	0.078	0.120	0.209	0.087	0.083
M1SB	0.004	0.038	0.091	0.127	0.394	0.131	0.155
M2SB	0.003	0.021	0.077	0.080	0.214	0.079	0.082
M3SB	0.003	0.025	0.066	0.124	0.337	0.111	0.135
M4SB	0.003	0.020	0.030	0.079	0.175	0.062	0.070
M5SB	0.002	0.023	0.031	0.040	0.123	0.044	0.046
M6SB	0.002	0.015	0.018	0.020	0.111	0.033	0.044

The average chloride solution absorption was increased at 61th, 91th, 121th, and 160th days as when compared to 31th day which could in the range varied (61th -31th day) as in control concrete cubes, and solvent based impregnation concrete cubes. The variation of chloride absorption in FSC cubes at different time duration as represented in Table 3-89. The chloride solution absorption was increase in fully saturated conditioned concrete cubes at 61th day as compared to early age 31th day in control concrete cubes (M1-3%-89.59%, M2-3%-82.45%, M3-3%-90.33%) for in case of constant higher compressive strength and varied slump value (0-10, 10-30, and 60-180 mm). Whereas chloride solution absorption were varied in the following range (M4-2%-84.53%, M5-2%-91.20%, and M6-2%-85.03%) for in case of varied, compressive strength (25-30-40 N/mm^2) and constant slump value (10-30 mm). Chloride solution absorption was decrease in solvent-based impregnation concrete cubes (M1SB-90.69%, M2SB-85.08%, M3SB-86.77%) and water based impregnation concrete cubes M1WB-85.90%, M2WB-89.69%, M3WB-87.33%) respectively. Similarly, the chloride solution concentration was goes on increase at 91th day, 121th day, and 160th day in control concrete cubes as against solvent based and water based impregnation concrete cubes respectively.

Table 3-89 Variation of chloride solution absorption in FSC cubes

Chloride solution absorption in FSC concrete cubes									
Cube ID	31 day	61 day	Incr (%)	91 day	Incr (%)	121day	Incr (%)	160 day	Incr (%)
M1-3%	0.0051	0.0490	89.59	0.12908	96.05	0.26122	98.05	0.68522	99.26
M2-3%	0.0044	0.0250	82.45	0.09208	95.24	0.13475	96.75	0.22353	98.04
M3-3%	0.0044	0.0453	90.33	0.11847	96.30	0.1874	97.66	0.48873	99.10
M4-3%	0.0036	0.0233	84.53	0.0900	95.99	0.13461	97.32	0.22187	98.38
M5-3%	0.0038	0.0433	91.20	0.09891	96.14	0.18332	97.92	0.47805	99.20
M6-3%	0.0034	0.0230	85.03	0.07779	95.57	0.12008	97.13	0.20945	98.36
M1SB	0.0035	0.0379	90.69	0.09111	96.12	0.12659	97.21	0.39376	99.10
M2SB	0.0032	0.0215	85.08	0.0770	95.84	0.07959	95.97	0.21352	98.50
M3SB	0.0033	0.0252	86.77	0.06631	94.98	0.1240	97.32	0.33736	99.01
M4SB	0.0028	0.0199	85.90	0.03034	90.75	0.07928	96.46	0.17528	98.40
M5SB	0.0024	0.0232	89.69	0.03051	92.15	0.03992	94.00	0.12257	98.05
M6SB	0.0019	0.0150	87.33	0.01766	89.27	0.02005	90.55	0.11093	98.29

The chloride absorption was increase in control concrete cubes as when compared to solvent-based impregnation concrete cubes. Chloride absorption was decrease in solvent-based impregnation concrete cubes as when compared to control concrete cubes as shown in Table 3-90.

Table 3-90 Determination of sodium chloride solution absorption in FSC/IC cubes

Sodium chloride absorption in FSC/IC cubes		
Cube ID	%,inc FSC-SB	%,decr SB-FSC
Time, days	Aver (31-160 day)	Aver (31-160 day)
M1-3%	42.20	57.80
M2-3%	17.70	82.30
M3-3%	34.13	65.87
M4-3%	35.02	64.98
M5-3%	72.92	27.08
M6-3%	61.85	38.15

3.11.9 Chloride solution absorption in PSC (WB) impregnation concrete cubes

In this research work, for chloride absorption test, totally 12 concrete cubes of size (100 mm) was casted as well as pre-conditioned to achieved moisture content (Mc = 2%), out of which 6 control concrete cubes, and 6 water based impregnation concrete cubes were used for this experimental work. The chloride absorption test was carry out with 10% sodium chloride solution that was fully submerge in order to achieve partially saturated condition (PSC) for about 160 days.

It is interpret from the results that for higher compressive strength and varied slump value, the chloride absorption was to be slightly higher in magnitude as when compared to water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more/less as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days salt ponding and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride absorption as well as standard deviation values at different time duration (31th -160th day) was represented in all mixture type (M1-M6). The interpretation of average chloride absorption and standard deviation in PSC concrete cubes as represented in Table 3-91.

Table 3-91 Variation of chloride solution absorption in PSC cubes

Sodium chloride solution absorption in PSC concrete cubes							
Cube ID						Aver (31-160)	STD (31-160)
Time, days	31	61	91	121	160	Days	Days
M1-2%	0.0086	0.0092	0.0148	0.3317	1.1095	0.295	0.476
M2-2%	0.0076	0.0085	0.0101	0.0904	0.4304	0.109	0.183
M3-2%	0.0080	0.0087	0.0137	0.2089	0.7407	0.196	0.316
M4-2%	0.0076	0.0082	0.0091	0.0685	0.3127	0.081	0.132
M5-2%	0.0078	0.0081	0.0102	0.1778	0.6818	0.177	0.291
M6-2%	0.0076	0.0080	0.0086	0.0633	0.2707	0.072	0.114
M1WB	0.0087	0.0090	0.0097	0.1530	0.5723	0.151	0.244
M2WB	0.0076	0.0084	0.0092	0.0912	0.2527	0.074	0.106
M3WB	0.0080	0.0087	0.0095	0.1108	0.5206	0.132	0.222
M4WB	0.0073	0.0083	0.0088	0.0529	0.2415	0.064	0.101
M5WB	0.0076	0.0082	0.0093	0.0793	0.4655	0.114	0.199
M6WB	0.0071	0.0075	0.0080	0.0384	0.2324	0.059	0.098

The average chloride absorption was increased at 61th, 91th, 121th, and 160th days as when compared to 31th day which could in the range varied (60th -31th day) as in control concrete cubes, and water based impregnation concrete cubes as shown in Table 3-92.

The chloride solution absorption was increase in partially saturated conditioned concrete cubes at 61th day as compared to early age 31th day in control concrete cubes (M1-2%-7.04%, M2-2%-10.54%, M3-2%-8.21%) for in case of constant higher compressive strength and varied slump value (0-10, 10-30, and 60-180 mm). Whereas chloride solution absorption was, vary in the following range (M4-2%-7.48%, M5-2%-4.58%, and M6-2%-4.86%) for in case of varied compressive strength (25-30-40 N/mm^2) and constant slump value (10-30 mm). Chloride solution absorption was decrease in solvent-based impregnation concrete cubes (M1WB-2.98%, M2WB-9.97%, M3WB-8.83%) and water based impregnation concrete cubes M1WB-11.39%, M2WB-8.03%, M3WB-4.85%) respectively. Similarly, the chloride solution concentration was goes on increase at 91th day, 121th day, and 160th day in control concrete cubes as against solvent based and water based impregnation concrete cubes respectively.

Table 3-92 Estimation of chloride solution absorption in PSC cubes

Chloride solution absorption in PSC concrete cubes										
Cube ID	31 day	61 day	Incr (%)	91 day	Incr (%)	121 day	Incr (%)	160 day	Incr (%)
M1-2%	0.00858	0.0092	7.04	0.01476	41.86	0.33167	97.41	1.10953	99.23
M2-2%	0.00761	0.0085	10.53	0.01013	24.94	0.0904	91.59	0.43044	98.23
M3-2%	0.0080	0.0087	8.21	0.01374	41.53	0.20887	96.15	0.74068	98.92
M4-2%	0.00757	0.0082	7.48	0.0091	16.83	0.06854	88.96	0.31266	97.58
M5-2%	0.00776	0.0081	4.58	0.01024	24.24	0.17784	95.64	0.68183	98.86
M6-2%	0.00762	0.0080	4.86	0.00859	11.28	0.06333	87.96	0.27072	97.18
M1WB	0.00875	0.0090	2.98	0.00971	9.92	0.1530	94.28	0.57229	98.47
M2WB	0.00759	0.0084	9.97	0.00921	17.54	0.09122	91.68	0.25268	97.00
M3WB	0.0080	0.0087	8.83	0.00946	15.75	0.11078	92.80	0.52059	98.47
M4WB	0.00733	0.0083	11.39	0.00878	16.52	0.05288	86.14	0.24147	96.96
M5WB	0.00759	0.0082	8.03	0.00935	18.85	0.07927	90.43	0.46553	98.37
M6WB	0.00709	0.0075	4.85	0.0080	10.96	0.03838	81.51	0.23237	96.95

The chloride absorption was increase in control concrete cubes as when compared to water based impregnation concrete cubes. In the other way, the chloride absorption was decrease in water based impregnation concrete cubes as when compared to control concrete cubes. The interpretation of average chloride absorption in PSC/IC cubes as represented in Table 3-93.

Table 3-93 Variation of sodium chloride solution absorption in PSC/IC cubes

Sodium chloride absorption in PSC/IC cubes		
Cube ID	%,inc PSC-WB	%,decr WB-PSC
Time, days	Aver (31-160 day)	Aver (31-160 day)
M1-2%	48.92	51.08
M2-2%	32.53	67.47
M3-2%	32.91	67.09
M4-2%	21.50	78.50
M5-2%	35.65	64.35
M6-2%	18.14	81.86

3.11.10 Chloride absorption in FSC (WB) impregnation concrete cubes

In this research work, for chloride absorption test, totally 12 concrete cubes of size (100 mm) was casted as well as pre-conditioned to achieved moisture content (Mc = 3%), out of which 6 control concrete cubes, and 6 water based impregnation concrete cubes were used for this experimental work. The chloride absorption test was carry out with 10% sodium chloride solution, which was fully submerge in order to achieve fully saturated condition (FSC) for about 160 days.

It is interpret from the results that for higher compressive strength and varied slump value, the chloride absorption was slightly higher in magnitude as when compared to water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more/less as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days salt ponding and its average value such as chloride absorption as well as their standard deviation was varied in all mixtures type. The variation of average values of chloride solution absorption as well as standard deviation values at different time duration (31th -160th day) was represented in all mixture type (M1-M6) was shown in Table 3-94.

Table 3-94 Variation of sodium chloride solution absorption in FSC cubes

Sodium chloride solution absorption in FSC concrete cubes							
Cube ID						Aver (31-160)	STD (31-160)
Time, days	31	61	91	121	160	Days	Days
M1-3%	0.0066	0.0117	0.2298	0.3325	0.7062	0.257	0.288
M2-3%	0.0051	0.0097	0.0756	0.1282	0.2385	0.091	0.097
M3-3%	0.0050	0.0122	0.2222	0.3095	0.5017	0.210	0.210
M4-3%	0.0041	0.0062	0.1029	0.1287	0.2357	0.096	0.096
M5-3%	0.0052	0.0117	0.1267	0.2492	0.4947	0.177	0.203
M6-3%	0.0026	0.0079	0.0779	0.1727	0.2113	0.094	0.095
M1WB	0.0048	0.0100	0.1126	0.2535	0.4959	0.175	0.206
M2WB	0.0029	0.0080	0.0355	0.123	0.2187	0.078	0.092
M3WB	0.0046	0.0057	0.0966	0.2259	0.3524	0.137	0.151
M4WB	0.0025	0.0031	0.0363	0.114	0.1793	0.067	0.078
M5WB	0.0038	0.0045	0.0553	0.1186	0.1662	0.070	0.072
M6WB	0.0021	0.0026	0.0486	0.086	0.1294	0.054	0.055

The average chloride solution absorption was increased at 61th, 91th, 121th, and 160th days as when compared to 31th day which could in the range varied (60th -31th day) as in control concrete cubes, and water based impregnation concrete cubes. The variation of chloride solution absorption in FSC concrete cubes at different time duration as represented in Table 3-95.

The chloride solution absorption was increase in fully saturated conditioned concrete cubes at 61th day as compared to early age 31th day in control concrete cubes (M1-3%-43.38%, M2-3%-47.89%, M3-3%-58.78%) for in case of constant higher compressive strength and varied slump value (0-10, 10-30, and 60-180 mm). Whereas chloride solution absorption were varied in the following range (M4-3%-33.57%, M5-3%-55.67%, and M6-3%-67.45%) for in case of varied, compressive strength (25-30-40 N/mm^2) and constant slump value (10-30 mm). Chloride solution absorption was decrease in solvent-based impregnation concrete cubes (M1WB-52.08%, M2WB-63.38%, M3WB-19.44%) and water based impregnation concrete cubes M1WB-20.34%, M2WB-16.45%, M3WB-17.06%) respectively. Similarly, the chloride solution concentration was goes on increase at 91th day, 121th day, and 160th day in control concrete cubes as against solvent based and water based impregnation concrete cubes respectively.

Table 3-95 Interpretation of chloride solution absorption in FSC cubes

Chloride solution absorption in FSC concrete cubes									
Cube ID	31 day	61 day	Incr (%)	91 day	Incr (%)	121 day	Incr (%)	160 day	Incr (%)
M1-3%	0.00665	0.0117	43.38	0.22984	97.11	0.33245	98.00	0.70624	99.06
M2-3%	0.00507	0.0097	47.89	0.07558	93.30	0.12816	96.05	0.23849	97.88
M3-3%	0.0050	0.0122	58.78	0.22217	97.74	0.30955	98.38	0.50169	99.00
M4-3%	0.00415	0.0062	33.57	0.10286	95.97	0.12868	96.78	0.23566	98.24
M5-3%	0.00517	0.0117	55.67	0.12672	95.92	0.24921	97.93	0.49468	98.95
M6-3%	0.00258	0.0079	67.45	0.07791	96.69	0.17269	98.51	0.21128	98.78
M1WB	0.00478	0.0100	52.08	0.11257	95.76	0.25346	98.12	0.49594	99.04
M2WB	0.00291	0.0080	63.38	0.03555	91.81	0.12297	97.63	0.21874	98.67
M3WB	0.00461	0.0057	19.34	0.09661	95.22	0.22588	97.96	0.35244	98.69
M4WB	0.00246	0.0031	20.34	0.03628	93.21	0.11403	97.84	0.17935	98.63
M5WB	0.00378	0.0045	16.45	0.05526	93.15	0.11863	96.81	0.16621	97.72
M6WB	0.00213	0.0026	17.06	0.04860	95.62	0.0860	97.53	0.12938	98.36

The chloride absorption was increase in control concrete cubes as when compared to water based impregnation concrete cubes. Chloride absorption was decrease in water based impregnation concrete cubes as when compared to control concrete cubes. The comparative study of average chloride absorption in FSC/IC concrete cubes as represented in Table 3-96.

Table 3-96 Determination sodium chloride solution absorption in FSC/IC cubes

Sodium chloride absorption in FSC/IC cubes		
Cube ID	%,inc FSC-WB	%,decr-WB-FSC
Time, days	Aver (31-160 day)	Aver (31-160 day)
M1-3%	31.88	68.12
M2-3%	15.08	84.92
M3-3%	34.77	65.23
M4-3%	29.81	70.19
M5-3%	60.74	39.26
M6-3%	43.12	56.88

3.11.11 Summary

- The chloride penetration and moisture diffusion are two most important transport properties responsible for the long-term durability of concrete structure. The chloride penetration and moisture transfer in concrete are consider as the two coupled transport processes. The interaction between moisture diffusion and chloride penetration in concrete affects the durability of reinforced concrete structures.
- Thus in the present research work chloride absorption test was carried out on 66 pre-conditioned concrete cubes (100x100x100) mm such as DCC/PSC/FSC concrete cubes in order to evaluate an effectiveness of two impregnation materials (SB/WB) respectively.

- In turn to interpret an effectiveness of impregnation concrete cubes with control cubes for six mixtures type under pre-conditioned concrete cubes with constant compressive strength (40 N/mm^2), and varied slump (0-10, 10-30, 60-180) mm in one case as well as varied compressive strength (25-30-40 N/mm^2) with constant slump (10-30) mm in second case.

- Finally to produce sorptivity values for in case of concrete cubes with differential desired moisture content (Mc =2%, and Mc =3%) which was fully submerged in salt solution with/without impregnation.

- It is observe from results that, the chloride absorption in DCC-Mc-0% control concrete cubes was increase as when compared to PSC-Mc-2%, and PSC (SB)-Mc-2% concrete cubes. It’s also observed from results that, the chloride absorption in DCC(WB)-Mc-0% impregnation concrete cubes was increased in six all mixtures type as when compared to PSC(WB)-Mc-2% concrete cubes.

- The chloride absorption in DCC-Mc-0% control concrete cubes was increase as when compared to FSC-Mc-3% concrete cubes. Chloride absorption in DCC (SB)-Mc-0% and DCC (WB)-Mc-0% impregnation concrete cubes was increase as when compared to FSC (SB)-Mc-3% and FSC (WB)-Mc-3% concrete cubes.

- It is observed from results that, the chloride absorption in FSC-Mc-3% control concrete cubes was increased in six all mixtures type as when compared to PSC-Mc-2% concrete cubes.

CHAPTER 4 **RESULTS AND DISCUSSIONS**

4.1 Introduction

This chapter briefly summarises the main results and discussions from the present research work. It is divide in to sections such as non-destructive testing, initial surface absorption test, sorptivity test, salt ponding test on concrete cubes/slabs, and chloride absorption test in the concrete cubes with finite moisture content according to the experimental work carried in the present research work.

4.2 NDT on concrete cubes

4.2.1 Rebound hammer test on concrete cubes

The obtained rebound hammer number as well as compressive strength are average values taken on four sides of concrete cubes in the present research work was as shown in

Figure *4-1*). The hardness value of the concrete cubes were proportionally (exponentially) increased with compressive strength for in the case of all concrete mixtures type (M1-M6) respectively.

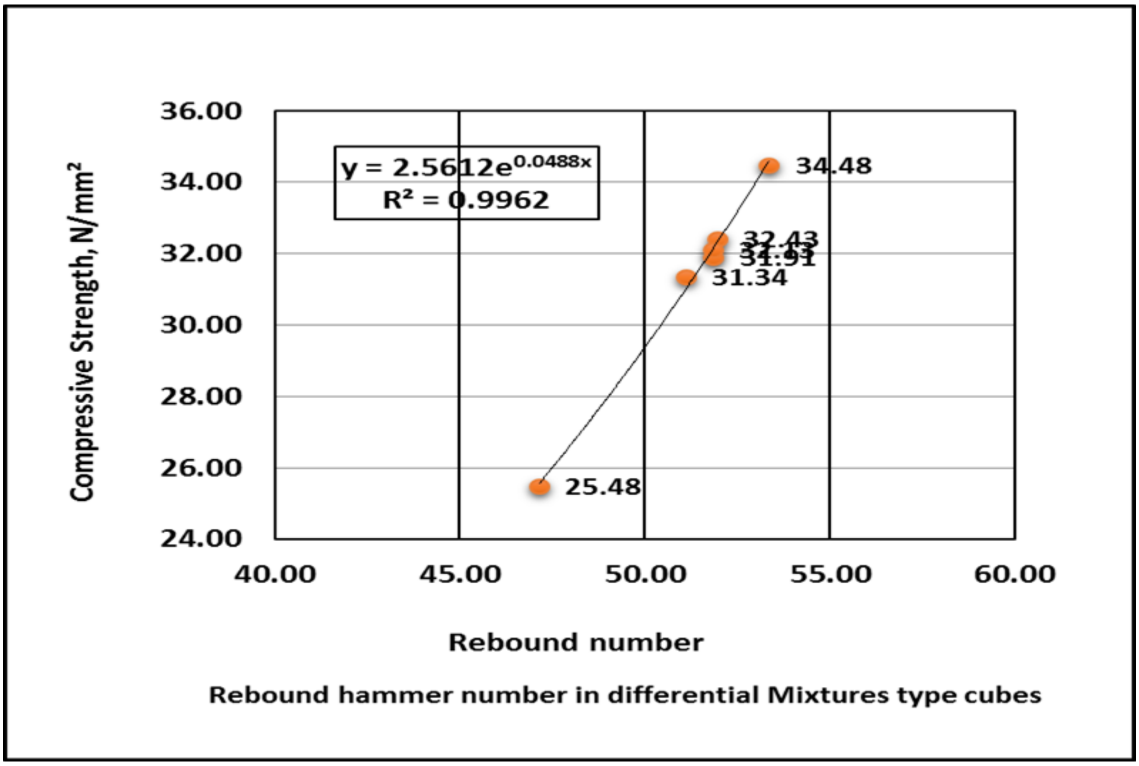
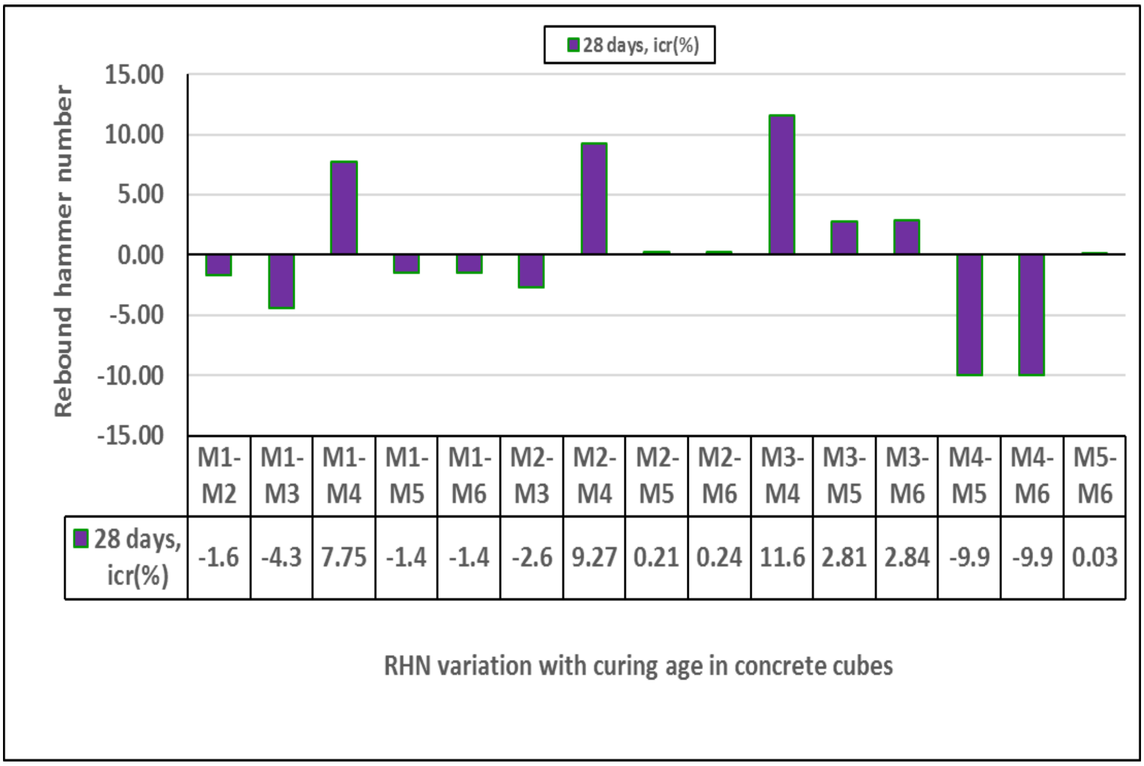


Figure 4-1 Variation of RHN with compressive strength

The rebound hammer number was increase in concrete mix design (M2, M3, M5 and M6) as when compared to concrete mix design (M1). Whereas the rebound hammer number was decrease in the concrete mix design (M4, M5, M6) as when compared to concrete mix design (M2). However, the rebound hammer number was increase in the concrete mix design (M3) as against concrete mix design (M4, M5, and M6). In addition to that, the rebound hammer number was decrease in the concrete mix design (M4) as when compared with the concrete mix design (M5, and M6) and rebound hammer was also slightly increase in the concrete mix design (M5) as against the concrete mix design (M6). The variation of rebound hammer number in the different concrete mix designs were represent as in

Figure *4-2* respectively.

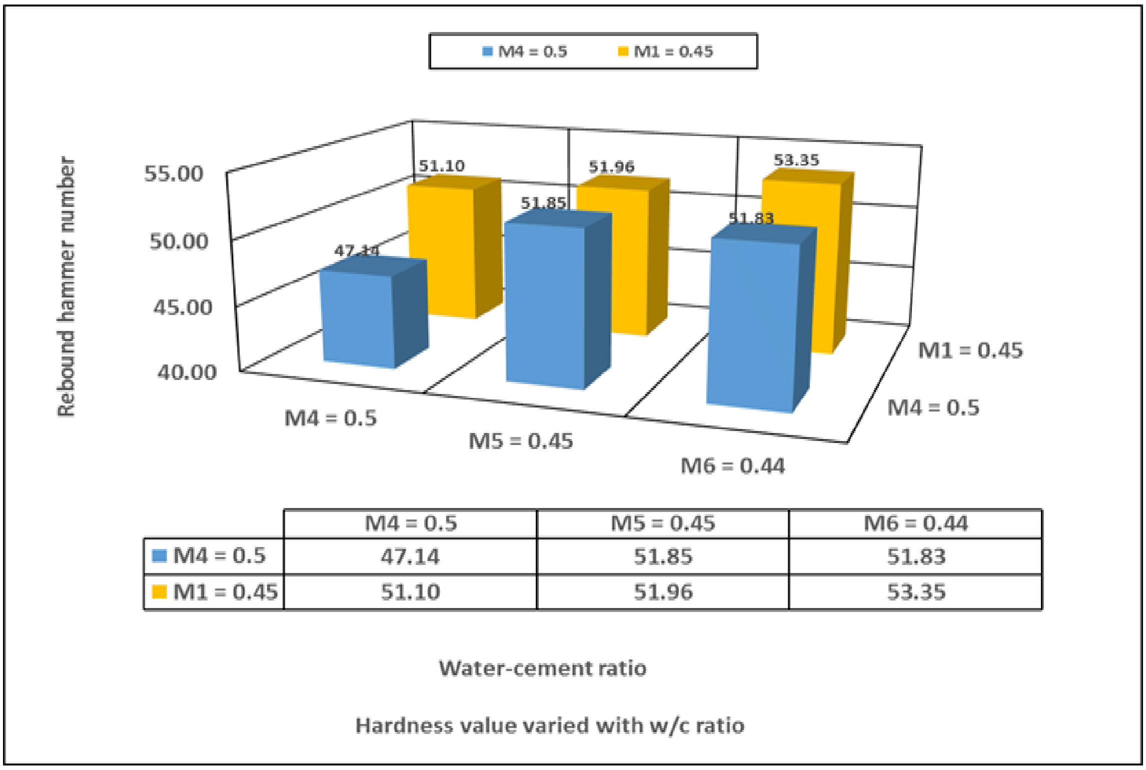


	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
■ 28 days, icr(%)	-1.6	-4.3	7.75	-1.4	-1.4	-2.6	9.27	0.21	0.24	11.6	2.81	2.84	-9.9	-9.9	0.03

Figure 4-2 RHN variation in different concrete mixes

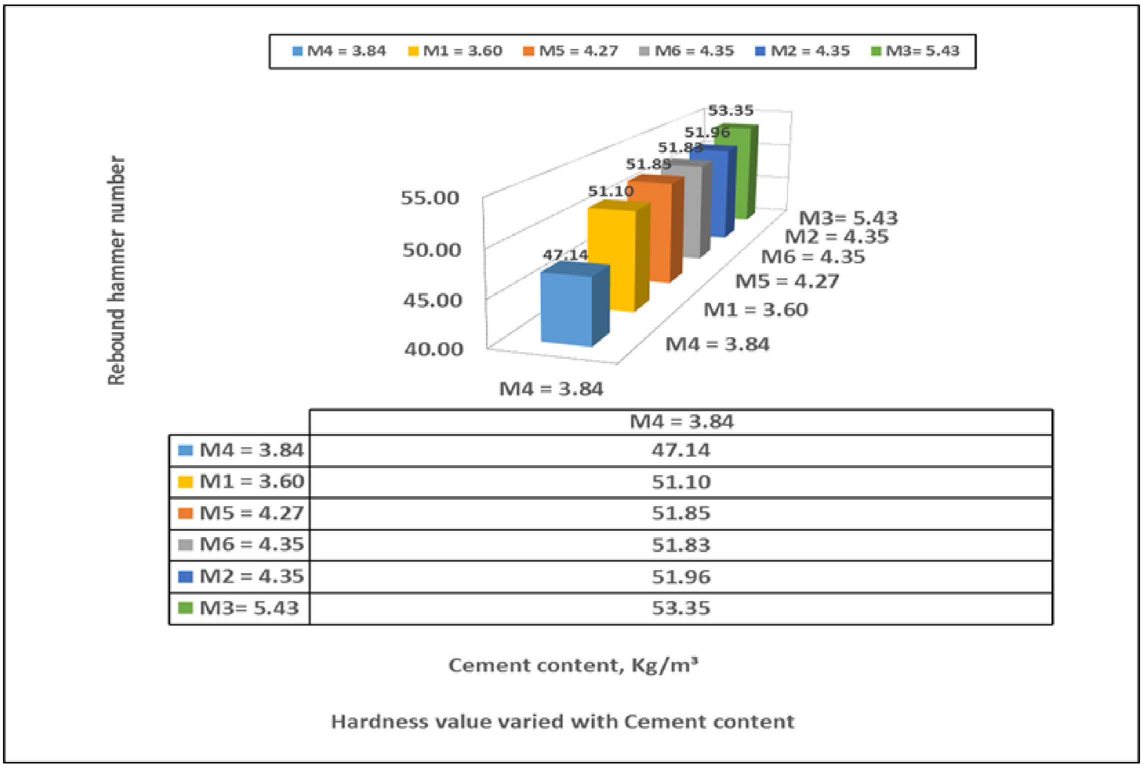
The rebound hammer number was increase in the concrete mix design with lower w/c ratio (M5 and M6) as when compare to concrete mix design (M4). Whereas the rebound hammer number was, also increase in the concrete mix design (M1 and M2) with lower w/c ratio as when compared to concrete mix design (M3) with higher w/c ratio. The variation of rebound hammer number in the different concrete mix designs were represent as in

Figure *4-3* respectively. As observed from the results that, the rebound hammer number was predominantly increase in the concrete mix design with higher cement content (M5, M6, M2, and M3) as when compare to concrete mix design (M1 and M4). Variation of the rebound hammer number in the different concrete mix designs as against cement content were represent as in Figure 4-4 respectively.



	M4 = 0.5	M5 = 0.45	M6 = 0.44
🟦 M4 = 0.5	47.14	51.85	51.83
🟨 M1 = 0.45	51.10	51.96	53.35

Figure 4-3 RHN-w/c ratio variation in different concrete mixes



	M4 = 3.84
🟦 M4 = 3.84	47.14
🟨 M1 = 3.60	51.10
🟧 M5 = 4.27	51.85
⬜ M6 = 4.35	51.83
🟦 M2 = 4.35	51.96
🟩 M3= 5.43	53.35

Figure 4-4 RHN-cement content variation in different concrete mixes

4.2.2 Ultrasonic pulse velocity test on concrete cubes (UPVT)

The interpreted ultrasonic pulse velocity as well as compressive strength are average values taken on four sides of concrete cubes in the present research work with their variation as shown in (Figure 4-5). The ultrasonic pulse velocity value of the concrete cubes were proportionally (linearly) increased with compressive strength for in the case of all concrete mixtures type (M1-M6) respectively.

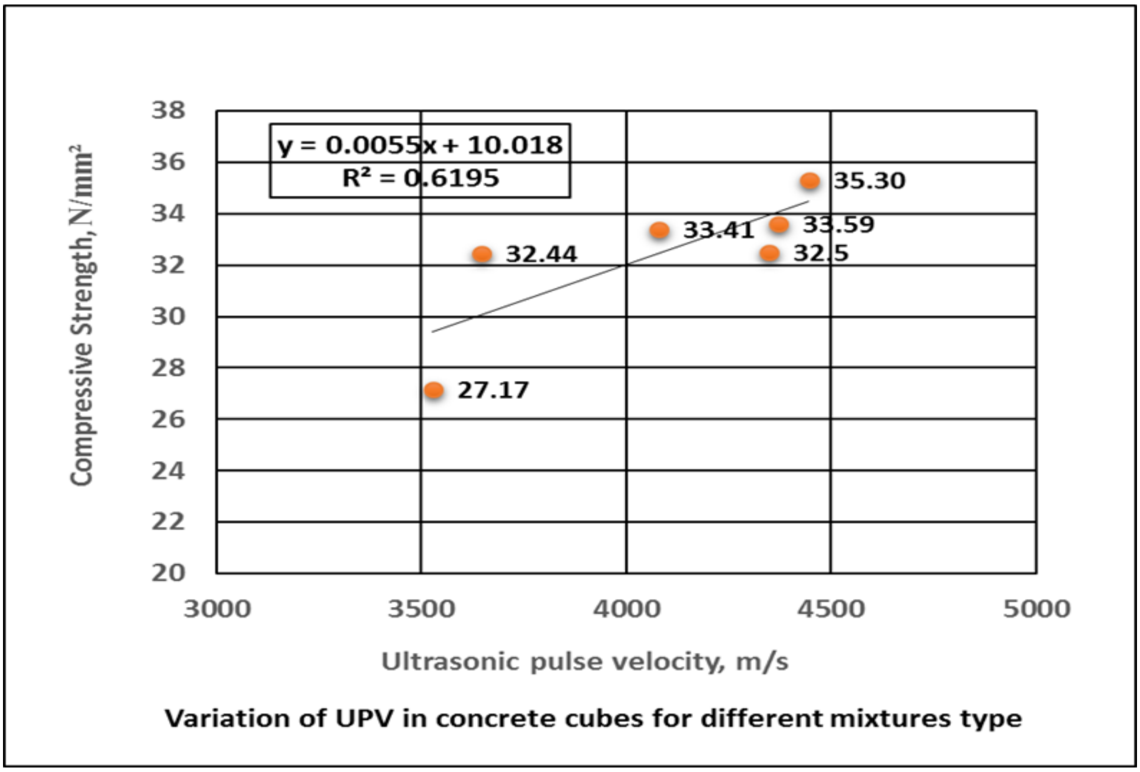
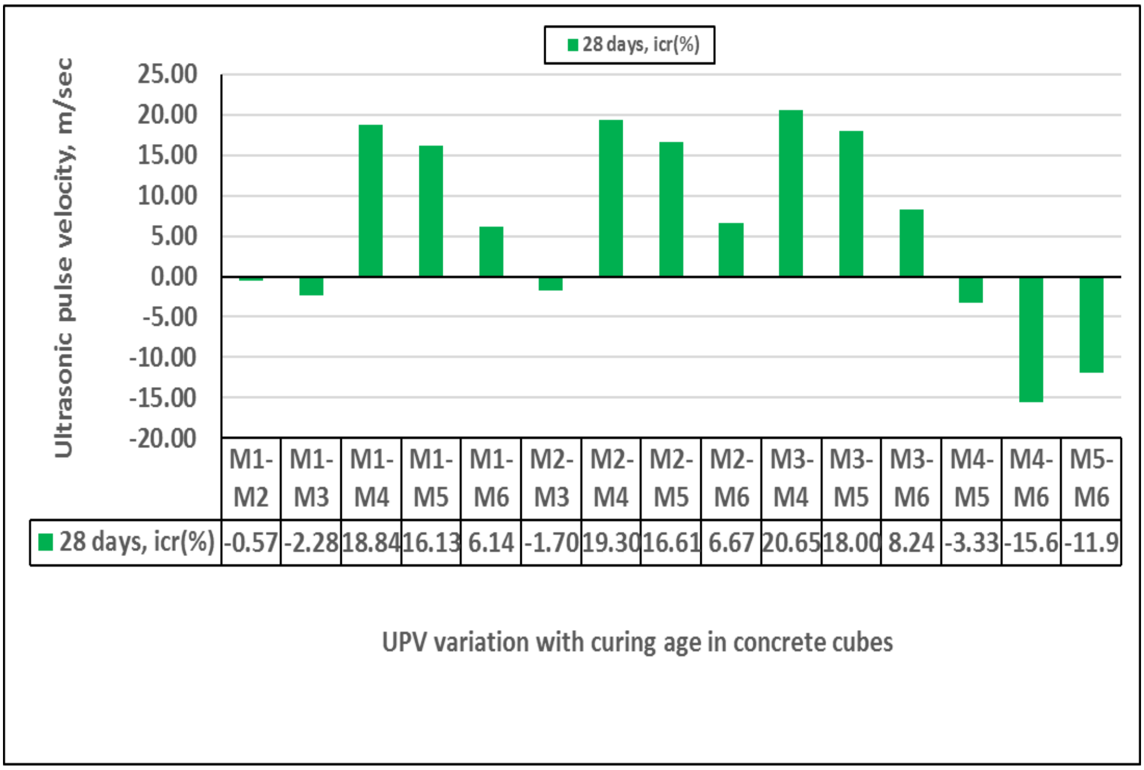


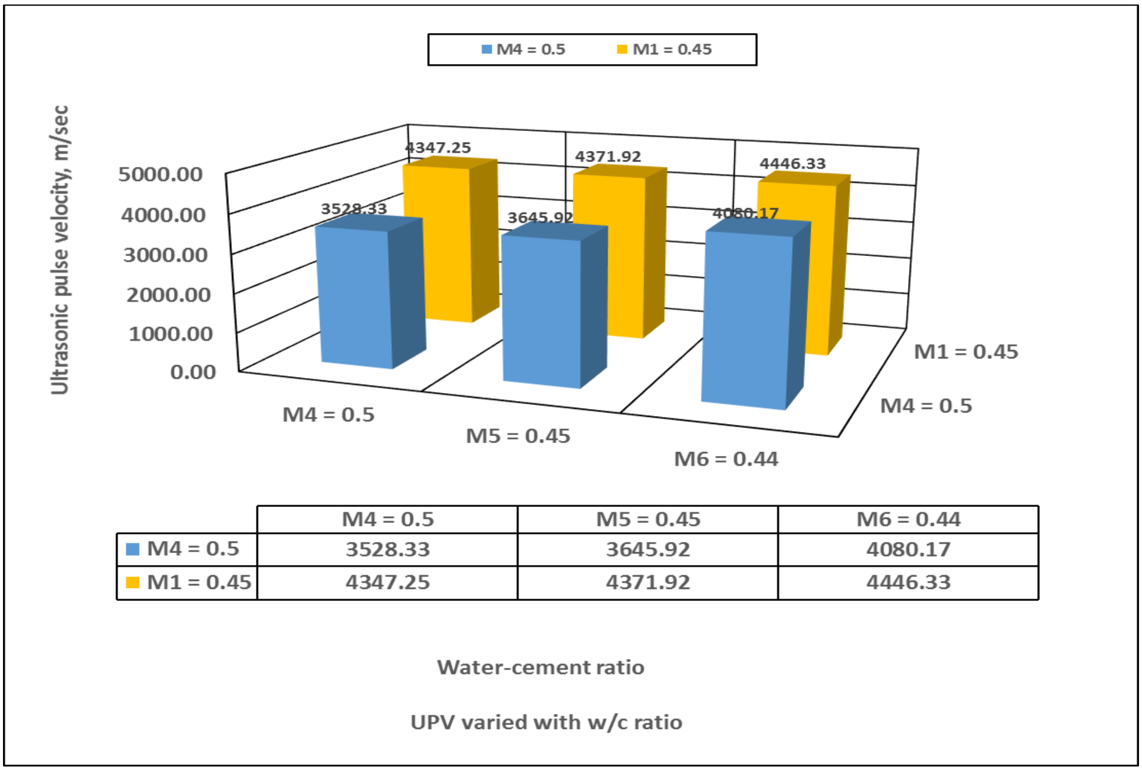
Figure 4-5 Variation of Ultrasonic pulse velocity with compressive strength

The ultrasonic pulse velocity was decrease in the concrete mix design (M4, M5 and M6) as when compared to concrete mix design (M1). Whereas the ultrasonic pulse velocity was increase in the concrete mix design (M2, and M3) as when compared to concrete mix design (M1). However, the ultrasonic pulse velocity was increase in the concrete mix design (M2) as against concrete mix design (M4, M5, and M6). In addition to that, the ultrasonic pulse velocity was decrease in the concrete mix design (M2) as when compared with the concrete mix design (M3) and ultrasonic pulse velocity was increase in the concrete mix design (M3) as against the concrete mix design (M4, M5, and M6). Similarly, the ultrasonic pulse velocity was decrease in the concrete mix design (M4) as when compare to the concrete mix design (M5 and M6) and it is also decrease in the concrete mix design (M5) as when compare to the mix design (M6). The variation of ultrasonic pulse velocity in the different concrete mix designs were represent as in the Figure 4-6.



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
🟩 28 days, icr(%)	-0.57	-2.28	18.84	16.13	6.14	-1.70	19.30	16.61	6.67	20.65	18.00	8.24	-3.33	-15.6	-11.9

Figure 4-6 Ultrasonic pulse velocity-curing age varied in different concrete mixes

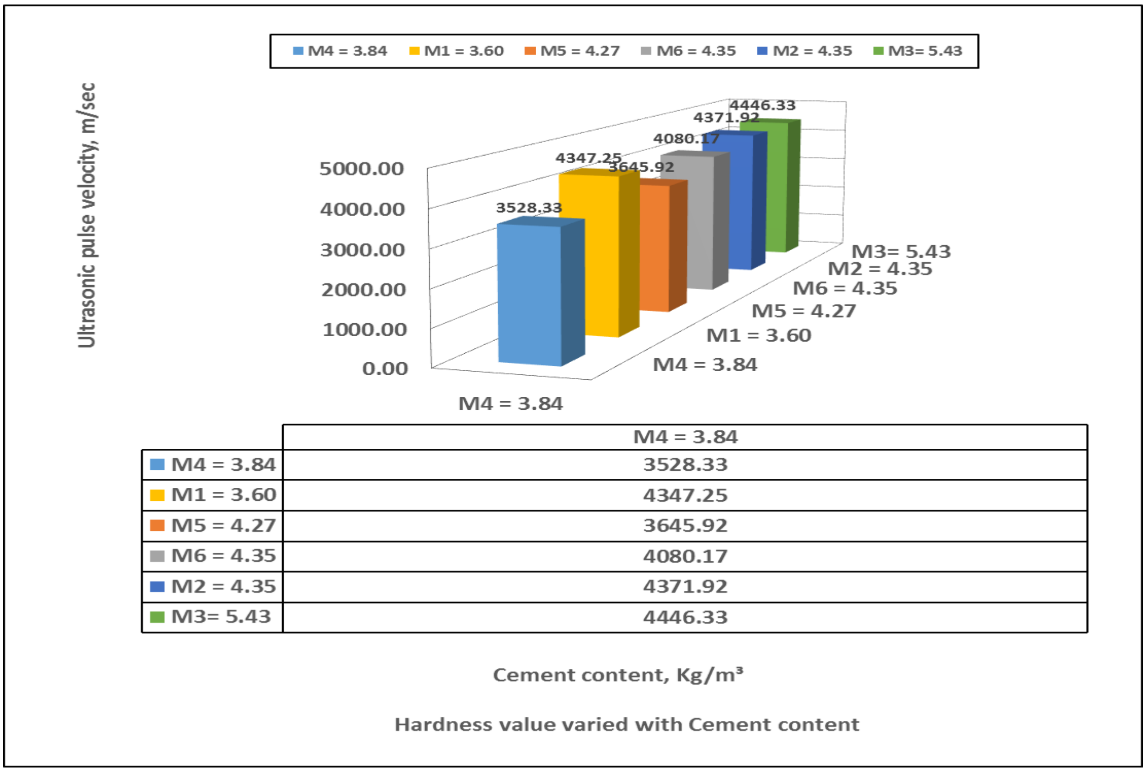


	M4 = 0.5	M5 = 0.45	M6 = 0.44
🟦 M4 = 0.5	3528.33	3645.92	4080.17
🟨 M1 = 0.45	4347.25	4371.92	4446.33

Figure 4-7 UPV-w/c ratio varied in different concrete mixes

The ultrasonic pulse velocity was increase in the concrete mix design with lower w/c ratio (M5 and M6) as when compare to concrete mix design (M4). Whereas the ultrasonic pulse velocity was, also increase in the concrete mix design (M1 and M2) with lower w/c ratio as when compared to concrete mix design (M3) with higher w/c ratio. The variation of rebound hammer number-w/c ratio in the different concrete mix designs were represent as in Figure 4-7 respectively. Its observed from the results that, the ultrasonic pulse velocity was predominantly increase in the concrete mix design with higher cement content (M5, M6, M2, and M3) as when compare to concrete mix design (M1 and M4). Variation of the ultrasonic pulse velocity in the different concrete mix designs as against cement content were represent as in

Figure 4-8 respectively.



	M4 = 3.84
🟦 M4 = 3.84	3528.33
🟨 M1 = 3.60	4347.25
🟧 M5 = 4.27	3645.92
⬜ M6 = 4.35	4080.17
🟦 M2 = 4.35	4371.92
🟩 M3= 5.43	4446.33

Figure 4-8 UPV-cement content varied in different concrete mixes

4.3 Sorptivity test on concrete cubes

4.3.1 Water absorption-time variation in concrete cubes

The variation of water absorption in concrete cubes at different time duration up to 28 days for all mixture type (M1-M6) was represent as shown in

Figure 4-9. The water absorption was slightly increase in the concrete mix design (M1) as when compare to concrete mix design (M3). Whereas the water absorption was predominantly increase in the concrete mix design (M2) as when compare to the concrete mix designs (M3, M5, and M6). However, the water absorption was predominantly increase in the concrete mix design (M4) as when compare to the mix designs (M5 and M6) respectively. The variation in the water absorption was very less in the concrete mix design (M5) as against the mix design (M6). Similarly, the water absorption was decrease in the concrete mix design (M1) as when compare to the concrete mix design (M2, M4, and M5) and it is also decrease in the concrete mix design (M2) as against the concrete mix design (M4). However, the water absorption was more increase in the concrete mix design (M3) as against the concrete mix design (M4) and it is slightly decrease in the concrete mix designs (M5 and M6) respectively.

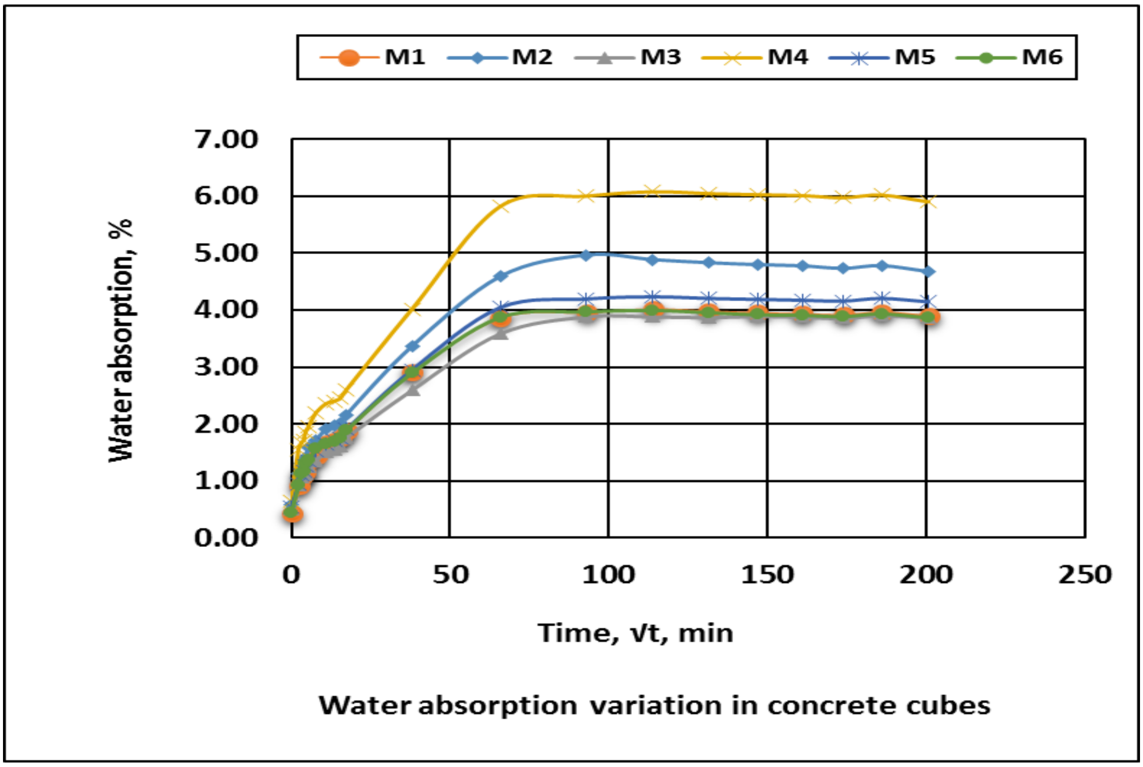
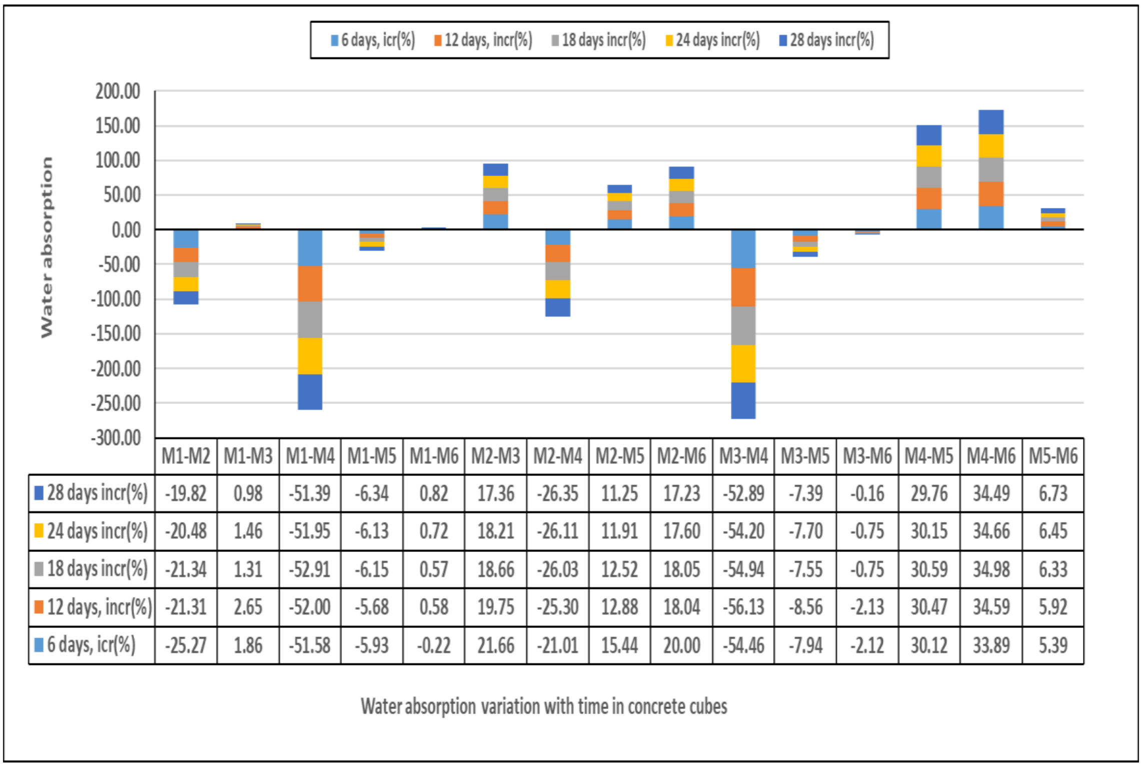


Figure 4-9 Water absorption-time variation in different concrete mixes

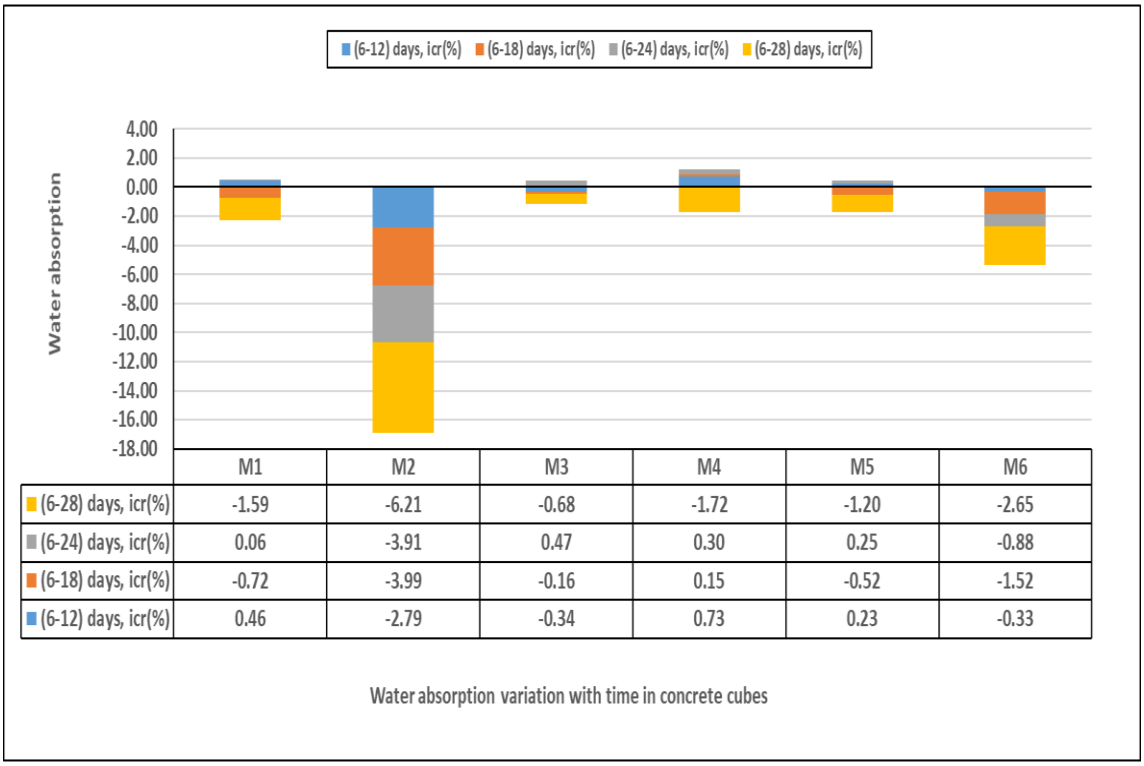


	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
28 days incr(%)	-19.82	0.98	-51.39	-6.34	0.82	17.36	-26.35	11.25	17.23	-52.89	-7.39	-0.16	29.76	34.49	6.73
24 days incr(%)	-20.48	1.46	-51.95	-6.13	0.72	18.21	-26.11	11.91	17.60	-54.20	-7.70	-0.75	30.15	34.66	6.45
18 days incr(%)	-21.34	1.31	-52.91	-6.15	0.57	18.66	-26.03	12.52	18.05	-54.94	-7.55	-0.75	30.59	34.98	6.33
12 days, incr(%)	-21.31	2.65	-52.00	-5.68	0.58	19.75	-25.30	12.88	18.04	-56.13	-8.56	-2.13	30.47	34.59	5.92
6 days, icr(%)	-25.27	1.86	-51.58	-5.93	-0.22	21.66	-21.01	15.44	20.00	-54.46	-7.94	-2.12	30.12	33.89	5.39

Water absorption variation with time in concrete cubes

Figure 4-10 Water absorption-time variation in different concrete mixes

An overall water absorption variation in the concrete cubes at different time duration in all mixtures type (M1-M6) was represent as shown in (Figure 4-10 and Figure 4-11)



	M1	M2	M3	M4	M5	M6
(6-28) days, icr(%)	-1.59	-6.21	-0.68	-1.72	-1.20	-2.65
(6-24) days, icr(%)	0.06	-3.91	0.47	0.30	0.25	-0.88
(6-18) days, icr(%)	-0.72	-3.99	-0.16	0.15	-0.52	-1.52
(6-12) days, icr(%)	0.46	-2.79	-0.34	0.73	0.23	-0.33

Water absorption variation with time in concrete cubes

Figure 4-11 Water absorption-time variation in concrete cubes

4.3.2 Water absorption-sorptivity coefficient variation in concrete cubes

The variation of water absorption with sorptivity coefficient in concrete cubes at different time duration up to 28 days for all mixture type (M1-M6) was represent as shown in Figure 4-12. The water absorption was increase in different concrete mix design at an initial time duration for lower sorptivity coefficient value. It has correlated by exponential relationship between water absorption and sorptivity coefficient. The variation in water absorption value was lesser for in case of higher compressive strength and varied slump value as when compare to lower concrete compressive strength as well as for constant slump value. Also the variation of water diffusion coefficient with water absorption in concrete cubes at different time duration up to 28 days for all mixture type (M1-M6) was represent as shown in

Figure *4-13*. As observed from the results that, the water diffusion coeffient was predominantly increase for lower water absorption value and its goes on reduces with increase in water absorption in all concrete mix design. It is also confirm from the results that, the water diffusion coefficient-water absorption variation was reduce for in case of higher concrete compressive strength and varied slump value.

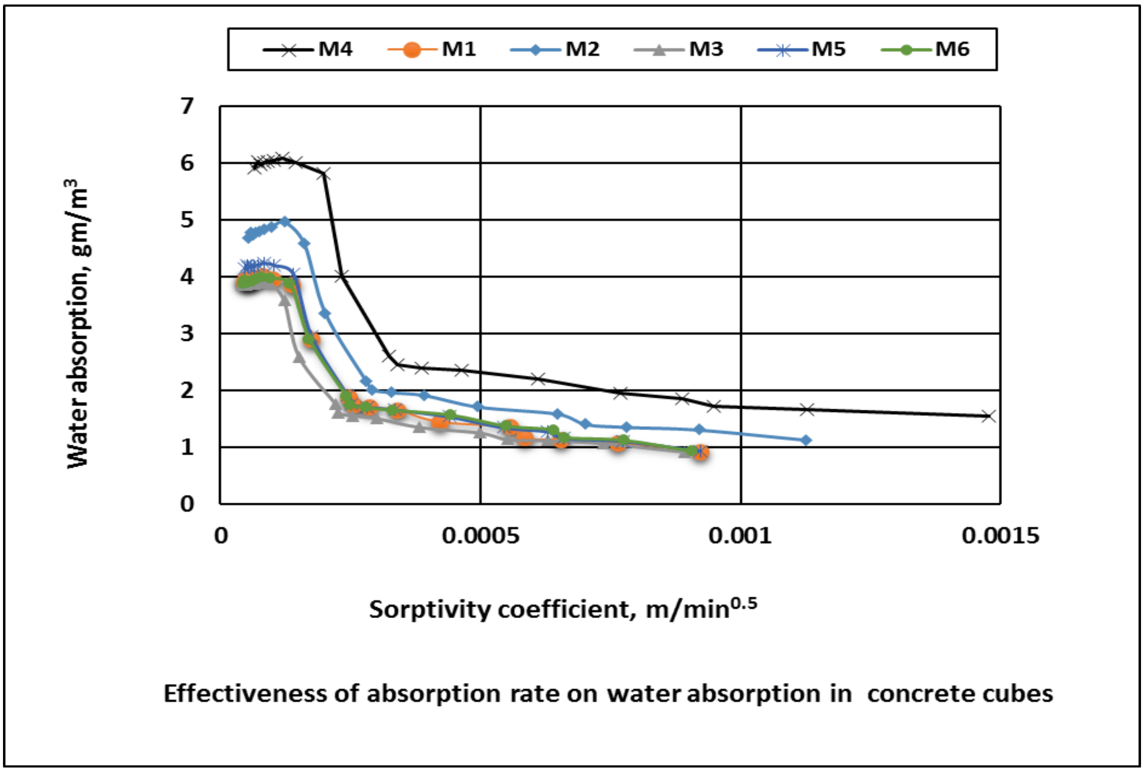


Figure 4-12 Water absorption-sorptivity coefficient in different concrete mixes

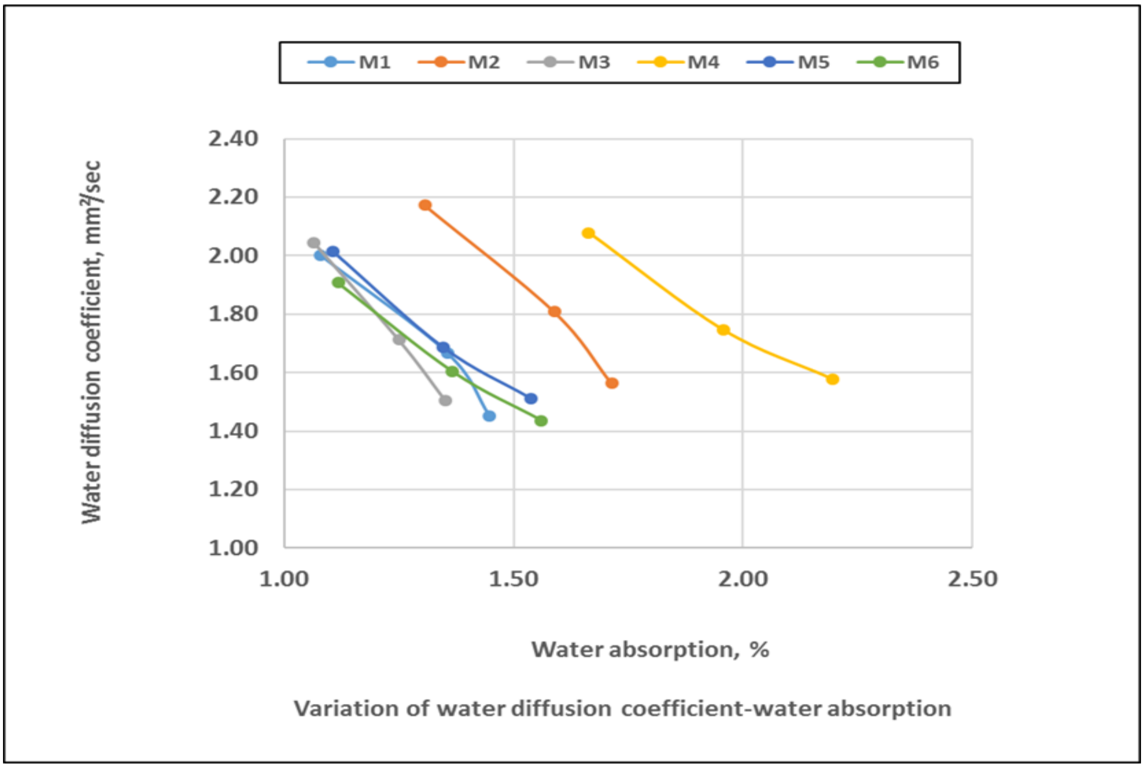


Figure 4-13 Water diffusion coefficient-water absorption in different concrete mixes

4.3.3 Moisture content-time variation in concrete cubes

The moisture content variation in concrete cubes at different time duration up to 28 days for all mixture type (M1-M6) was represent as shown in Figure 4-14. It is also possible to compare the moisture content-time variation in the different concrete mix designs that is represent as shown in (Figure 4-15 and Figure 4-16).

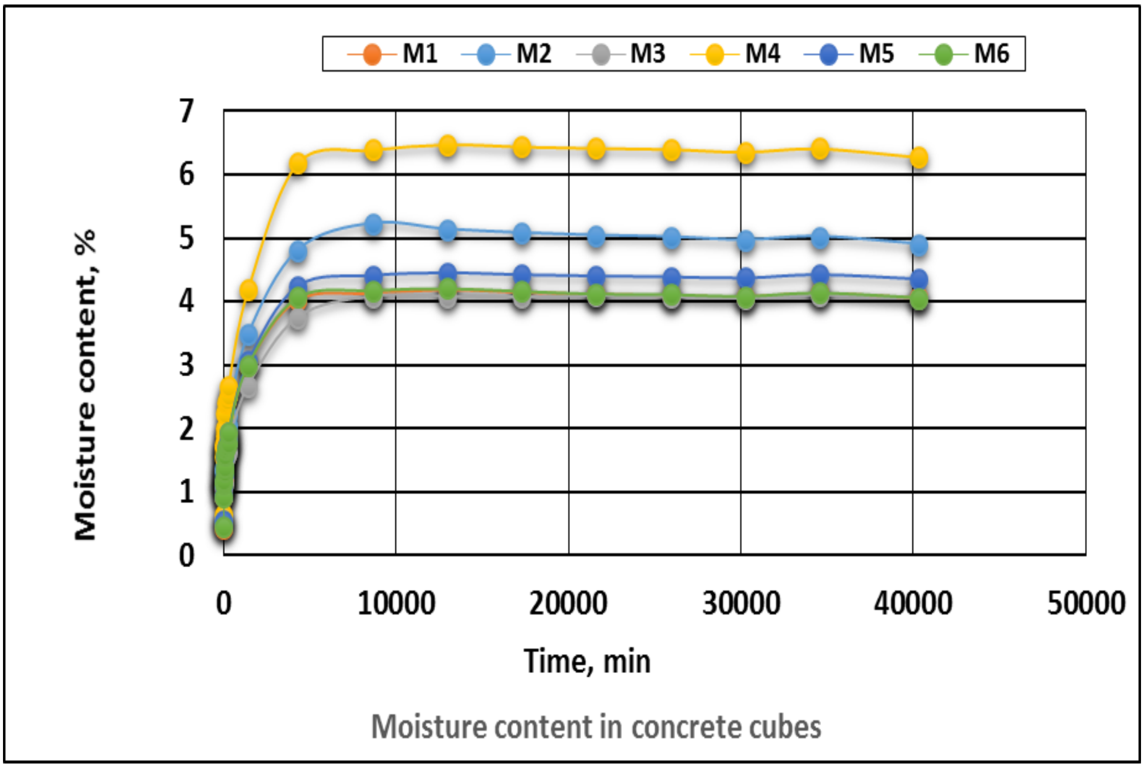
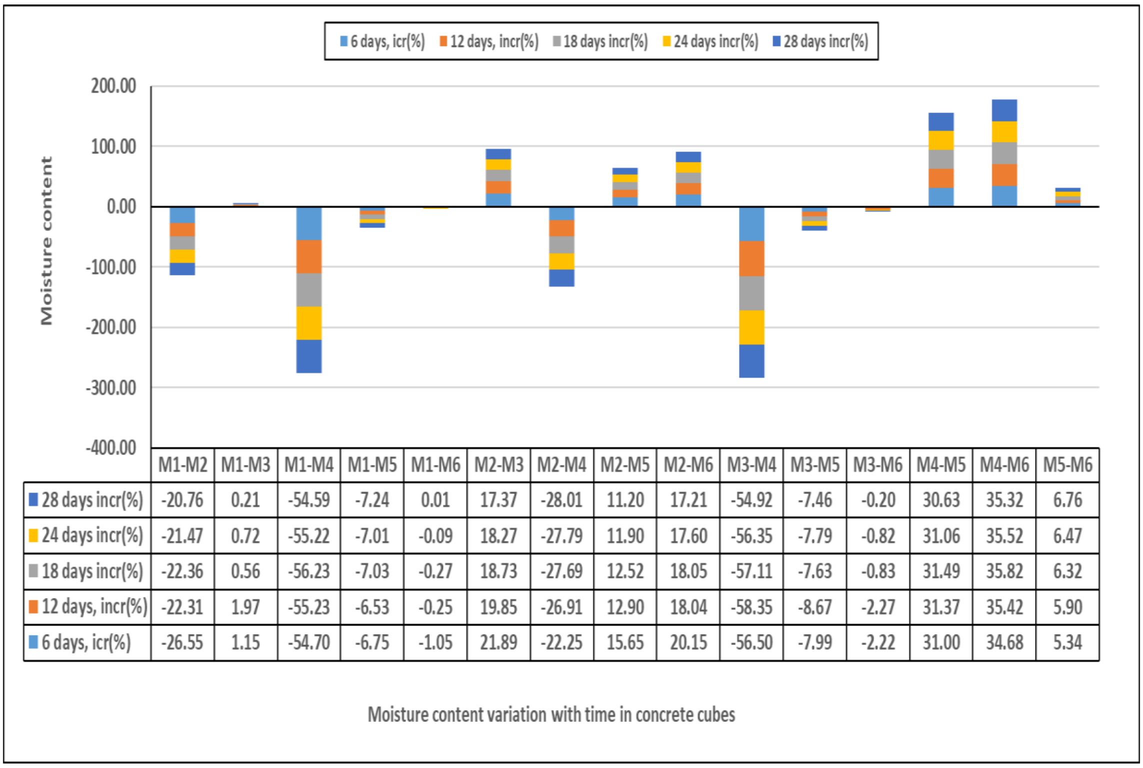


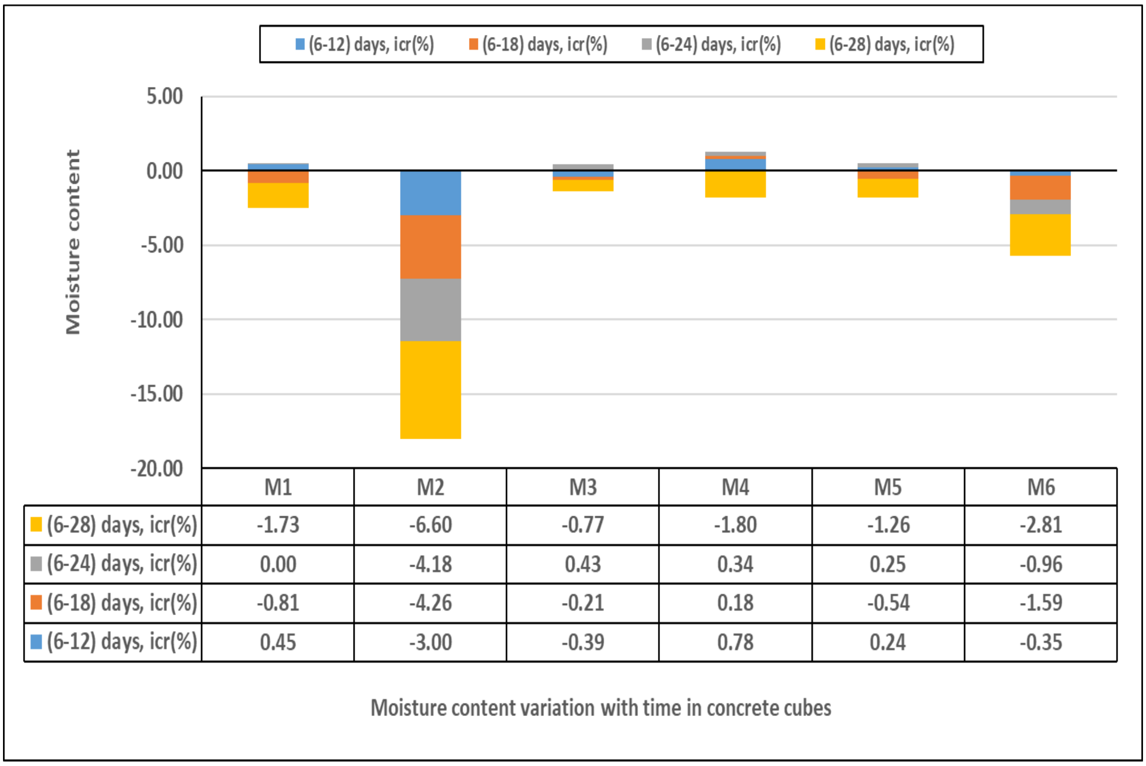
Figure 4-14 Moisture content-time in different concrete mixes

The moisture content was decrease in the concrete mix design (M1) as when compare to concrete mix design (M2, M4, and M5). Whereas the moisture content in the concrete mix design (M2) was decrease as when compare to the concrete mix designs (M5, and M6). However, the moisture content was predominantly decrease in the concrete mix design (M3) as when compare to the mix designs (M4, M5 and M6) respectively. Similarly, the moisture content was decrease in the concrete mix design (M4 and M5) as when compare to the concrete mix design (M6).



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
■ 28 days incr(%)	-20.76	0.21	-54.59	-7.24	0.01	17.37	-28.01	11.20	17.21	-54.92	-7.46	-0.20	30.63	35.32	6.76
■ 24 days incr(%)	-21.47	0.72	-55.22	-7.01	-0.09	18.27	-27.79	11.90	17.60	-56.35	-7.79	-0.82	31.06	35.52	6.47
■ 18 days incr(%)	-22.36	0.56	-56.23	-7.03	-0.27	18.73	-27.69	12.52	18.05	-57.11	-7.63	-0.83	31.49	35.82	6.32
■ 12 days, incr(%)	-22.31	1.97	-55.23	-6.53	-0.25	19.85	-26.91	12.90	18.04	-58.35	-8.67	-2.27	31.37	35.42	5.90
■ 6 days, icr(%)	-26.55	1.15	-54.70	-6.75	-1.05	21.89	-22.25	15.65	20.15	-56.50	-7.99	-2.22	31.00	34.68	5.34

Figure 4-15 Moisture content-time increase at different time interval



	M1	M2	M3	M4	M5	M6
■ (6-28) days, icr(%)	-1.73	-6.60	-0.77	-1.80	-1.26	-2.81
■ (6-24) days, icr(%)	0.00	-4.18	0.43	0.34	0.25	-0.96
■ (6-18) days, icr(%)	-0.81	-4.26	-0.21	0.18	-0.54	-1.59
■ (6-12) days, icr(%)	0.45	-3.00	-0.39	0.78	0.24	-0.35

Figure 4-16 Moisture content-time increase in different concrete mixes

4.3.4 Cumulative absorption-time variation in concrete cubes

The variation of cumulative absorption in concrete cubes for different mixtures type (M1-M6) was as shown in the

Figure *4-17*. The cumulative absorption was varied proportional (linearly) to time duration up to certain time and after that, the cumulative absorption was slightly decline with time interval as well as saturation of pore structure within the concrete matrix. The cumulative absorption variation in the concrete cubes at different time interval up to 28 days for all mixture type (M1-M6) was represent as shown in

Figure *4-18*. The cumulative absorption was decrease in the concrete mix design (M1) as when compare to concrete mix design (M2, M4, and M5) and its increase in the concrete mix design (M1) as against the concrete mix design (M3 and M6). Whereas, the cumulative absorption in the concrete mix design (M2) was increase as when compare to the concrete mix designs (M3, and M5). However, the cumulative absorption was predominantly decrease in the concrete mix design (M2) as when compare to the mix designs (M4) respectively. Similarly, the cumulative absorption was decrease in the concrete mix design (M3) as when compare to the concrete mix design (M4, M5, and M6) respectively. However, the cumulative absorption was increase in the concrete mix design (M4) as when compare to the concrete mix designs (M5 and M6) as well as its also increase in the concrete mix design (M5) as against the concrete mix design (M6).

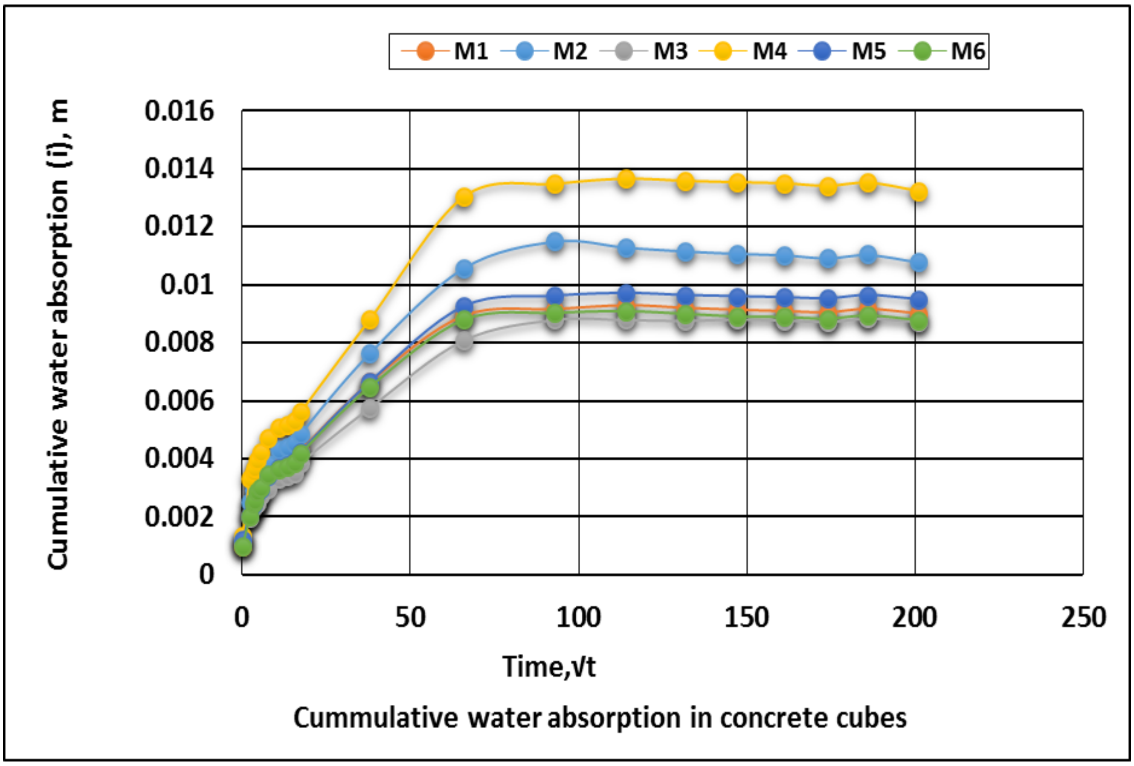
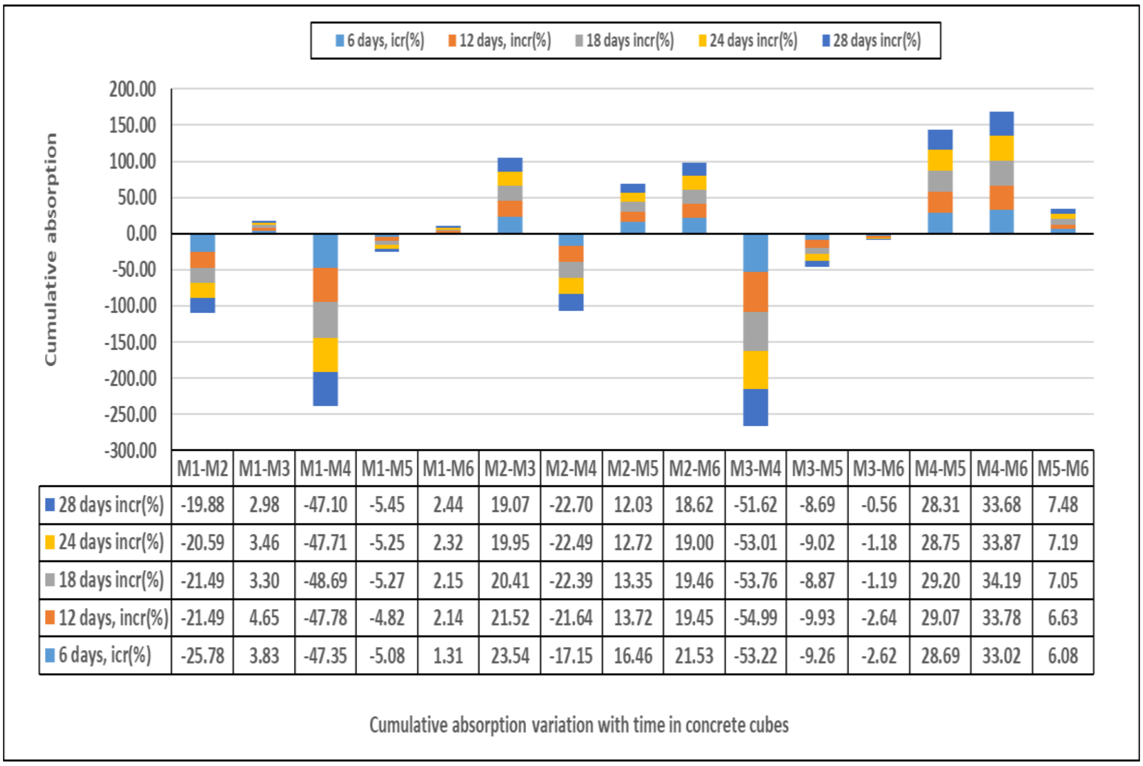


Figure 4-17 Cumulative absorption in concrete cubes for different concrete mixes



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
■ 28 days incr(%)	-19.88	2.98	-47.10	-5.45	2.44	19.07	-22.70	12.03	18.62	-51.62	-8.69	-0.56	28.31	33.68	7.48
■ 24 days incr(%)	-20.59	3.46	-47.71	-5.25	2.32	19.95	-22.49	12.72	19.00	-53.01	-9.02	-1.18	28.75	33.87	7.19
■ 18 days incr(%)	-21.49	3.30	-48.69	-5.27	2.15	20.41	-22.39	13.35	19.46	-53.76	-8.87	-1.19	29.20	34.19	7.05
■ 12 days, incr(%)	-21.49	4.65	-47.78	-4.82	2.14	21.52	-21.64	13.72	19.45	-54.99	-9.93	-2.64	29.07	33.78	6.63
■ 6 days, icr(%)	-25.78	3.83	-47.35	-5.08	1.31	23.54	-17.15	16.46	21.53	-53.22	-9.26	-2.62	28.69	33.02	6.08

Figure 4-18 Cumulative absorption-time variation in different concrete mixes

4.3.5 Sorptivity coefficient-time variation in concrete cubes

The interpretation of average sorptivity coefficient at different time interval in the concrete cubes for different mixtures type (M1-M6) was as shown in

Figure *4-19*. The variation of sorptivity coefficient at different time interval was correlate by a power type of equation for in case of various concrete mixtures type with correlation equation Y = $0.0017x^{-0.644}$ and ($R^2 = 0.9921$) respectively.

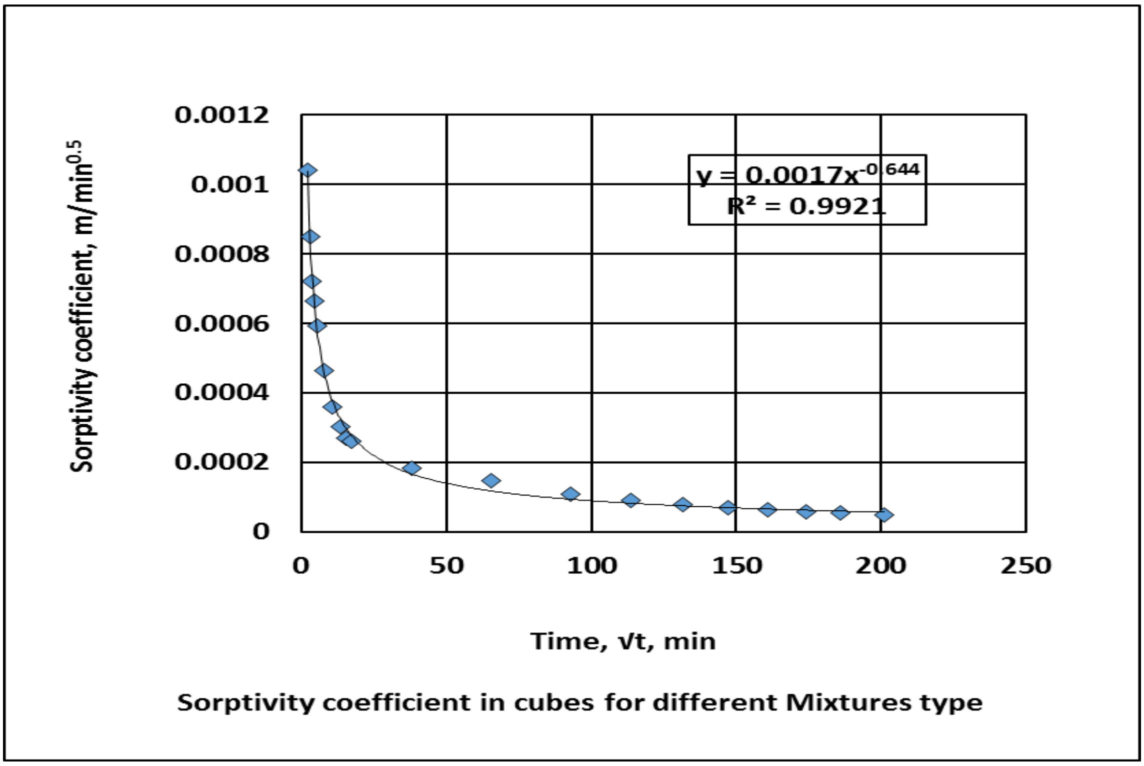
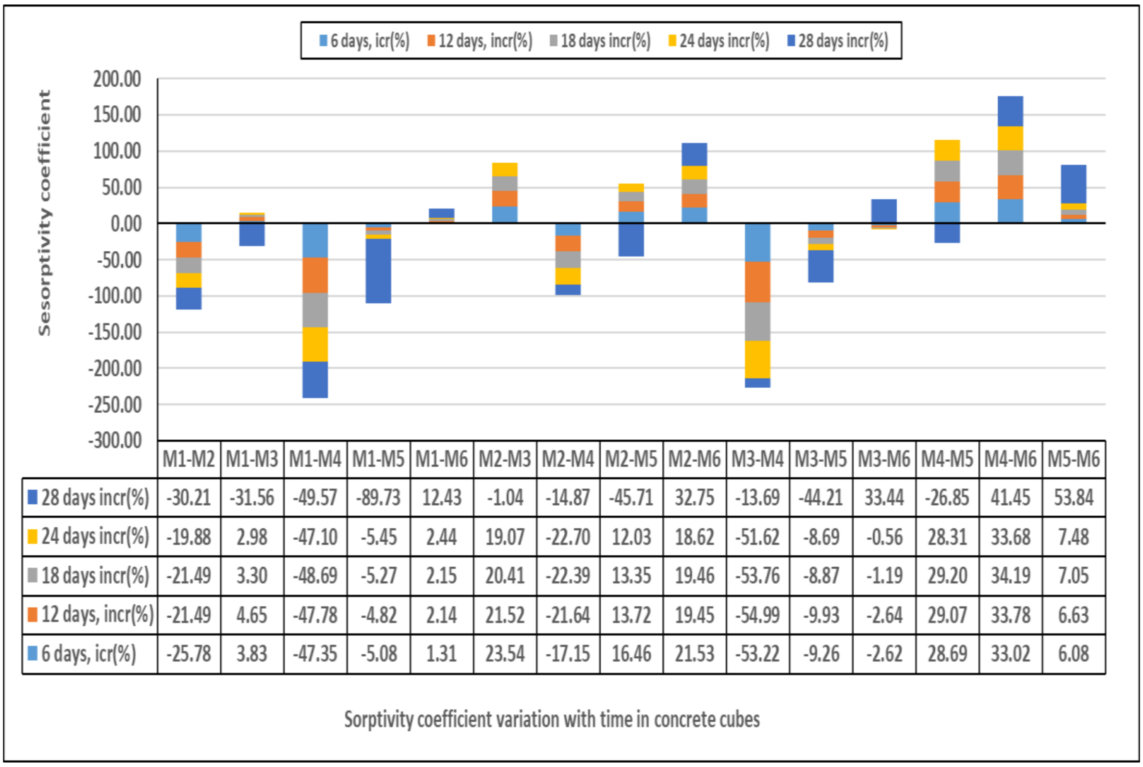


Figure 4-19 Sorptivity coefficient-time in different concrete mixes

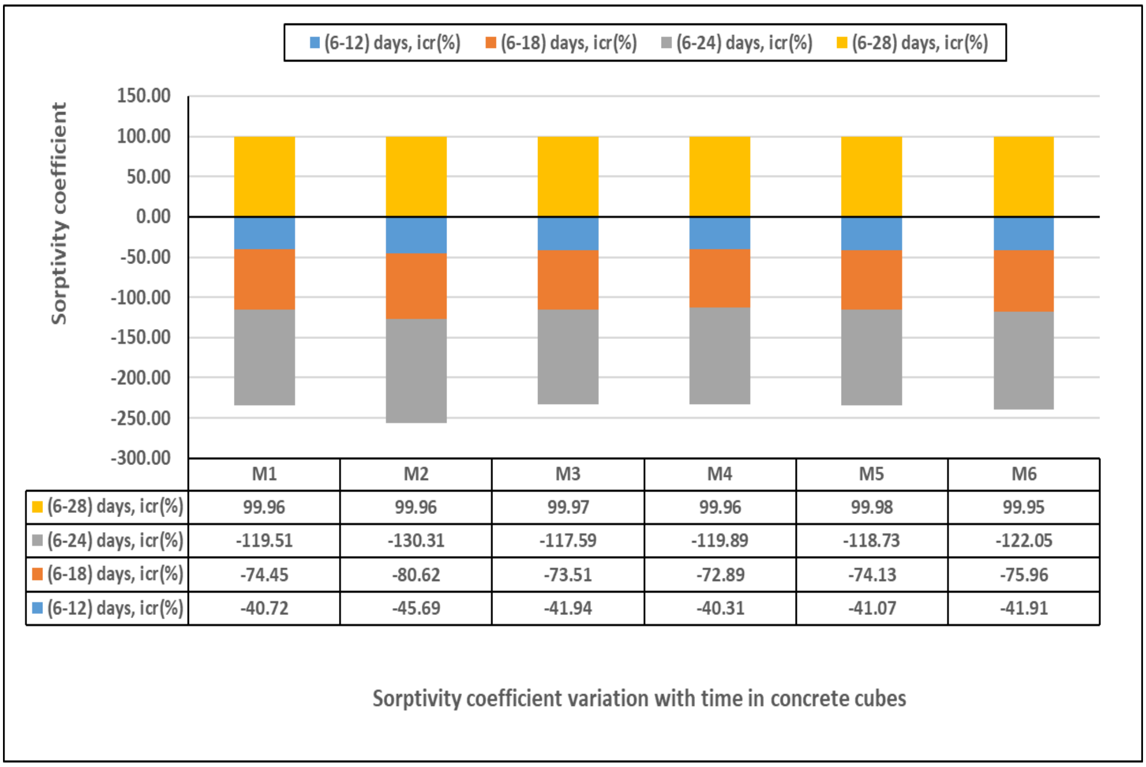
As observed from the results (
Figure 4-20 and
Figure 4-21) that, the sorptivity coefficient was vary parabolically to time duration up to certain time and after that, it was goes on reduces with time interval as well as saturation of pore structure within the concrete matrix. The sorptivity coefficient was decrease in the concrete mix design (M1) as when compare to concrete mix design (M2, M3, M4, and M5) and its increase in the concrete mix design (M1) as against the concrete mix design (M6). Whereas, the sorptivity coefficient in the concrete mix design (M2) was decrease as when compare to the concrete mix designs (M3,

M4, and M5). However, the sorptivity coefficient was increase in the concrete mix design (M2) as when compare to the mix designs (M6) respectively. Similarly, the sorptivity coefficient was decrease in the concrete mix design (M3) as when compare to the concrete mix design (M4, and M5) respectively. However, the sorptivity was decrease in the concrete mix design (M4) as when compare to the concrete mix designs (M5) as well as its also increase in the concrete mix design (M4) as against the concrete mix design (M6). Whereas in the case of concrete mix design (M5), the sorptivity coefficient was decrease as when compare to the concrete mix design (M6).



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
28 days incr(%)	-30.21	-31.56	-49.57	-89.73	12.43	-1.04	-14.87	-45.71	32.75	-13.69	-44.21	33.44	-26.85	41.45	53.84
24 days incr(%)	-19.88	2.98	-47.10	-5.45	2.44	19.07	-22.70	12.03	18.62	-51.62	-8.69	-0.56	28.31	33.68	7.48
18 days incr(%)	-21.49	3.30	-48.69	-5.27	2.15	20.41	-22.39	13.35	19.46	-53.76	-8.87	-1.19	29.20	34.19	7.05
12 days, incr(%)	-21.49	4.65	-47.78	-4.82	2.14	21.52	-21.64	13.72	19.45	-54.99	-9.93	-2.64	29.07	33.78	6.63
6 days, icr(%)	-25.78	3.83	-47.35	-5.08	1.31	23.54	-17.15	16.46	21.53	-53.22	-9.26	-2.62	28.69	33.02	6.08

Figure 4-20 Sorptivity coefficient-time in different concrete mixes



	M1	M2	M3	M4	M5	M6
🟨 (6-28) days, icr(%)	99.96	99.96	99.97	99.96	99.98	99.95
⬜ (6-24) days, icr(%)	-119.51	-130.31	-117.59	-119.89	-118.73	-122.05
🟧 (6-18) days, icr(%)	-74.45	-80.62	-73.51	-72.89	-74.13	-75.96
🟦 (6-12) days, icr(%)	-40.72	-45.69	-41.94	-40.31	-41.07	-41.91

Figure 4-21 Sorptivity coefficient-time variation in different concrete mixes

4.3.6 Sorptivity coefficient-cumulative absorption variation in concrete cubes

Its confirm from the results that, the sorptivity coefficient with cumulative absorption in the concrete cubes for in case of different mixtures type was represent as in the

Figure *4-22*. It is observe from the results that, the sorptivity coefficient was increase at lower cumulative absorption in all the concrete mix design. It is also observe from the results that, the sorptivity coefficient was slightly lower at lower cumulative absorption value for in case of concrete mix design (M1-M3) as when compare to concrete mix design (M4-M6) respectively.

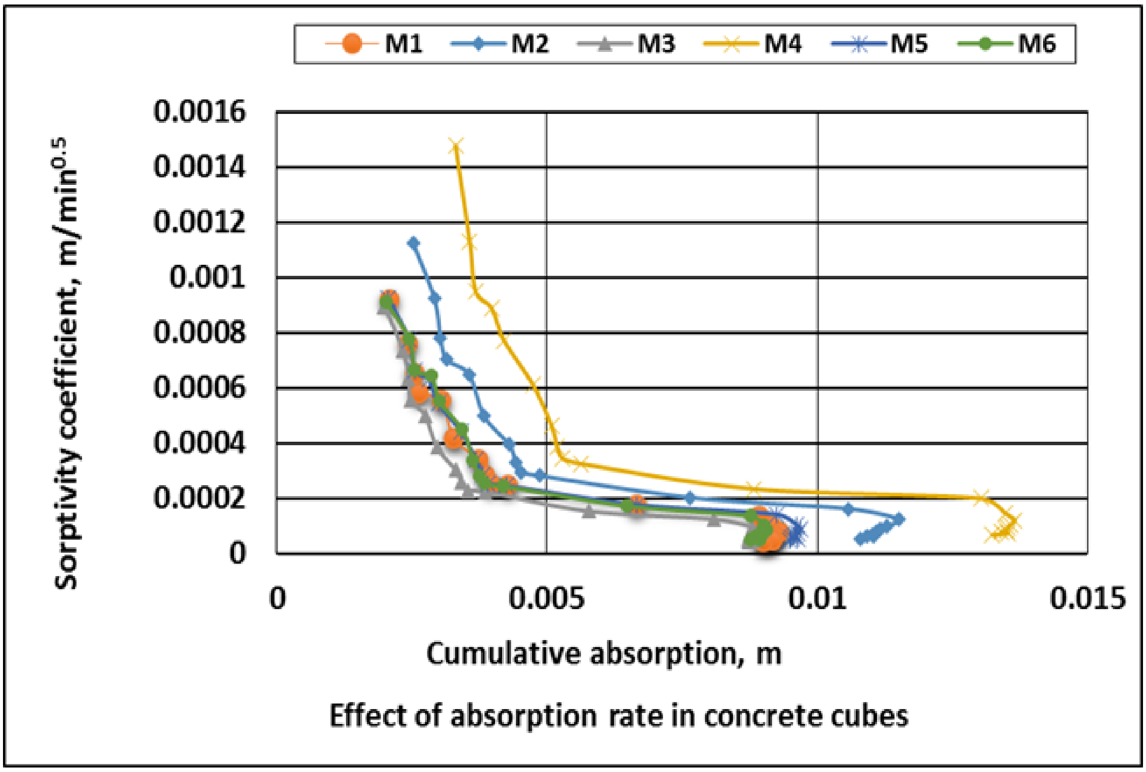


Figure 4-22 Sorptivity coefficient-cumulative absorption in different concrete mixes

4.3.7 Water diffusion coefficient-time variation in concrete cubes

The average diffusion coefficient in concrete cubes for different mixtures type (M1-M6) as shown in Figure 4-23. The variation of water diffusion coefficient at different time interval was correlate by a logarithmic type of equation for in case of various concrete mixtures type with correlation equation $Dw = -0.345\ln(\sqrt{t})+2.2999$ and ($R^2 = 0.9652$) respectively. As observed from the results (Figure *4-24* and Figure *4-25*) that, the water diffusion coefficient was higher at an initial time duration up to certain time and after that, it was goes on reduces with time interval for in case of all designed concrete mix. The water diffusion coefficient was decrease in the concrete mix design (M1) as when compare to concrete mix design (M2, M3, M4, and M5) and its increase in the concrete mix design (M1) as against the concrete mix design (M6). Water diffusion coefficient in the concrete mix design (M2) was decrease as when compare to the concrete mix designs (M3, M4, and M5).

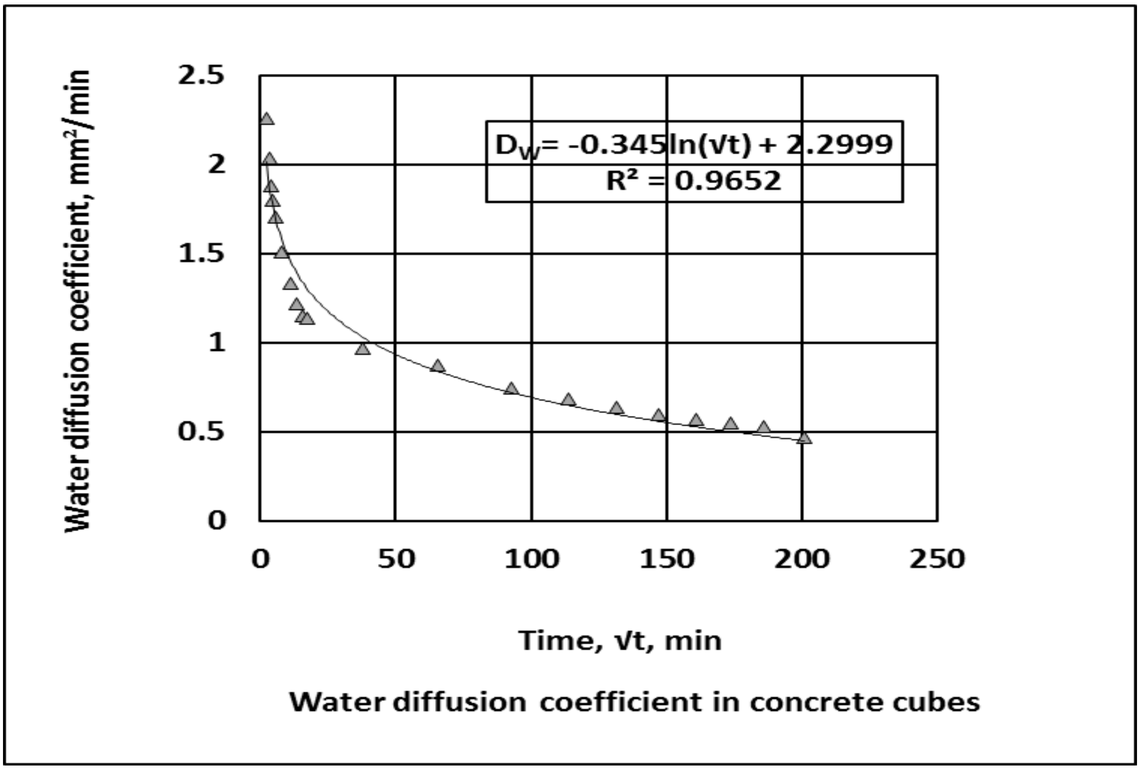
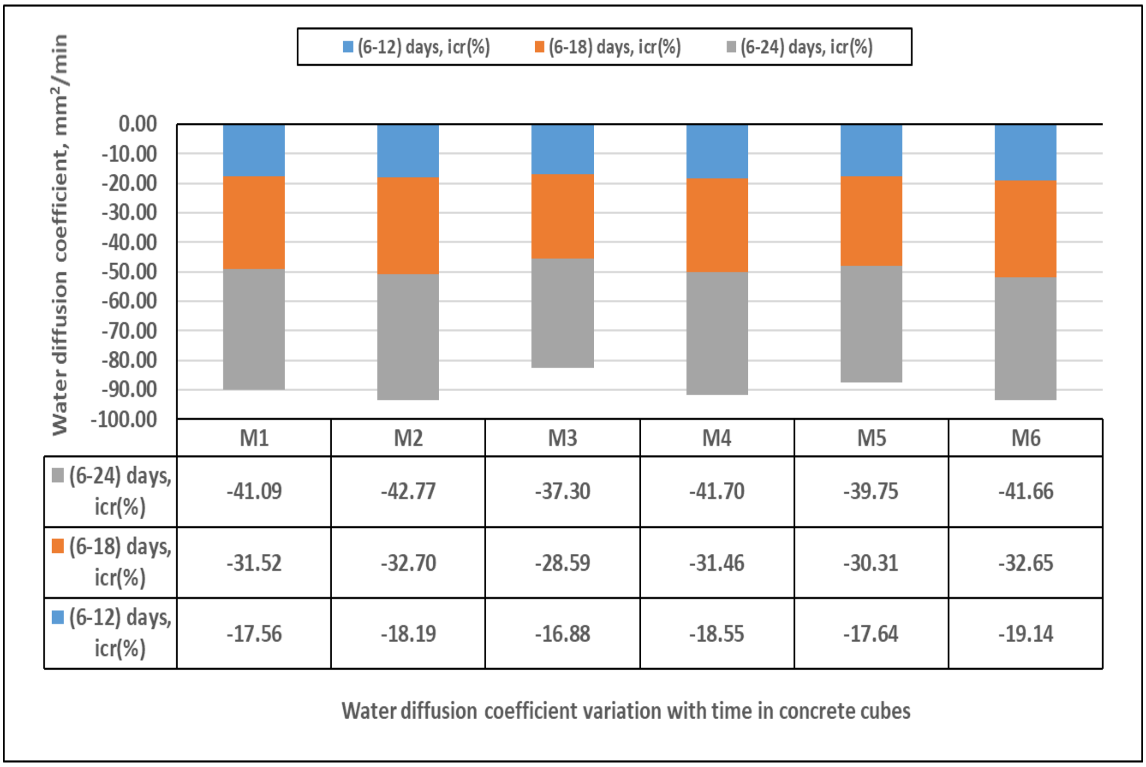


Figure 4-23 Water diffusion coefficient-time variation in different concrete mixes

	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
24 days incr(%)	-5.24	-11.86	-20.08	-8.98	5.93	-6.29	-14.10	-3.56	10.62	-7.35	2.57	15.91	9.24	21.67	13.69
18 days incr(%)	-5.55	-11.33	-20.65	-8.95	6.36	-5.48	-14.31	-3.23	11.28	-8.37	2.14	15.89	9.70	22.39	14.05
12 days, incr(%)	-5.93	-9.49	-19.60	-7.88	6.80	-3.36	-12.91	-1.84	12.02	-9.23	1.47	14.88	9.80	22.07	13.61
6 days, icr(%)	-6.50	-8.86	-20.61	-7.95	5.55	-2.21	-13.25	-1.37	11.31	-10.79	0.83	13.23	10.49	21.69	12.51

Figure 4-24 Water diffusion coefficient-time variation in different concrete mixes

However, the water diffusion coefficient was increase in the concrete mix design (M2) as when compare to the mix designs (M6) respectively. Similarly, the water diffusion coefficient was decrease in the concrete mix design (M3) as when compare to the concrete mix design (M4) respectively. However, the water diffusion coefficient was increase in the concrete mix design (M3) as when compare to the concrete mix designs (M5 and M6). Whereas in the case of concrete mix design (M4), the water diffusion coefficient was increase as when compare to the concrete mix design (M5 and M6). In addition to that, the water diffusion coefficient in the concrete mix design (M5) increase as when compare to the concrete mix design (M6).



	M1	M2	M3	M4	M5	M6
(6-24) days, icr(%)	-41.09	-42.77	-37.30	-41.70	-39.75	-41.66
(6-18) days, icr(%)	-31.52	-32.70	-28.59	-31.46	-30.31	-32.65
(6-12) days, icr(%)	-17.56	-18.19	-16.88	-18.55	-17.64	-19.14

Figure 4-25 Water diffusion coefficient-time variation in different concrete mixes

4.3.8 Water diffusion coefficient-moisture content variation in concrete cubes

The variation of water diffusion coefficient with moisture content value for in case of different mixtures type as shown in Figure 4-26 . It is confirm from the results that, the water diffusion coefficient was decrease at higher moisture content in the concrete mix design (M1-M3). Also, for higher the moisture content, the water diffusion coefficient was further decrease for in case of concrete mix design (M4-M6).

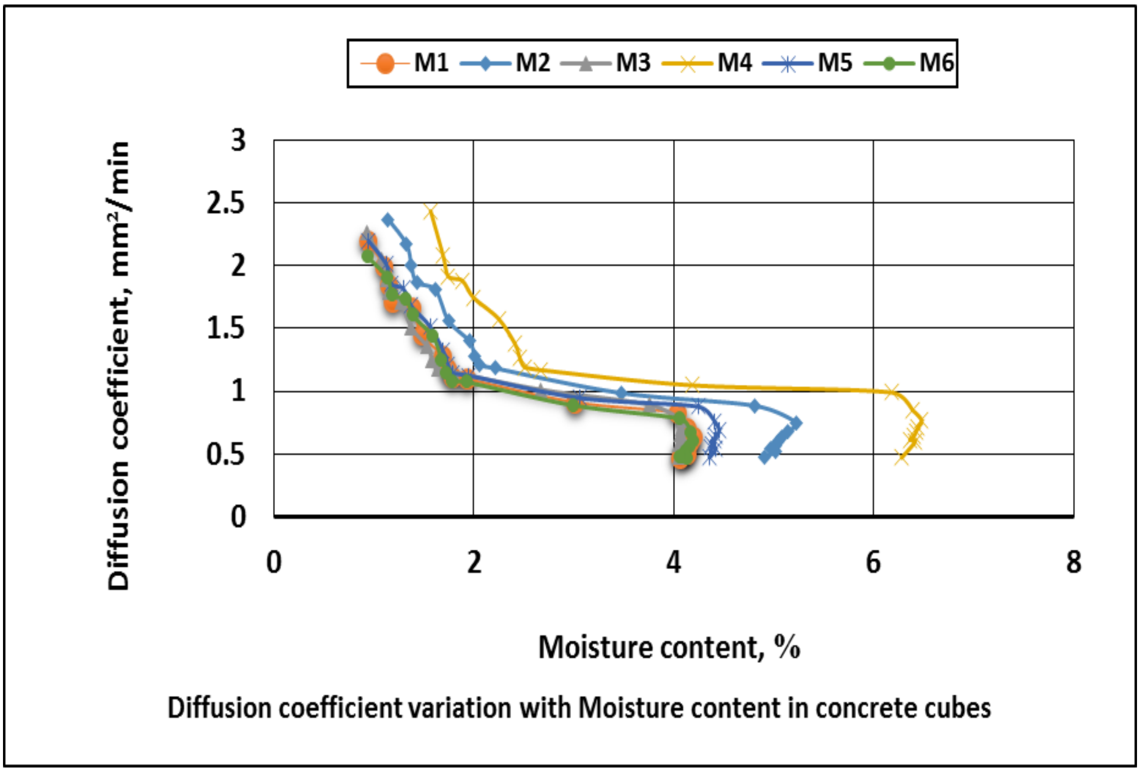


Figure 4-26 Relationship between Water diffusion coefficient-moisture content

4.3.9 Moisture content ratio coefficient-time variation in concrete cubes

The variation of moisture content at any particular time duration to moisture content at an infinite time duration was studied in the present research work for in case of designed mixtures type (M1-M6) at different time duration which was represented as shown in

Figure *4-27*. The moisture content ratio coefficient was linearly increase with certain time duration and after that, the moisture content coefficient ratio was goes on decrease with time and finally reaches equilibrium state. The moisture content ratio was decrease for in case of concrete mix design (M1) as when compare to the concrete mix design (M2, M4, and M5) and its increase in the concrete mix design (M1) as when compared to the concrete mix design (M3 and M6). For in case of concrete mix design (M2), the moisture content ratio coefficient was increase as when compare to the concrete mix design (M3, M5 and M6) and its decrease as against the concrete mix design (M4). The moisture content ratio coefficient was decrease in the concrete mix design (M3) as against the concrete mix design (M4 and M5) and its increase in the concrete mix design (M6). For in case of concrete mix design, the moisture content ratio coefficient (M4), is confirm to be predominantly increase as when compare to the concrete mix design (M5 and M6). For in the concrete mix design (M5), the moisture content ratio coefficient was to be highly decrease as when compare to the concrete mix design (M6). The variation of moisture content ratio coefficient with time was represent as shown in the following (Figure 4-28 and Figure 4-29).

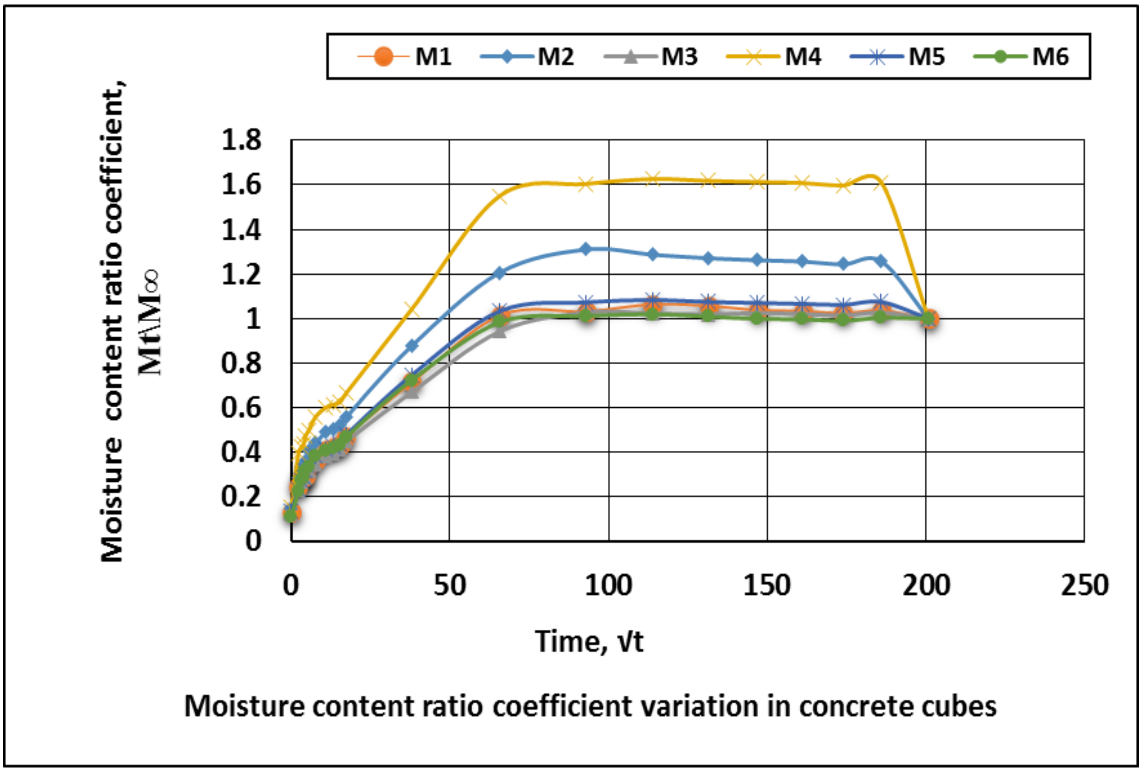
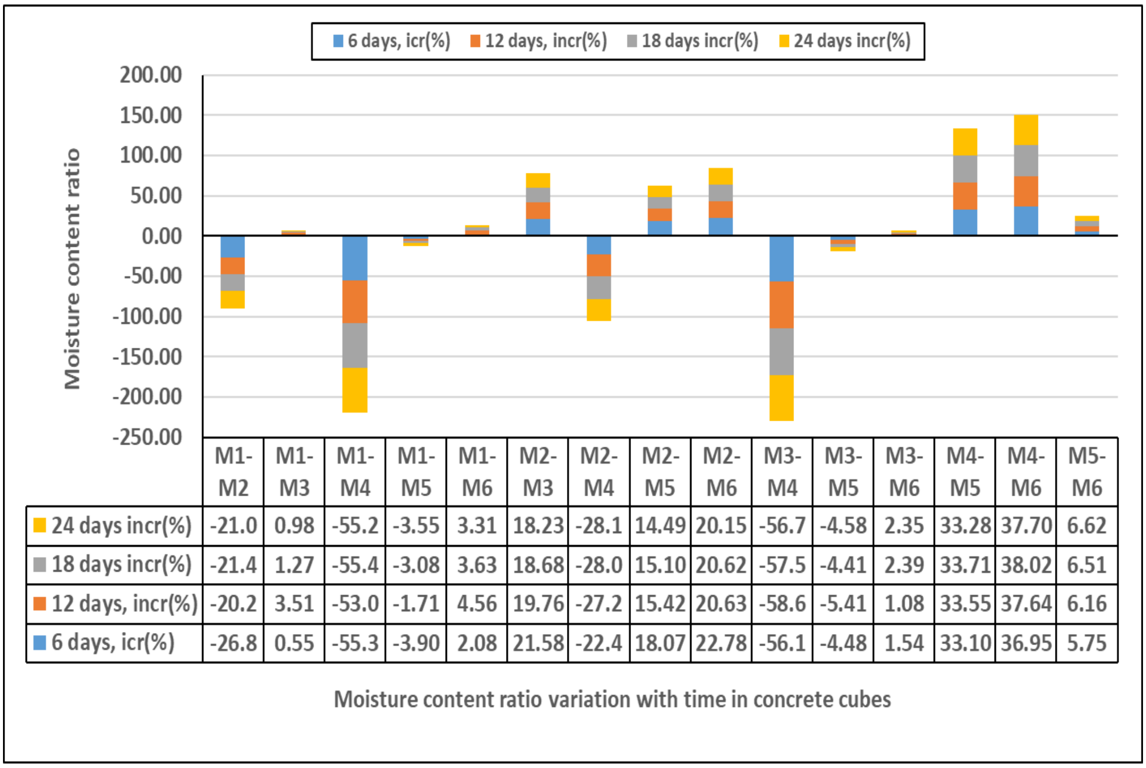
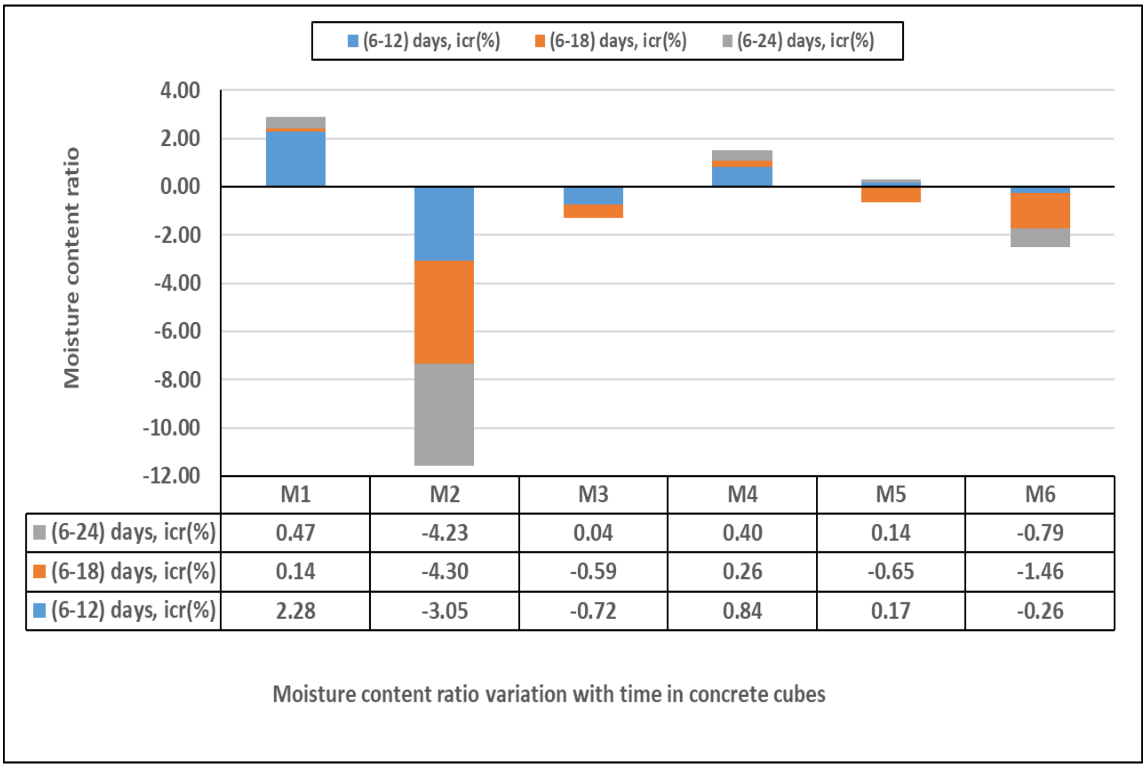


Figure 4-27 Variation of Moisture content ratio coefficient with time in concrete cubes



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
🟨 24 days incr(%)	-21.0	0.98	-55.2	-3.55	3.31	18.23	-28.1	14.49	20.15	-56.7	-4.58	2.35	33.28	37.70	6.62
⬜ 18 days incr(%)	-21.4	1.27	-55.4	-3.08	3.63	18.68	-28.0	15.10	20.62	-57.5	-4.41	2.39	33.71	38.02	6.51
🟧 12 days, incr(%)	-20.2	3.51	-53.0	-1.71	4.56	19.76	-27.2	15.42	20.63	-58.6	-5.41	1.08	33.55	37.64	6.16
🟦 6 days, icr(%)	-26.8	0.55	-55.3	-3.90	2.08	21.58	-22.4	18.07	22.78	-56.1	-4.48	1.54	33.10	36.95	5.75

Figure 4-28 Variation of Moisture content ratio coefficient with time in concrete cubes



	M1	M2	M3	M4	M5	M6
⬜ (6-24) days, icr(%)	0.47	-4.23	0.04	0.40	0.14	-0.79
🟧 (6-18) days, icr(%)	0.14	-4.30	-0.59	0.26	-0.65	-1.46
🟦 (6-12) days, icr(%)	2.28	-3.05	-0.72	0.84	0.17	-0.26

Figure 4-29 Variation of Moisture content ratio coefficient-time in concrete cubes

4.3.10 Water diffusion-sorptivity coefficient variation in concrete cubes

There was a relationship exists in the present research between water diffusion coefficient and sorptivity coefficient for in case of designed mixtures type (M1-M6). It follows linearly proportional state at some short time afterwards it gradually deviates and takes inverse parabolic shape as shown in Figure 4-30.

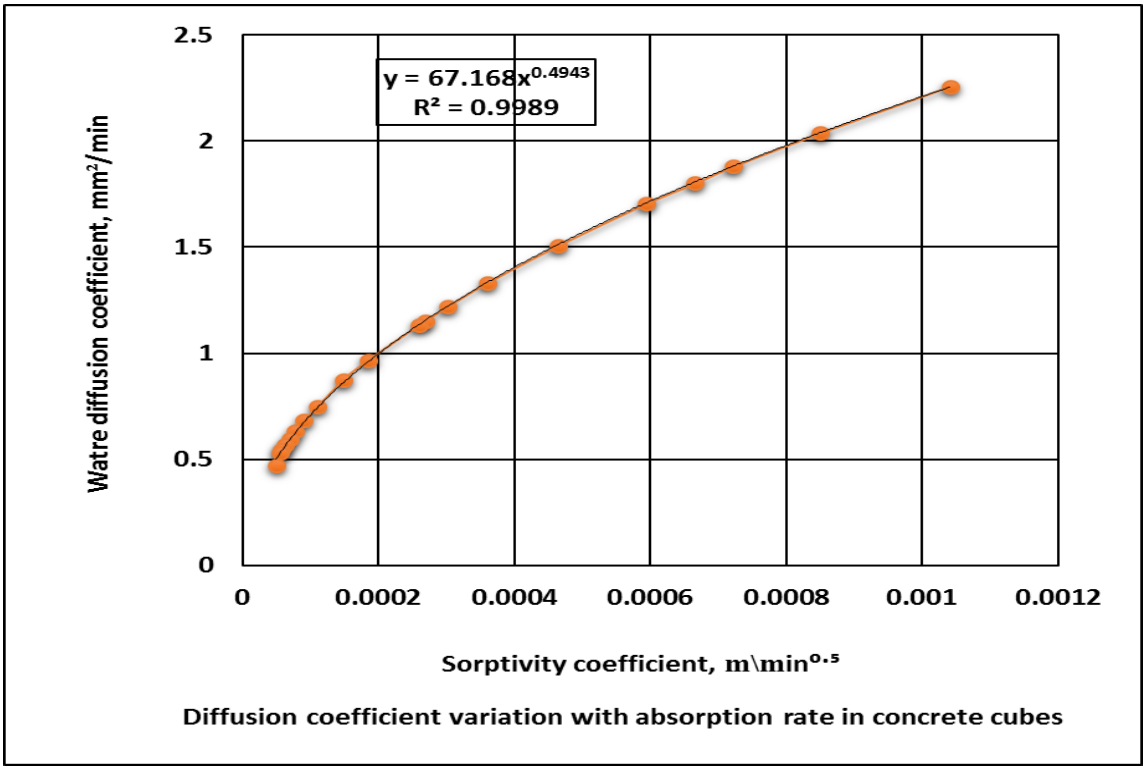


Figure 4-30 Water diffusion and sorptivity coefficient in concrete cubes

4.3.11 Water absorption-moisture content ratio variation in concrete cubes

The water absorption-moisture content ratio was varied linearly proportional with higher magnitude at initial time duration in all mixtures type (M1-M6) as referred from Figure 4-31. The water absorption-moisture content ratio was varied linearly proportional with higher magnitude at initial time duration in all mixtures type (M1-M6). However, it goes on gradually decreases with linearly proportional pattern up to sometime duration and afterwards it deviates at some extent, finally reaches equilibrium state. The ratio was higher at initial stage, because water absorption was not high at an initial stage, which in turn depends on moisture content within concrete matrix. If the concrete matrix was porous media, in that case, pore structure formation problem, cement paste formation, aggregate volume fraction, w-c ratio, slump, and compressive strength. In this ratio depends on proper mixture proportion. From this ratio, it is possible to predict time duration in any mixtures type (M1-M6). The variation in water absorption-moisture content ratio was found to be varied in between (w/m$_{5\ min}$ = 0.989, and w/m$_{5\ m}$ = 0.987) for in case mixtures type (M1-M3) and (M4-M6) as well as (w/m $_{28\ day}$ = 0.988, and w/m $_{28\ day}$ = 0.951) for in case of mixtures type (M1-M6).

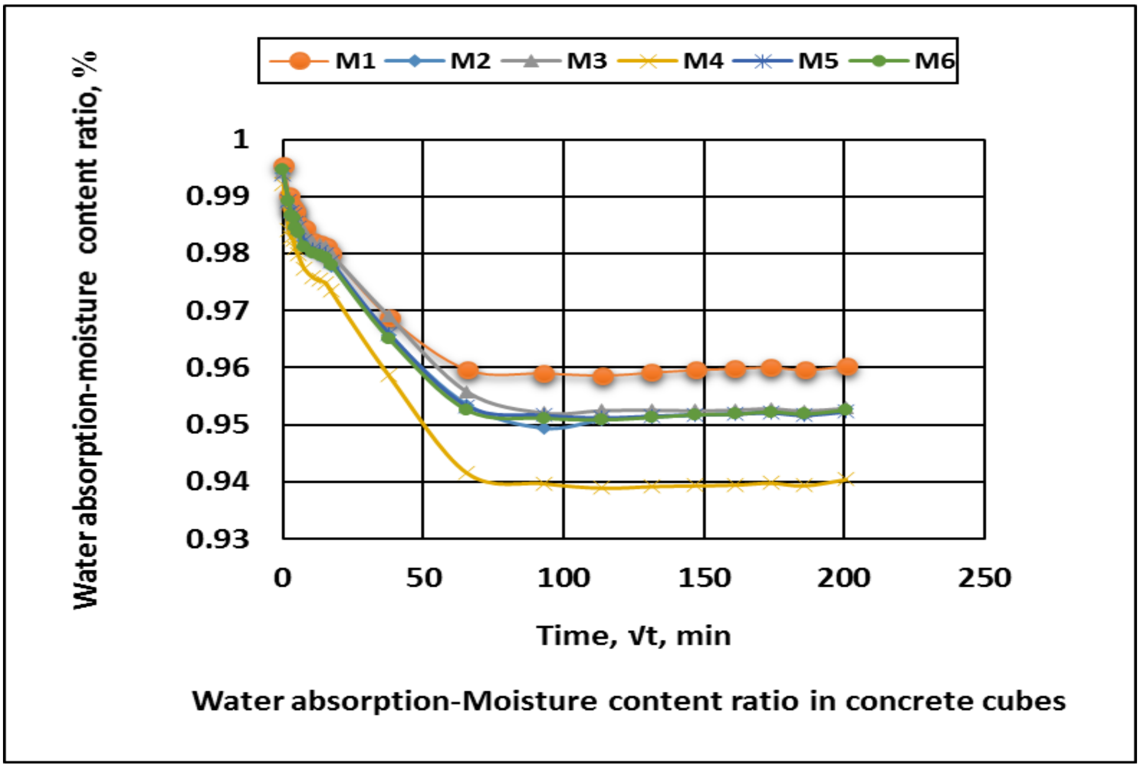


Figure 4-31 Water absorption-moisture content ratio in different concrete mix design

4.3.12 Desorption-time variation in concrete cubes

The de-sorptivity coefficient was investigate in all mixtures type (M1-M6) at different time interval for up to 28 days with variation as shown in Figure 4-32. The de-sorptivity coefficient was varied may be due to temperature, humidity, location dependent, slump value, water to cement ratio, and pore structure degree of saturation. The desorption coefficient was the opposite phase of sorptivity coefficient. The variation in desorption coefficient was found to be varied in between (De$_{5\ min}$ = 43.96 g/m^2/min$^{0.5}$, and De$_{200.79\ min}$ = 0.312 g/m^2/min$^{0.5}$) for in case mixtures type (M1-M6) and (De$_{5\ min}$ = 43.17 g/m^2/min$^{0.5}$, and De$_{200.79\ min}$ = 0.286 g/m^2/min$^{0.5}$) for in case of mixtures type (M1-M3), as well as (De$_{5\ min}$ = 44.75 g/m^2/min$^{0.5}$, and De$_{200.79\ min}$ = 0.338 g/m^2/min$^{0.5}$) in mixtures type (M4-M6).

The variation of de-sorptivity coefficient with time in the different concrete mix design was as shown in the (Figure 4-33 and Figure 4-34) respectively. It is clear from the results that, the de-sorptivity coefficient was decrease in the concrete mix design (M1) as when compare to the concrete mix design (M2, M3, M4, and M5) and its decrease in the concrete mix design (M6).

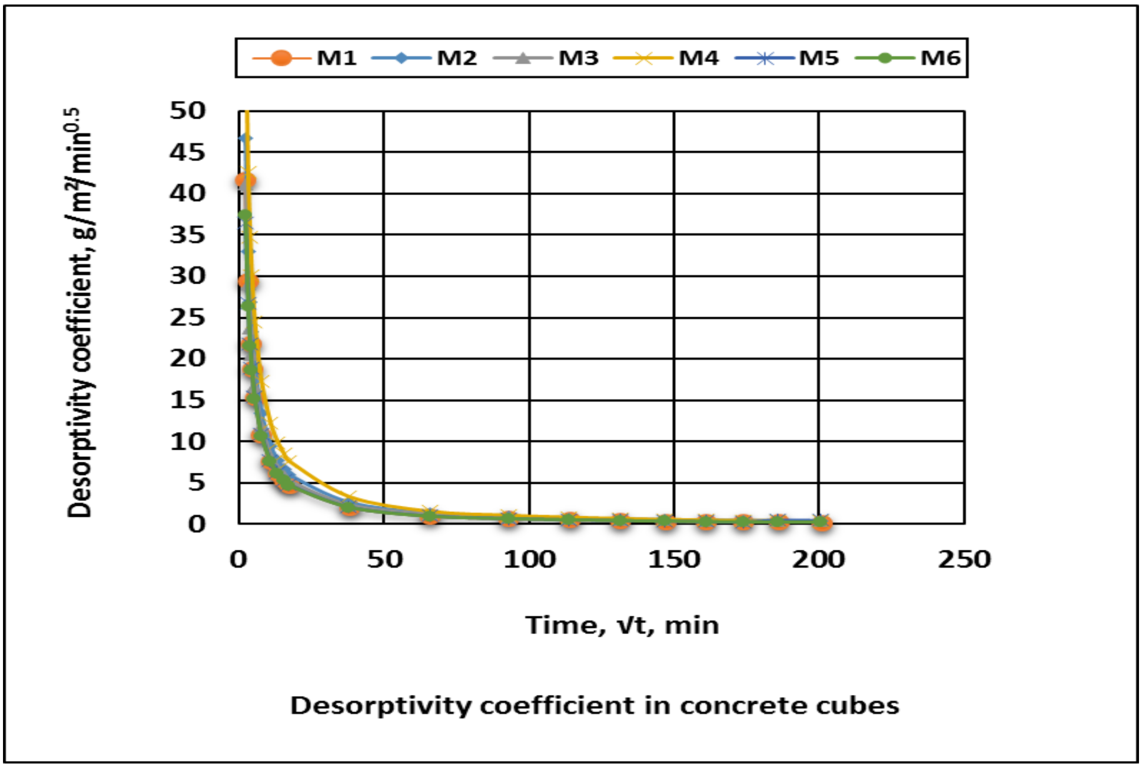
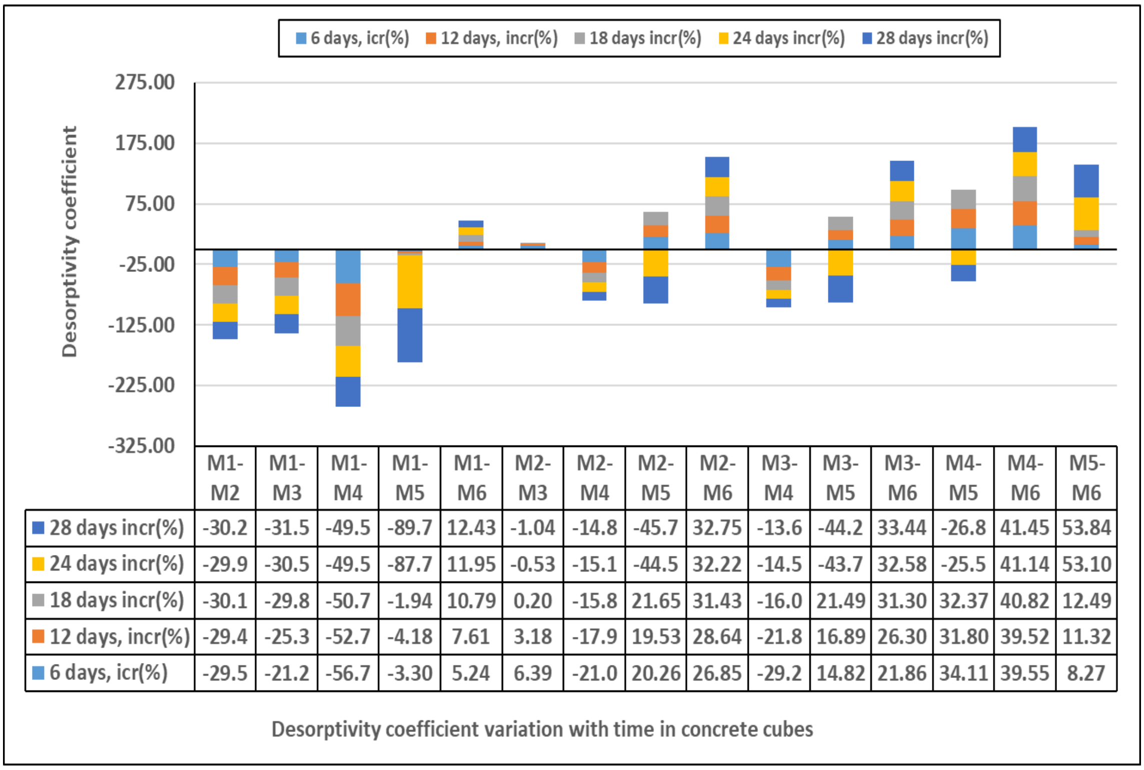


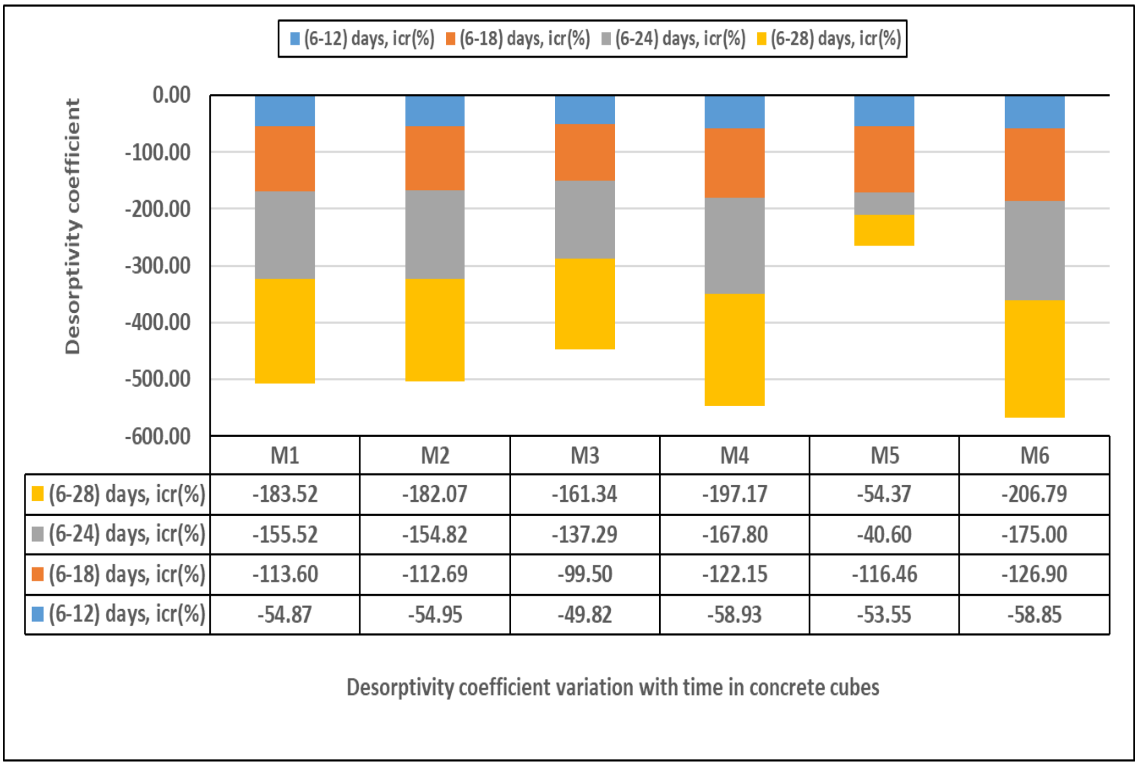
Figure 4-32 De-sorptivity coefficient-time variation in different concrete mixes



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
🟦 28 days incr(%)	-30.2	-31.5	-49.5	-89.7	12.43	-1.04	-14.8	-45.7	32.75	-13.6	-44.2	33.44	-26.8	41.45	53.84
🟨 24 days incr(%)	-29.9	-30.5	-49.5	-87.7	11.95	-0.53	-15.1	-44.5	32.22	-14.5	-43.7	32.58	-25.5	41.14	53.10
▨ 18 days incr(%)	-30.1	-29.8	-50.7	-1.94	10.79	0.20	-15.8	21.65	31.43	-16.0	21.49	31.30	32.37	40.82	12.49
🟧 12 days, incr(%)	-29.4	-25.3	-52.7	-4.18	7.61	3.18	-17.9	19.53	28.64	-21.8	16.89	26.30	31.80	39.52	11.32
🟦 6 days, icr(%)	-29.5	-21.2	-56.7	-3.30	5.24	6.39	-21.0	20.26	26.85	-29.2	14.82	21.86	34.11	39.55	8.27

Figure 4-33 De-sorptivity coefficient-time variation in different concrete mixes

For in case of concrete mix design (M2), the de-sorptivity coefficient was decrease as when compare to the concrete mix design (M3, M4, and M5) and its decrease for in case of M3 as against the concrete mix design (M4, and M5). Whereas in the case of concrete mix design (M4 and M5) as when compare to the concrete mix design (M6).



	M1	M2	M3	M4	M5	M6
🟨 (6-28) days, icr(%)	-183.52	-182.07	-161.34	-197.17	-54.37	-206.79
⬜ (6-24) days, icr(%)	-155.52	-154.82	-137.29	-167.80	-40.60	-175.00
🟧 (6-18) days, icr(%)	-113.60	-112.69	-99.50	-122.15	-116.46	-126.90
🟦 (6-12) days, icr(%)	-54.87	-54.95	-49.82	-58.93	-53.55	-58.85

Figure 4-34 De-sorptivity coefficient variation in different concrete mixes

4.3.13 Sorption-desorptivity coefficient-time variation in concrete cubes

The variation of sorptivity-de-sorptivity coefficient was at different time interval in all mixtures type (M1-M6) with their variation as shown in

Figure *4-35*. The interpretation of sorptivity to de-sorptivity coefficient was evaluate at different time interval in all mixtures type (M1-M6) as represent in (

Figure *4-36* and Figure 4-37). The ratio varies due environmental conditions and location. Actually the rate of absorption was not suddenly increased/decreased in turn depends on concrete matrix, and mixture proportion, but rate of absorption was increases gradually with time duration. Similarly, the rate of decrease of water from any structure was not so easy because the pore structure formation, compactness and if it is properly mixture designed. In fact, rate of desorption was very slow in all mixtures type. From this ratio, it is possible to predict time duration in any designed mixtures type in turn it is possible to interpret the particular mixture type characteristics such as compressive strength, slump, w-c ratio, Fine-coarse aggregate volume fraction, cement paste and concrete matrix.

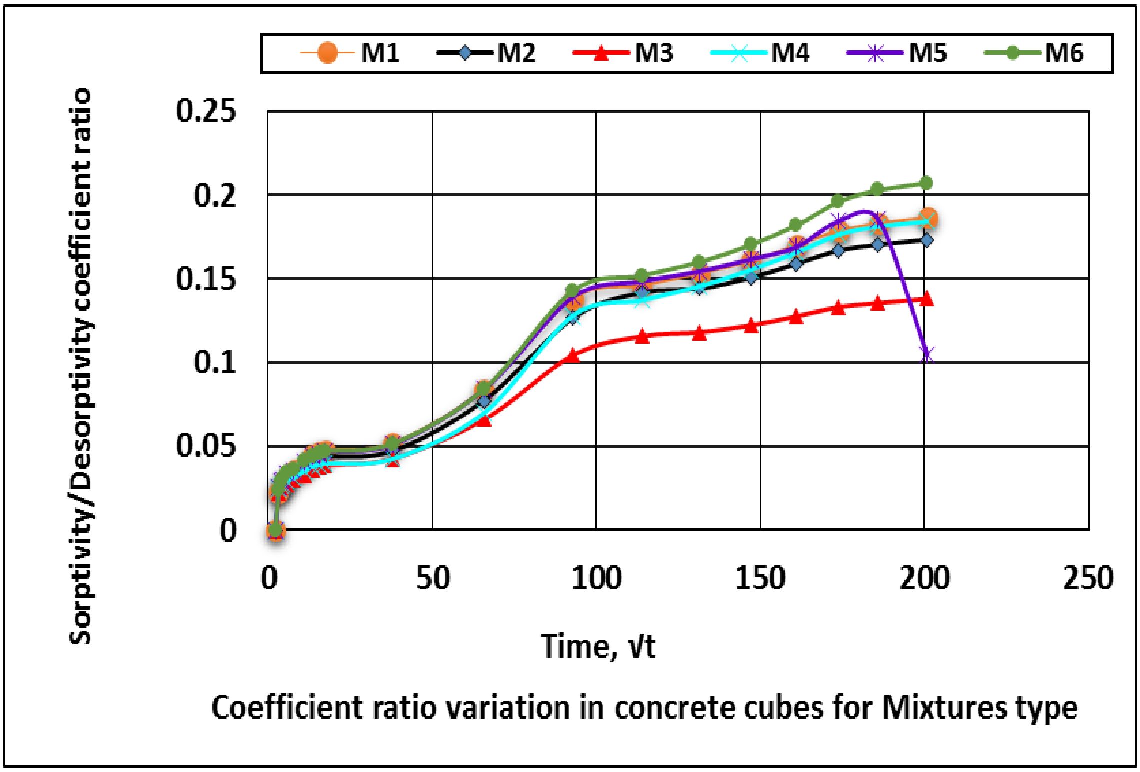
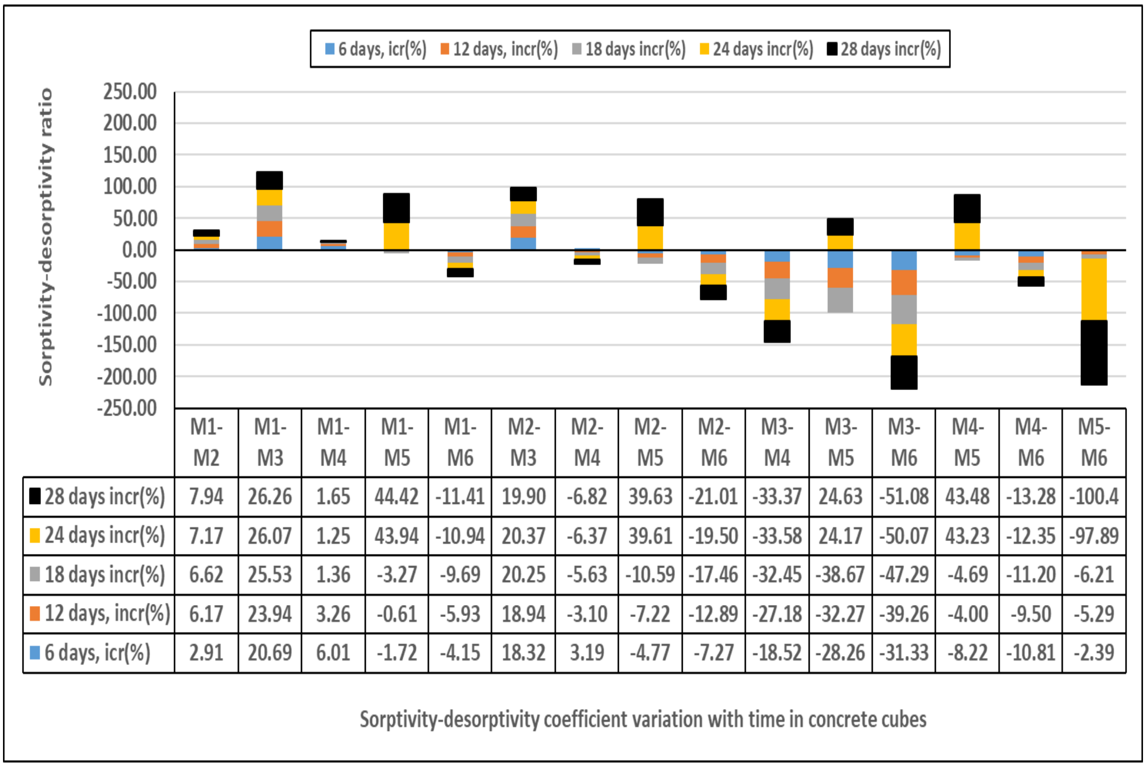


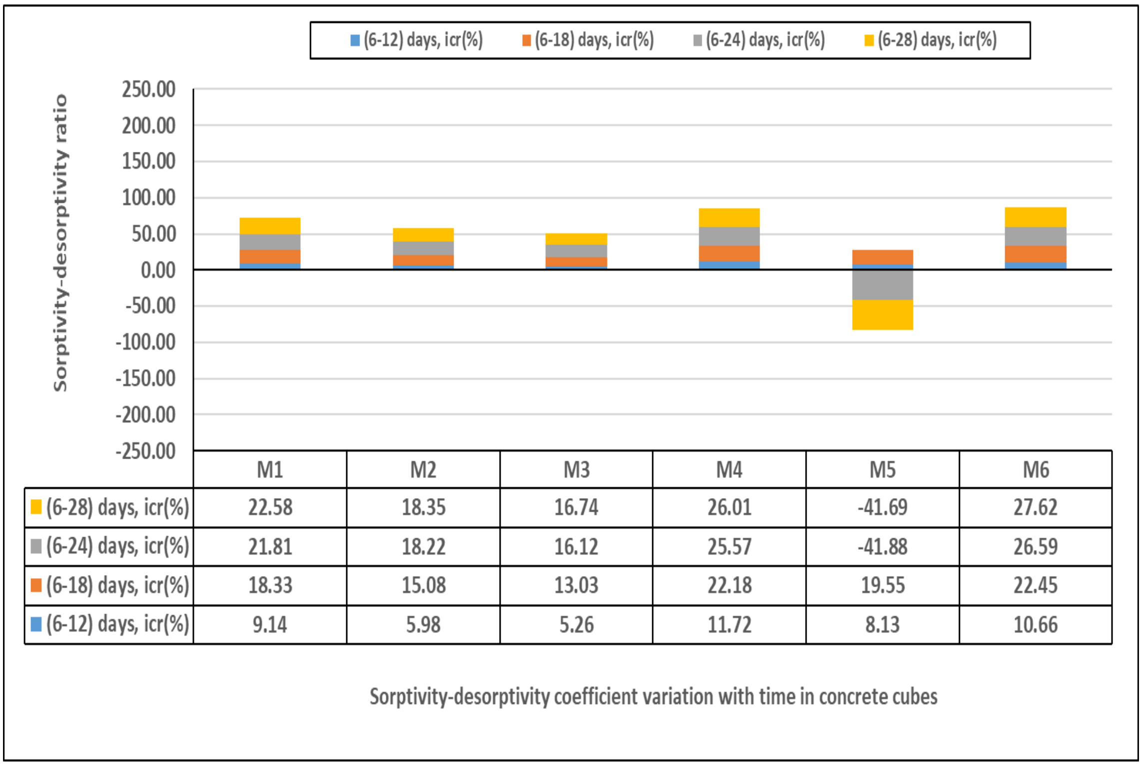
Figure 4-35 Coefficient ratio variation in concrete cubes for different concrete mixes



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
■ 28 days incr(%)	7.94	26.26	1.65	44.42	-11.41	19.90	-6.82	39.63	-21.01	-33.37	24.63	-51.08	43.48	-13.28	-100.4
■ 24 days incr(%)	7.17	26.07	1.25	43.94	-10.94	20.37	-6.37	39.61	-19.50	-33.58	24.17	-50.07	43.23	-12.35	-97.89
■ 18 days incr(%)	6.62	25.53	1.36	-3.27	-9.69	20.25	-5.63	-10.59	-17.46	-32.45	-38.67	-47.29	-4.69	-11.20	-6.21
■ 12 days, incr(%)	6.17	23.94	3.26	-0.61	-5.93	18.94	-3.10	-7.22	-12.89	-27.18	-32.27	-39.26	-4.00	-9.50	-5.29
■ 6 days, icr(%)	2.91	20.69	6.01	-1.72	-4.15	18.32	3.19	-4.77	-7.27	-18.52	-28.26	-31.33	-8.22	-10.81	-2.39

Figure 4-36 Coefficient ratio variation in different concrete mixes

The variation in Sorptivity-desorption coefficient ratio was found to be varied in between (S/D$_{5\ \text{min}}$ = 0.023, and De$_{200.79\ \text{min}}$ = 0.166) for in case mixtures type (M1-M6) and (S/D$_{5\ \text{min}}$ = 0.022, and S/D$_{200.79\ \text{min}}$ = 0.167) for in case of mixtures type (M1-M3), as well as (S/D$_{5\ \text{min}}$ = 0.024, and S/D$_{200.79\ \text{min}}$ = 0.166) in mixtures type (M4-M6).



	M1	M2	M3	M4	M5	M6
🟨 (6-28) days, icr(%)	22.58	18.35	16.74	26.01	-41.69	27.62
⬜ (6-24) days, icr(%)	21.81	18.22	16.12	25.57	-41.88	26.59
🟧 (6-18) days, icr(%)	18.33	15.08	13.03	22.18	19.55	22.45
🟦 (6-12) days, icr(%)	9.14	5.98	5.26	11.72	8.13	10.66

Figure 4-37 Coefficient ratio variation in different concrete mixes

4.4 Initial surface absorption test on concrete cubes

The ISAT was carry out on 72 dry conditioned concrete cubes (100x100x100) mm. The initial surface absorption was increased (2.26-2.9 ml/m^2/s) in mixtures type (M1-M3) at initial time duration (10 min) as when compared to longer time duration (60 min) which was ranged between (1.17-1.71 ml/m^2/s) for in case of same mixtures type. Whereas the ISAT was more increased (2.9-2.7 ml/m^2/s) in mixtures type (M4-M6) at an initial time duration (10 min) as when compared to longer time duration (1.9-2.08 ml/m^2/s) at 60 min. In fact, the rate of ISAT was confirm to be lesser in concrete cubes for mixtures type (M1-M3) at an initial time duration for constant grade of concrete and varied slump value as when compare to mixtures type (M4-M6) with different grade of concrete and constant slump value. The variation of ISAT with different time duration for in all mixtures type (M1-M6) was represent as shown in Figure 4-38.

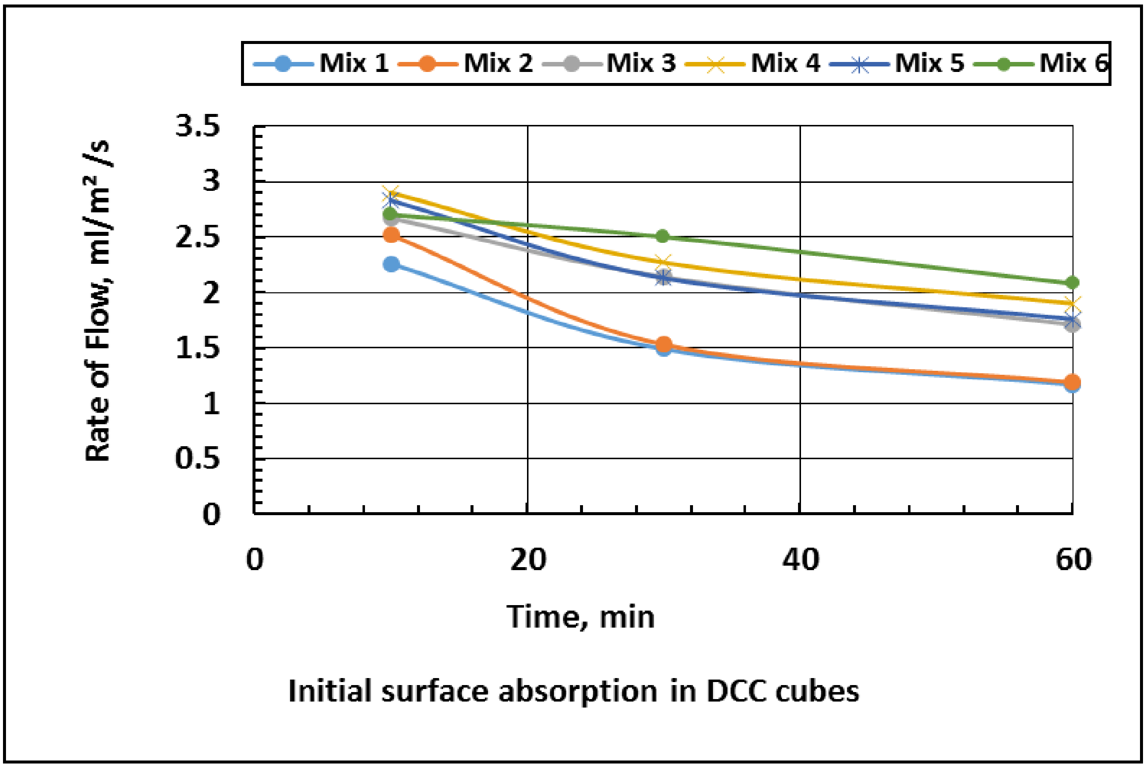


Figure 4-38 ISAT on DCC cubes in different concrete mixes

The variation of ISAT in PSC concrete cubes with time different time duration for in all mixtures type (M1-M6) was represent as shown in Figure 4-39. The initial surface absorption was increased (0.30-0.36 ml/m^2/s) in mixtures type (M1-M3) at initial time duration (10 min) as when compared to longer time duration (60 min) which was ranged between (0.21-0.22 ml/m^2/s) for in case of mixtures type (M1-M3). Whereas the ISAT was increased (0.21-0.29 ml/m^2/s) in mixtures type (M4-M6) at an initial time duration (10 min), as when compared to longer time duration (0.14-0.2 ml/m^2/s) at 60 min. Rate of ISAT was predominantly decreased in concrete cubes as when compared to dry conditioned concrete cubes due to pre-determined partially saturated condition. The ISAT was increase in mixtures type (M1-M3) with constant grade of concrete and varied slump value at initial time duration. Whereas the rate of ISAT was lesser in mixtures type (M4-M6) with it constant, slump value and varied grade of concrete. This factor indicates that, the rate of initial surface absorption decreases with increased grade of concrete for in case of mixtures type (M4-M6).

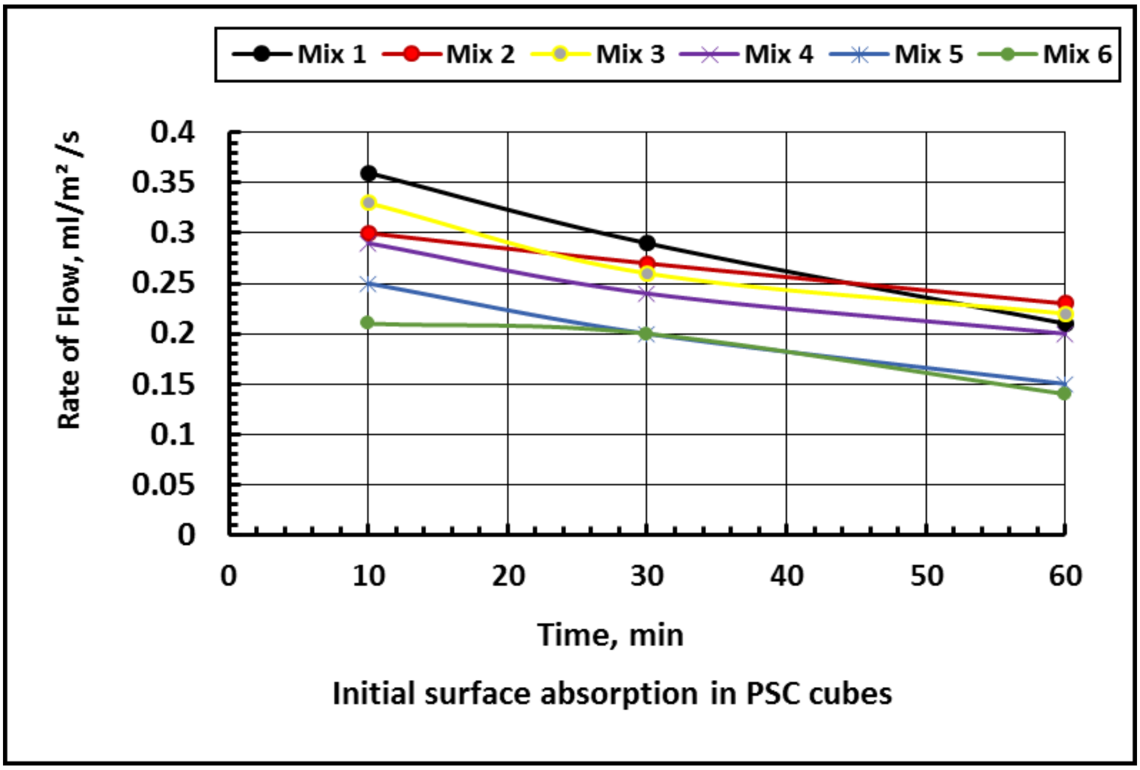


Figure 4-39 ISAT in PSC cubes for different concrete mixes

The variation of ISAT value for in all mixtures type (M1-M6) in FSC concrete cubes was represent as shown in Figure 4-40. The initial surface absorption was increased (0.23-0.24 ml/m^2/s) in mixtures type (M1-M3) at initial time duration (10 min) as when compared to longer time duration (60 min) which was ranged between (0.14-0.17 ml/m^2/s) for in case of mixtures type (M1-M3). Whereas the initial surface absorption was also increased (0.17-0.23 ml/m^2/s) in mixtures type (M4-M6) at initial time duration (10 min) as when compared to longer time duration (0.11-0.19 ml/m^2/s) at 60 min. Rate of ISAT was predominantly decrease in concrete cubes as when compared to dry and partially saturated conditioned concrete cubes. The rate of initial surface absorption was more or less constant in mixtures type (M1-M6) at initial time duration (10 min) as when compare to a longer time (60 min). In Fully saturated conditioned concrete, its observed that, the rate of initial surface absorption was found out be predominantly affected by fully saturated condition, constant grade of concrete, and varied slump value at longer time duration for in case of different mixtures type.

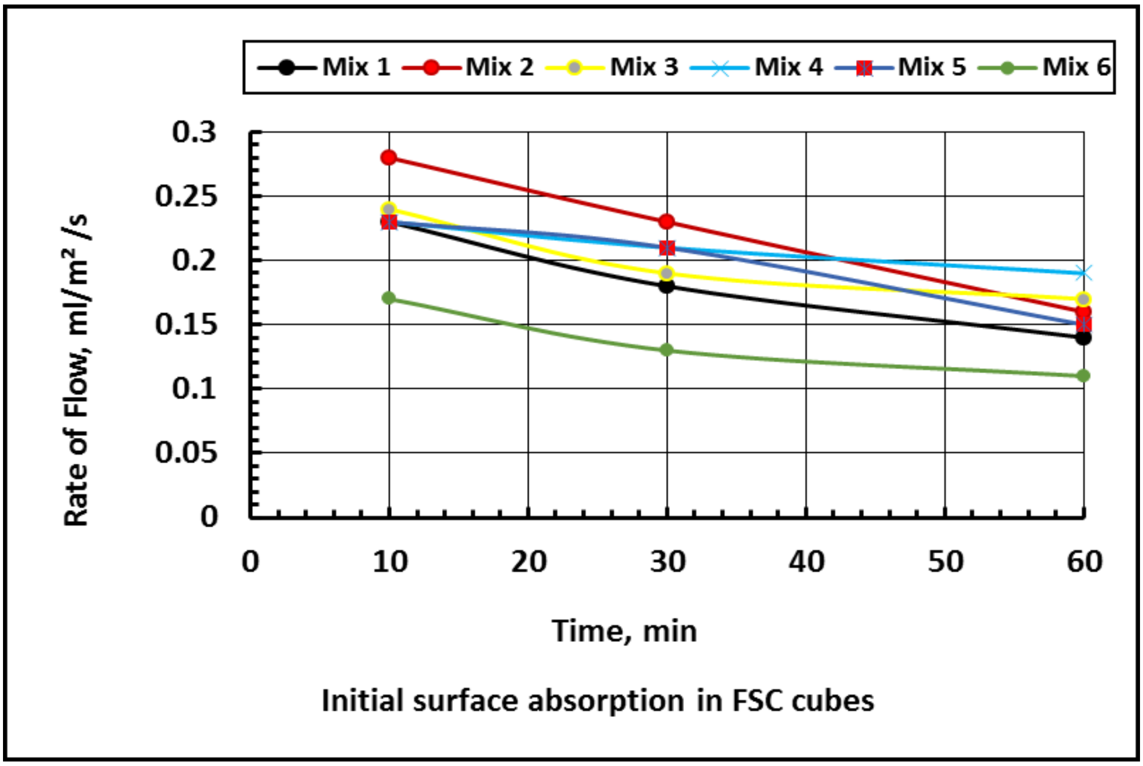


Figure 4-40 ISAT on FSC cubes for different concrete mixes

The variation of ISAT on Pre-conditioned concrete cubes (PCC) for different mixtures type (M1-M6) is indicate in Figure 4-41.

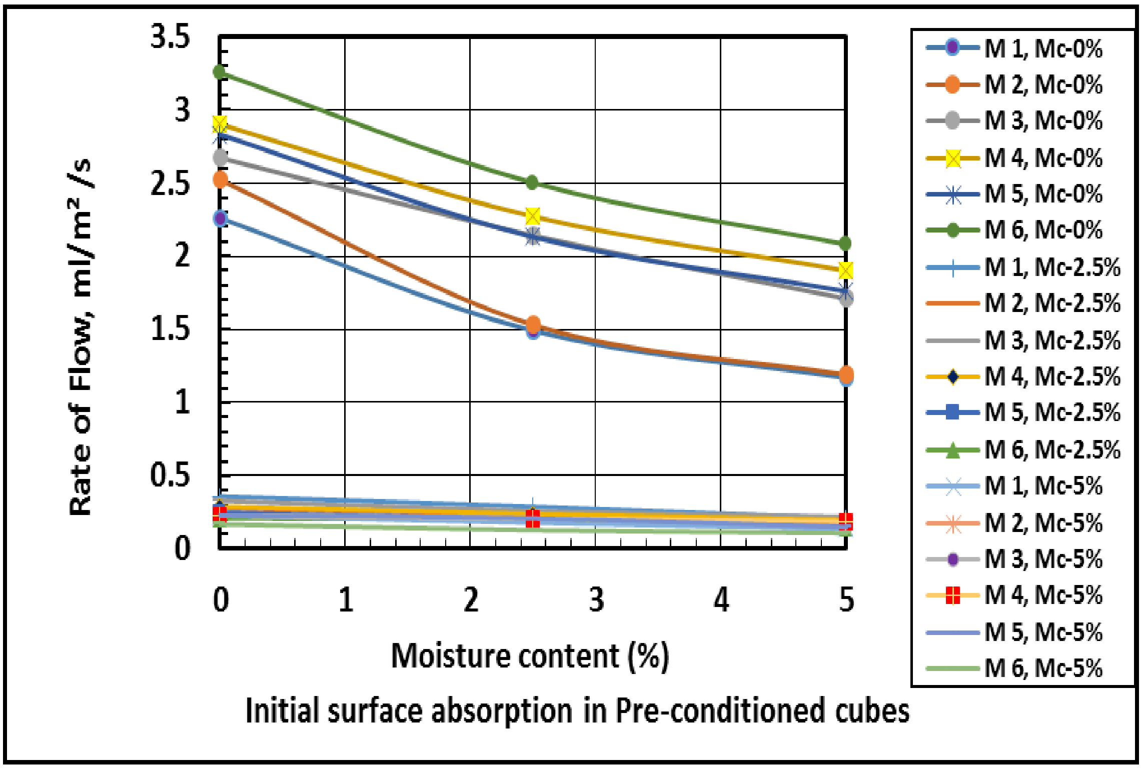


Figure 4-41 ISAT on PCC cubes for different concrete mixes

The variation of ISAT on Pre-conditioned saturated concrete cubes (SCC) for different mixtures type (M1-M6) was indicate in Figure 4-42.

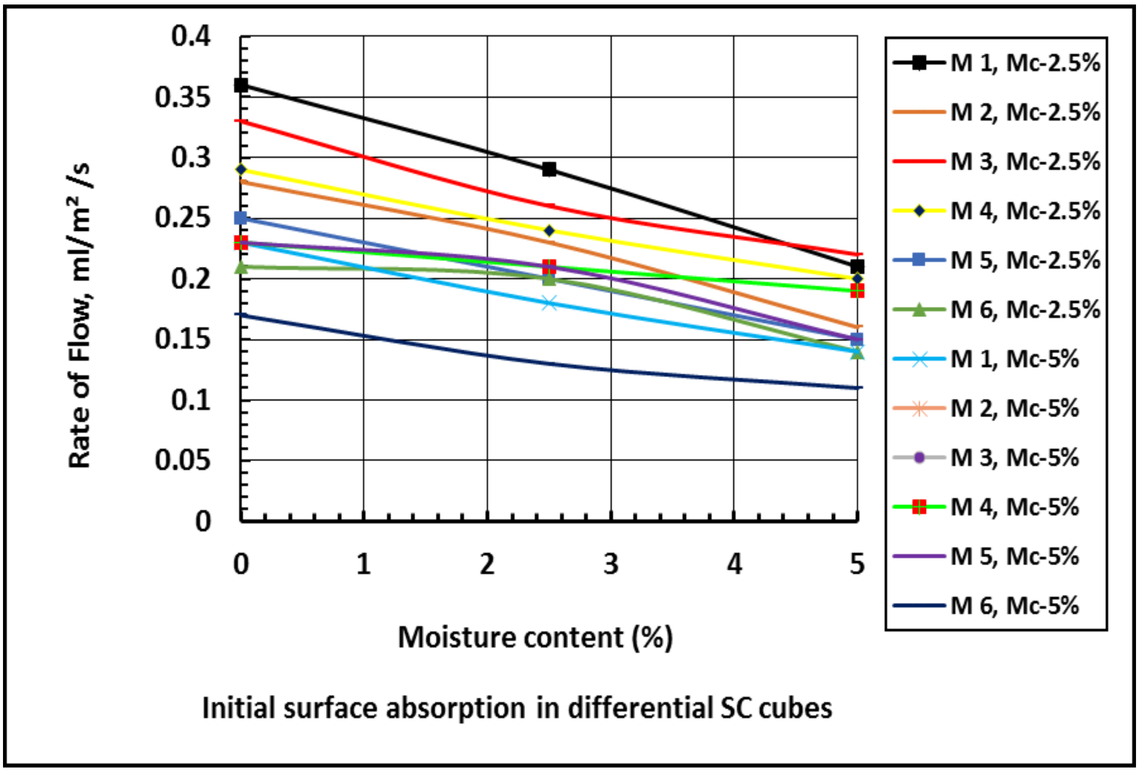


Figure 4-42 ISAT on SCC cubes for different concrete mixes

Whereas the rate of ISAT (dry/fully saturated conditioned concreter cubes) was increased (89.82%, 88.80%, 96.01%, 92.06%, 91.87%, and 94.76%) in different mixtures type (M1-M6) at initial time duration (10 min). As when compare (dry/fully saturated conditioned concrete cubes) to longer time duration (60 min) which was ranged between (88.03%, 86.55%, 90.05%, 90%, 91.47%, and 94.71%) for in case of mixtures type (M1-M6). Rate of initial surface absorption (partially/fully saturated conditioned concreter cubes) was increased/decreased (36.10%, 6.60%, 27.27%, 20.68%, 8%, and 19.04%) in different mixtures type (M1-M6) at an initial time duration (10 min). As when compare (partially/fully saturated conditioned concrete cubes) to longer time duration (60 min) which was ranged between (33.30%, 30.43%, 22.72%, 5%, 0%, and 21.42%) for in case of mixtures type (M1-M6).

4.4.1 Effectiveness of moisture content on initial surface absorption

The effectiveness of moisture content was studied in all pre-conditioned concrete cubes such as dry/partially saturated/fully saturated condition in turn interpret their effectiveness in all six designed mixtures type (M1-M6). It is observe from results that; the initial surface absorption was more in DCC cubes as when compared PSC as well as FSC concrete cubes. The ISAT for in case of DCC concrete cubes was found to be more as compared to PSC concrete which was in the range between 45.75% and 22% at time duration as when compared 10 min to 30 min. Similarly, the ISAT for in case of DCC concrete cubes was found to be more as compared to PSC concrete which was in the range between 28.21% and 9.54% at time duration as when compared 10 min to 60 min. Furthermore, the ISAT for in case of DCC concrete cubes was found to be more as compared to FSC concrete which was in the range between 35.15% and 24.01% at time duration as when compared 10 min to 30 min. In addition to that, the ISAT for in case of DCC concrete cubes was found to be more as compared to FSC concrete which was in the range between 18.83% and 8.18% at time duration as when compared 10 min to 60 min.

4.4.2 Effectiveness of saturated condition on initial surface absorption

The effectiveness of moisture content was studied in all pre-conditioned concrete cubes such as partially saturated/fully saturated condition in turn interpret their effectiveness in all six designed mixtures type (M1-M6). It is observe from results that, initial surface absorption was more in PSC cubes as when compared FSC concrete cubes. The ISAT for in case of PSC concrete cubes was found to be more as compared to FSC concrete which was in the range between 16.18% and 51.97% at time duration as when compared 10 min to 30 min. Similarly, the ISAT for in case of PSC concrete cubes was found to be more as compared to FSC concrete which was in the range between 11.55% and 29.60% at time duration as when compared 10 min to 60 min.

4.4.3 Compressive strength effectiveness on ISAT in concrete cubes

The effectiveness of constant compressive strength on ISAT for mixtures type (M1-M3) in DCC concrete cubes at different time duration was indicate in Figure 4-43. ISAT values was varied in mixtures type (M1-M3) for constant higher compressive strength with varied slump at different time duration such as at 10 min as (2.26, 2.52, and 2.67) ml/m^2/s, at 30 min (1.49, 1.53, and 2.14) ml/m^2/s as well as at 60 min (1.17, 1.19, and 1.71) ml/m^2/s. In mixtures type (M4-M6), the ISAT was found to be more at 10 min time duration with their values as (2.9, 2.83, and 2.7) ml/m^2/s, (2.27, 2.13, and 2.5) ml/m^2/s, and (1.9, 1.76, and 2.08) ml/m^2/s respectively. Thus, it has confirmed that, the ISAT was to be more in lower compressive strength as when compared to higher compressive strength value with constant slump. Similarly the ISAT values in mixtures type (M1-M3) at time duration 60 min in which, the ISAT was increased in mixture type M2 and whereas in mixture type M3, its slightly higher compared to time duration at 10 min and 30 min with higher compressive strength (30-40 N/mm^2) and constant slump. This may be due to the fact that, if cement content was more, it creates cracks in concrete cubes in turn there exists a differential membrane between cement paste and concrete matrix. Because of that, segregation was occur due that, cement content starts settled at top layer and concrete matrix settled at bottom with variations in ingredient such as aggregate volume fraction and w-c ratio.

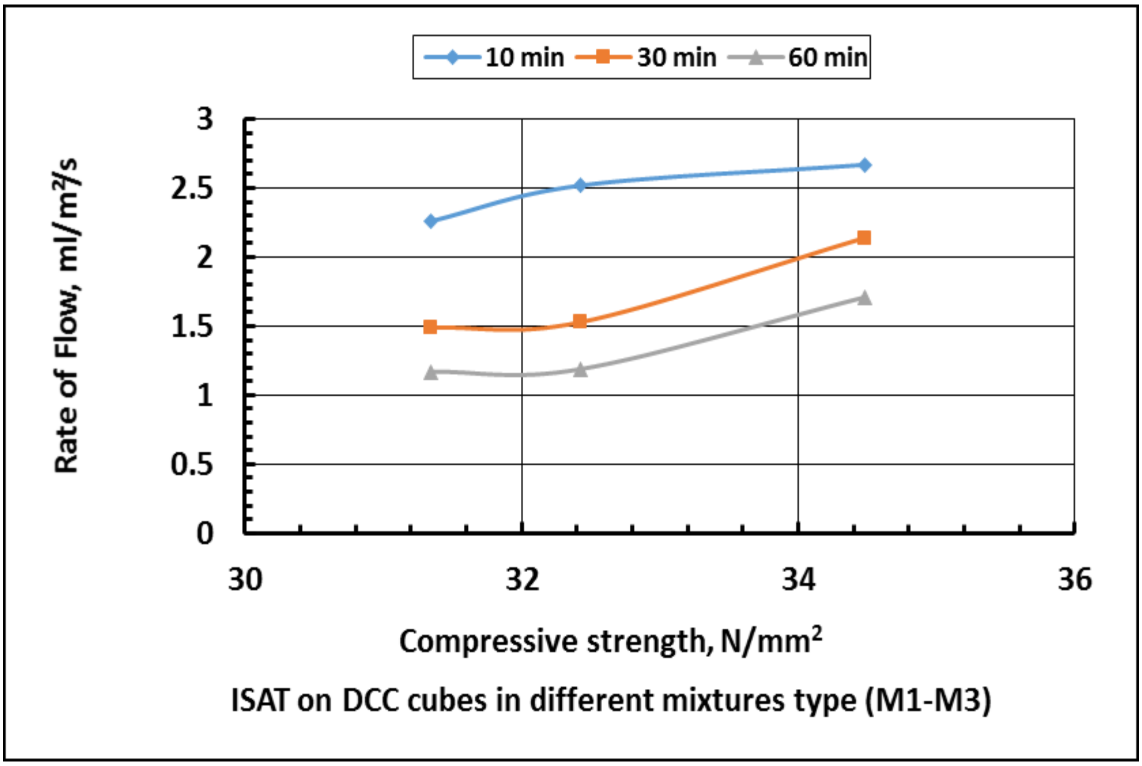


Figure 4-43 Effectiveness of constant compressive strength on ISAT in DCC concrete cubes

ISAT values was varied in mixtures type (M4-M6) for different compressive strength with constant slump at different time duration such as 10 min as (2.9, 2.83, and 2.7) ml/m^2/s, at 30 min (2.27, 2.13, and 2.5) ml/m^2/s as well as at 60 min (1.9, 1.76, and 2.08) ml/m^2/s. In mixtures type (M4-M6), the ISAT was found to be more at 10 min time duration with their values as (2.9, 2.27, and 1.9) ml/m^2/s, as when compared to time duration at 30 min (2.83, 2.13, and 1.76) ml/m^2/s, and at 60 min (2.7, 2.5, and 2.08) ml/m^2/s respectively. It has confirmed that, the ISAT was to be more in lower compressive strength as when compared to higher compressive strength value with constant slump. Similarly, the ISAT values in mixtures type (M4-M6) at time duration 60 min, in which the ISAT was slightly decreased in mixture type M6 and whereas in mixtures type M4 and M5, its slightly higher compared to time duration at 60 min with higher compressive strength and constant slump. The effectiveness of different compressive strength (25, 30, and 40 N/mm^2) on ISAT for mixtures type (M4-M6) in DCC concrete cubes at different time duration is as show in Figure 4-44.

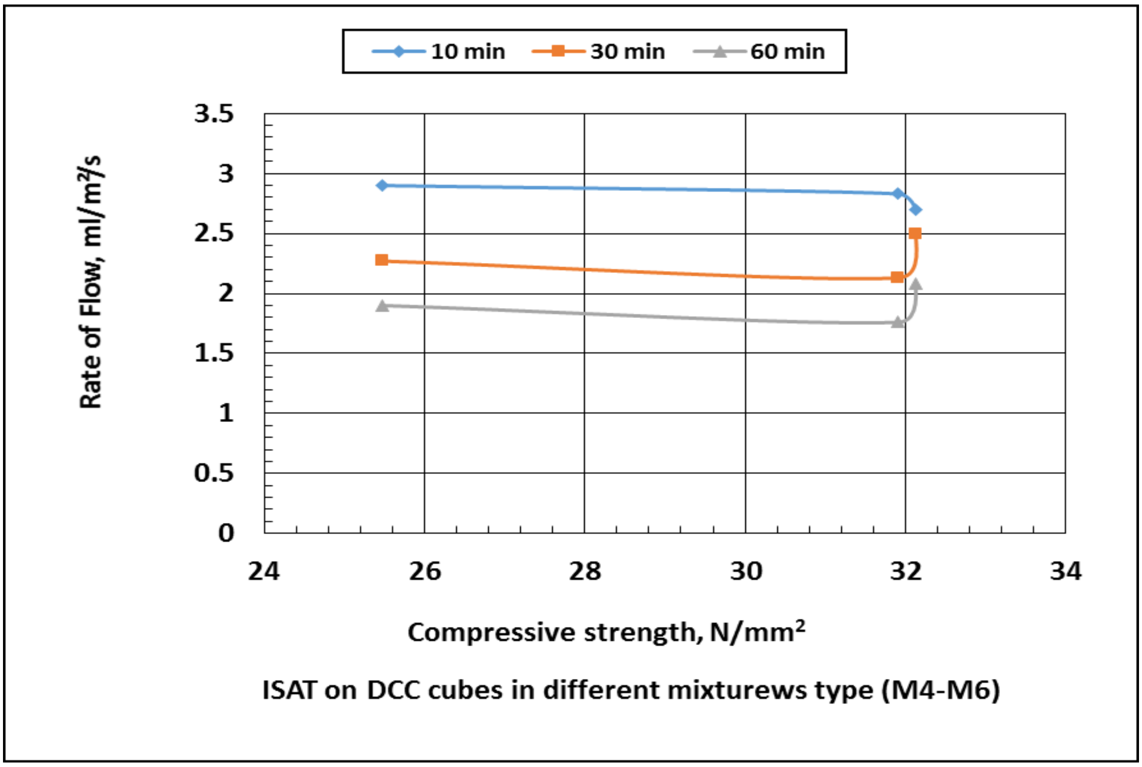


Figure 4-44 Effectiveness of different compressive strength on ISAT in DCC concrete cubes

The effectiveness of constant higher compressive strength on ISAT for mixtures type (M1-M3) in PSC concrete cubes at different time duration was as shown in Figure 4-45. ISAT values was varied in mixtures type (M1-M3) for same higher compressive strength with varied slump at time 10 min as (0.36, 0.30, and 0.33) ml/m^2/s, at 30 min (0.29, 0.27, and 0.26) ml/m^2/s as well as at 60 min (0.21, 0.23, and 0.22) ml/m^2/s. In mixtures type (M4-M6), the ISAT was found to be more at 10 min time duration with their values as (0.29, 0.25, and 0.21) ml/m^2/s, (0.24, 0.20, and 0.20) ml/m^2/s, and (0.20, 0.15, and 0.14) ml/m^2/s respectively. Thus, it has confirmed that, the ISAT was to be lesser in higher compressive strength with different slump for in case of mixture type (M1-M3). Similarly, the ISAT values in mixtures type (M1-M3) at time duration 60 min in which, the ISAT was decreased in mixture type M2 and M3, at time duration 10 min and 30 min with higher compressive strength (30-40 N/mm^2) with different slump.

The ISAT was decrease for in case of PSC concrete cubes as when compared to DCC concrete cubes. This may be due to the fact that, the concrete cubes was in partially saturated condition. In fact, there are several in situ tests, which are intend to measure the permeation characteristics of concrete structures. The permeation measurements from them has been confirm to provide durability indices, which correlate with the results from accelerated exposure testing. However, the major difficulty in applying these tests in situ is that their measurements are substantially affect by the amount of water already present in the concrete, and it has been shown that any uncertainties about the original moisture content lead to poor reproducibility of the result. For this reason, meaningful in situ testing of concrete for permeation properties has not been possible.

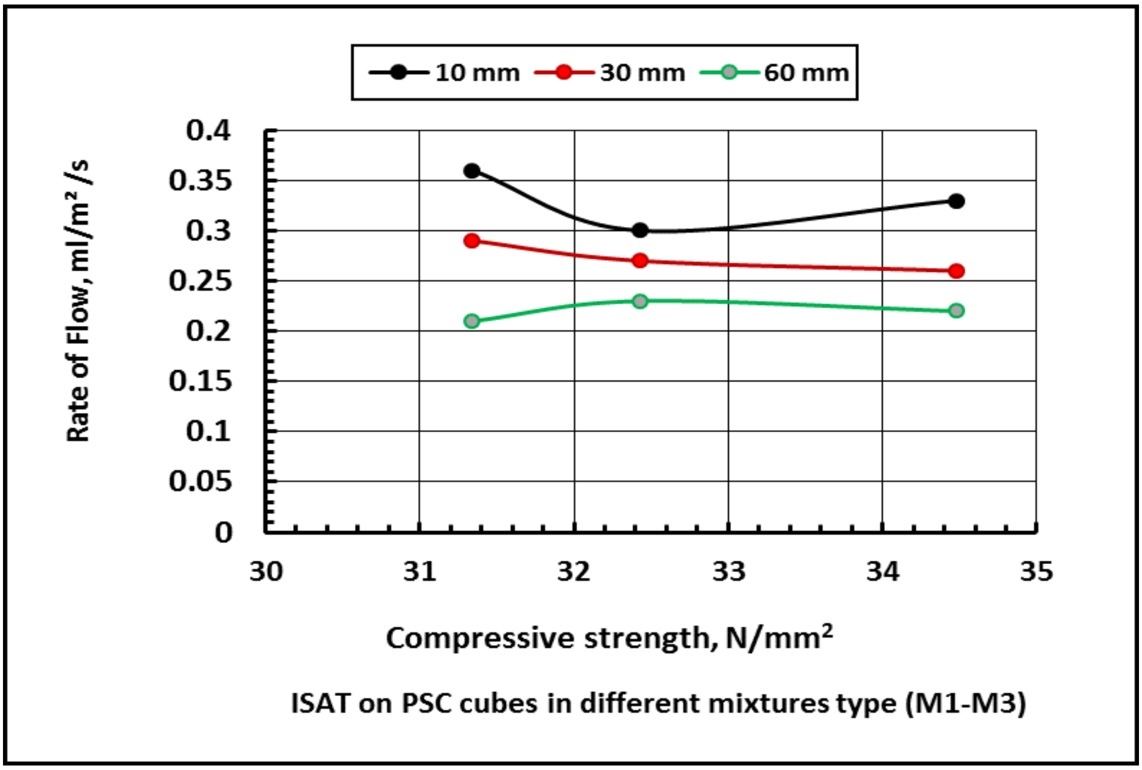


Figure 4-45 Effectiveness of different compressive strength on ISAT in PSC concrete cubes

There are two possible approaches to overcoming this problem. The first is to measure the moisture content and compensate for it in the results, and the second is to precondition the sample by removing the moisture. It has been suggest that the presence of moisture is beneficial to concrete, and absorption should therefore be measure in naturally occurring conditions. This would give lower values of absorption, indicating higher durability for structures in moist conditions. It is believe that drying prior to absorption testing is essential, since porous or cracked concrete would have a high moisture content. This would yield low absorption values (indicating high durability) if the concrete had not been dried before testing.

Similarly, the ISAT was increase at 10 min and 30 min for lower compressive strength as when compare to longer time duration at 60 min. In which the ISAT values was varied in mixtures type (M4-M6) for different compressive strength with constant slump at different time duration such as 10 min as (0.29, 0.25, and 0.21) ml/m^2/s, at 30 min (0.24, 0.20, and 0.20) ml/m^2/s as well as at 60 min (0.2, 0.15, and 0.14) ml/m^2/s. Thus, it has confirmed that, the ISAT was more in lower compressive strength as when compared to higher compressive strength value with constant slump. Similarly, the ISAT values in mixtures type (M4-M6) at time duration 60 min, in which the ISAT was slightly decreased in mixture type M6 and whereas in mixtures type M4 and M5, its slightly higher compared to time duration at 60 min with higher compressive strength and constant slump. The effectiveness of different compressive strength (25, 30, and 40 N/mm^2) on ISAT for mixtures type (M4-M6) in PSC concrete cubes at different time duration is represent in Figure 4-46.

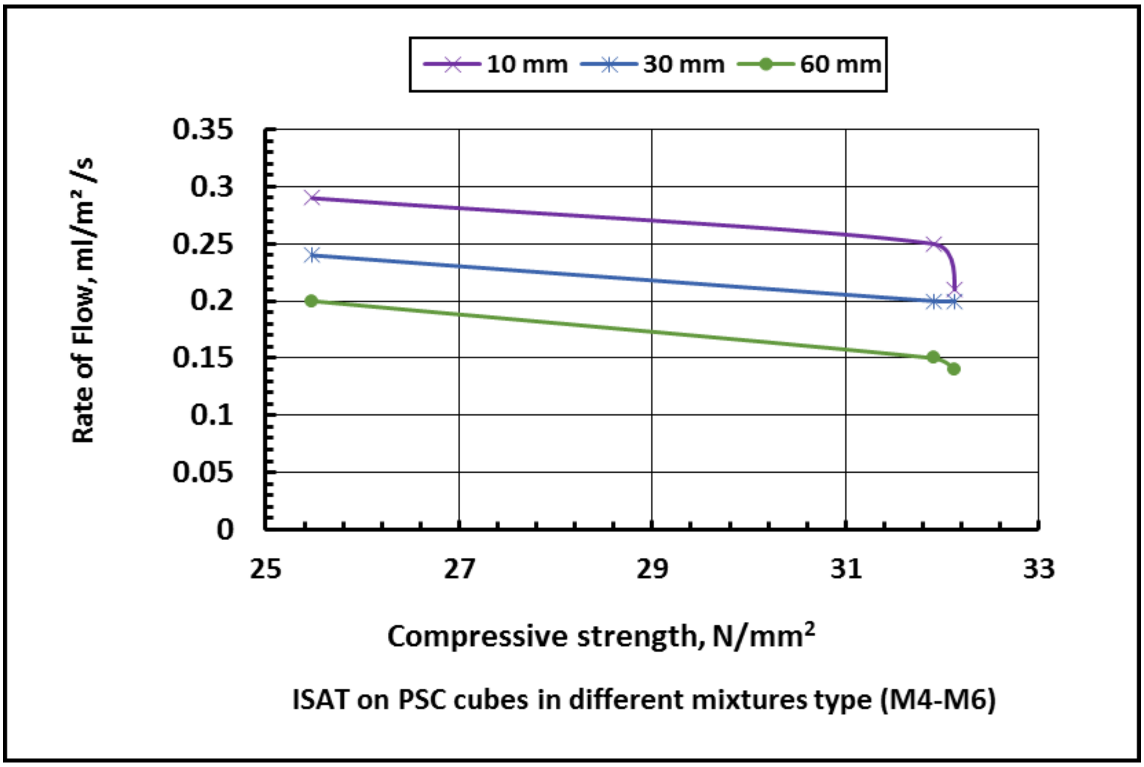


Figure 4-46 Effectiveness of different compressive strength on ISAT in PSC concrete cubes

The effectiveness of constant higher compressive strength on ISAT for mixtures type (M1-M3) in FSC concrete cubes at different time duration was as shown in Figure 4-47. The ISAT was lesser at 30 min and 60 min as when compare to initial time duration at 10 min. ISAT values was varied in mixtures type (M1-M3) for same higher compressive strength with varied slump at different time at 10 min as (0.23, 0.28, and 0.24) ml/m^2/s, at 30 min (0.18, 0.23, and 0.19) ml/m^2/s as well as at 60 min (0.14, 0.16, and 0.17) ml/m^2/s. In mixtures type (M4-M6), the ISAT was found to be more at 10 min time duration with their values as (0.23, 0.23, and 0.17) ml/m^2/s, (0.21, 0.21, and 0.13) ml/m^2/s, and (0.19, 0.15, and 0.11) ml/m^2/s respectively. Thus, it has confirmed that, the ISAT was lesser in higher compressive strength with different slump for in case of mixture type (M1-M3). Similarly the ISAT values in mixtures type (M1-M3) at time duration 60 min in which, the ISAT was decreased as compared to mixture type M2 and M3 at time duration 10 min and 30 min with higher compressive strength (40 N/mm^2) with different slump. The ISAT was decrease for in case of FSC concrete cubes as when compared to DCC concrete cubes as well as PSC concrete cubes. This may be because; the concrete cubes were in fully saturated condition. Thus, the presence of increased moisture content is beneficial to concrete; in turn, this would give still lower values of absorption, indicating higher durability for structures in moist conditions.

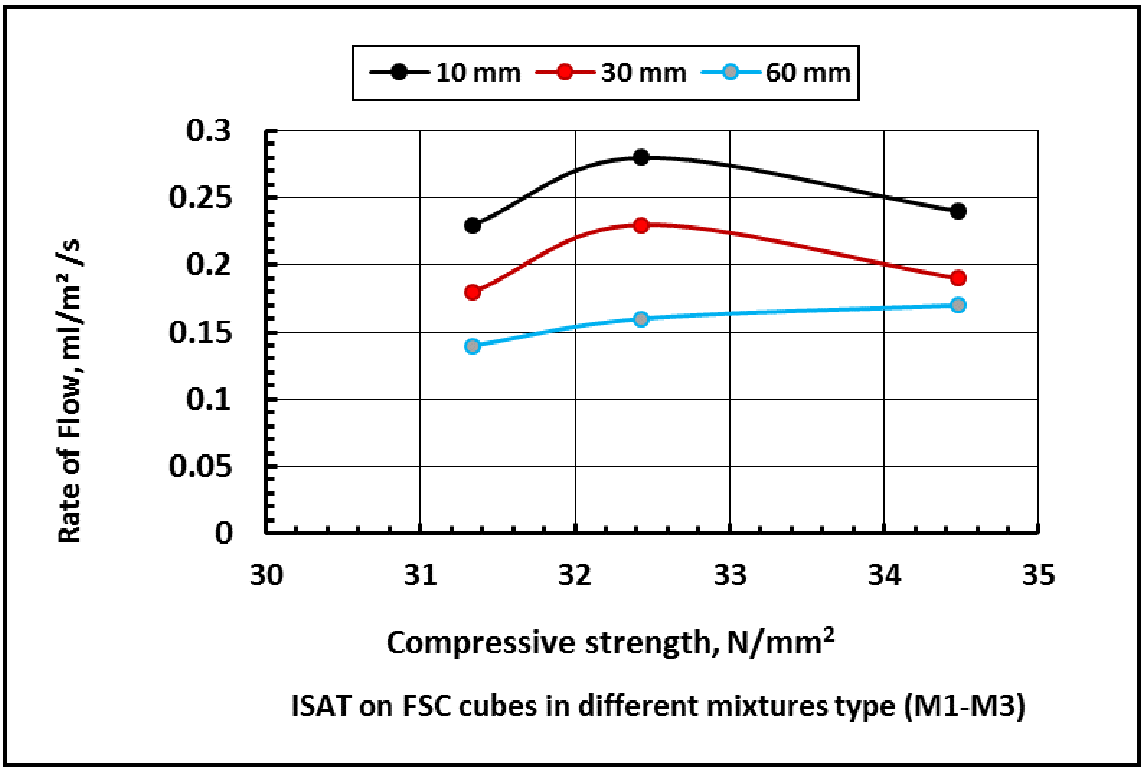


Figure 4-47 Effectiveness of compressive strength on ISAT in FSC concrete cubes

The effectiveness of different compressive strength (25, 30, and 40 N/mm^2) on ISAT for mixtures type (M4-M6) in FSC concrete cubes at different time duration was as shown in Figure 4-48. Similarly, the ISAT was slightly increase at 10 min and 30 min for lower compressive strength as when compared to longer time duration at 60 min. In fact the ISAT was more for in case of mixture type M4 and M5 as compared to mixture type M6 with their values ranged between (0.23, 0,21, and 0,19) ml/m^2/s, (0.23, 0,21, and 0,15) ml/m^2/s as well as (0.17, 0,13, and 0,11) ml/m^2/s. In which the ISAT values was varied in mixtures type (M4-M6) for different compressive strength with constant slump at different time duration such as 10 min as (0.23, 0.23, and 0.17) ml/m^2/s, at 30 min (0.21, 0.21, and 0.13) ml/m^2/s as well as at 60 min (0.19, 0.15, and 0.11) ml/m^2/s. Thus, it's confirm that, the ISAT was to be more in lower compressive strength as when compared to higher compressive strength value with constant slump. Similarly, the ISAT values in mixtures type (M4-M6) at time duration 60 min, in which the ISAT was slightly decreased in mixture type M6 and whereas in mixtures type M4 and M5, its slightly higher compared to time duration at 60 min with lower compressive strength and constant slump.

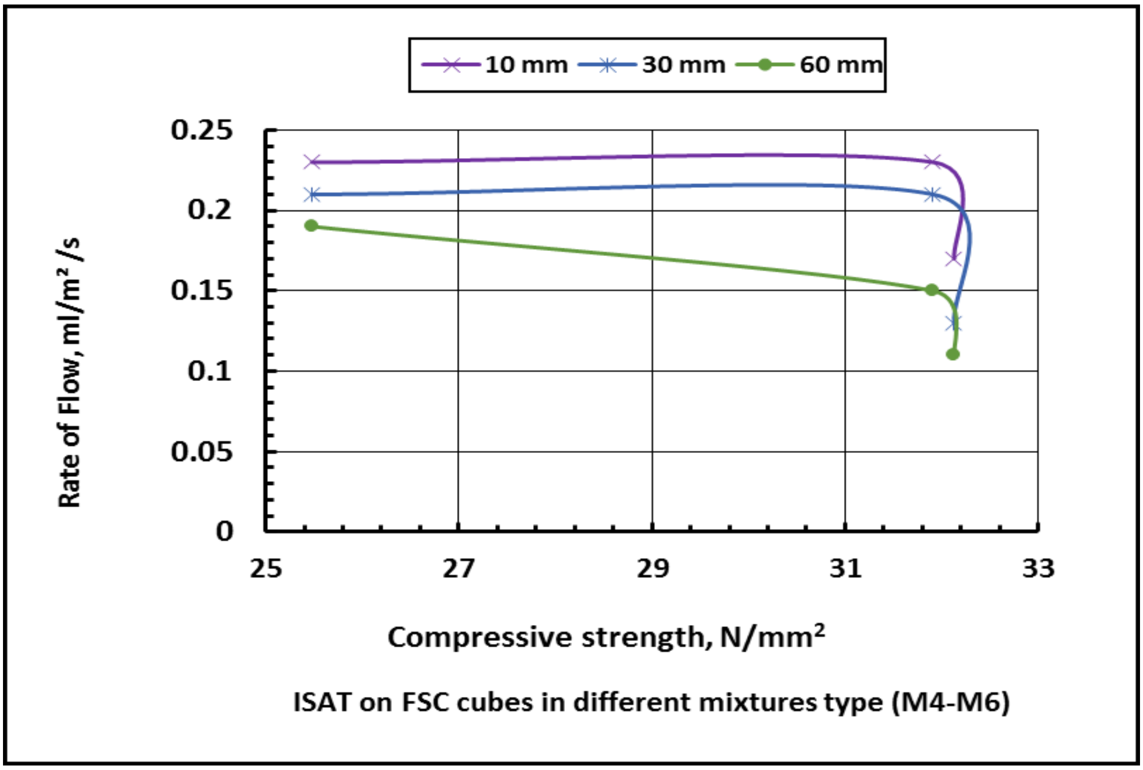
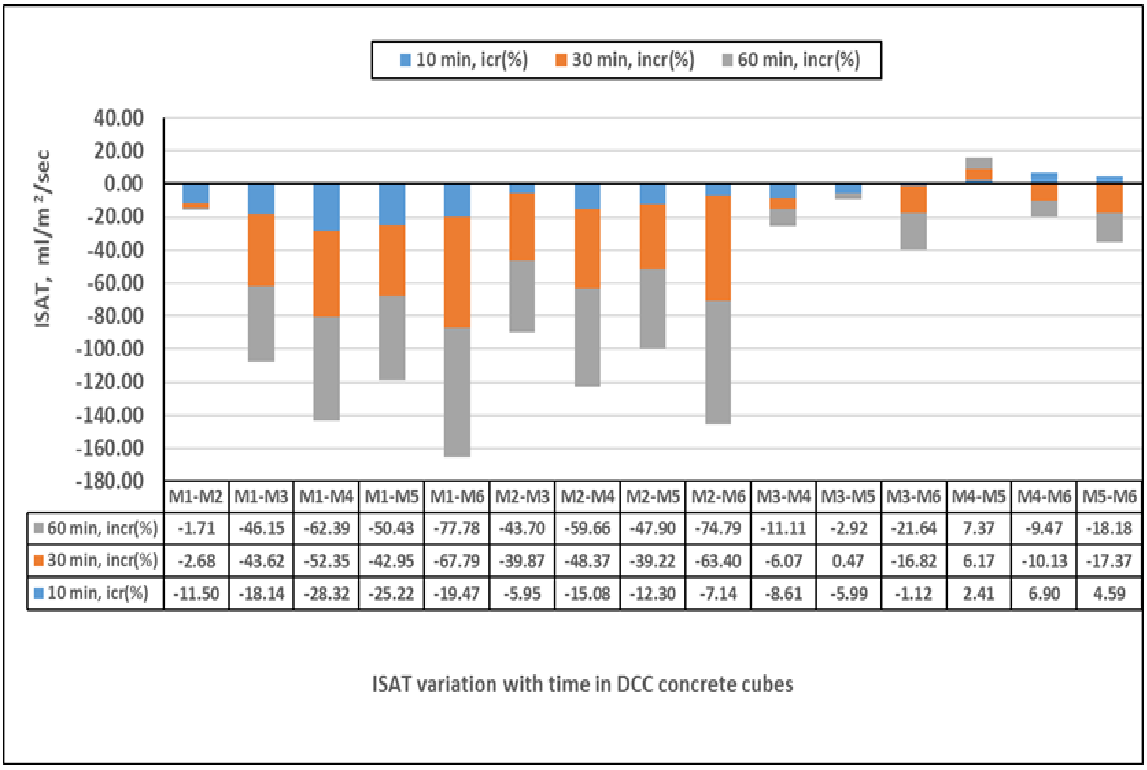


Figure 4-48 Effectiveness of compressive strength on ISAT in FSC concrete cubes

The variation of ISAT values in DCC concrete cubes was decrease in the concrete mix design (M1) at time interval 10, 30, and 60 min as when compare to the concrete mix designs (M2, M3, M4, M5, and M6) respectively as observe from experimental results (Figure 4-49 ISAT variation in DCC concrete cubes. Its observe that, the ISAT was predominantly decrease in the concrete mix design (M2) at time interval 10, 30, and 60 min as when compare to the concrete mix design (M3, M4, M5, and M6). Whereas in the case of the concrete mix design (M3), the ISAT values was decrease as when compare to the concrete mix designs (M4, M5 and M6) which was less in magnitude as against the concrete mix design (M2). ISAT values were slightly increase in the concrete mix design (M4) as when compare to the concrete mix design (M5) at different time interval. For in the case of the concrete mix designs (M4 and M5), the ISAT values were to be decrease as against the concrete mix design (M6). The variation of ISAT values in DCC concrete cubes was decrease in the concrete mix design (M1) at time interval 10, 30, and 60 min as when compare to the concrete mix designs (M2, M3, M4, M5, and M6) respectively as observe from experimental results (Figure 4-49 ISAT variation in DCC concrete cubes. Its observe that, the ISAT was predominantly decrease in the concrete mix design (M2) at time interval 10, 30, and 60 min as when compare to the concrete mix design (M3, M4, M5, and M6). Whereas in the case of the concrete mix design (M3), the ISAT values was decrease as when compare to the concrete mix designs (M4, M5 and M6) which was less in magnitude as against the concrete mix design (M2).



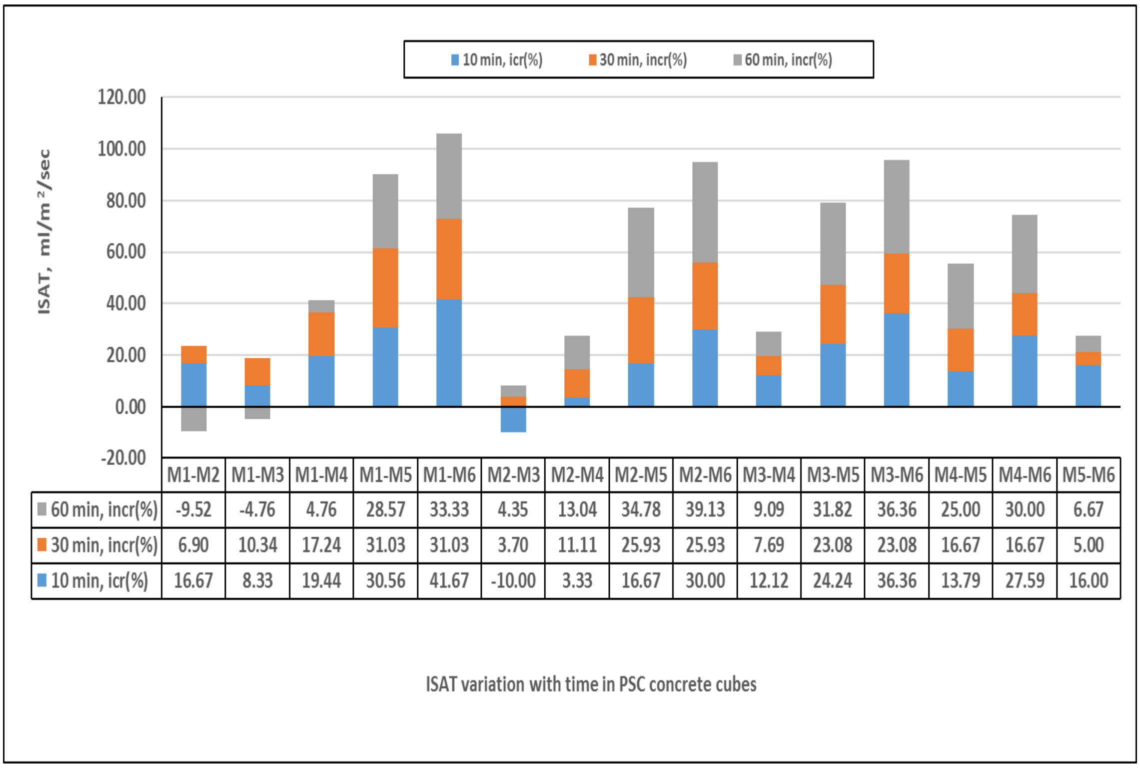
	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
■ 60 min, incr(%)	-1.71	-46.15	-62.39	-50.43	-77.78	-43.70	-59.66	-47.90	-74.79	-11.11	-2.92	-21.64	7.37	-9.47	-18.18
■ 30 min, incr(%)	-2.68	-43.62	-52.35	-42.95	-67.79	-39.87	-48.37	-39.22	-63.40	-6.07	0.47	-16.82	6.17	-10.13	-17.37
■ 10 min, icr(%)	-11.50	-18.14	-28.32	-25.22	-19.47	-5.95	-15.08	-12.30	-7.14	-8.61	-5.99	-1.12	2.41	6.90	4.59

Figure 4-49 ISAT variation in DCC concrete cubes at different time interval

ISAT values were slightly increase in the concrete mix design (M4) as when compare to the concrete mix design (M5) at different time interval. For in the case of the concrete mix designs (M4 and M5), the ISAT values were to be decrease as against the concrete mix design (M6).

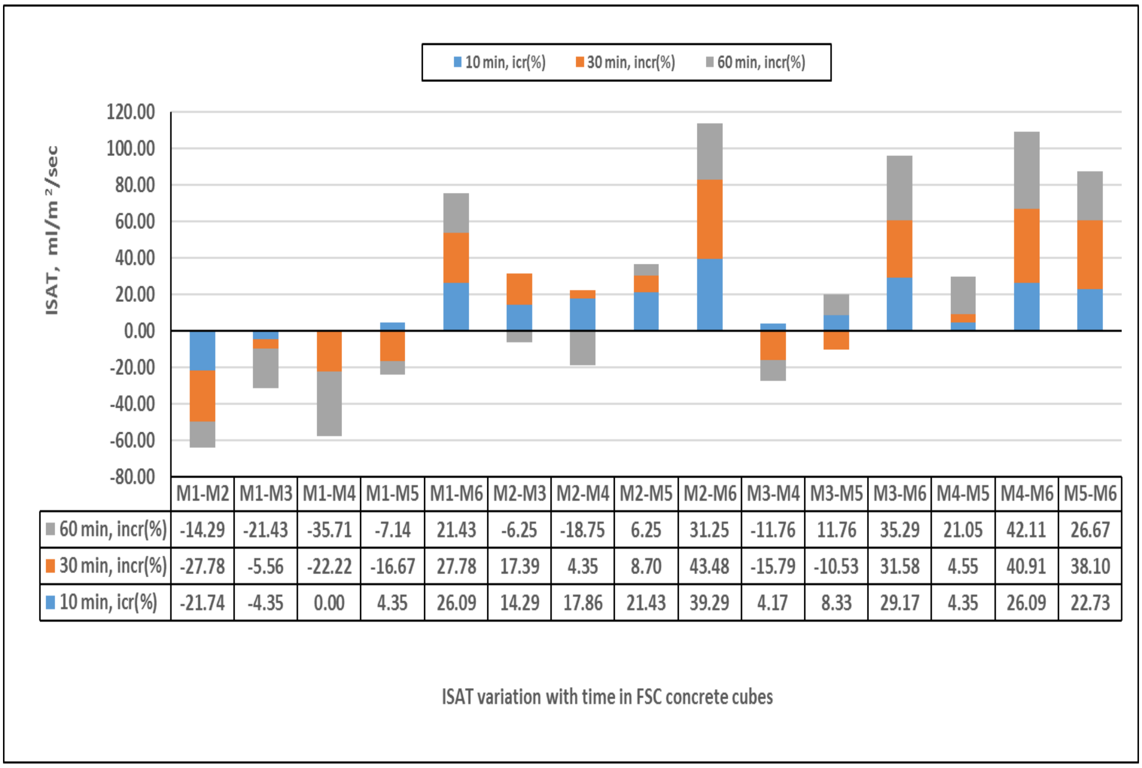
The variation of ISAT values in PSC concrete cubes was increase in the concrete mix design (M1) at time interval 10, 30, and 60 min as when compare to the concrete mix designs (M4, M5, and M6) respectively as observe from experimental results (Figure 4-49 ISAT variation in DCC concrete cubes. Its observe that, the ISAT was increase in the concrete mix design (M2) at time interval 10, 30, and 60 min as when compare to the concrete mix design (M4, M5, and M6).

Whereas in the case of the concrete mix design (M3), the ISAT values was increase as when compare to the concrete mix designs (M4, M5 and M6). ISAT values were increase in the concrete mix design (M4) as when compare to the concrete mix design (M5 and M6) at different time interval. ISAT values in FSC concrete cubes was decrease in the concrete mix design (M1) at time interval 10, 30, and 60 min as when compare to the concrete mix designs (M2, M3, M4, and M5) respectively as observe from (Figure 4-51Figure 4-49 ISAT variation in DCC concrete cubes.



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
▨ 60 min, incr(%)	-9.52	-4.76	4.76	28.57	33.33	4.35	13.04	34.78	39.13	9.09	31.82	36.36	25.00	30.00	6.67
▨ 30 min, incr(%)	6.90	10.34	17.24	31.03	31.03	3.70	11.11	25.93	25.93	7.69	23.08	23.08	16.67	16.67	5.00
▨ 10 min, icr(%)	16.67	8.33	19.44	30.56	41.67	-10.00	3.33	16.67	30.00	12.12	24.24	36.36	13.79	27.59	16.00

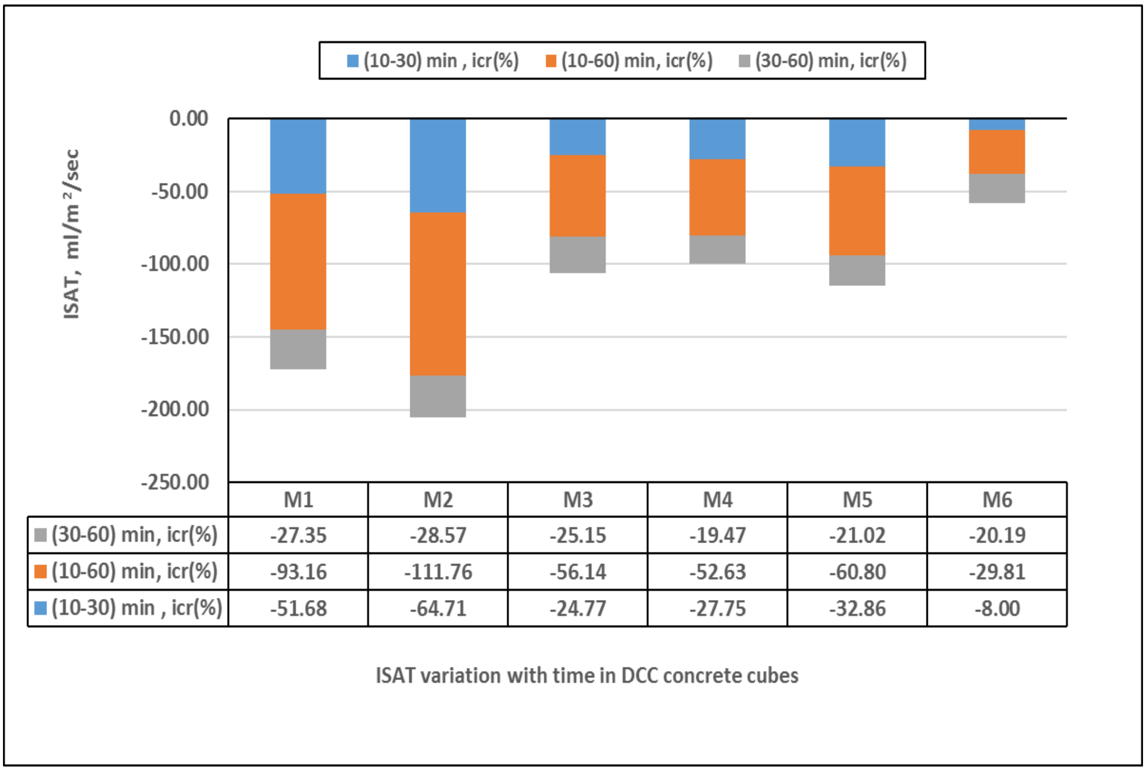
Figure 4-50 ISAT values variation in PSC concrete cubes at different time interval



	M1-M2	M1-M3	M1-M4	M1-M5	M1-M6	M2-M3	M2-M4	M2-M5	M2-M6	M3-M4	M3-M5	M3-M6	M4-M5	M4-M6	M5-M6
60 min, incr(%)	-14.29	-21.43	-35.71	-7.14	21.43	-6.25	-18.75	6.25	31.25	-11.76	11.76	35.29	21.05	42.11	26.67
30 min, incr(%)	-27.78	-5.56	-22.22	-16.67	27.78	17.39	4.35	8.70	43.48	-15.79	-10.53	31.58	4.55	40.91	38.10
10 min, icr(%)	-21.74	-4.35	0.00	4.35	26.09	14.29	17.86	21.43	39.29	4.17	8.33	29.17	4.35	26.09	22.73

Figure 4-51 ISAT values in FSC concrete cubes at different drill depths at time interval

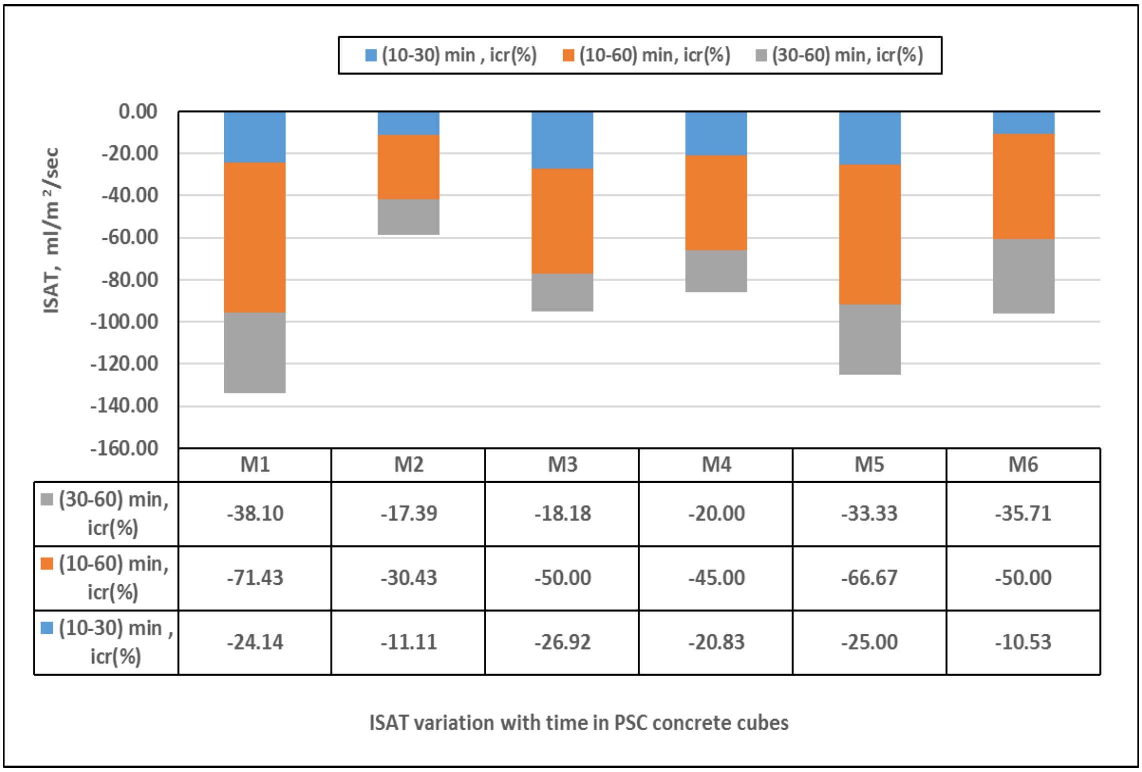
Its increases in the concrete mix design (M1) as against the concrete mix design (M6). ISAT values were also increase in the concrete mix design (M3) as when compare to the concrete mix design (M5 and (M6). Similarly for in case of concrete mix design (M4 and M5), the ISAT values were increase as against the concrete mix designs (M5 and M6). As observe from the (Figure 4-52) that, ISAT values were predominantly decrease in the concrete mix designs (M1-M3) as when compare to the concrete mix designs (M4-M6) for in case of DCC concrete cubes. At time interval 30 min, and 60 min as when compare to the time interval 10 min, and 30 min. ISAT values were more decrease at time interval 60 min as when compare to the 10 min time interval in all designed concrete mix.



	M1	M2	M3	M4	M5	M6
▨ (30-60) min, icr(%)	-27.35	-28.57	-25.15	-19.47	-21.02	-20.19
🟧 (10-60) min, icr(%)	-93.16	-111.76	-56.14	-52.63	-60.80	-29.81
🟦 (10-30) min , icr(%)	-51.68	-64.71	-24.77	-27.75	-32.86	-8.00

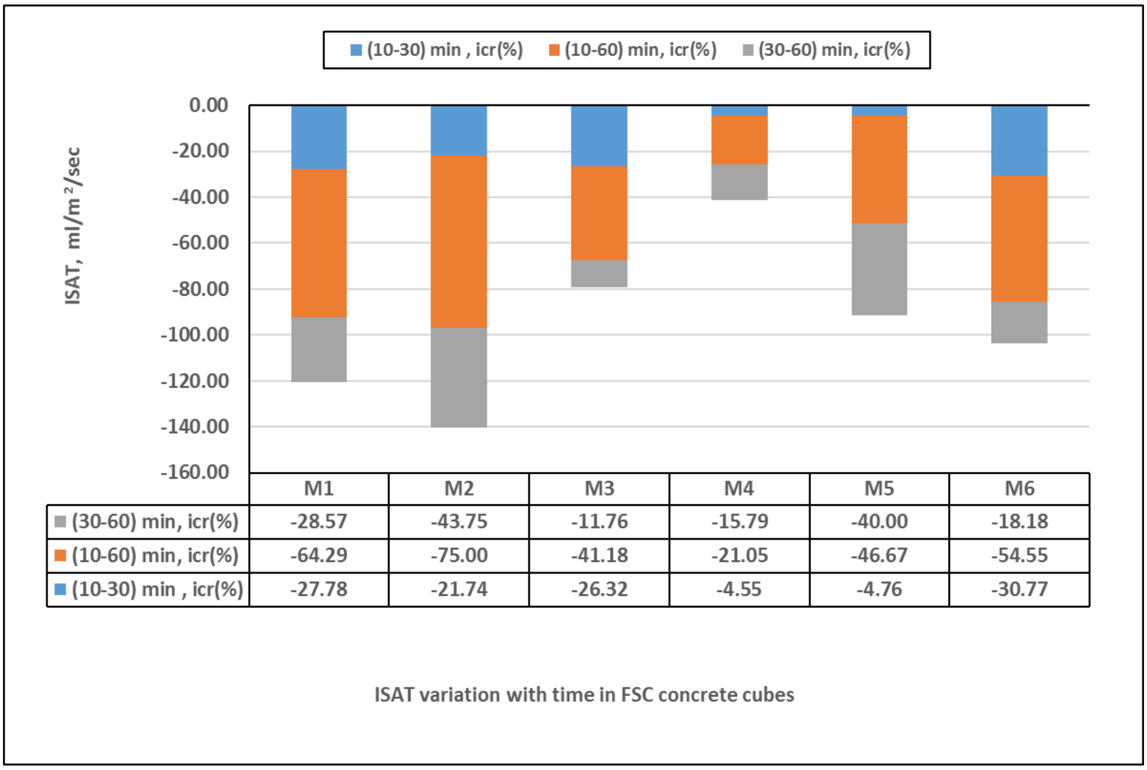
Figure 4-52 comparison of ISAT in DCC concrete cubes at different time interval

It is clear from the (Figure 4-53) that, ISAT values were predominantly decrease in the concrete mix designs (M1-M3) as when compare to the concrete mix designs (M4-M6) for in the case of PSC concrete cubes. At time interval 30 min, and 60 min as when compare to the time interval 10 min, and 30 min. ISAT values were more decrease at time interval 60 min as when compare to the 10 min time interval in all designed concrete mix. However, the increased ISAT values were reduce at different time interval (10-30) min, (10-60) min and (30-60) min for in the case of PSC concrete cubes as when compare to the DCC concrete cubes.



	M1	M2	M3	M4	M5	M6
■ (30-60) min, icr(%)	-38.10	-17.39	-18.18	-20.00	-33.33	-35.71
■ (10-60) min, icr(%)	-71.43	-30.43	-50.00	-45.00	-66.67	-50.00
■ (10-30) min , icr(%)	-24.14	-11.11	-26.92	-20.83	-25.00	-10.53

Figure 4-53 Variation of ISAT in PSC concrete cubes at different time interval



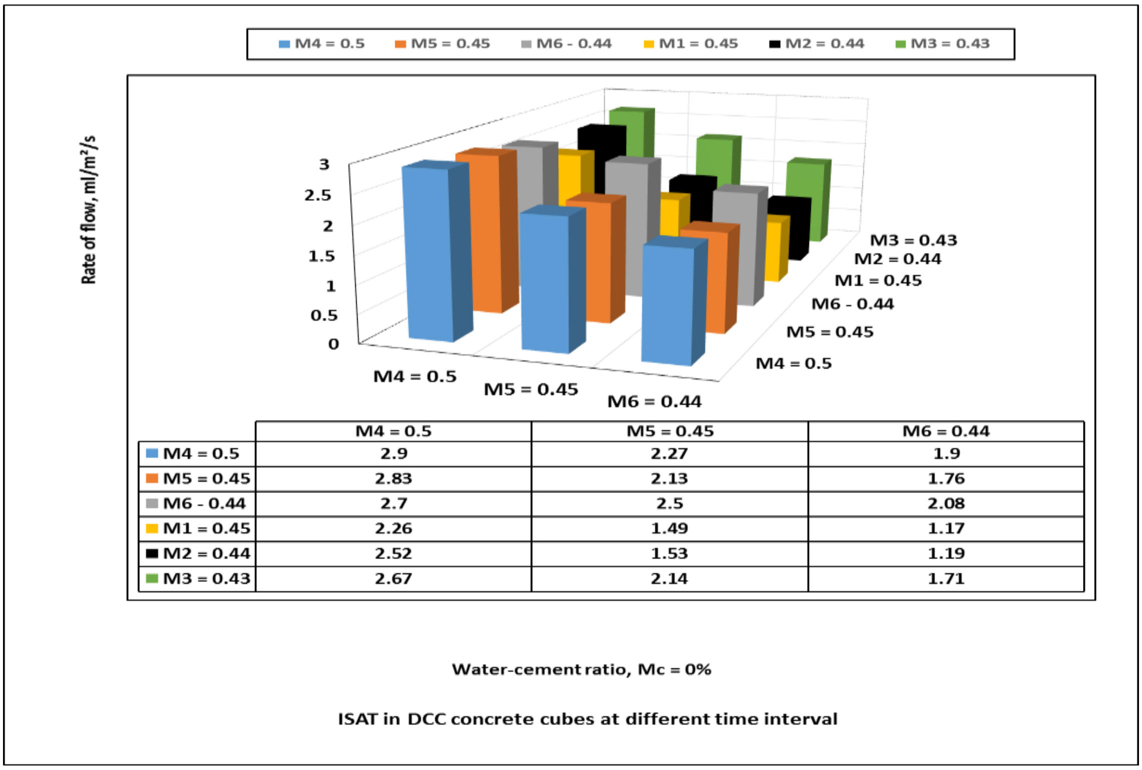
	M1	M2	M3	M4	M5	M6
■ (30-60) min, icr(%)	-28.57	-43.75	-11.76	-15.79	-40.00	-18.18
■ (10-60) min, icr(%)	-64.29	-75.00	-41.18	-21.05	-46.67	-54.55
■ (10-30) min , icr(%)	-27.78	-21.74	-26.32	-4.55	-4.76	-30.77

Figure 4-54 Interpretation of ISAT in FSC concrete cubes at different time interval

From the (Figure 4-54) that, ISAT values were decrease in the concrete mix designs (M1-M3) as when compare to the concrete mix designs (M4-M6) for in the case of FSC concrete cubes. At time interval 30 min, and 60 min as when compare to the time interval 10 min, and 30 min. ISAT values were more decrease at time interval 60 min as when compare to the 10 min time interval in all designed concrete mix. However, the increased ISAT values were reduce at different time interval (10-30) min, (10-60) min and (30-60) min for in the case of PSC and FSC concrete cubes.

4.4.4 Effectiveness w/c ratio on ISAT in concrete cubes

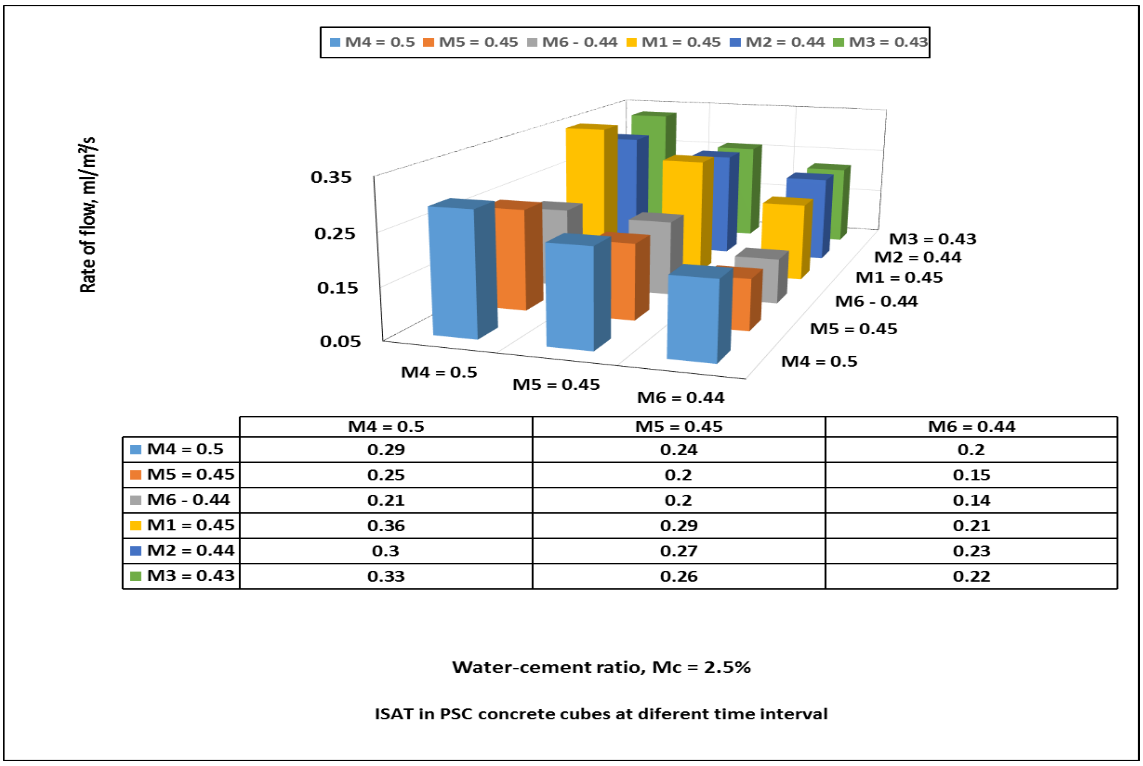
The main ingredients that can be blend and proportioned numerous ways to make concrete more durable was such as an aggregate, cement and water. In concrete, the single most significant influence on most or all of the properties is the amount of water used in the mix. Thus, it is two prominent ingredients, which are responsible for binding everything together in the concrete matrix. ISAT values was decreases in DCC concrete cubes with lower w/c ratio in all designed concrete mix (M1-M6) as observe from the results (Figure 4-55).



	M4 = 0.5	M5 = 0.45	M6 = 0.44
🟦 M4 = 0.5	2.9	2.27	1.9
🟧 M5 = 0.45	2.83	2.13	1.76
⬜ M6 - 0.44	2.7	2.5	2.08
🟨 M1 = 0.45	2.26	1.49	1.17
⬛ M2 = 0.44	2.52	1.53	1.19
🟩 M3 = 0.43	2.67	2.14	1.71

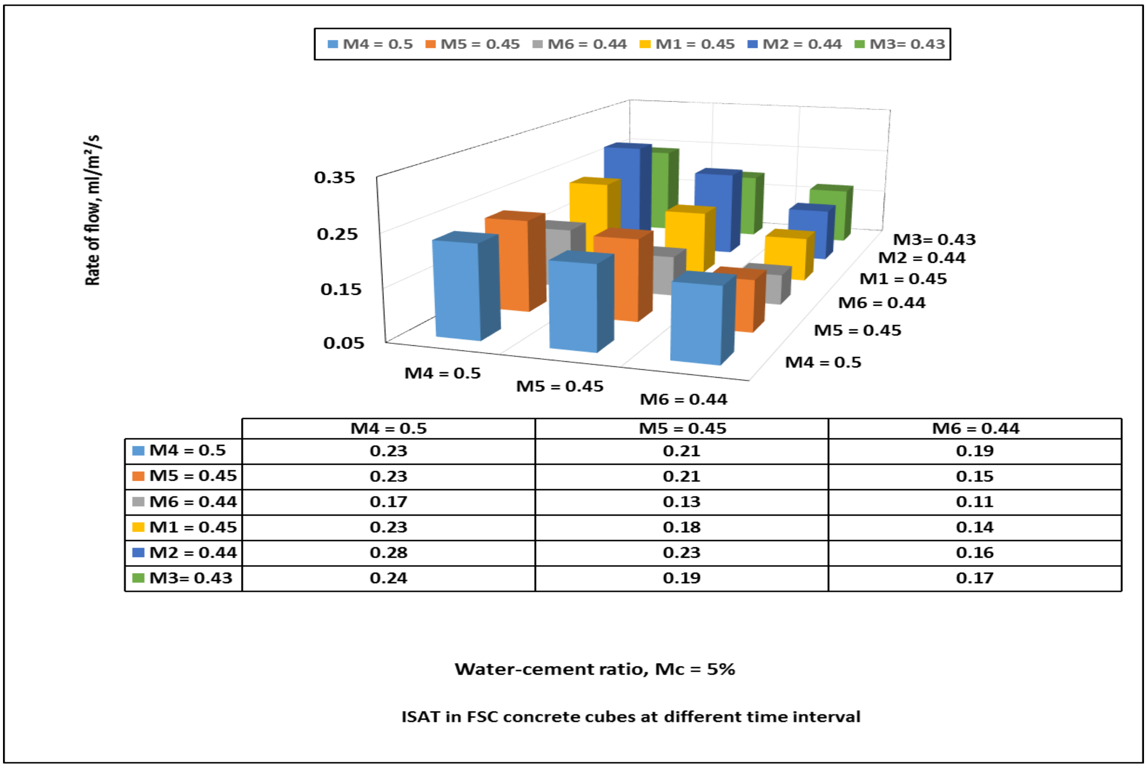
Figure 4-55 ISAT variation with w/c ratio in DCC concrete cubes

ISAT values was varied in PSC and FSC concrete cubes with moisture content (Mc = 2.5% and Mc = 5%) in all designed concrete mix (M1-M6) as shown (Figure 4-56 and Figure 4-57).



	M4 = 0.5	M5 = 0.45	M6 = 0.44
■ M4 = 0.5	0.29	0.24	0.2
■ M5 = 0.45	0.25	0.2	0.15
■ M6 - 0.44	0.21	0.2	0.14
■ M1 = 0.45	0.36	0.29	0.21
■ M2 = 0.44	0.3	0.27	0.23
■ M3 = 0.43	0.33	0.26	0.22

Figure 4-56 ISAT variation with w/c ratio in PSC concrete cubes



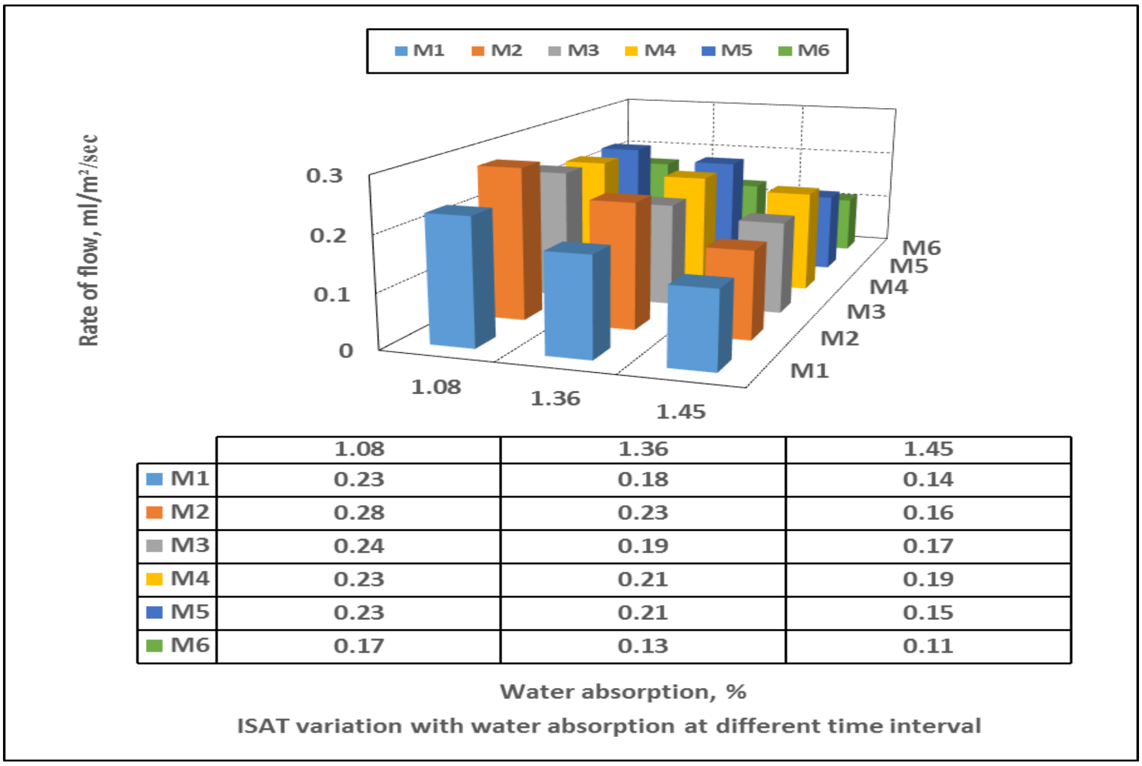
	M4 = 0.5	M5 = 0.45	M6 = 0.44
■ M4 = 0.5	0.23	0.21	0.19
■ M5 = 0.45	0.23	0.21	0.15
■ M6 = 0.44	0.17	0.13	0.11
■ M1 = 0.45	0.23	0.18	0.14
■ M2 = 0.44	0.28	0.23	0.16
■ M3= 0.43	0.24	0.19	0.17

Figure 4-57 ISAT variation with w/c ratio in FSC concrete cubes

ISAT values were observe to be lower for in the case of saturated conditioned concrete cubes as when compare to the DCC concrete cubes for in the case of concrete mix design (M4-M6) as the concrete mix design (M1-M3) with lower w/c ratio.

4.4.5 Effectiveness water absorption on ISAT in concrete cubes

The most important properties of a good quality concrete is low permeability. A concrete with low permeability resists ingress of water and is not as susceptible to freezing and thawing. Water enters pores in the cement paste and aggregate. ISAT values were higher at lower water absorption and its goes on reduces with increased water absorption value for in the case of designed concrete mix (M1-M6). ISAT values were predominantly decrease for in the case of designed concrete mix (M1-M3) as against the concrete mix design (M4-M6) as shown in (Figure 4-58).

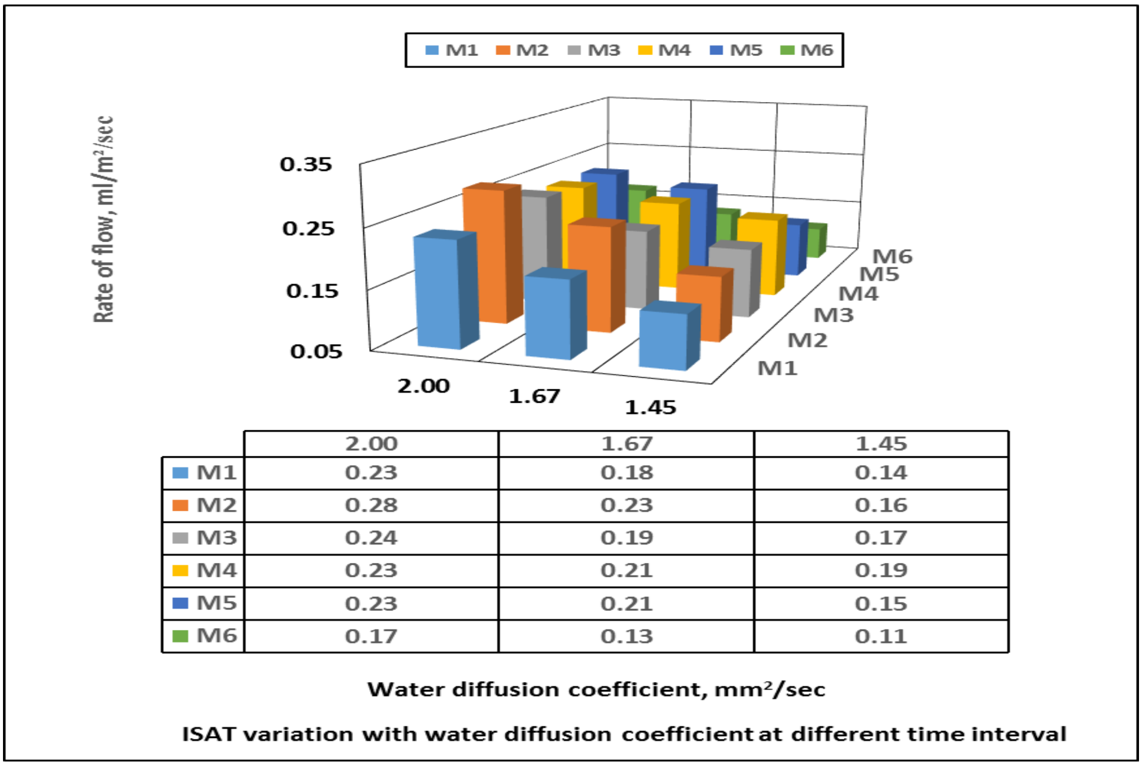


	1.08	1.36	1.45
M1	0.23	0.18	0.14
M2	0.28	0.23	0.16
M3	0.24	0.19	0.17
M4	0.23	0.21	0.19
M5	0.23	0.21	0.15
M6	0.17	0.13	0.11

Figure 4-58 ISAT variation with water absorption in FSC concrete cubes

4.4.6 Effectiveness water diffusion coefficient on ISAT in concrete cubes

The diffusion occurs when particles spread (gas or liquid). They move from a region where they are in high concentration to a region where they are in low concentration. Particles continue to move from a high to a low concentration while there is a concentration gradient occurs in any medium. ISAT values were to be increase at higher water concentration gradient, which was, exists between wet to dry surface interface within the concrete matrix at an initial time duration and its goes on decreases with longer time duration. ISAT values were slightly increase for in the case of designed concrete mix (M1-M3) as against the concrete mix design (M4-M6) as interpret in (Figure 4-59).

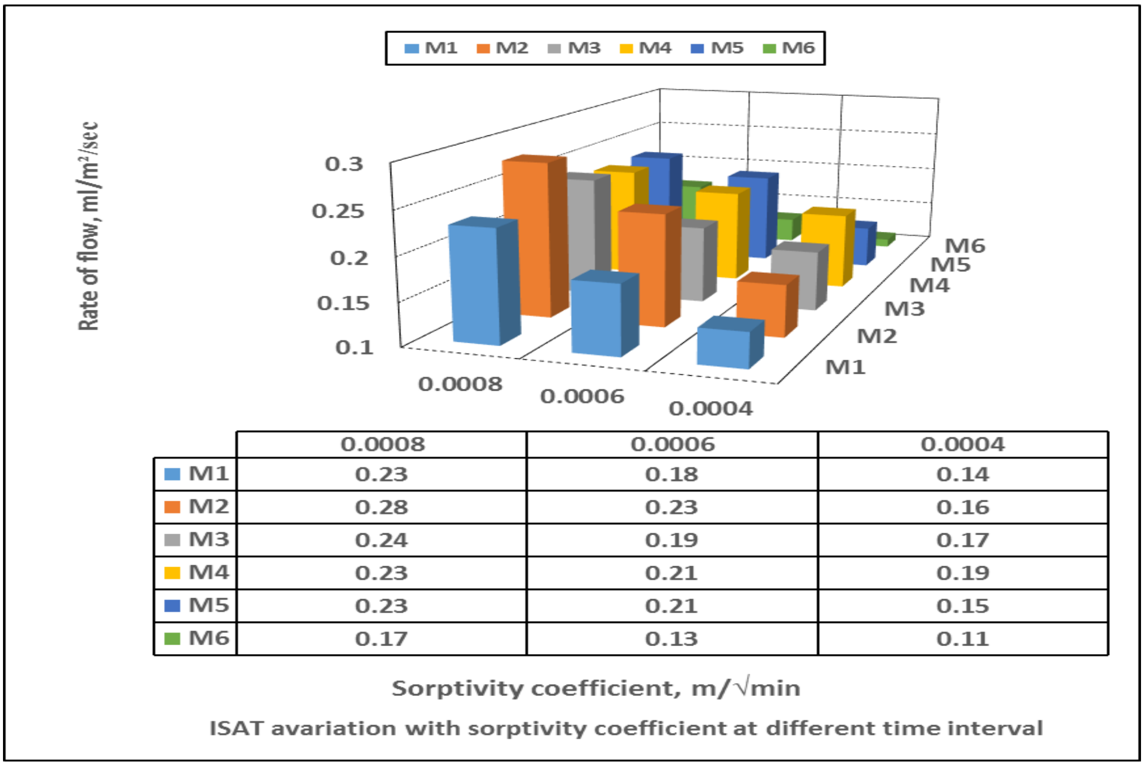


	2.00	1.67	1.45
🟦 M1	0.23	0.18	0.14
🟧 M2	0.28	0.23	0.16
⬜ M3	0.24	0.19	0.17
🟨 M4	0.23	0.21	0.19
🟦 M5	0.23	0.21	0.15
🟩 M6	0.17	0.13	0.11

Figure 4-59 ISAT variation with water diffusion coefficient in FSC concrete cubes

4.4.7 Effectiveness sorptivity coefficient on ISAT in concrete cubes

The sorptivity coefficient was increases with an initial time duration and goes on reduces with time duration for in the case of all designed concrete mix (M1-M6). It is observe from the results that, the ISAT values were to be increase in magnitude for increased sorptivity coefficient value at initial time duration (10 min) as against time duration (30 and 60 min) for in the designed concrete mix design, which was as shown in (Figure 4-60).



	0.0008	0.0006	0.0004
🟦 M1	0.23	0.18	0.14
🟧 M2	0.28	0.23	0.16
⬜ M3	0.24	0.19	0.17
🟨 M4	0.23	0.21	0.19
🟦 M5	0.23	0.21	0.15
🟩 M6	0.17	0.13	0.11

Figure 4-60 ISAT variation with sorptivity coefficient in FSC concrete cubes

4.5 Salt ponding test on concrete cubes

4.5.1 Water absorption in PCC concrete cubes

The pre-dry conditioning was induce in 24 concrete cubes which were expose to natural room temperature for about 28 days and recorded their dry weight at subsequent time duration from 0-3880 min as shown in (Figure 4-61). The pre-conditioned fully saturated condition was achieve in 24 concrete cubes by partially submerged in water with one surface exposed for about 31 days, and noted their saturated weight at subsequent time duration from 0-43200 min (Figure *4-62*). The pre-conditioned partially saturated condition was assess in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 21 days well as recorded their saturated weight at subsequent time duration from 0-30240 min (Figure *4-63*).

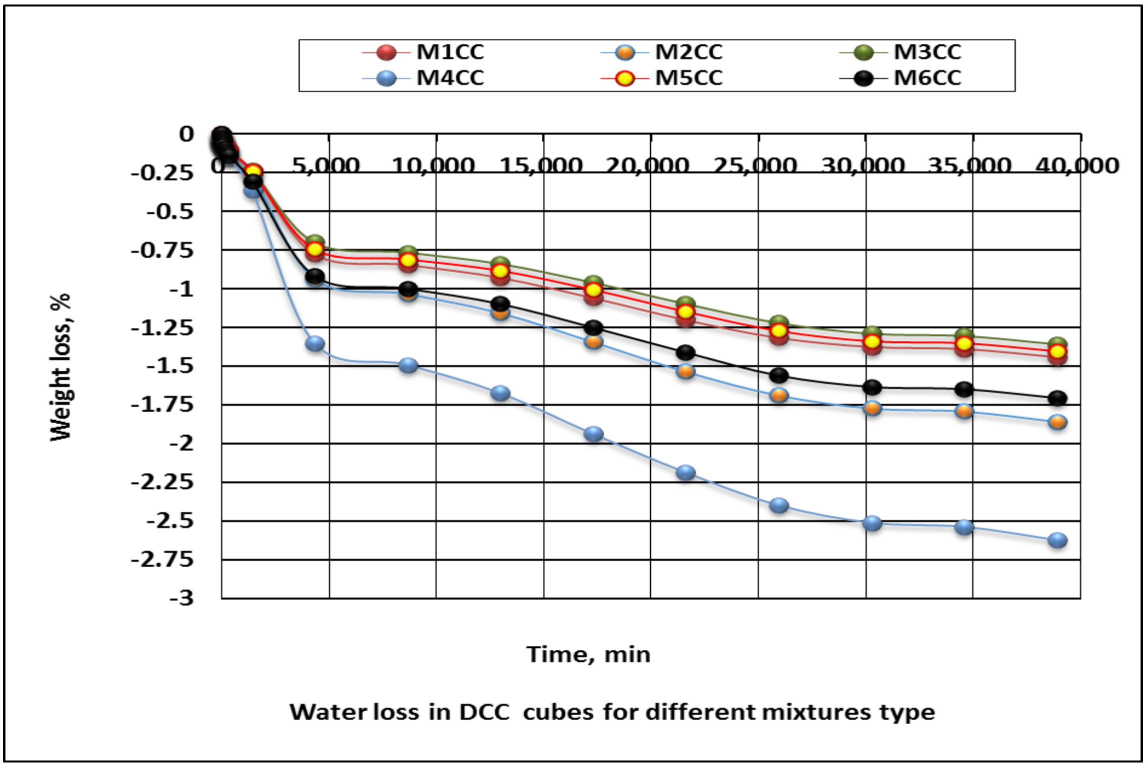


Figure 4-61 Dry conditioned concrete cubes in water for pre-conditioning

The variation of fully saturated conditioned concrete cubes in water for different mixtures type (M1-M6) was as shown in Figure 4-62.

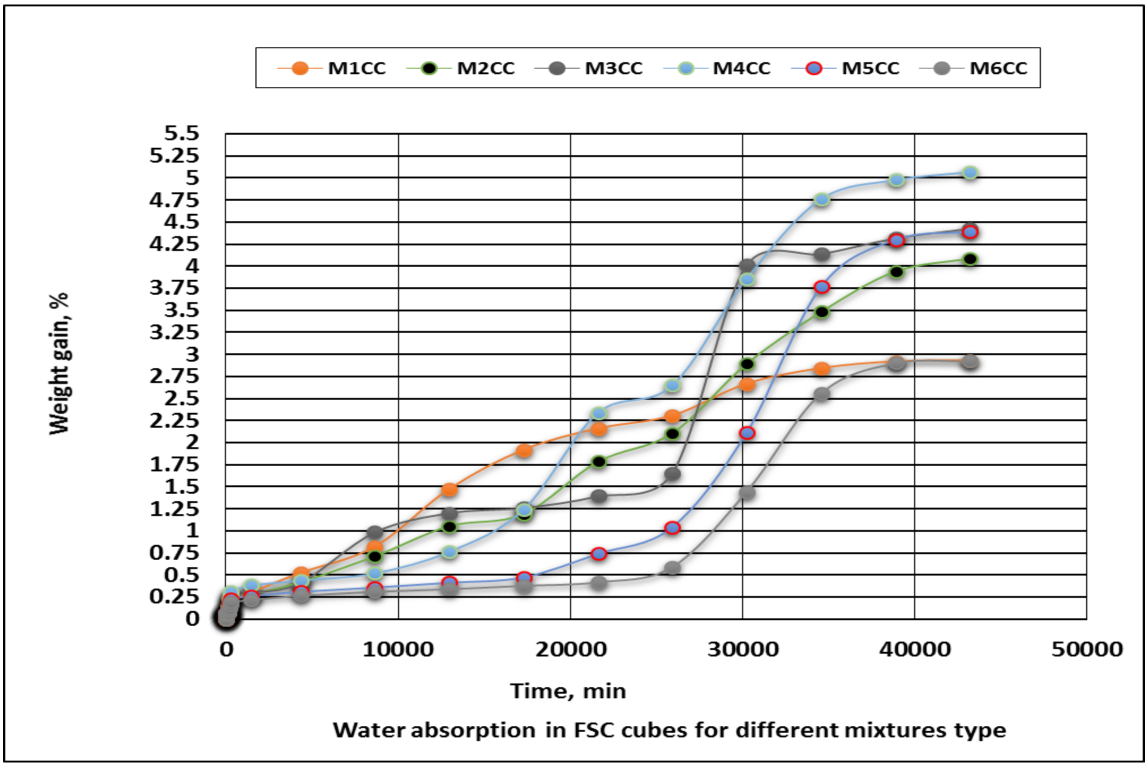


Figure 4-62 Fully saturated concrete cubes in water for pre-conditioning

The variation of partially saturated conditioned concrete cubes in water for different mixtures type (M1-M6) was as shown in Figure 4-63.

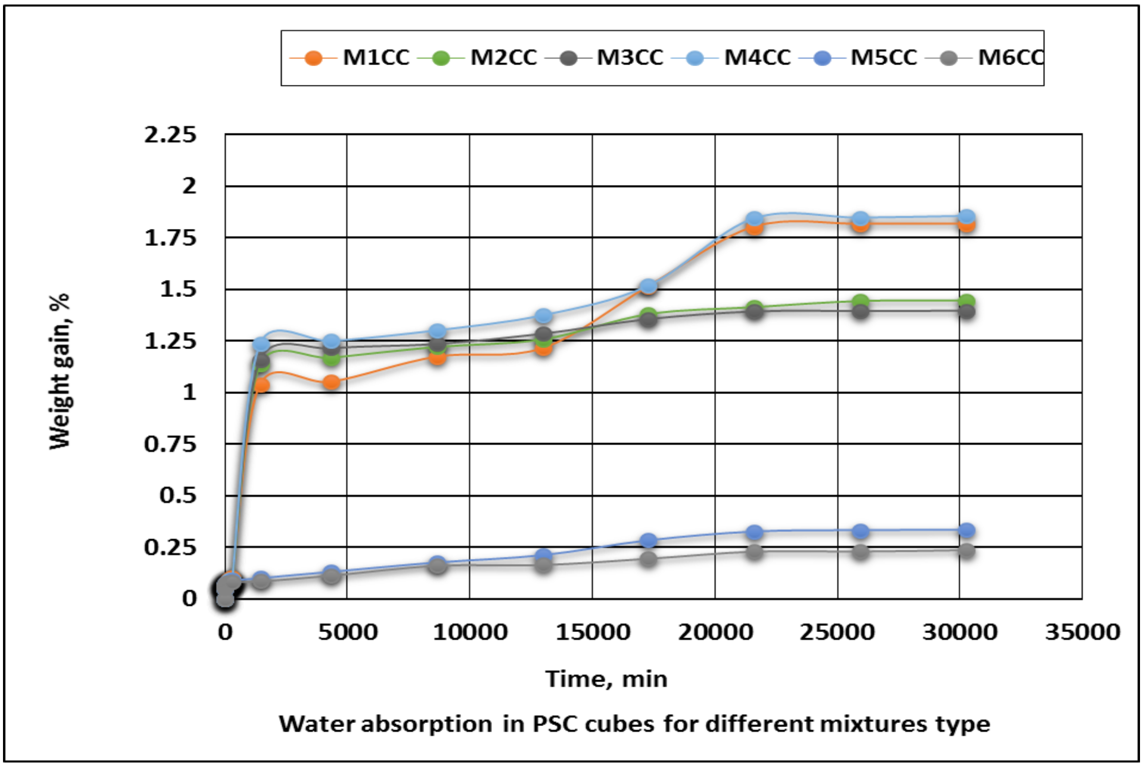


Figure 4-63 partially saturated concrete cubes in water for pre-conditioning

4.5.2 Chloride solution absorption in PCC concrete cubes

The variation of DCC concrete cubes in chloride solution absorption for different mixtures type (M1-M6) was as shown in Figure 4-64. Its confirmed from the results that, the overall average values of chloride absorption for time (160 days) for instance in all mixtures type (M1-M6) in which, the control concrete cubes (M1CC-M3CC) in turn the chloride absorption was found to be lower for higher compressive strength and varied slump value. Similarly, the chloride absorption was extremely more due lower compressive strength and constant slump for in case of mixture type M4CC (3.167%), M4SB (2.616%), and M4WB (2.820%) respectively. Furthermore, the chloride absorption was predominantly lesser higher compressive strength and constant slump value for in case of mixture type M5CC (2.379%), M5SB (1.628%), M5WB (1.893%) as well as chloride absorption was still more reduced for in case of mixture type M6CC (2.185%), M6SB (1.661%), and M6WB (1.995%) respectively.

It has confirmed that for higher compressive strength and varied slump value, the chloride absorption was to be lesser in magnitude. Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be more as when compared to higher compressive strength for in case of mixtures type (M5-M6).

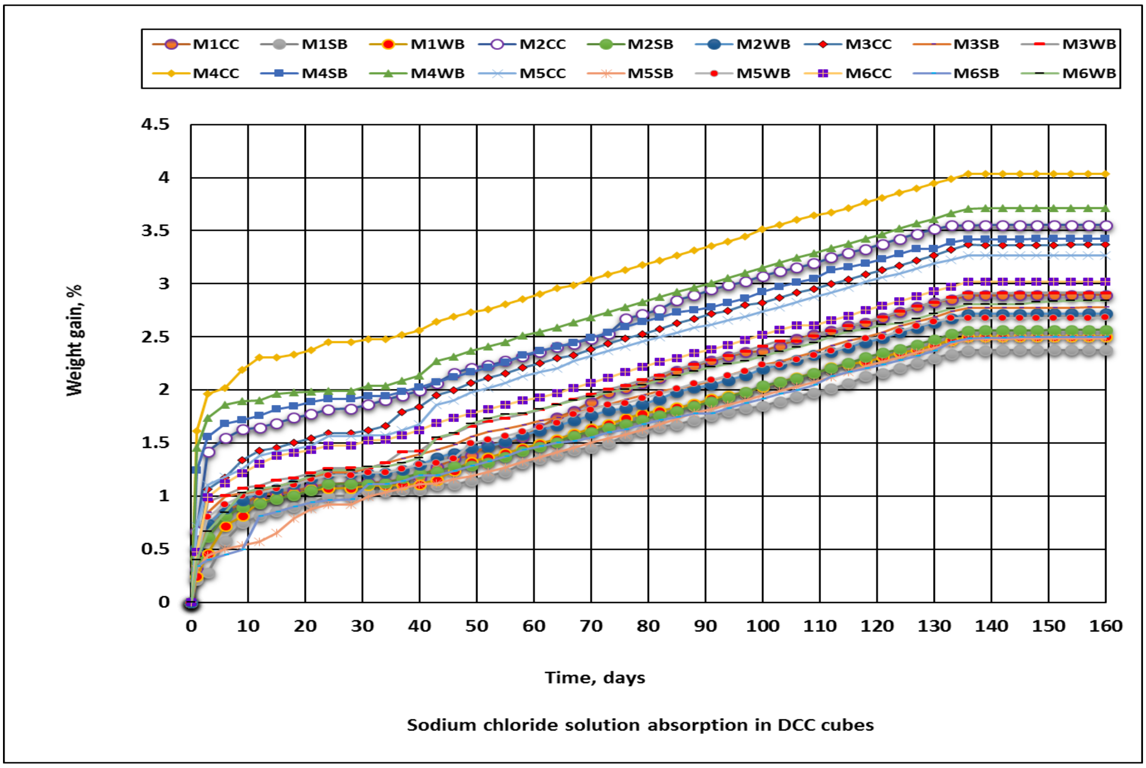


Figure 4-64 Chloride solution absorption in DCC cubes

The variation of PSC concrete cubes in chloride solution for different mixtures type (M1-M6) was as shown in Figure 4-65. Its confirmed from the results that, the overall average values of chloride absorption for time (160 days) for instance in all mixtures type (M1-M6) in which, the control concrete cubes (M1CC-M3CC) in turn the chloride absorption was found to be higher for higher compressive strength and varied slump value. Similarly, the chloride absorption was extremely more due lower compressive strength and constant slump for in case of mixture type M4CC (0.824%), M4SB (0.634%), and M4WB (0.669%) respectively. Furthermore, the chloride absorption was predominantly lesser for higher compressive strength and constant slump value for in case of mixture type M5CC (0.734%), M5SB (0.619%), M5WB (0.637%) as well as chloride absorption was still more reduced for in case of mixture type M6CC (0.66%), M6SB (0.607%), and M6WB (0.626%) respectively.

It has confirmed that for higher compressive strength and varied slump value, the chloride absorption was to be lesser in magnitude from chloride solution absorption. Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be more as when compared to higher compressive strength for in case of mixtures type (M5-M6).

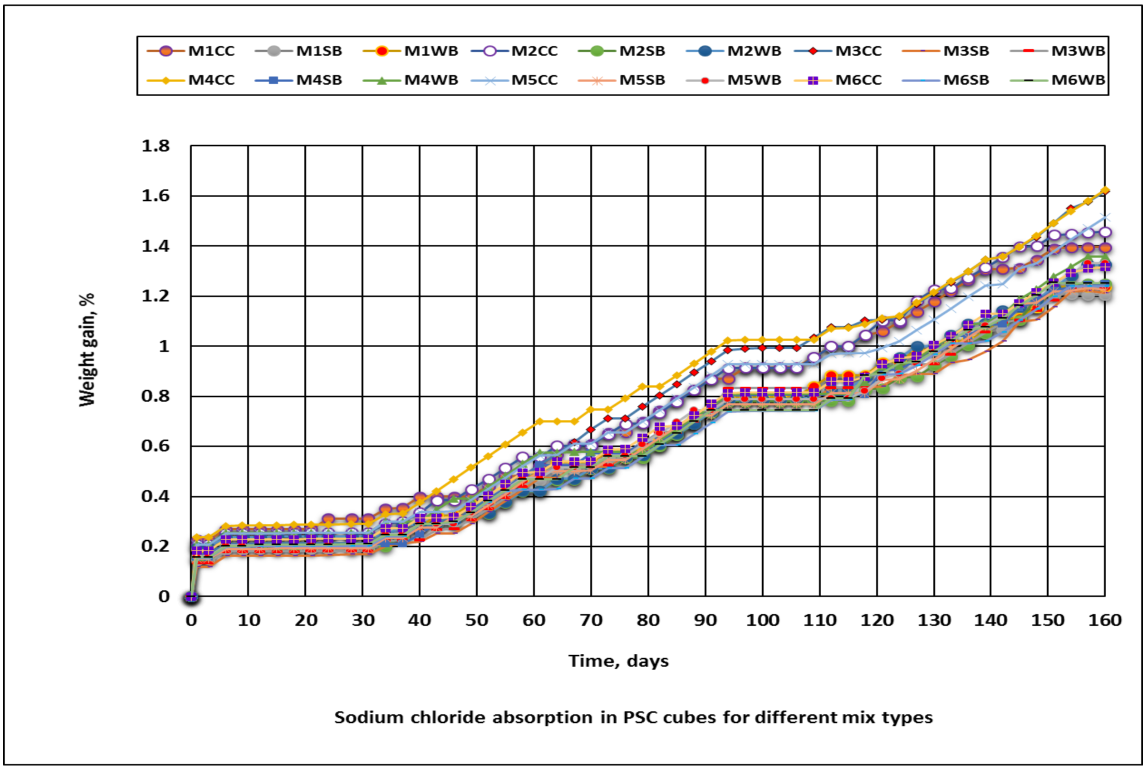


Figure 4-65 Chloride solution absorption in PSC concrete cubes

The variation of FSC concrete cubes in chloride solution for different mixtures type (M1-M6) was as shown in Figure 4-66. It is clear from the results that, the overall average values of chloride absorption for time duration (160 days) in which the control concrete cubes (M1CC-M3CC) chloride absorption was to be higher for higher compressive strength and varied slump value. Similarly, the chloride absorption was extremely more due lower compressive strength and constant slump for in case of mixture type M4CC (0.434%), M4SB (0.222%), and M4WB (0.245%) respectively. Furthermore, the chloride absorption was predominantly lesser for higher compressive strength and constant slump value for in case of mixture type M5CC (0.312%), M5SB (0.188%), M5WB (0.209%) as well as chloride absorption was still more reduced for in case of mixture type M6CC (0.240%), M6SB (0.166%), and M6WB (0.196%) respectively.

From chloride solution absorption value that, it has confirmed that for higher compressive strength and varied slump value, the chloride absorption was confirm to be lesser in magnitude. Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be more as when compared to higher compressive strength for in case of mixtures type (M5-M6).

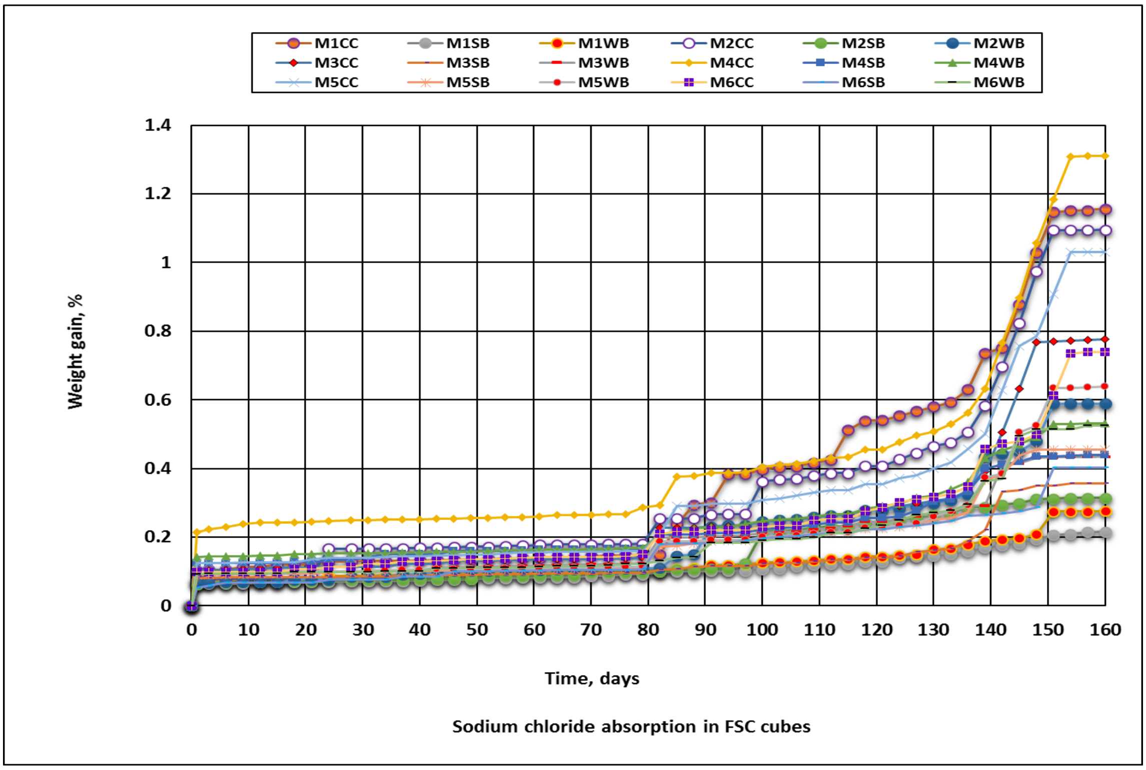
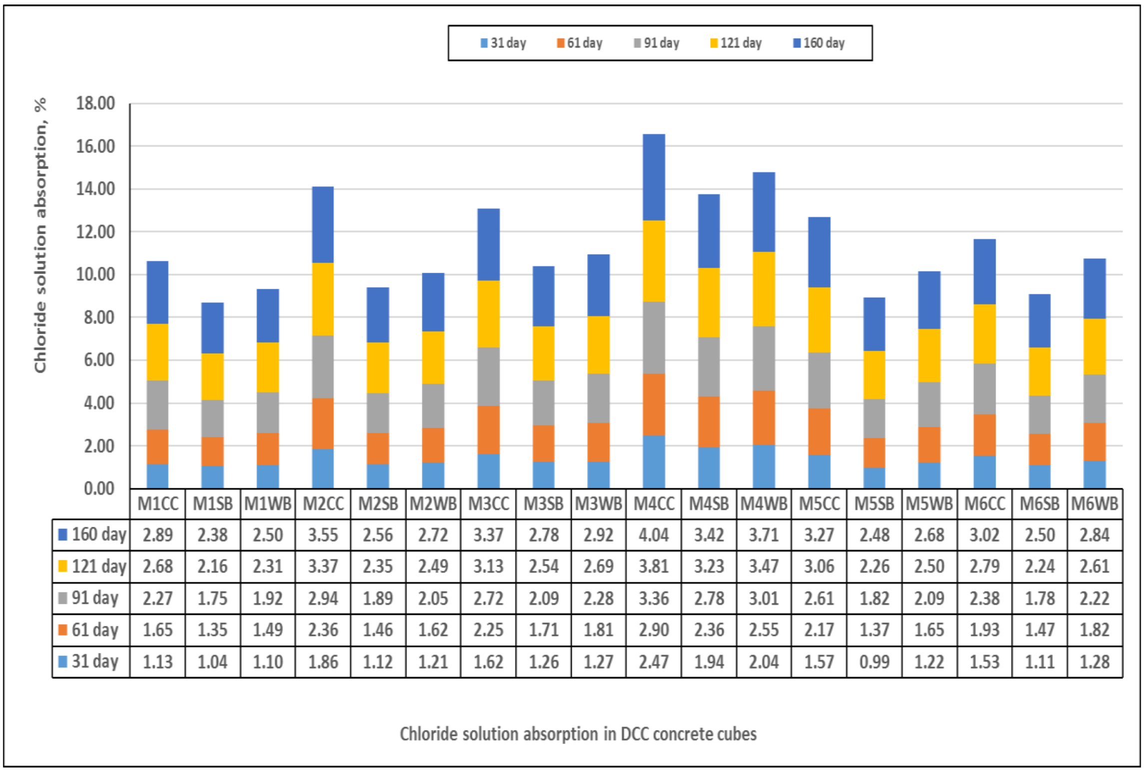


Figure 4-66 Chloride solution absorption in FSC concrete cubes

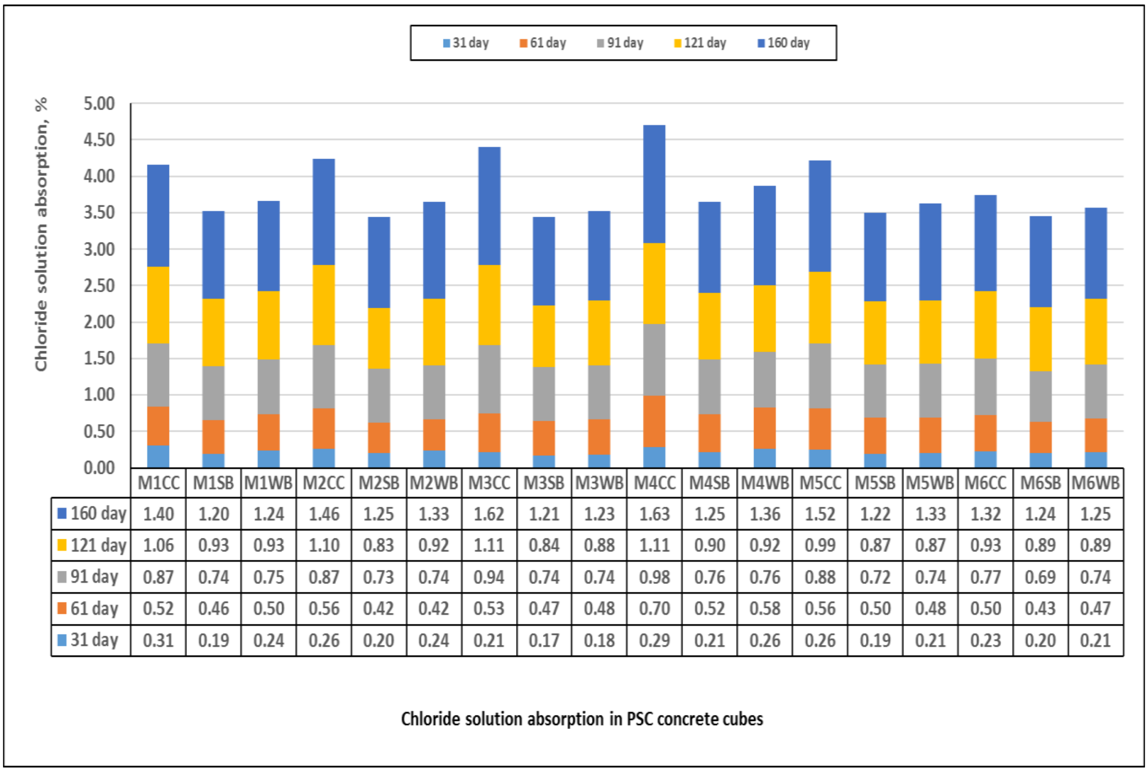
4.5.3 Chloride solution absorption in PCC/IC concrete cubes

The variation of chloride solution absorption in all DCC designed control/IC concrete mix at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure *4-67*). Chloride solution absorption was confirm to be more for in the case of control concrete cubes (M1CC-M6CC) as against the impregnated concrete cubes (M1SB-M6SB, and M1WB-M6WB) respectively. It is also clear from the results that, the chloride solution absorption was more for in the case of designed control concrete cube with lower compressive strength (M4CC) and constant slump value. Chloride solution absorption was goes on reduces with increase in compressive strength and constant slump value for in the case of control (M5CC, and M6CC)/impregnated concrete cubes (M5SB, M6SB, M5WB, and M6WB). Chloride solution absorption in all designed PSC control/IC concrete mix at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure 4-68). Chloride solution absorption was more for in the case of control concrete cubes (M1CC-M6CC) as against the impregnated concrete cubes (M1SB-M6SB, and M1WB-M6WB) respectively.



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
160 day	2.89	2.38	2.50	3.55	2.56	2.72	3.37	2.78	2.92	4.04	3.42	3.71	3.27	2.48	2.68	3.02	2.50	2.84
121 day	2.68	2.16	2.31	3.37	2.35	2.49	3.13	2.54	2.69	3.81	3.23	3.47	3.06	2.26	2.50	2.79	2.24	2.61
91 day	2.27	1.75	1.92	2.94	1.89	2.05	2.72	2.09	2.28	3.36	2.78	3.01	2.61	1.82	2.09	2.38	1.78	2.22
61 day	1.65	1.35	1.49	2.36	1.46	1.62	2.25	1.71	1.81	2.90	2.36	2.55	2.17	1.37	1.65	1.93	1.47	1.82
31 day	1.13	1.04	1.10	1.86	1.12	1.21	1.62	1.26	1.27	2.47	1.94	2.04	1.57	0.99	1.22	1.53	1.11	1.28

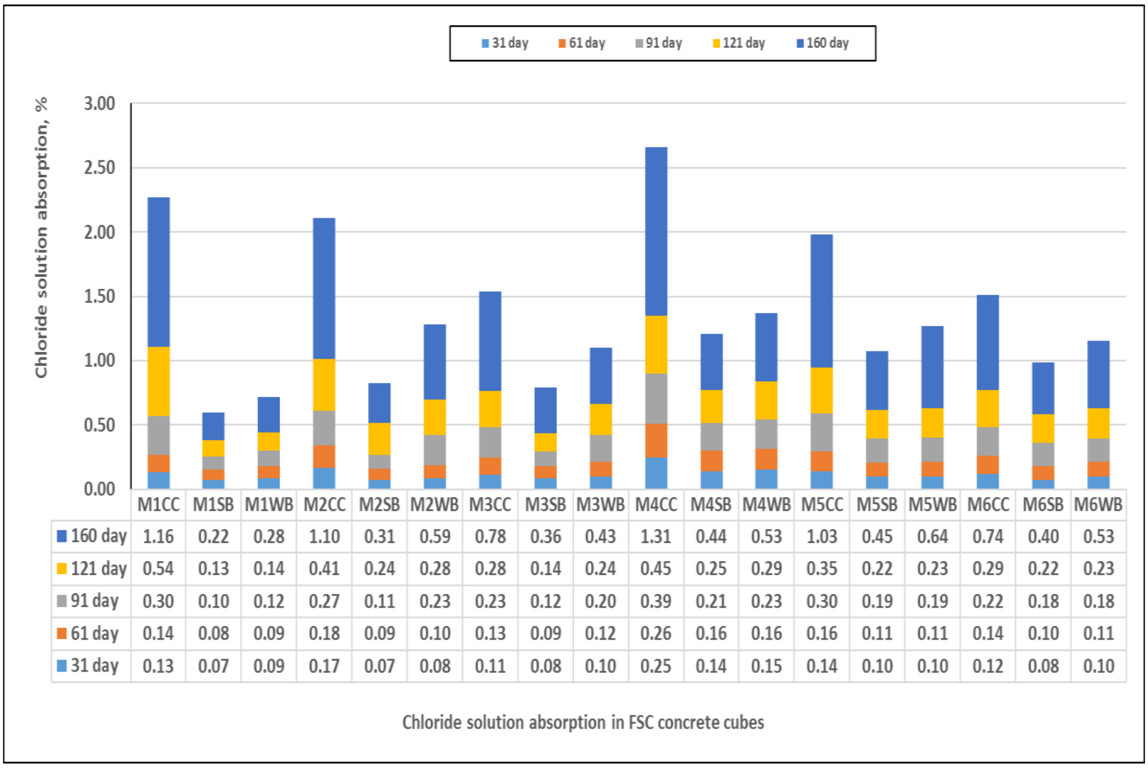
Figure 4-67 Chloride solution absorption in DCC cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
160 day	1.40	1.20	1.24	1.46	1.25	1.33	1.62	1.21	1.23	1.63	1.25	1.36	1.52	1.22	1.33	1.32	1.24	1.25
121 day	1.06	0.93	0.93	1.10	0.83	0.92	1.11	0.84	0.88	1.11	0.90	0.92	0.99	0.87	0.87	0.93	0.89	0.89
91 day	0.87	0.74	0.75	0.87	0.73	0.74	0.94	0.74	0.74	0.98	0.76	0.76	0.88	0.72	0.74	0.77	0.69	0.74
61 day	0.52	0.46	0.50	0.56	0.42	0.42	0.53	0.47	0.48	0.70	0.52	0.58	0.56	0.50	0.48	0.50	0.43	0.47
31 day	0.31	0.19	0.24	0.26	0.20	0.24	0.21	0.17	0.18	0.29	0.21	0.26	0.26	0.19	0.21	0.23	0.20	0.21

Figure 4-68 Chloride solution absorption in PSC cubes

The chloride solution absorption was more for in the case of designed control concrete cube with lower compressive strength (M4CC) and constant slump value. Chloride solution absorption was goes on reduces with increase in compressive strength and constant slump value for in the case of control (M5CC, and M6CC)/impregnated concrete cubes (M5SB, M6SB, M5WB, and M6WB). Chloride solution absorption was slightly decrease for in the case of PSC/IC concrete cubes as against the chloride solution absorption in the DCC/IC concrete cubes. The variation of chloride solution absorption in all designed FSC control/IC concrete mix at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure 4-69). Chloride solution absorption was goes on decrease for in the case of control concrete cubes (M1CC-M6CC). Chloride solution absorption was also decrease in impregnation concrete cubes (M1SB-M6SB) as against the impregnated concrete cubes (M1WB-M6WB) respectively. The chloride solution absorption was predominantly decrease in the control/IC concrete cubes as when compare to control/IC DCC and PSC concrete cubes.

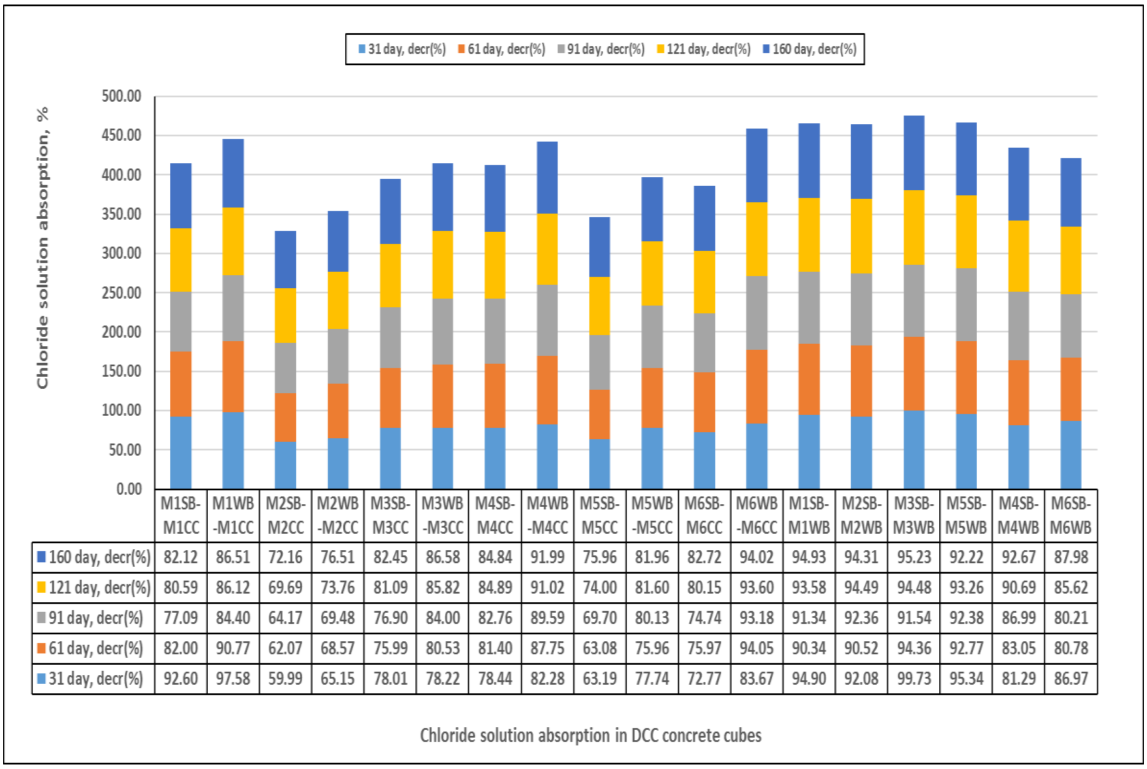


	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
■ 160 day	1.16	0.22	0.28	1.10	0.31	0.59	0.78	0.36	0.43	1.31	0.44	0.53	1.03	0.45	0.64	0.74	0.40	0.53
■ 121 day	0.54	0.13	0.14	0.41	0.24	0.28	0.28	0.14	0.24	0.45	0.25	0.29	0.35	0.22	0.23	0.29	0.22	0.23
■ 91 day	0.30	0.10	0.12	0.27	0.11	0.23	0.23	0.12	0.20	0.39	0.21	0.23	0.30	0.19	0.19	0.22	0.18	0.18
■ 61 day	0.14	0.08	0.09	0.18	0.09	0.10	0.13	0.09	0.12	0.26	0.16	0.16	0.16	0.11	0.11	0.14	0.10	0.11
■ 31 day	0.13	0.07	0.09	0.17	0.07	0.08	0.11	0.08	0.10	0.25	0.14	0.15	0.14	0.10	0.10	0.12	0.08	0.10

Figure 4-69 Chloride solution absorption in FSC cubes

4.5.4 Comparison of chloride solution absorption in PCC/IC concrete cubes

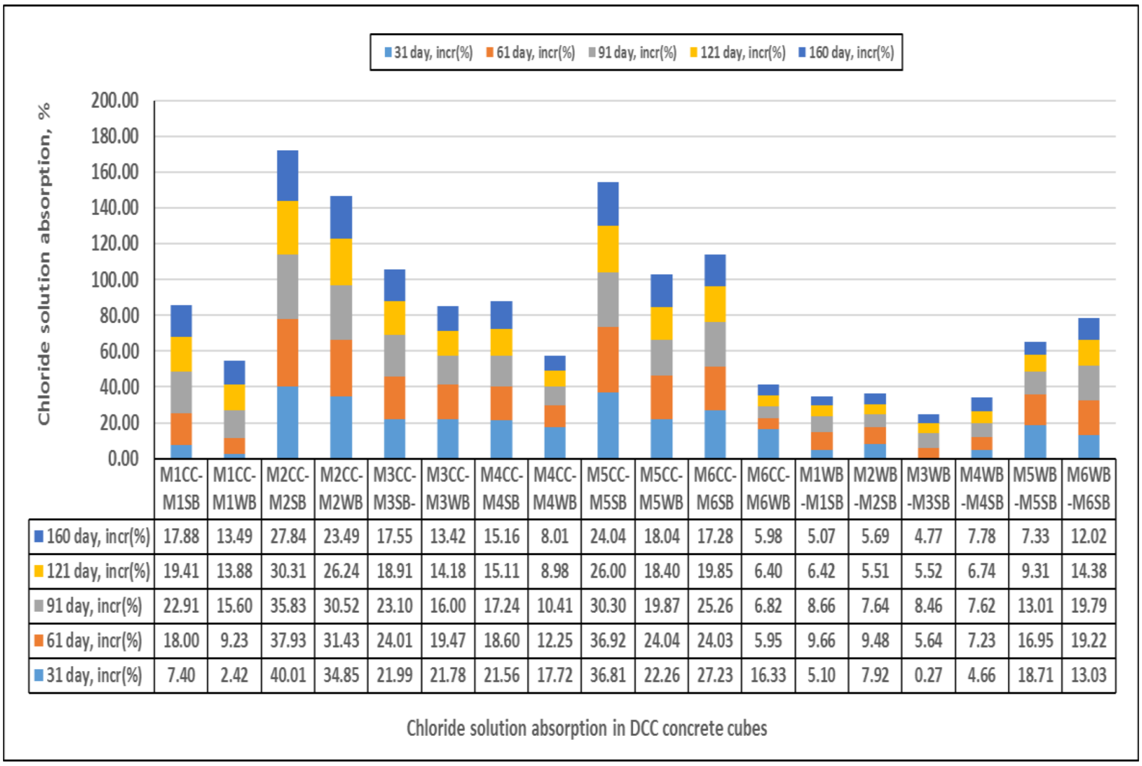
It’s possible to investigate an effectiveness of impregnation (SB/WB) against chloride solution absorption in all DCC designed control/IC concrete cubes at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure *4-70*). Chloride solution absorption was decrease for case of impregnation concrete cubes in designed concrete mix (M1SB-M6SB-80% and M1WB-M6WB-90%) as when compare to control concrete cubes (M1CC-M6CC). It is also from the results that, the chloride solution absorption was more decrease (95%) for in the case of solvent-based designed impregnation concrete cubes (SB) as when compare to water based (WB) impregnation concrete cubes in designed concrete mix. Whereas the chloride solution absorption was increase (20%) for in the case of DCC control concrete cubes (M1CC-M6CC) as when compare to an impregnated concrete cubes (M1SB-M6SB). It is also increase (15%) in chloride solution absorption for in the case of DCC control concrete cubes (M1CC-M6CC) as against impregnation concrete cubes (M1WB-M6WB). Chloride solution absorption in impregnation concrete cubes (M1WB-M3WB) was also increase (6%) as against impregnation concrete cubes (M1SB-M3SB). Furthermore, the chloride solution absorption was higher (10%) for in the case of impregnation cubes (M4WB-M6WB) as against impregnation concrete cubes (M4SB-M6SB) at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure 4-71).



	M1SB-M1CC	M1WB-M1CC	M2SB-M2CC	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
■ 160 day, decr(%)	82.12	86.51	72.16	76.51	82.45	86.58	84.84	91.99	75.96	81.96	82.72	94.02	94.93	94.31	95.23	92.22	92.67	87.98
■ 121 day, decr(%)	80.59	86.12	69.69	73.76	81.09	85.82	84.89	91.02	74.00	81.60	80.15	93.60	93.58	94.49	94.48	93.26	90.69	85.62
■ 91 day, decr(%)	77.09	84.40	64.17	69.48	76.90	84.00	82.76	89.59	69.70	80.13	74.74	93.18	91.34	92.36	91.54	92.38	86.99	80.21
■ 61 day, decr(%)	82.00	90.77	62.07	68.57	75.99	80.53	81.40	87.75	63.08	75.96	75.97	94.05	90.34	90.52	94.36	92.77	83.05	80.78
■ 31 day, decr(%)	92.60	97.58	59.99	65.15	78.01	78.22	78.44	82.28	63.19	77.74	72.77	83.67	94.90	92.08	99.73	95.34	81.29	86.97

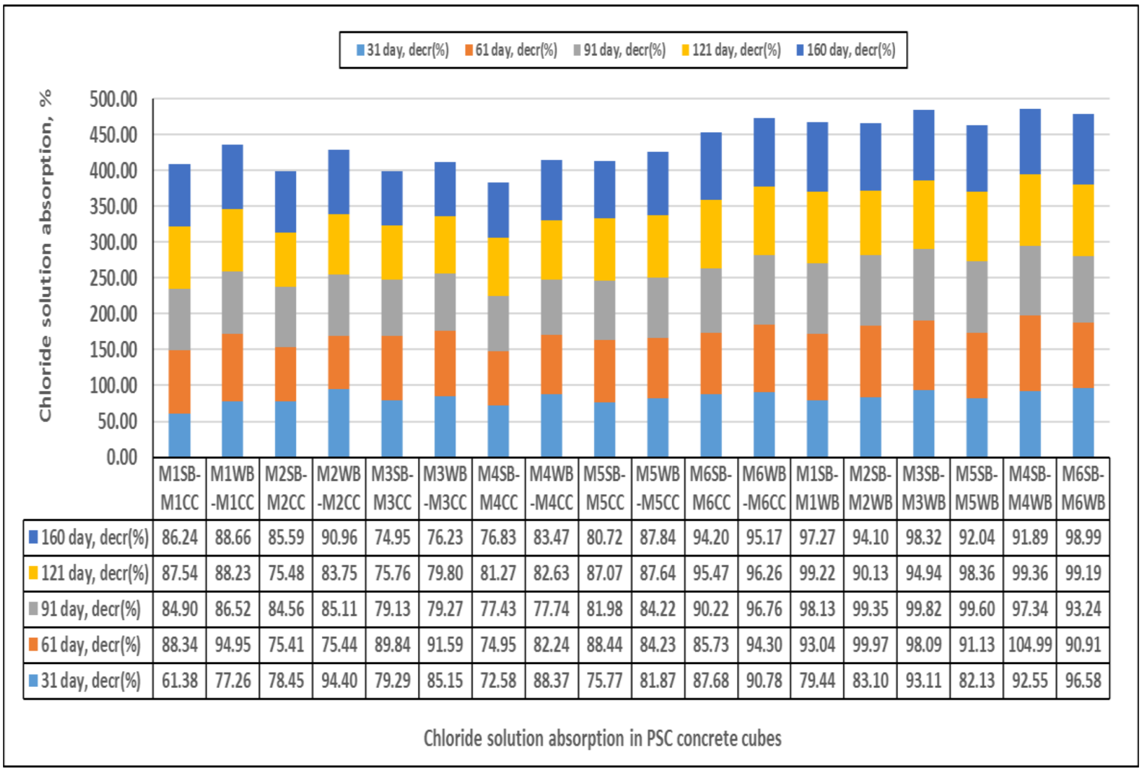
Figure 4-70 Chloride solution absorption in DCC (SB/WB/CC) concrete cubes

An effectiveness of impregnation (SB/WB) and control concrete cubes against ingress of chloride solution absorption in all PSC designed control/IC concrete cubes at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure 4-72). Chloride solution absorption was decrease for case of impregnation concrete cubes in designed concrete mix (M1SB-M6SB-85%, and M1WB-M6WB-95%) as when compare to control concrete cubes (M1CC-M6CC).



	M1CC-M1SB	M1CC-M1WB	M2CC-M2SB	M2CC-M2WB	M3CC-M3SB-	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M5SB	M5CC-M5WB	M6CC-M6SB	M6CC-M6WB	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
■ 160 day, incr(%)	17.88	13.49	27.84	23.49	17.55	13.42	15.16	8.01	24.04	18.04	17.28	5.98	5.07	5.69	4.77	7.78	7.33	12.02
■ 121 day, incr(%)	19.41	13.88	30.31	26.24	18.91	14.18	15.11	8.98	26.00	18.40	19.85	6.40	6.42	5.51	5.52	6.74	9.31	14.38
■ 91 day, incr(%)	22.91	15.60	35.83	30.52	23.10	16.00	17.24	10.41	30.30	19.87	25.26	6.82	8.66	7.64	8.46	7.62	13.01	19.79
■ 61 day, incr(%)	18.00	9.23	37.93	31.43	24.01	19.47	18.60	12.25	36.92	24.04	24.03	5.95	9.66	9.48	5.64	7.23	16.95	19.22
■ 31 day, incr(%)	7.40	2.42	40.01	34.85	21.99	21.78	21.56	17.72	36.81	22.26	27.23	16.33	5.10	7.92	0.27	4.66	18.71	13.03

Figure 4-71 Chloride solution absorption in DCC (CC/SB/WB) concrete cubes

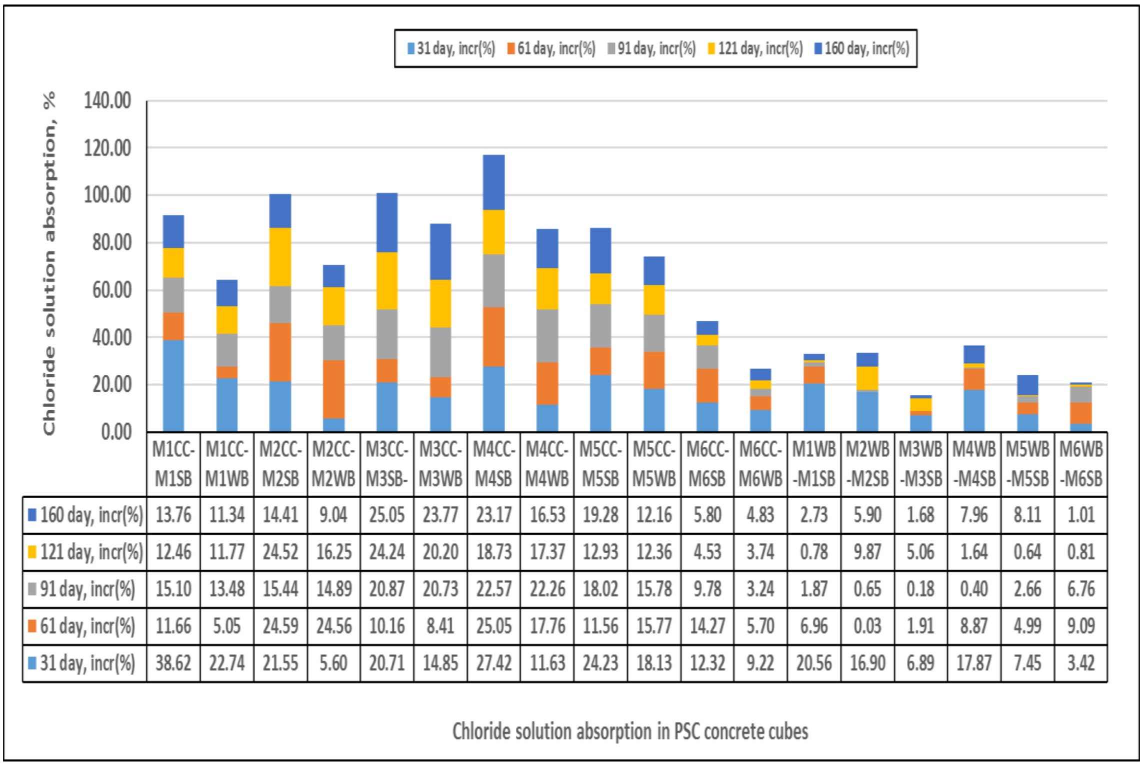


	M1SB-M1CC	M1WB-M1CC	M2SB-M2CC	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
■ 160 day, decr(%)	86.24	88.66	85.59	90.96	74.95	76.23	76.83	83.47	80.72	87.84	94.20	95.17	97.27	94.10	98.32	92.04	91.89	98.99
■ 121 day, decr(%)	87.54	88.23	75.48	83.75	75.76	79.80	81.27	82.63	87.07	87.64	95.47	96.26	99.22	90.13	94.94	98.36	99.36	99.19
■ 91 day, decr(%)	84.90	86.52	84.56	85.11	79.13	79.27	77.43	77.74	81.98	84.22	90.22	96.76	98.13	99.35	99.82	99.60	97.34	93.24
■ 61 day, decr(%)	88.34	94.95	75.41	75.44	89.84	91.59	74.95	82.24	88.44	84.23	85.73	94.30	93.04	99.97	98.09	91.13	104.99	90.91
■ 31 day, decr(%)	61.38	77.26	78.45	94.40	79.29	85.15	72.58	88.37	75.77	81.87	87.68	90.78	79.44	83.10	93.11	82.13	92.55	96.58

Figure 4-72 Chloride solution absorption in PSC (SB/WB/CC) concrete cubes

It is also observe that, the chloride solution absorption predominantly decrease for in case of impregnation concrete cubes (M4SB-M6SB) as against control concrete cubes (M4CC-M6CC). It is also from the results that, the chloride solution absorption was more decrease (98%) for in the case of PSC solvent-based designed impregnation concrete cubes (SB), as when compare to water based (WB) impregnation concrete cubes in designed concrete mix.

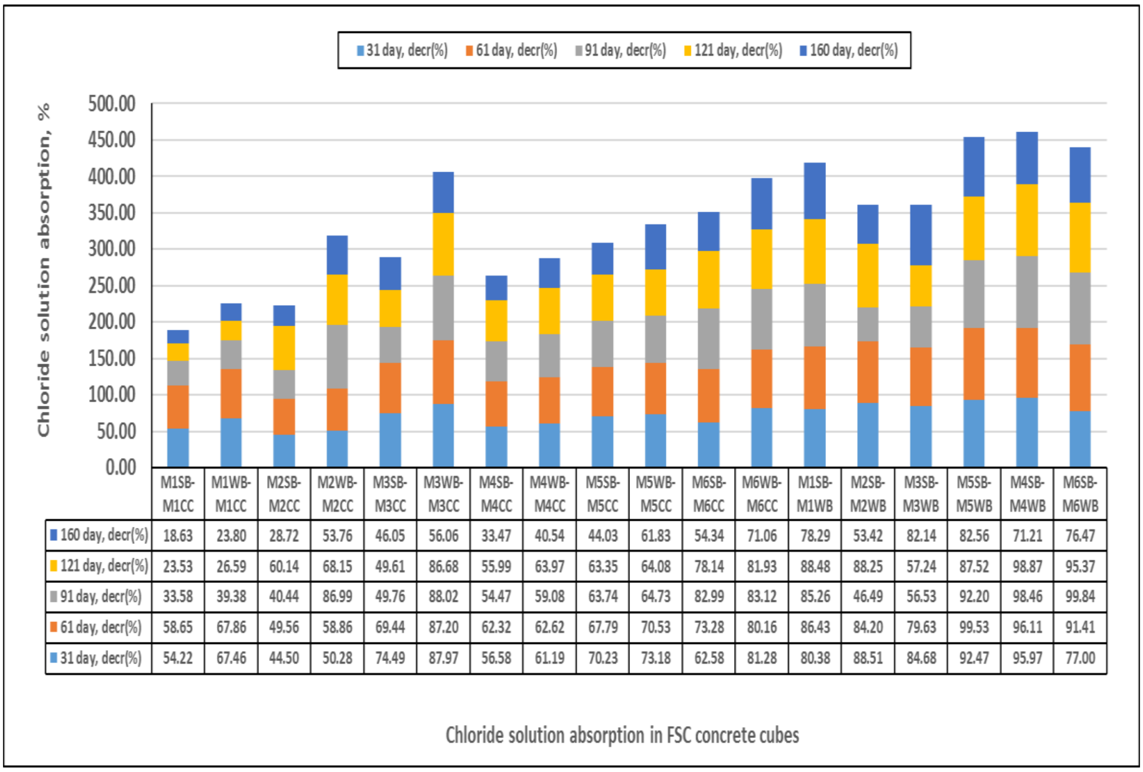
Chloride solution absorption was increase (24%) for in the case of PSC control concrete cubes (M1CC-M6CC) as when compare to an impregnated concrete cubes (M1SB-M6SB). It is also increase (18%) in chloride solution absorption for in the case of PSC control concrete cubes (M1CC-M6CC) as against impregnation concrete cubes (M1WB-M6WB). Chloride solution absorption in impregnation concrete cubes (M1WB-M3WB) was also predominantly less increase (4%) as against impregnation concrete cubes (M1SB-M3SB). Furthermore, the chloride solution absorption was higher (6%) for in the case of impregnation cubes (M4WB-M6SB) as against impregnation concrete cubes (M4SB-M6SB) at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure 4-73).



	M1CC-M1SB	M1CC-M1WB	M2CC-M2SB	M2CC-M2WB	M3CC-M3SB-	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M5SB	M5CC-M5WB	M6CC-M6SB	M6CC-M6WB	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
160 day, incr(%)	13.76	11.34	14.41	9.04	25.05	23.77	23.17	16.53	19.28	12.16	5.80	4.83	2.73	5.90	1.68	7.96	8.11	1.01
121 day, incr(%)	12.46	11.77	24.52	16.25	24.24	20.20	18.73	17.37	12.93	12.36	4.53	3.74	0.78	9.87	5.06	1.64	0.64	0.81
91 day, incr(%)	15.10	13.48	15.44	14.89	20.87	20.73	22.57	22.26	18.02	15.78	9.78	3.24	1.87	0.65	0.18	0.40	2.66	6.76
61 day, incr(%)	11.66	5.05	24.59	24.56	10.16	8.41	25.05	17.76	11.56	15.77	14.27	5.70	6.96	0.03	1.91	8.87	4.99	9.09
31 day, incr(%)	38.62	22.74	21.55	5.60	20.71	14.85	27.42	11.63	24.23	18.13	12.32	9.22	20.56	16.90	6.89	17.87	7.45	3.42

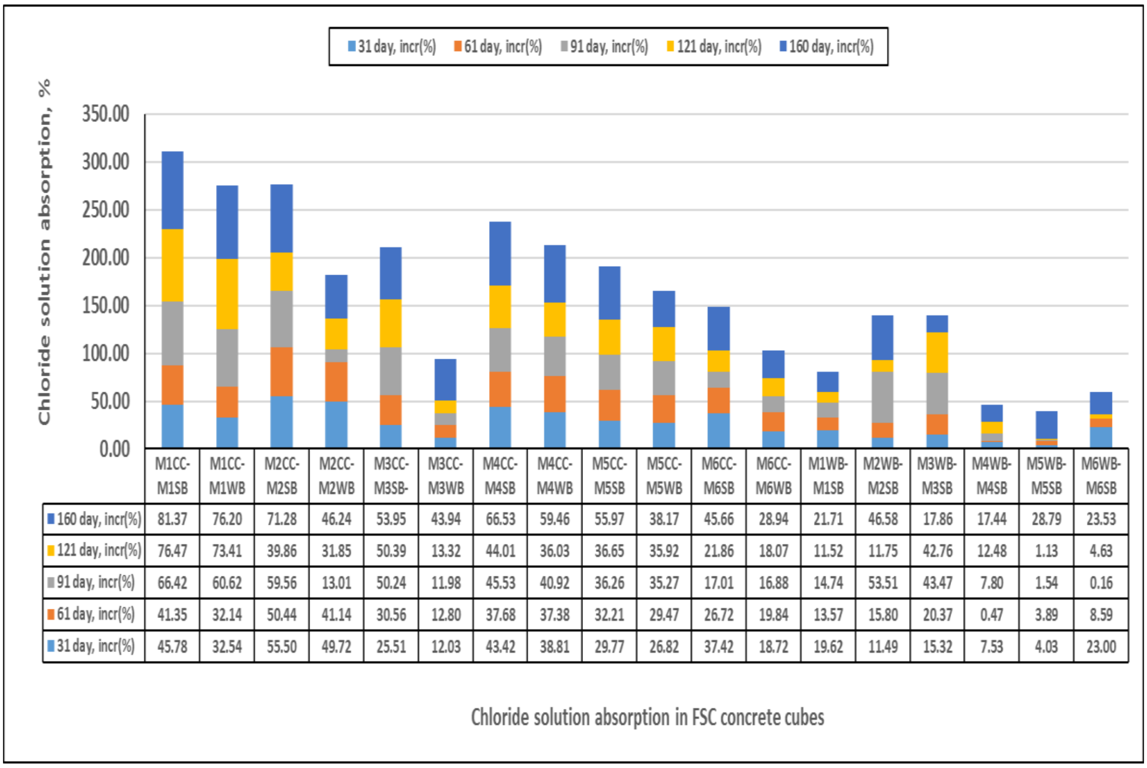
Figure 4-73 Chloride solution absorption in PSC (CC/SB/WB) concrete cubes

The performance of impregnation (SB/WB) and control concrete cubes against ingress of chloride solution absorption in all FSC designed control/IC concrete cubes at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure *4-74*).



	M1SB-M1CC	M1WB-M1CC	M2SB-M2CC	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
160 day, decr(%)	18.63	23.80	28.72	53.76	46.05	56.06	33.47	40.54	44.03	61.83	54.34	71.06	78.29	53.42	82.14	82.56	71.21	76.47
121 day, decr(%)	23.53	26.59	60.14	68.15	49.61	86.68	55.99	63.97	63.35	64.08	78.14	81.93	88.48	88.25	57.24	87.52	98.87	95.37
91 day, decr(%)	33.58	39.38	40.44	86.99	49.76	88.02	54.47	59.08	63.74	64.73	82.99	83.12	85.26	46.49	56.53	92.20	98.46	99.84
61 day, decr(%)	58.65	67.86	49.56	58.86	69.44	87.20	62.32	62.62	67.79	70.53	73.28	80.16	86.43	84.20	79.63	99.53	96.11	91.41
31 day, decr(%)	54.22	67.46	44.50	50.28	74.49	87.97	56.58	61.19	70.23	73.18	62.58	81.28	80.38	88.51	84.68	92.47	95.97	77.00

Figure 4-74 Chloride solution absorption in FSC (SB/WB/CC) concrete cubes



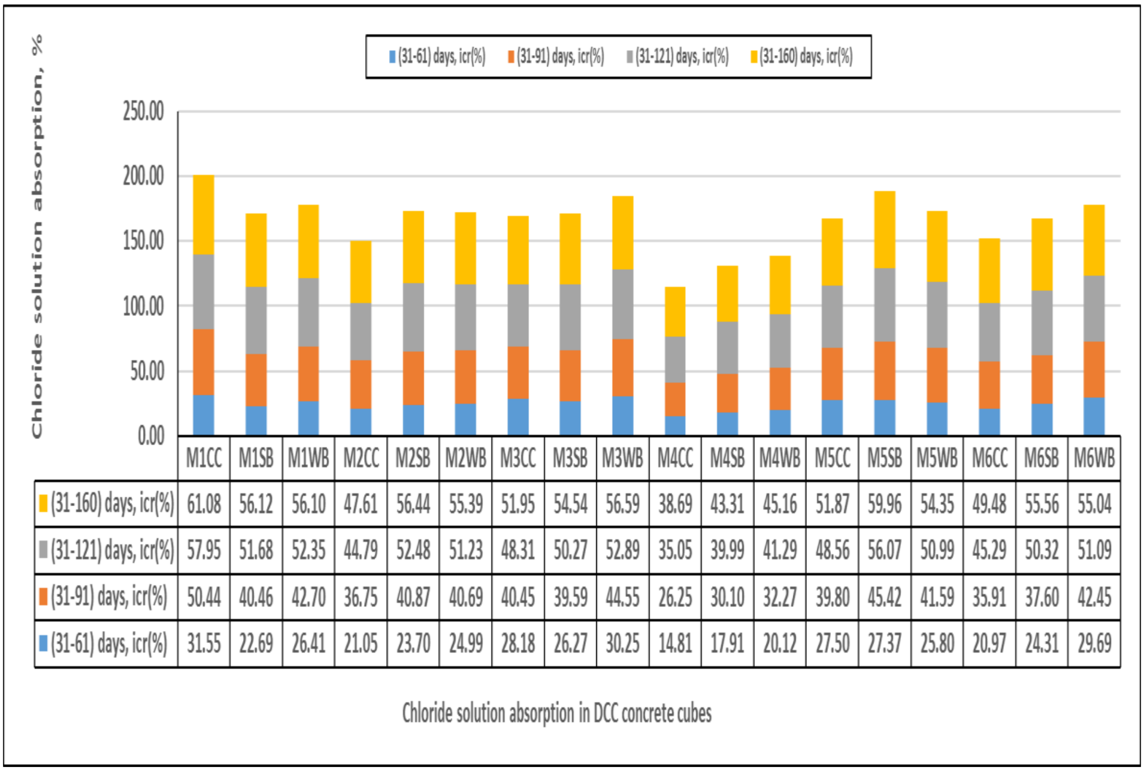
	M1CC-M1SB	M1CC-M1WB	M2CC-M2SB	M2CC-M2WB	M3CC-M3SB-	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M5SB
■160 day, incr(%)	81.37	76.20	71.28	46.24	53.95	43.94	66.53	59.46	55.97
■121 day, incr(%)	76.47	73.41	39.86	31.85	50.39	13.32	44.01	36.03	36.65
■91 day, incr(%)	66.42	60.62	59.56	13.01	50.24	11.98	45.53	40.92	36.26
■61 day, incr(%)	41.35	32.14	50.44	41.14	30.56	12.80	37.68	37.38	32.21
■31 day, incr(%)	45.78	32.54	55.50	49.72	25.51	12.03	43.42	38.81	29.77

	M5CC-M5WB	M6CC-M6SB	M6CC-M6WB	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
■160 day, incr(%)	38.17	45.66	28.94	21.71	46.58	17.86	17.44	28.79	23.53
■121 day, incr(%)	35.92	21.86	18.07	11.52	11.75	42.76	12.48	1.13	4.63
■91 day, incr(%)	35.27	17.01	16.88	14.74	53.51	43.47	7.80	1.54	0.16
■61 day, incr(%)	29.47	26.72	19.84	13.57	15.80	20.37	0.47	3.89	8.59
■31 day, incr(%)	26.82	37.42	18.72	19.62	11.49	15.32	7.53	4.03	23.00

Figure 4-75 Chloride solution absorption in FSC (CC/SB/WB) concrete cubes

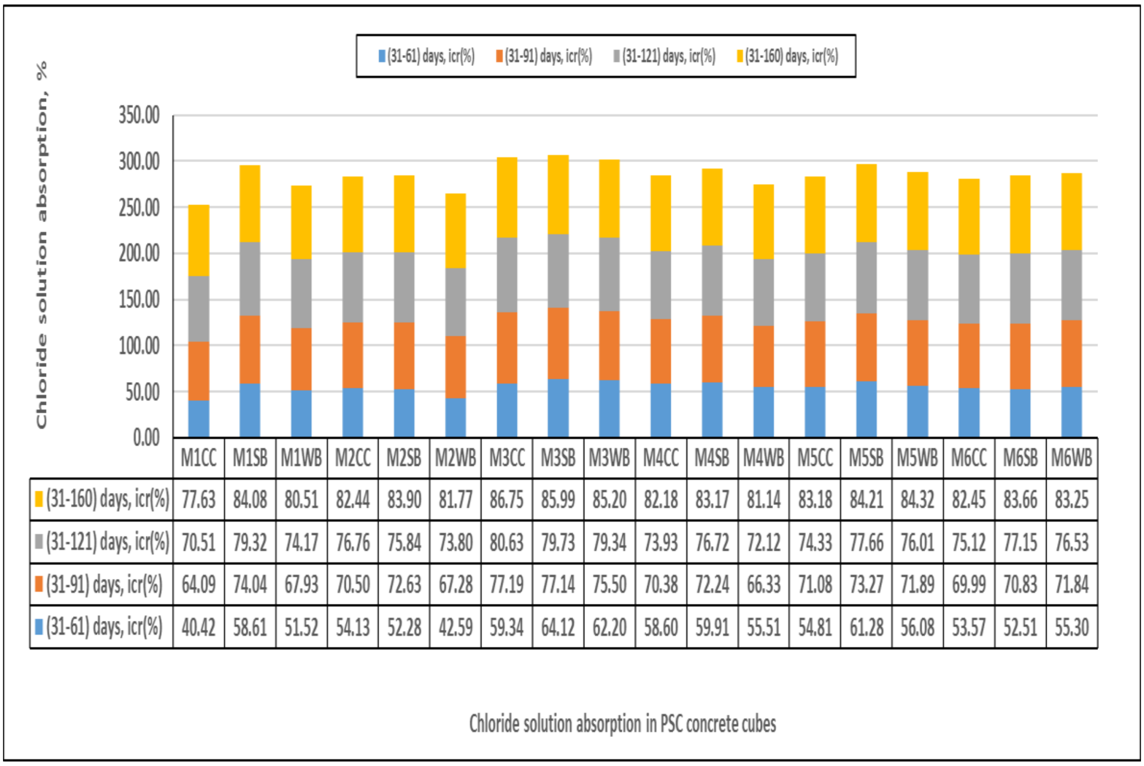
Chloride solution absorption was decrease for case of impregnation concrete cubes in designed concrete mix (M1SB-M3SB-55%, and M4SB-M6SB-65%) as when compare to control concrete cubes (M1CC-M6CC). Its also observe that, the chloride solution absorption predominantly decrease for in case of impregnation concrete cubes (M1WB-M6SWB-52%) as against control concrete cubes (M1CC-M6CC). It is also from the results that, the chloride solution absorption was more decrease (99%) for in the case of FSC solvent-based designed impregnation concrete cubes (SB), as when compare to water based (WB) impregnation concrete cubes in designed concrete mix.

Chloride solution absorption was higher for in the case of impregnation cubes (M1CC-M6CC) as against impregnation concrete cubes (M1SB-M6SB, and M1WB-M6WB) at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure 4-75). Chloride solution absorption was increase (60%) for in the case of FSC control concrete cubes (M1CC-M3CC) as when compare to an impregnated concrete cubes (M1SB-M3SB). It is also increase (40%) in chloride solution absorption for in the case of FSC control concrete cubes (M1CC-M3CC) as against impregnation concrete cubes (M1WB-M3WB). Chloride solution absorption in impregnation concrete cubes (M1WB-M6WB) was also predominantly increase (20%) as against impregnation concrete cubes (M1SB-M6SB). It is possible to compare the variation in chloride solution absorption (Figure 4-76, Figure 4-77 and Figure 4-78) for in the case of DCC/PSC/FSC control/IC (SB/WB) concrete cubes at different time interval (31-61th), (31-91th), (31-121th), and (31-160th) day respectively.



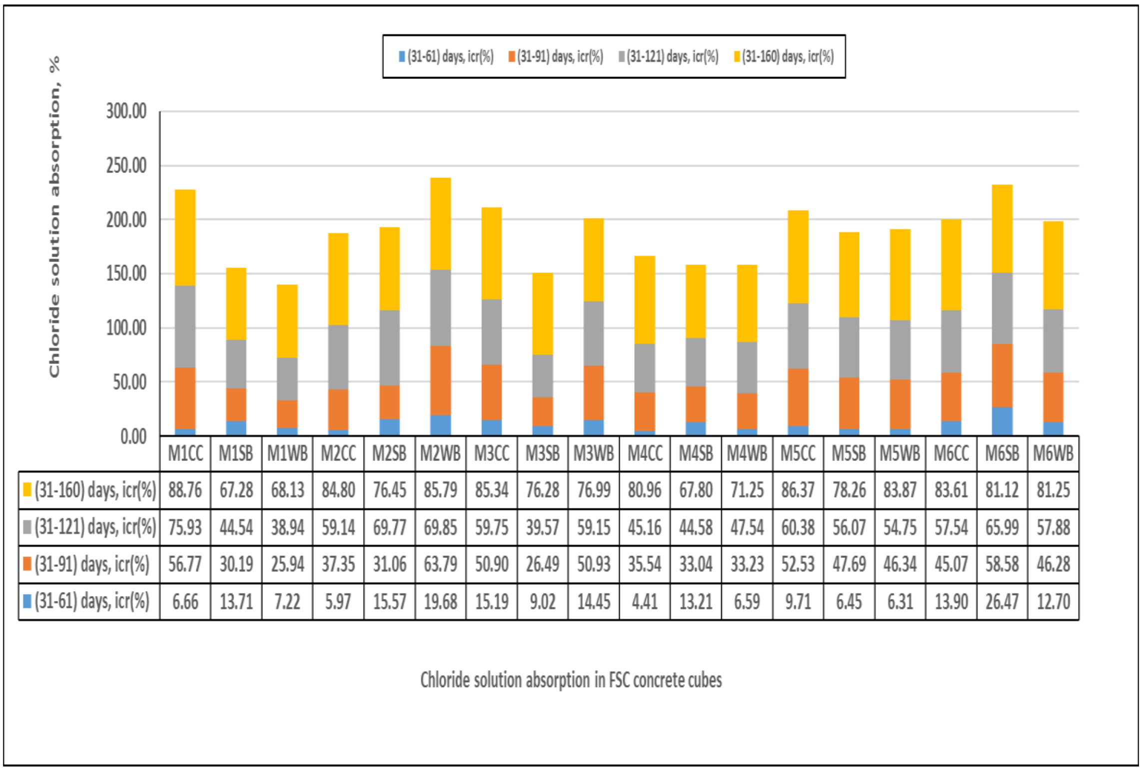
	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
🟨 (31-160) days, icr(%)	61.08	56.12	56.10	47.61	56.44	55.39	51.95	54.54	56.59	38.69	43.31	45.16	51.87	59.96	54.35	49.48	55.56	55.04
⬜ (31-121) days, icr(%)	57.95	51.68	52.35	44.79	52.48	51.23	48.31	50.27	52.89	35.05	39.99	41.29	48.56	56.07	50.99	45.29	50.32	51.09
🟧 (31-91) days, icr(%)	50.44	40.46	42.70	36.75	40.87	40.69	40.45	39.59	44.55	26.25	30.10	32.27	39.80	45.42	41.59	35.91	37.60	42.45
🟦 (31-61) days, icr(%)	31.55	22.69	26.41	21.05	23.70	24.99	28.18	26.27	30.25	14.81	17.91	20.12	27.50	27.37	25.80	20.97	24.31	29.69

Figure 4-76 Chloride solution absorption in DCC concrete cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
■ (31-160) days, icr(%)	77.63	84.08	80.51	82.44	83.90	81.77	86.75	85.99	85.20	82.18	83.17	81.14	83.18	84.21	84.32	82.45	83.66	83.25
■ (31-121) days, icr(%)	70.51	79.32	74.17	76.76	75.84	73.80	80.63	79.73	79.34	73.93	76.72	72.12	74.33	77.66	76.01	75.12	77.15	76.53
■ (31-91) days, icr(%)	64.09	74.04	67.93	70.50	72.63	67.28	77.19	77.14	75.50	70.38	72.24	66.33	71.08	73.27	71.89	69.99	70.83	71.84
■ (31-61) days, icr(%)	40.42	58.61	51.52	54.13	52.28	42.59	59.34	64.12	62.20	58.60	59.91	55.51	54.81	61.28	56.08	53.57	52.51	55.30

Figure 4-77 Chloride solution absorption in PSC concrete cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
■ (31-160) days, icr(%)	88.76	67.28	68.13	84.80	76.45	85.79	85.34	76.28	76.99	80.96	67.80	71.25	86.37	78.26	83.87	83.61	81.12	81.25
■ (31-121) days, icr(%)	75.93	44.54	38.94	59.14	69.77	69.85	59.75	39.57	59.15	45.16	44.58	47.54	60.38	56.07	54.75	57.54	65.99	57.88
■ (31-91) days, icr(%)	56.77	30.19	25.94	37.35	31.06	63.79	50.90	26.49	50.93	35.54	33.04	33.23	52.53	47.69	46.34	45.07	58.58	46.28
■ (31-61) days, icr(%)	6.66	13.71	7.22	5.97	15.57	19.68	15.19	9.02	14.45	4.41	13.21	6.59	9.71	6.45	6.31	13.90	26.47	12.70

Figure 4-78 Chloride solution absorption in FSC concrete cubes

4.5.5 Chloride solution penetration in PCC/IC concrete cubes

The variation of chloride solution concentration in DCC/IC cubes for different mixtures type (M1-M6) was shown in (Figure 4-79). Chloride solution penetration was lesser for in the case of control concrete cubes (M1CC-M6CC) as when compared to an impregnation concrete cubes (M1SB-M6SB and M1WB-M6WB) respectively.

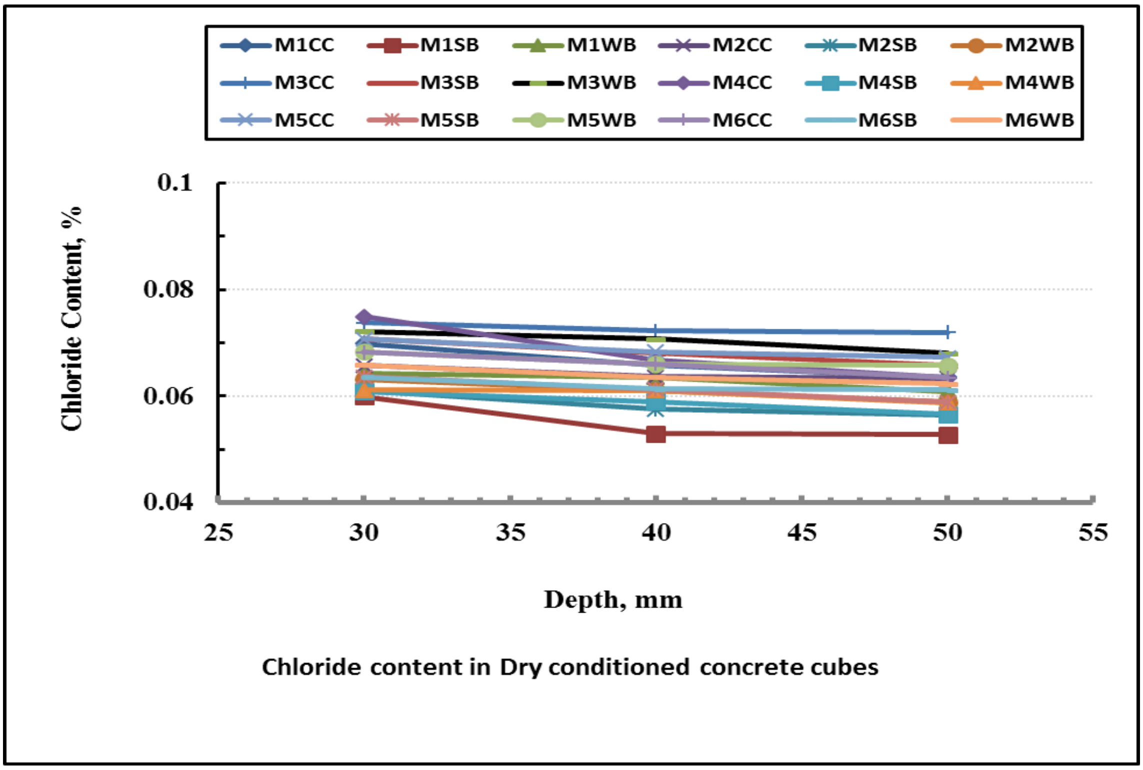


Figure 4-79 Chloride content in Dry conditioned concrete cubes

The variation of chloride concentration in PSC concrete cubes for different mixtures type (M1-M6) is as shown in (Figure 4-80).

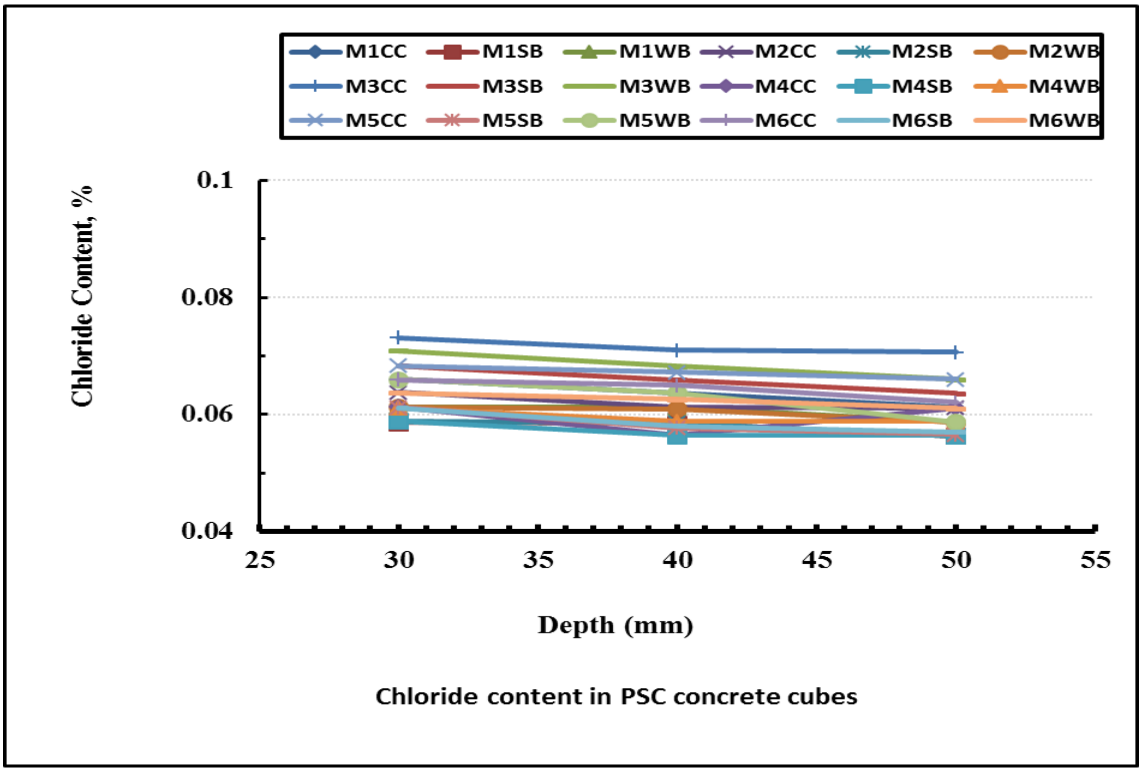


Figure 4-80 Chloride content in PSC concrete cubes

The variation of chloride concentration in FSC concrete cubes for different mixtures type (M1-M6) was as shown in (Figure 4-81).

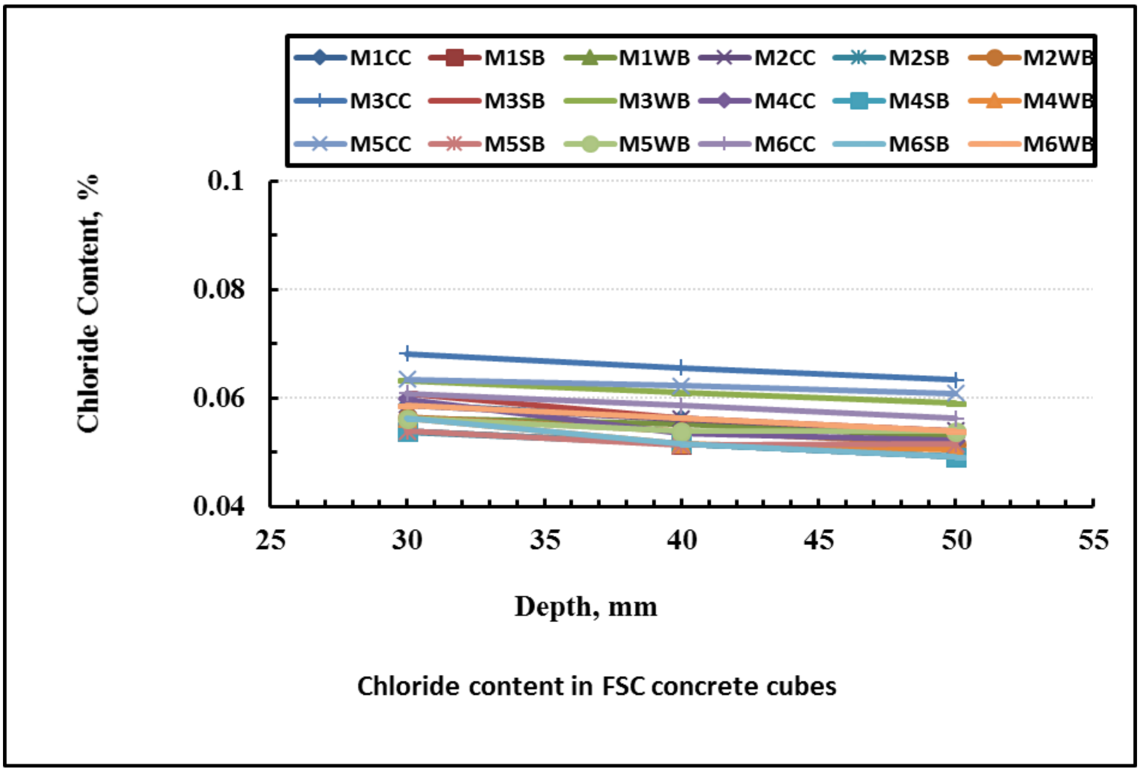
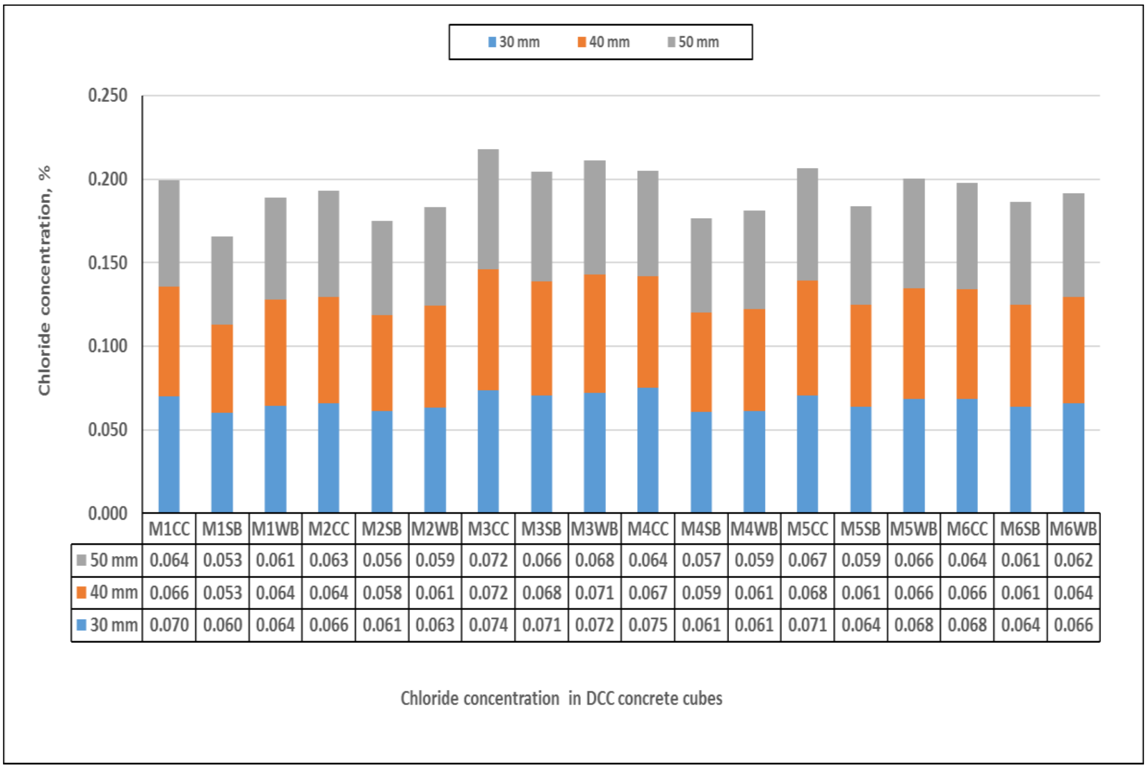


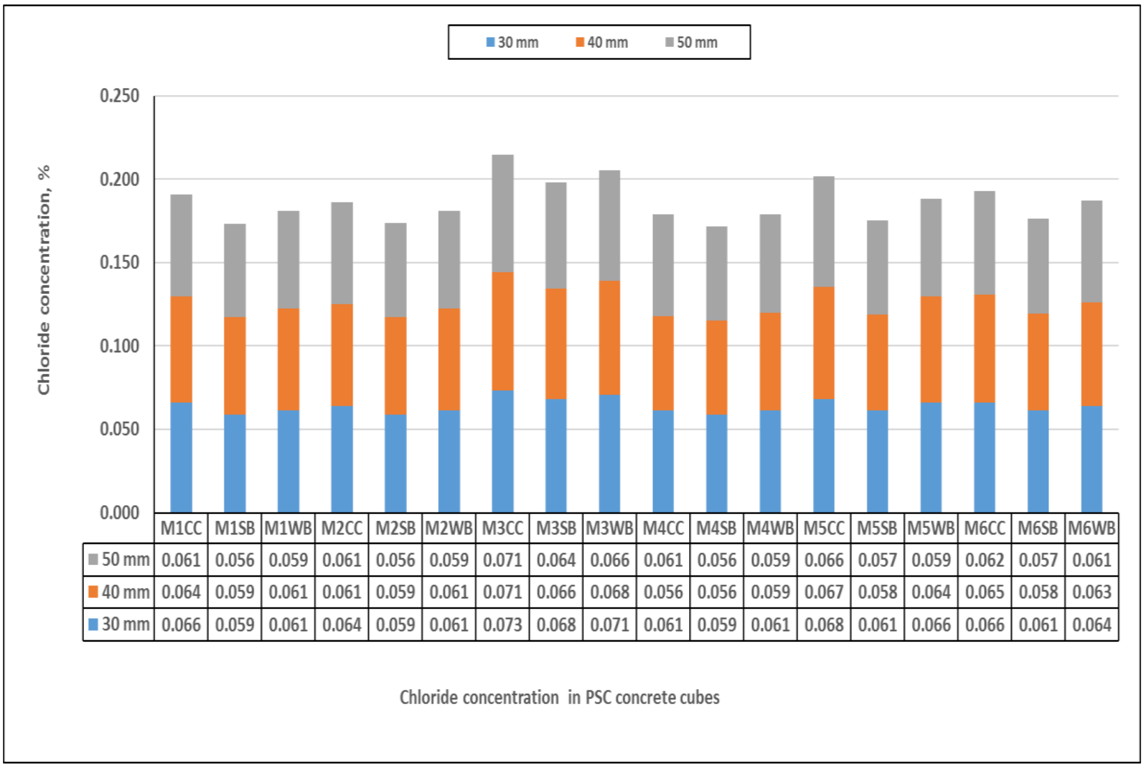
Figure 4-81 Chloride content in FSC concrete cubes

The chloride solution penetration in DCC/PSC/FSC concrete cubes for different mixtures type (M1-M6) at different drill depths (30, 40, and 50 mm) was as shown in (Figure 4-82, Figure 4-83 and Figure 4-84).



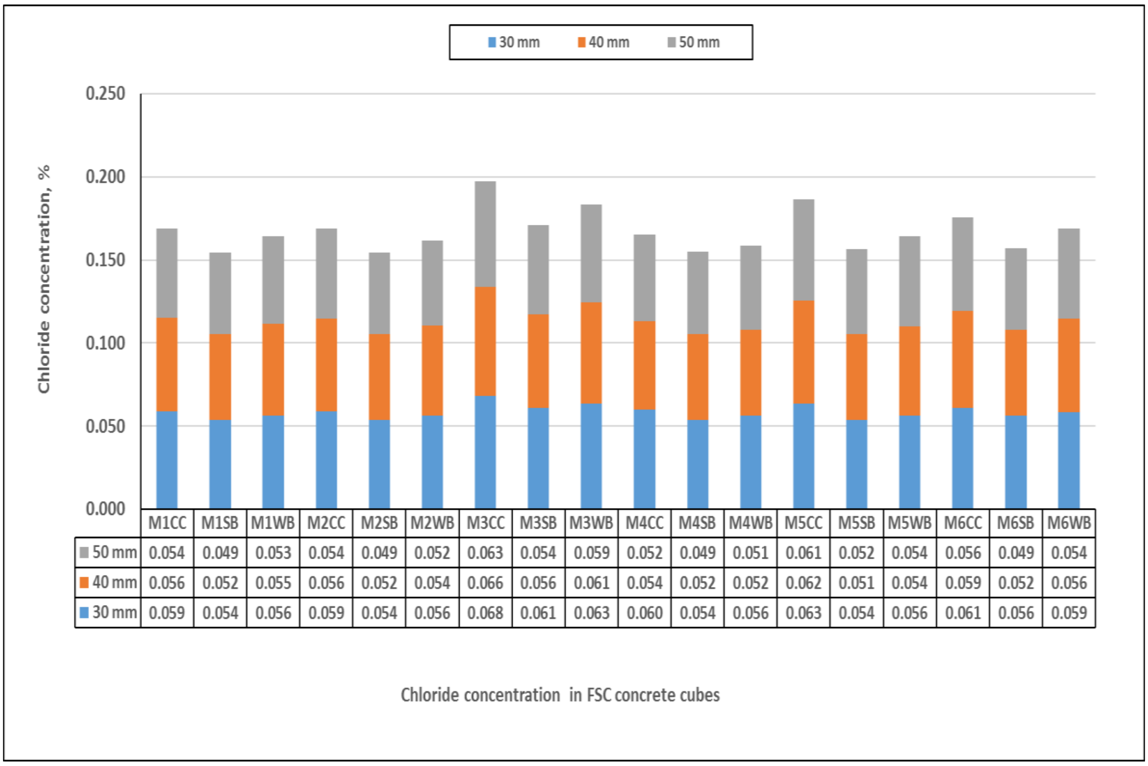
	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
50 mm	0.064	0.053	0.061	0.063	0.056	0.059	0.072	0.066	0.068	0.064	0.057	0.059	0.067	0.059	0.066	0.064	0.061	0.062
40 mm	0.066	0.053	0.064	0.064	0.058	0.061	0.072	0.068	0.071	0.067	0.059	0.061	0.068	0.061	0.066	0.066	0.061	0.064
30 mm	0.070	0.060	0.064	0.066	0.061	0.063	0.074	0.071	0.072	0.075	0.061	0.061	0.071	0.064	0.068	0.068	0.064	0.066

Figure 4-82 Chloride solution penetration in DCC (CC/SB/WB) concrete cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
▨ 50 mm	0.061	0.056	0.059	0.061	0.056	0.059	0.071	0.064	0.066	0.061	0.056	0.059	0.066	0.057	0.059	0.062	0.057	0.061
🟧 40 mm	0.064	0.059	0.061	0.061	0.059	0.061	0.071	0.066	0.068	0.056	0.056	0.059	0.067	0.058	0.064	0.065	0.058	0.063
🟦 30 mm	0.066	0.059	0.061	0.064	0.059	0.061	0.073	0.068	0.071	0.061	0.059	0.061	0.068	0.061	0.066	0.066	0.061	0.064

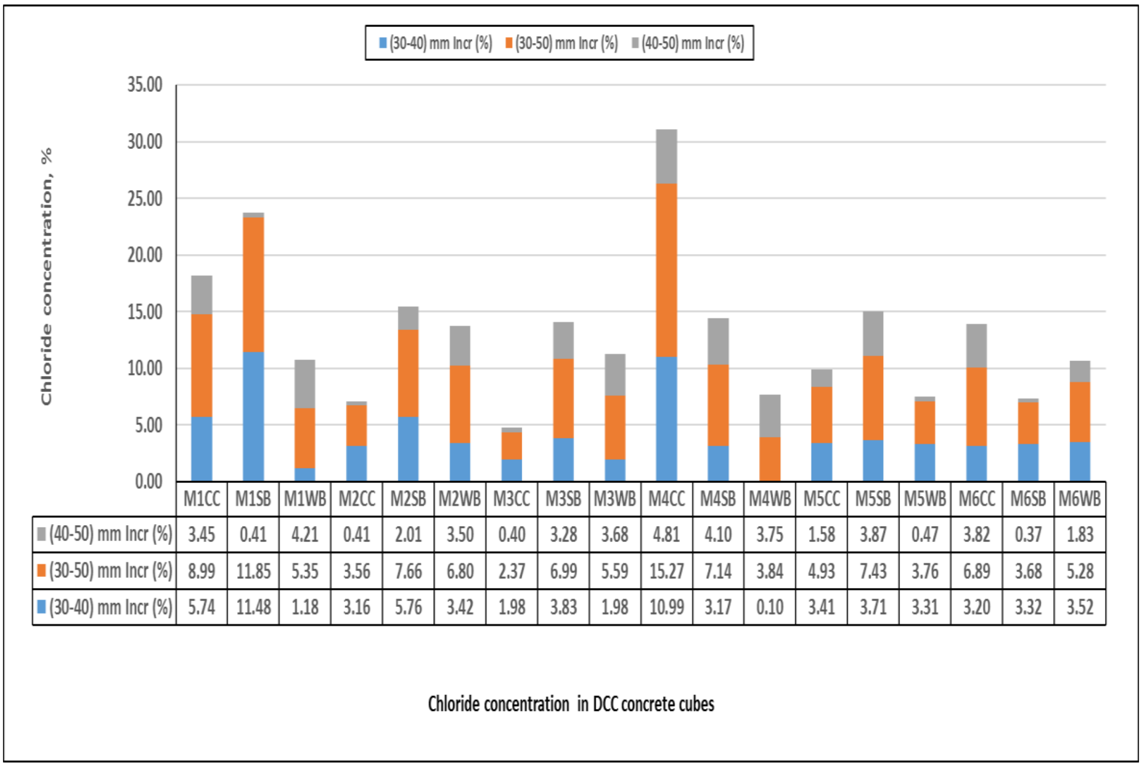
Figure 4-83 Chloride solution penetration in PSC (CC/SB/WB) concrete cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
▨ 50 mm	0.054	0.049	0.053	0.054	0.049	0.052	0.063	0.054	0.059	0.052	0.049	0.051	0.061	0.052	0.054	0.056	0.049	0.054
🟧 40 mm	0.056	0.052	0.055	0.056	0.052	0.054	0.066	0.056	0.061	0.054	0.052	0.052	0.062	0.051	0.054	0.059	0.052	0.056
🟦 30 mm	0.059	0.054	0.056	0.059	0.054	0.056	0.068	0.061	0.063	0.060	0.054	0.056	0.063	0.054	0.056	0.061	0.056	0.059

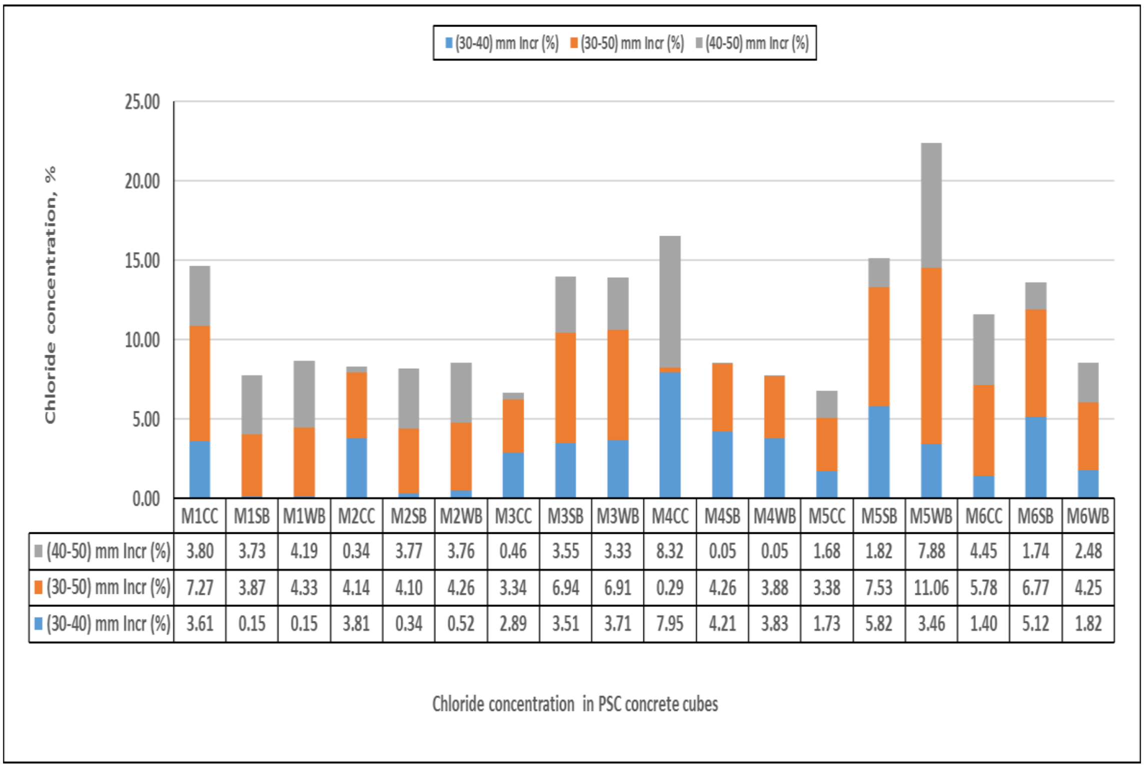
Figure 4-84 Chloride solution penetration in FSC (CC/SB/WB) concrete cubes

The comparative study of chloride solution penetration in DCC/PSC/FSC concrete cubes for different mixtures type (M1-M6) at different drill depths (30, 40, and 50 mm) was as shown in (Figure 4-85, Figure 4-86, and Figure 4-87).



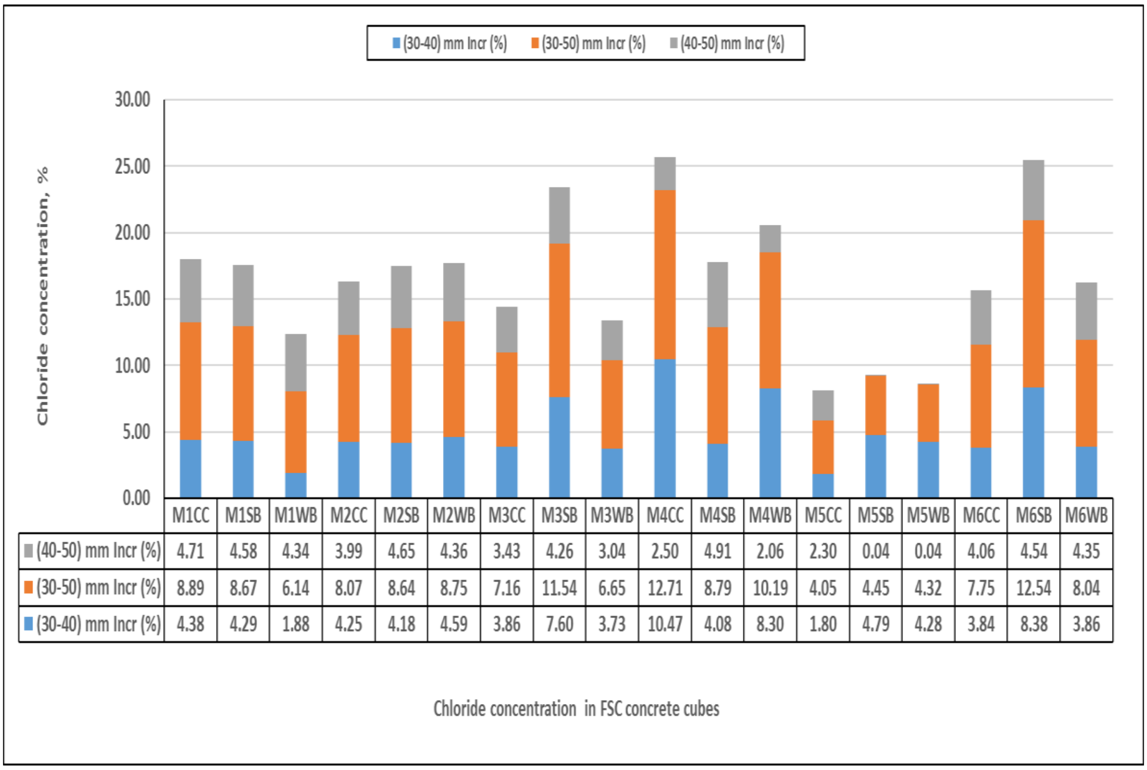
	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
■ (40-50) mm Incr (%)	3.45	0.41	4.21	0.41	2.01	3.50	0.40	3.28	3.68	4.81	4.10	3.75	1.58	3.87	0.47	3.82	0.37	1.83
■ (30-50) mm Incr (%)	8.99	11.85	5.35	3.56	7.66	6.80	2.37	6.99	5.59	15.27	7.14	3.84	4.93	7.43	3.76	6.89	3.68	5.28
■ (30-40) mm Incr (%)	5.74	11.48	1.18	3.16	5.76	3.42	1.98	3.83	1.98	10.99	3.17	0.10	3.41	3.71	3.31	3.20	3.32	3.52

Figure 4-85 Chloride solution penetration in DCC (CC/SB/WB) concrete cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
■ (40-50) mm Incr (%)	3.80	3.73	4.19	0.34	3.77	3.76	0.46	3.55	3.33	8.32	0.05	0.05	1.68	1.82	7.88	4.45	1.74	2.48
■ (30-50) mm Incr (%)	7.27	3.87	4.33	4.14	4.10	4.26	3.34	6.94	6.91	0.29	4.26	3.88	3.38	7.53	11.06	5.78	6.77	4.25
■ (30-40) mm Incr (%)	3.61	0.15	0.15	3.81	0.34	0.52	2.89	3.51	3.71	7.95	4.21	3.83	1.73	5.82	3.46	1.40	5.12	1.82

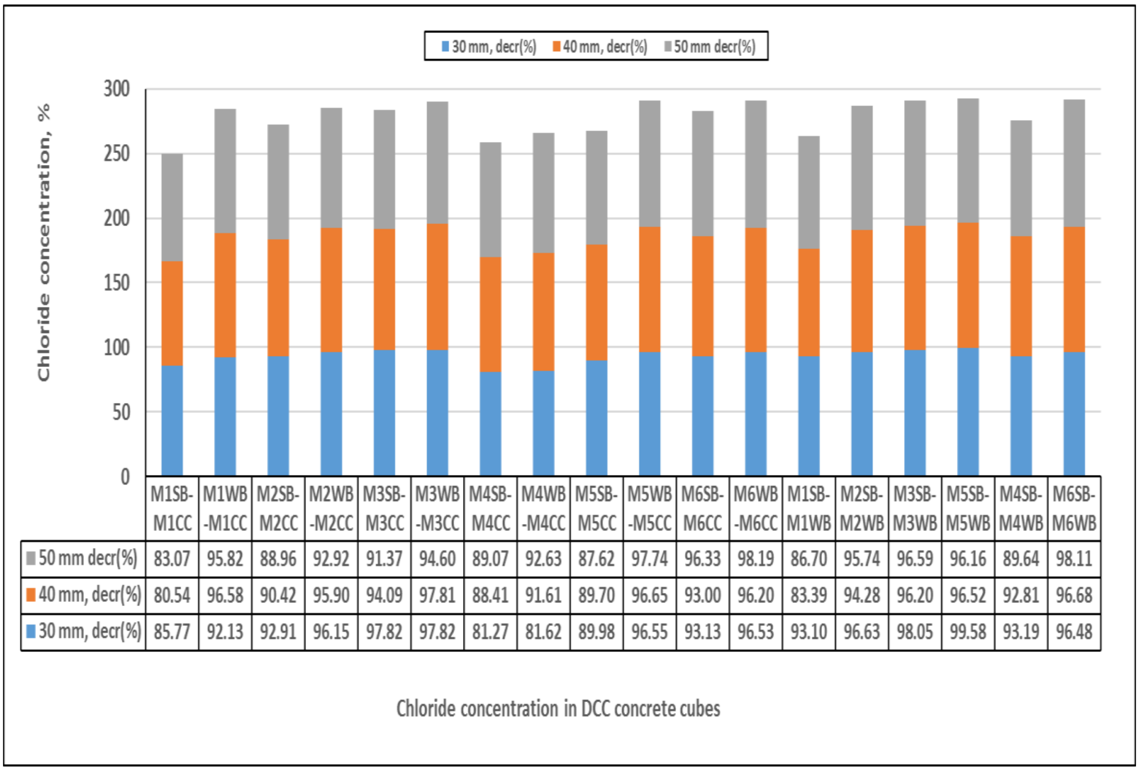
Figure 4-86 Chloride solution absorption in PSC (CC/SB/WB) concrete cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
■ (40-50) mm Incr (%)	4.71	4.58	4.34	3.99	4.65	4.36	3.43	4.26	3.04	2.50	4.91	2.06	2.30	0.04	0.04	4.06	4.54	4.35
■ (30-50) mm Incr (%)	8.89	8.67	6.14	8.07	8.64	8.75	7.16	11.54	6.65	12.71	8.79	10.19	4.05	4.45	4.32	7.75	12.54	8.04
■ (30-40) mm Incr (%)	4.38	4.29	1.88	4.25	4.18	4.59	3.86	7.60	3.73	10.47	4.08	8.30	1.80	4.79	4.28	3.84	8.38	3.86

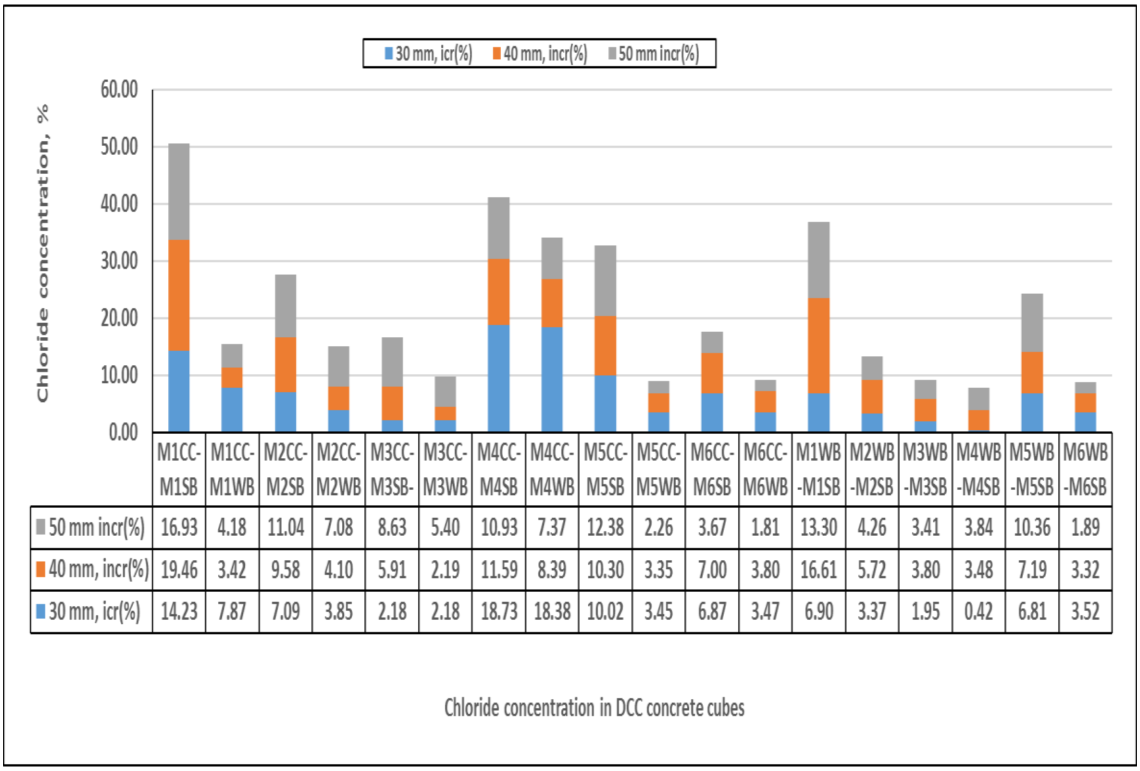
Figure 4-87 Chloride solution penetration in FSC (CC/SB/WB) concrete cubes

An interpretation of chloride solution penetration in DCC (SB/WB) as against control DCC control concrete cubes. Chloride penetration was decrease in an impregnation concrete cubes (SB/WB) as when compare to the concrete control concrete cubes for in the case of different mixtures type (M1-M6) at various drill depths (30, 40, and 50 mm) was as shown in (Figure 4-88, and Figure 4-89).



	M1SB-M1CC	M1WB-M1CC	M2SB-M2CC	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
■ 50 mm decr(%)	83.07	95.82	88.96	92.92	91.37	94.60	89.07	92.63	87.62	97.74	96.33	98.19	86.70	95.74	96.59	96.16	89.64	98.11
■ 40 mm, decr(%)	80.54	96.58	90.42	95.90	94.09	97.81	88.41	91.61	89.70	96.65	93.00	96.20	83.39	94.28	96.20	96.52	92.81	96.68
■ 30 mm, decr(%)	85.77	92.13	92.91	96.15	97.82	97.82	81.27	81.62	89.98	96.55	93.13	96.53	93.10	96.63	98.05	99.58	93.19	96.48

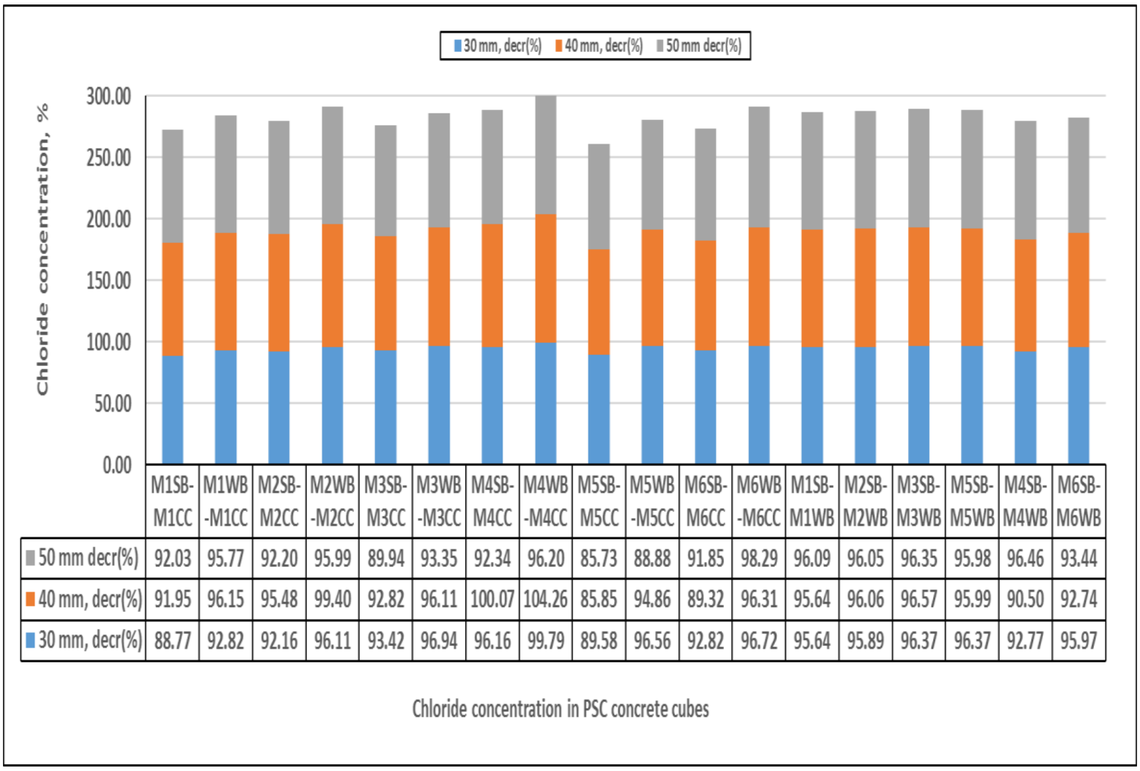
Figure 4-88 Chloride solution penetration in DCC (SB/WB/CC) concrete cubes



	M1CC-M1SB	M1CC-M1WB	M2CC-M2SB	M2CC-M2WB	M3CC-M3SB-	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M5SB	M5CC-M5WB	M6CC-M6SB	M6CC-M6WB	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
■ 50 mm incr(%)	16.93	4.18	11.04	7.08	8.63	5.40	10.93	7.37	12.38	2.26	3.67	1.81	13.30	4.26	3.41	3.84	10.36	1.89
■ 40 mm, incr(%)	19.46	3.42	9.58	4.10	5.91	2.19	11.59	8.39	10.30	3.35	7.00	3.80	16.61	5.72	3.80	3.48	7.19	3.32
■ 30 mm, icr(%)	14.23	7.87	7.09	3.85	2.18	2.18	18.73	18.38	10.02	3.45	6.87	3.47	6.90	3.37	1.95	0.42	6.81	3.52

Figure 4-89 Chloride solution penetration in DCC (CC/SB/WB) concrete cubes

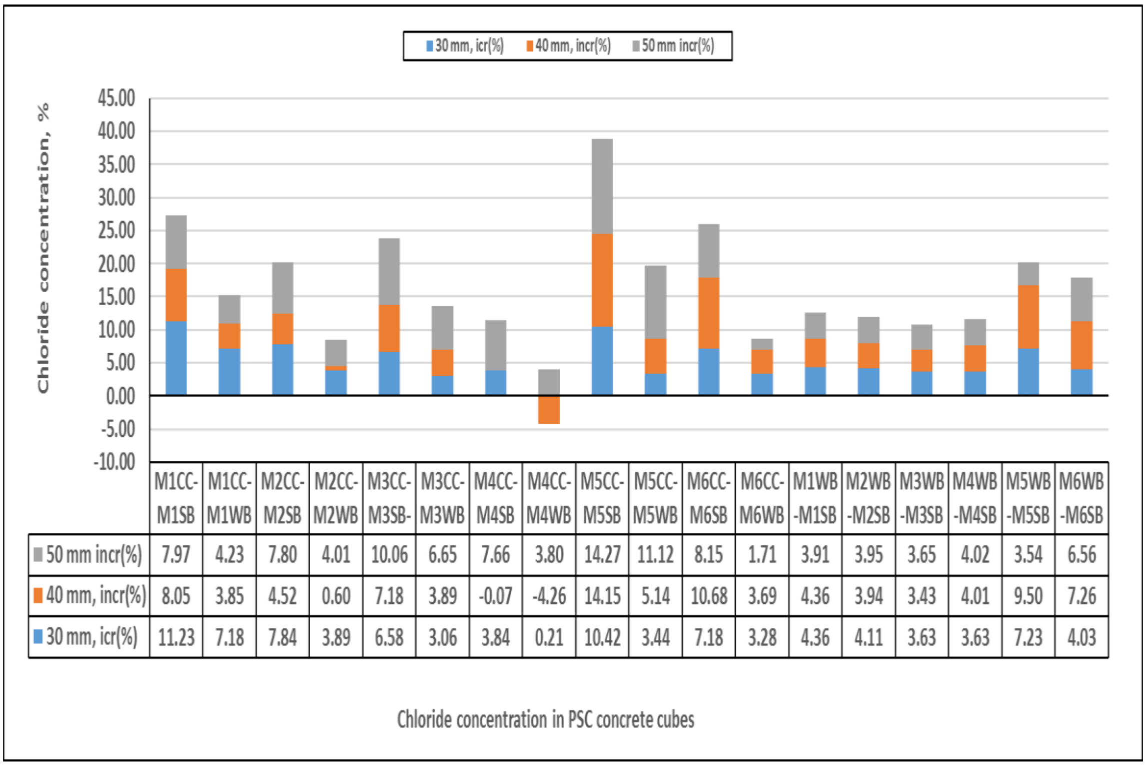
An assessment of chloride solution penetration in PSC (SB/WB) as against control PSC control concrete cubes for in the case of different designed concrete mix. Chloride penetration was decrease (96%) at different drill depths in an impregnation concrete cubes (SB/WB) as when compare to the concrete control concrete cubes for in the case of different mixtures type (M1-M6) at various drill depths (30, 40, and 50 mm) was as shown in (Figure 4-90). It’s also observe from the results that, the chloride solution penetration was predominantly decrease (97%) for in the case of solvent based impregnation concrete cubes (SB) as when compared to the water based impregnation concrete cubes (WB).



	M1SB-M1CC	M1WB-M1CC	M2SB-M2CC	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
■ 50 mm decr(%)	92.03	95.77	92.20	95.99	89.94	93.35	92.34	96.20	85.73	88.88	91.85	98.29	96.09	96.05	96.35	95.98	96.46	93.44
■ 40 mm, decr(%)	91.95	96.15	95.48	99.40	92.82	96.11	100.07	104.26	85.85	94.86	89.32	96.31	95.64	96.06	96.57	95.99	90.50	92.74
■ 30 mm, decr(%)	88.77	92.82	92.16	96.11	93.42	96.94	96.16	99.79	89.58	96.56	92.82	96.72	95.64	95.89	96.37	96.37	92.77	95.97

Figure 4-90 Chloride solution penetration in PSC (SB/WB/CC) concrete cubes

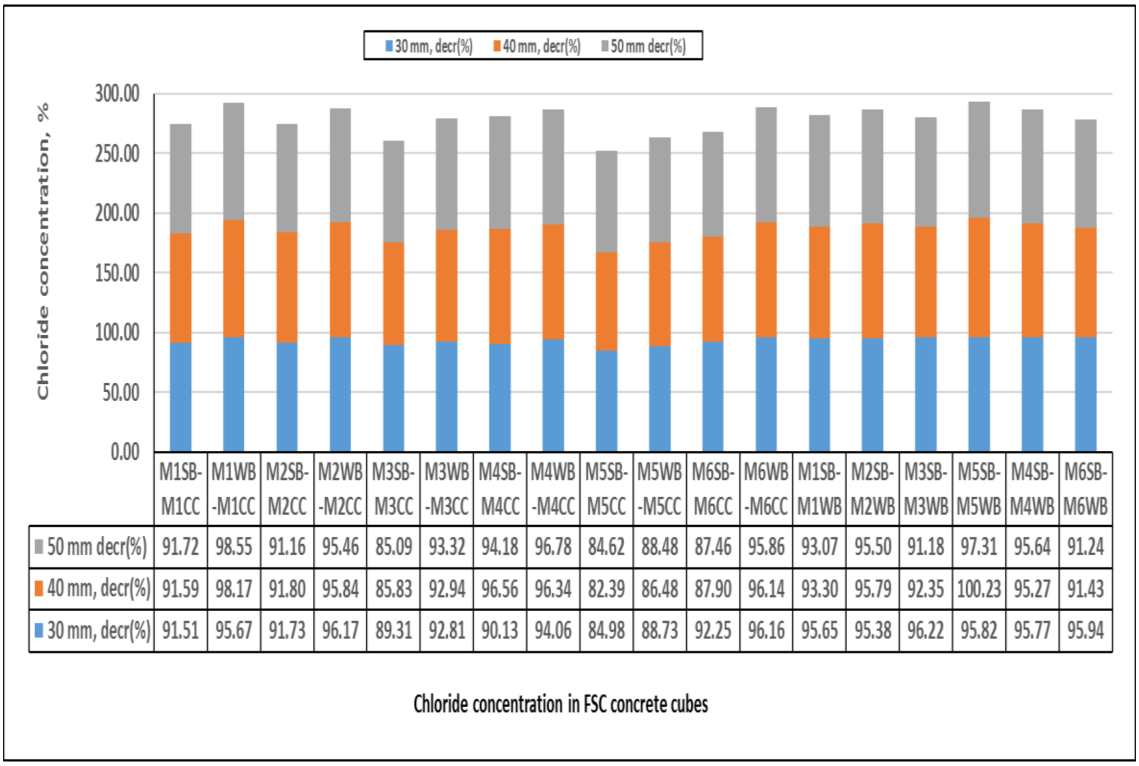
It is possible to compare chloride solution penetration in control PSC control concrete cubes as against PSC (SB/WB) for in the case of different designed concrete mix. Chloride penetration was increase around (11%) in control concrete cubes as against impregnation concrete cubes (SB/WB) for in the case of different mixtures type (M1-M6) at various drill depths (30, 40, and 50 mm) was as shown in (Figure 4-91). It’s also observe from the results that, the chloride solution penetration was predominantly increase (3.5%) for in the case of water based impregnation concrete cubes (WB) as when compared to the solvent based impregnation concrete cubes (SB) at different drill depths respectively.



	M1CC-M1SB	M1CC-M1WB	M2CC-M2SB	M2CC-M2WB	M3CC-M3SB-	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M5SB	M5CC-M5WB	M6CC-M6SB	M6CC-M6WB	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
■ 50 mm incr(%)	7.97	4.23	7.80	4.01	10.06	6.65	7.66	3.80	14.27	11.12	8.15	1.71	3.91	3.95	3.65	4.02	3.54	6.56
■ 40 mm, incr(%)	8.05	3.85	4.52	0.60	7.18	3.89	-0.07	-4.26	14.15	5.14	10.68	3.69	4.36	3.94	3.43	4.01	9.50	7.26
■ 30 mm, icr(%)	11.23	7.18	7.84	3.89	6.58	3.06	3.84	0.21	10.42	3.44	7.18	3.28	4.36	4.11	3.63	3.63	7.23	4.03

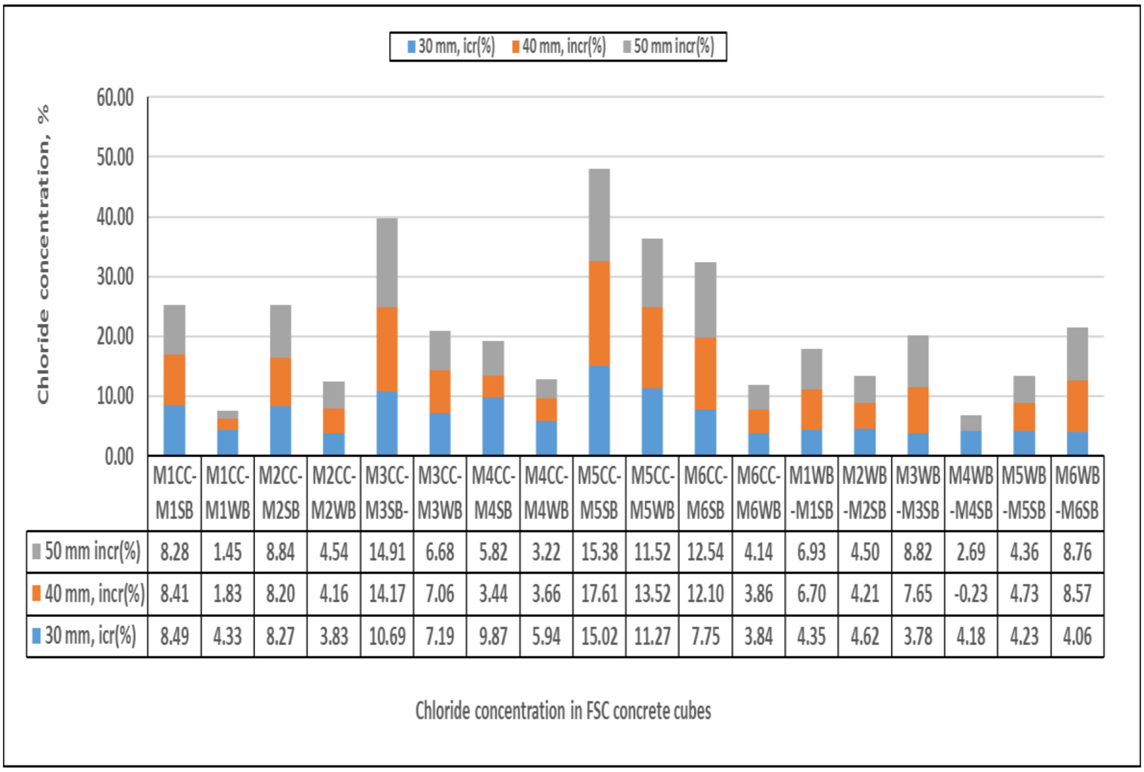
Figure 4-91 Chloride solution penetration in PSC (CC/SB/WB) concrete cubes

Furthermore, chloride solution penetration in FSC (SB/WB) as against control FSC control concrete cubes was analysed at different drill depths. Chloride penetration was also decrease in an impregnation concrete cubes (SB/WB) as when compare to the concrete control concrete cubes for in the case of different mixtures type (M1-M6) at various drill depths (30, 40, and 50 mm) with their variations was as shown in (Figure 4-92). Whereas, chloride solution penetration in control FSC concrete cubes as against FSC (SB/WB) was interpret at different drill depths. Chloride penetration was also increase in control concrete cubes as when compare to impregnation concrete cubes (SB/WB) for in the case of different mixtures type (M1-M6) at various drill depths (30, 40, and 50 mm) with their variations was as shown in (Figure 4-93).



	M1SB-M1CC	M1WB-M1CC	M2SB-M2CC	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
■ 50 mm decr(%)	91.72	98.55	91.16	95.46	85.09	93.32	94.18	96.78	84.62	88.48	87.46	95.86	93.07	95.50	91.18	97.31	95.64	91.24
■ 40 mm, decr(%)	91.59	98.17	91.80	95.84	85.83	92.94	96.56	96.34	82.39	86.48	87.90	96.14	93.30	95.79	92.35	100.23	95.27	91.43
■ 30 mm, decr(%)	91.51	95.67	91.73	96.17	89.31	92.81	90.13	94.06	84.98	88.73	92.25	96.16	95.65	95.38	96.22	95.82	95.77	95.94

Figure 4-92 Chloride solution penetration in FSC (SB/WB/CC) concrete cubes



	M1CC-M1SB	M1CC-M1WB	M2CC-M2SB	M2CC-M2WB	M3CC-M3SB-	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M5SB	M5CC-M5WB	M6CC-M6SB	M6CC-M6WB	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
■ 50 mm incr(%)	8.28	1.45	8.84	4.54	14.91	6.68	5.82	3.22	15.38	11.52	12.54	4.14	6.93	4.50	8.82	2.69	4.36	8.76
■ 40 mm, incr(%)	8.41	1.83	8.20	4.16	14.17	7.06	3.44	3.66	17.61	13.52	12.10	3.86	6.70	4.21	7.65	-0.23	4.73	8.57
■ 30 mm, icr(%)	8.49	4.33	8.27	3.83	10.69	7.19	9.87	5.94	15.02	11.27	7.75	3.84	4.35	4.62	3.78	4.18	4.23	4.06

Figure 4-93 Chloride soluton penetration in FSC (CC/SB/WB) concrete cubes

4.6 Salt ponding test on concrete slabs

4.6.1 Chloride solution penetration in control PCC/IC concrete slabs

The variation of chloride solution penetration in the control concrete (M1CS-M6CS), solvent based (M1S1-M2S3-M3S5-M4S9-M5S7-M6S11) as well as water based impregnation (M1S2-M2S4-M3S6-M4S10-M5SS8-M6S12) pre-conditioned concrete slabs at different drill depths was represent as shown in Figure 4-94. The chloride concentration was increase in control/impregnation concrete slabs. The percentage of increase was lesser at drill depth 40 mm as when compare to drill depth 50 mm. This may be due to the fact that, the surface chloride concentration was more at surface near zone in DCC concrete slabs. Similarly, the chloride concentration was predominantly increase in PSC concrete slabs at 30 mm drill depth. Furthermore, it is still more increase at drill depth 50 mm. But in case of FSC concrete slabs, there was slight increase in chloride concentration as when compared with drill depth (30-40) mm and as usually the percentage increase in chloride concentration at drill depth 50 mm was more when compared to drill depth (30-50) mm. However, this chloride concentration at drill depth 50 mm was more reduce as when compared to DCC, and PSC concrete slabs.

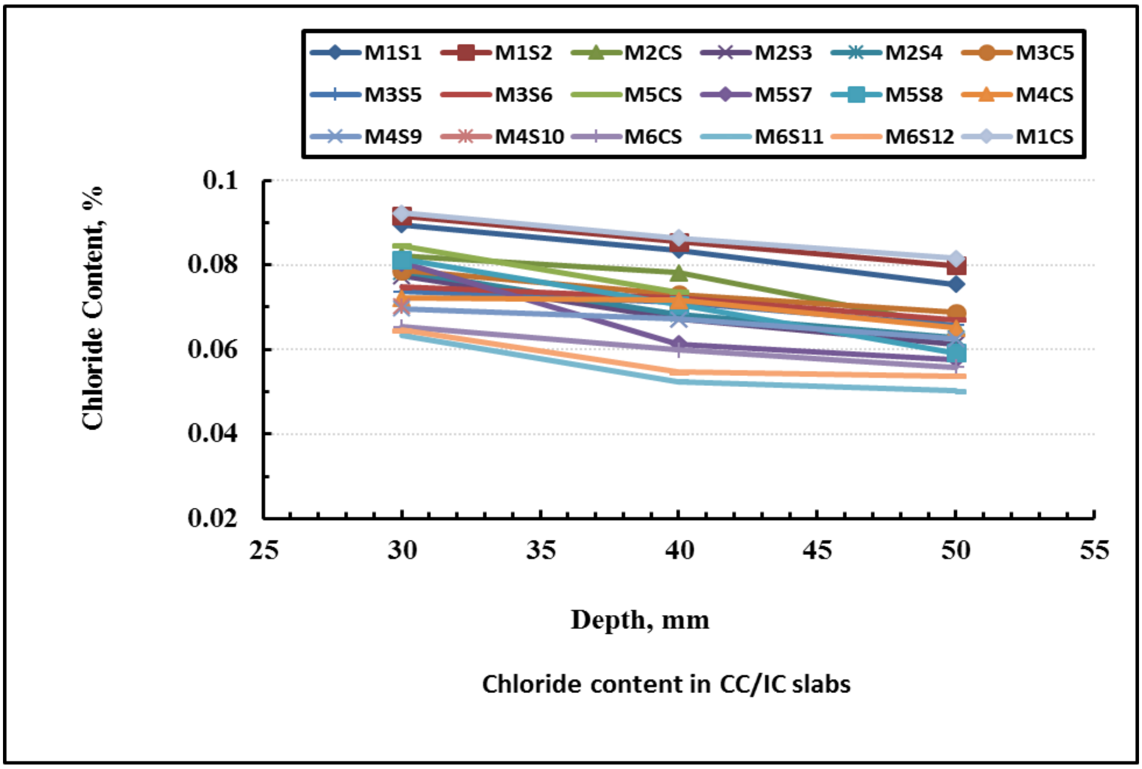


Figure 4-94 Chloride solution penetration in pre-conditioned concrete slabs

The chloride concentration was increase in control (CS)/solvent (SB)/water based (WB) impregnation DCC concrete slabs at drill depth (30 mm) as when compare to drill depth 40 mm (M1CS-6.42%, M1S1,SB-6.66%, M1S2,WB-6.68%, M2CS-4.85%, M2S3,SB-13.21%, M2S4,WB-12.80%). The chloride concentration was increase in control (CS)/solvent (SB)/water based (WB) impregnation concrete slabs at drill depth (30 mm) as when compare to drill depth 50 mm (M1CS-11.67%, M1S1,SB-15.78%, M1S2,WB-12.83%, M2CS-20.47%, M2S3,SB-20.74%, M2S4,WB-20.01%).

The chloride concentration was increase in control (CS)/solvent (SB)/water based (WB) impregnation PSC concrete slabs at drill depth (30 mm) as when compare to drill depth 40 mm (M1CS-7.13%, M1S1,SB-3.54%, M1S2,WB-3.46%, M2CS-12.94%, M2S3,SB-23.90%, M2S4,WB-13.25%). The chloride concentration was increase in control (CS)/solvent (SB)/water based (WB) impregnation concrete slabs at drill depth (30 mm) as when compare to drill depth 50 mm (M1CS-12.70%, M1S1,SB-10.85%, M1S2,WB-10.30%, M2CS-27.11%, M2S3,SB-28.49%, M2S4,WB-27.21%) respectively. The chloride concentration was increase in control (CS)/solvent (SB)/water based (WB) impregnation FSC concrete slabs at drill depth (30 mm) as when compare to drill depth 40 mm (M1CS-0.80%, M1S1,SB-3.48%, M1S2,WB-2.62%, M2CS-8.38%, M2S3,SB-17.33%, M2S4,WB-15.34%). The chloride concentration was increase in control (CS)/solvent (SB)/water based (WB) impregnation concrete slabs at drill depth (30 mm) as when compare to drill depth 50 mm (M1CS-9.88%, M1S1,SB-10.29%, M1S2,WB-9.88%, M2CS-14.61%, M2S3,SB-20.80%, M2S4,WB-16.91%) respectively

In DCC concrete slabs, the percentage of chloride concentration was more at drill depth 30 mm in solvent based and water based impregnation concrete slabs (M1S1, M1S2) as compared to control slabs (M1CS) and similarly more in impregnation concrete slabs (M2S3, M2S4) compared to control slabs (M2CS). However, it is found to be still more increase in chloride concentration for in case of impregnation concrete slabs (M1S1, M1S2, M2S3, and M2S4) compared to control slabs (M1CS, M2CS). Whereas in case of PSC concrete slabs, the percentage of chloride concentration in impregnation concrete slabs (M3S5, M3S6) is observe to be more or less increase/decrease as compared to control concrete slabs (M3CS, M5CS). Furthermore, as concern to FSC concrete slabs, the chloride concentration in impregnation concrete slabs (M4S9, M4S10) was decreased at drill depth 30 mm compared to control slabs (M4CS, M6CS) and its more increased compared to 30 mm drill depth as when concerned to drill depth (30-50) mm for in case of control/impregnation concrete slabs.

The variation of chloride solution penetration in DCC/PSC/FSC concrete slabs for different mixtures type (M1-M2) is as shown in Figure 4-95, Figure 4-96, and Figure 4-97).

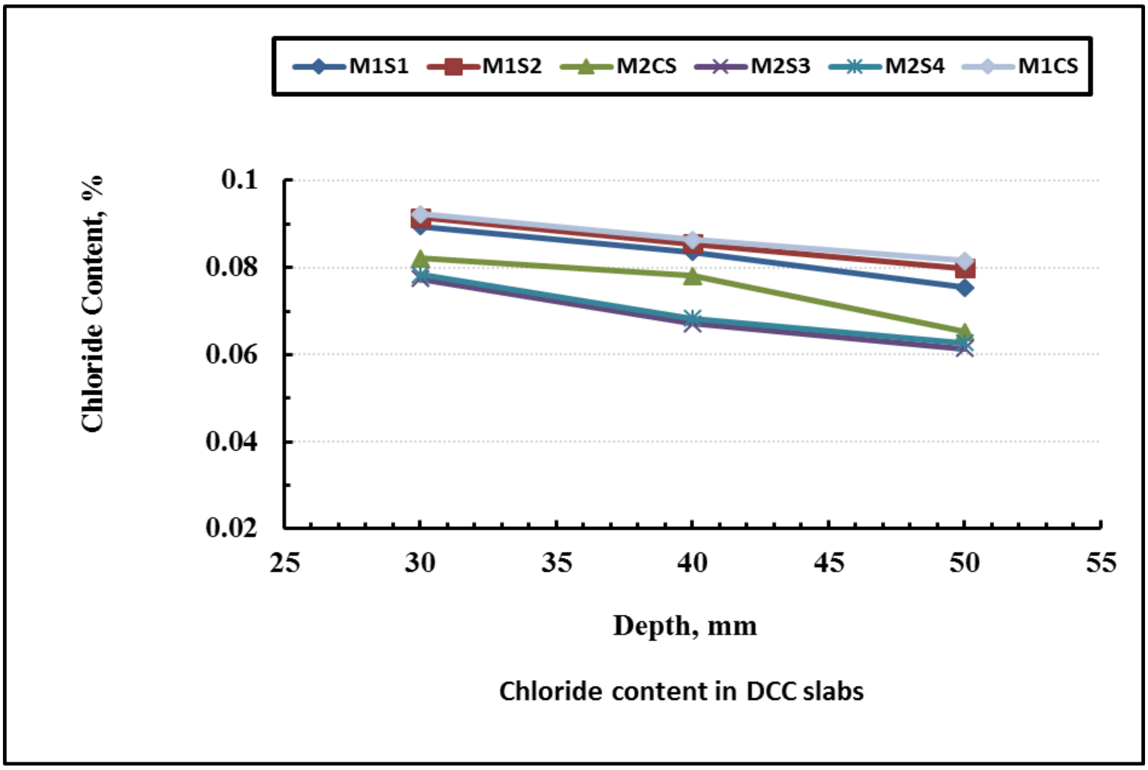


Figure 4-95 Chloride content in DCC concrete slabs

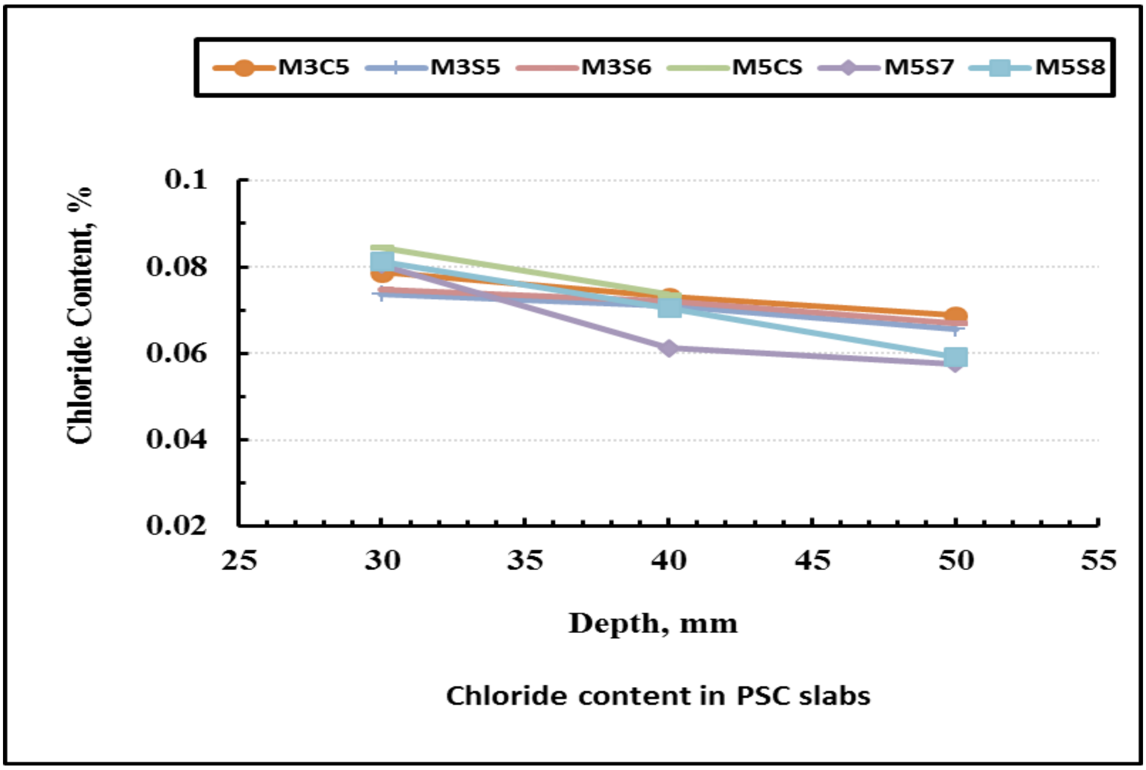


Figure 4-96 Chloride profile analysis in PSC concrete slabs

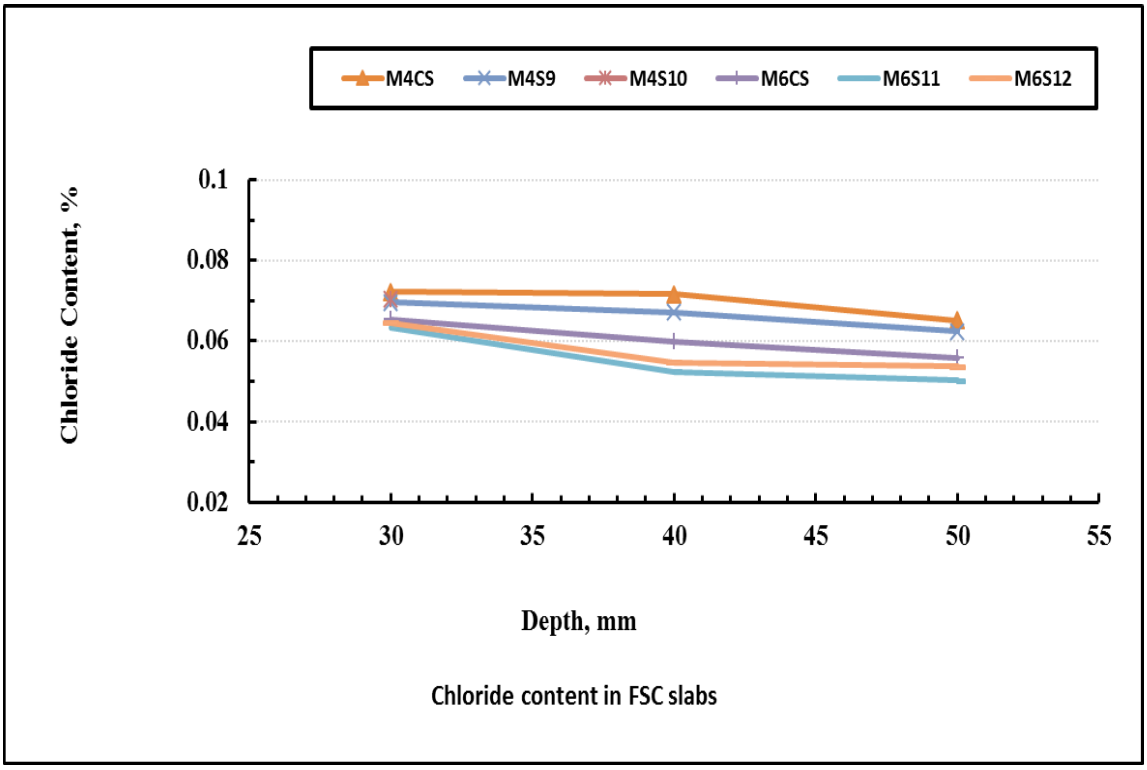


Figure 4-97 Chloride content in FSC concrete slabs

Similarly, the variation of chloride concentration in pre-conditioned control concrete slabs for different mixtures type (M1-M6) was as shown in Figure 4-98.

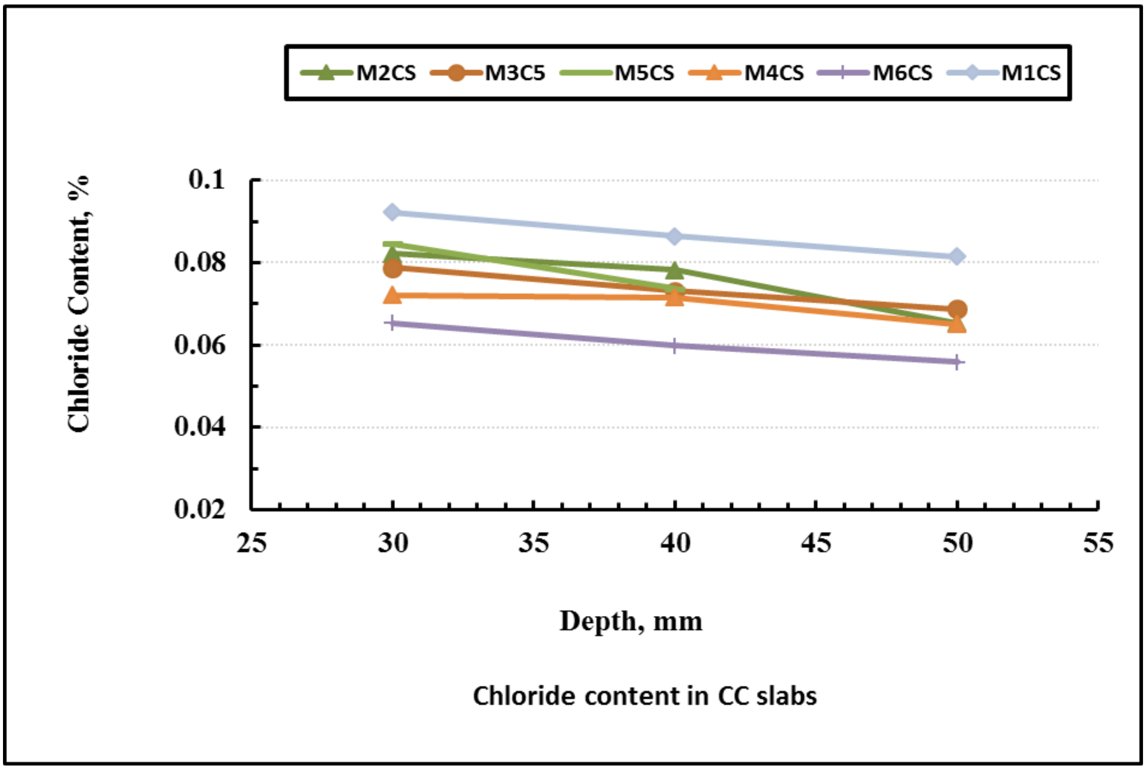
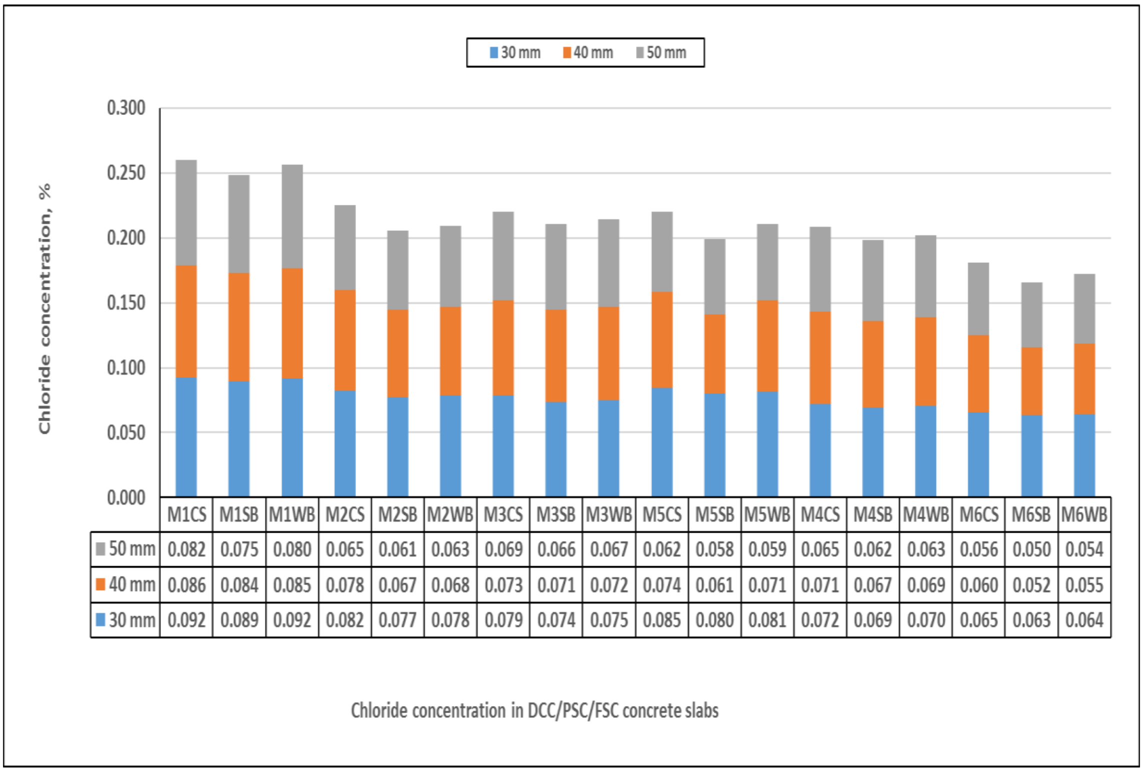


Figure 4-98 Chloride content penetration in PCC control concrete slabs

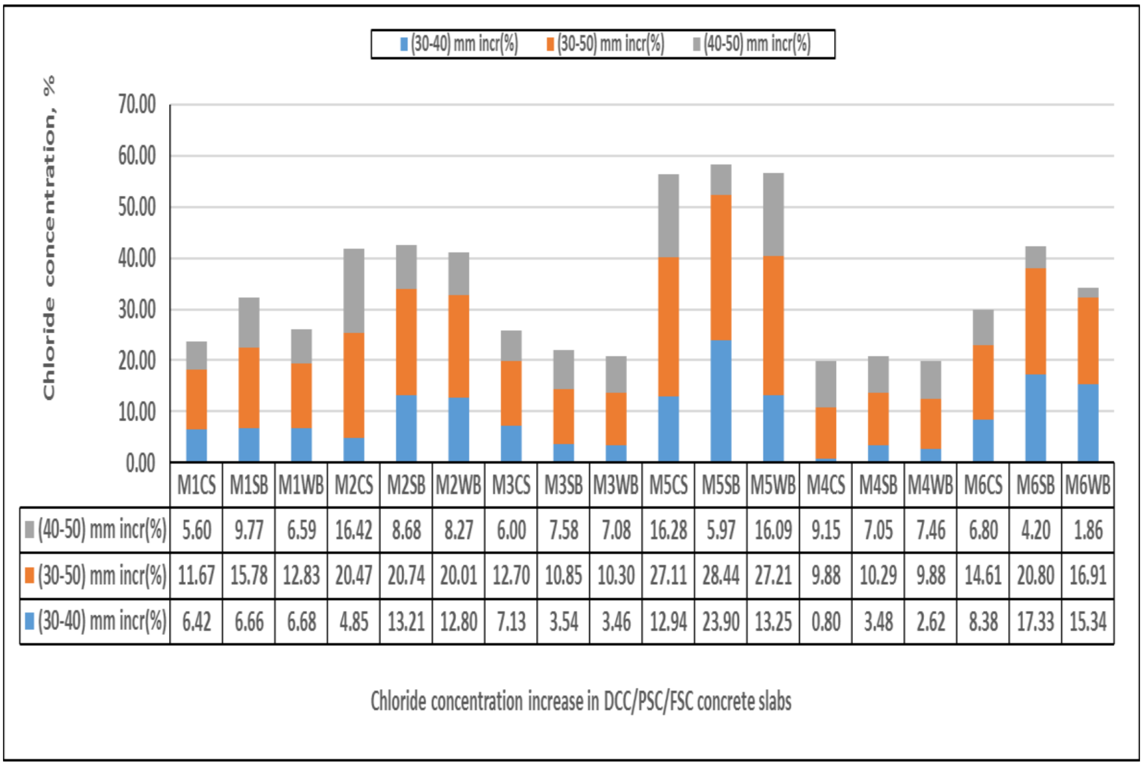
4.6.2 Comparison of chloride solution penetration in control PCC/IC concrete slabs

An evaluation of chloride solution penetration in pre-conditioned control concrete slabs (M1CS-M6CS) and impregnation concrete slabs (M1SB-M6SB, and M1WB-M6WB) for different mixtures type (M1-M6) was as shown in (Figure 4-99, Figure 4-100, and Figure 4-101). Its observe from the results that (Figure 4-99), the chloride solution absorption was goes on reduces with increased drill depths (30, 40, and 50 mm) in all concrete mixture types such as pre-conditioned control/IC concrete slabs (DCC/PSC/FSC) respectively. Chloride solution penetration was increase in DCC concrete slabs at different drill depths as when compare to PSC and FSC concrete slabs. It is also possible to compare chloride solution penetration in control/IC concrete slabs at different drill depths (30-40), (30-50), and (40-50) mm for in the case of pre-conditioned concrete slabs as shown (Figure 4-100). An attempt was made to compare the variations in chloride solution penetration in control concrete slabs (M1CS-M6CS) to impregnation concrete slabs (M1SB-M6SB, and M1WB-M6WB) at different drill depths (30, 40, and 50 mm) respectively (Figure 4-101). Chloride solution penetration was predominantly increase in control concrete slabs as against impregnation concrete slabs (SB/WB).



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
50 mm	0.082	0.075	0.080	0.065	0.061	0.063	0.069	0.066	0.067	0.062	0.058	0.059	0.065	0.062	0.063	0.056	0.050	0.054
40 mm	0.086	0.084	0.085	0.078	0.067	0.068	0.073	0.071	0.072	0.074	0.061	0.071	0.071	0.067	0.069	0.060	0.052	0.055
30 mm	0.092	0.089	0.092	0.082	0.077	0.078	0.079	0.074	0.075	0.085	0.080	0.081	0.072	0.069	0.070	0.065	0.063	0.064

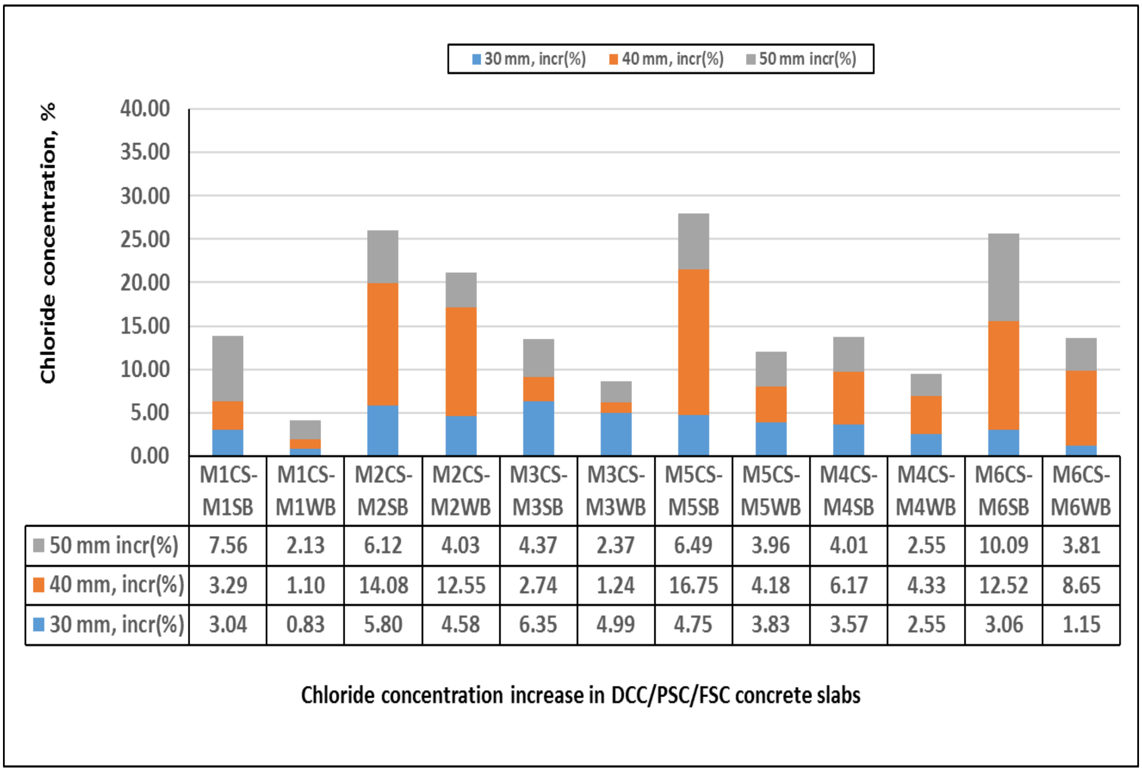
Figure 4-99 Chloride solution penetration in PCC (CS/SB/WB) concrete slabs



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
(40-50) mm incr(%)	5.60	9.77	6.59	16.42	8.68	8.27	6.00	7.58	7.08	16.28	5.97	16.09	9.15	7.05	7.46	6.80	4.20	1.86
(30-50) mm incr(%)	11.67	15.78	12.83	20.47	20.74	20.01	12.70	10.85	10.30	27.11	28.44	27.21	9.88	10.29	9.88	14.61	20.80	16.91
(30-40) mm incr(%)	6.42	6.66	6.68	4.85	13.21	12.80	7.13	3.54	3.46	12.94	23.90	13.25	0.80	3.48	2.62	8.38	17.33	15.34

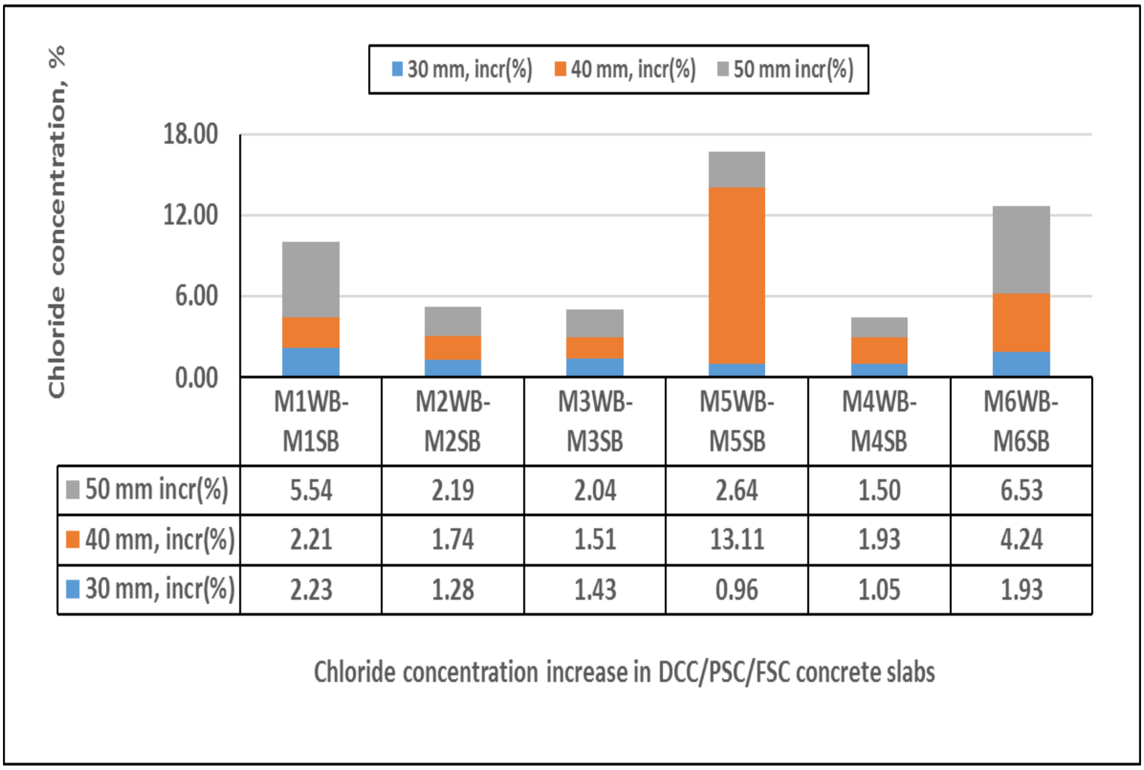
Figure 4-100 Chloride solution penetration in PCC (CS/SB/WB) concrete slabs

Chloride solution penetration was increase in impregnation concrete slabs (WB) as against the impregnation concrete slabs (SB) at different drill depths as shown in (Figure 4-102).



	M1CS-M1SB	M1CS-M1WB	M2CS-M2SB	M2CS-M2WB	M3CS-M3SB	M3CS-M3WB	M5CS-M5SB	M5CS-M5WB	M4CS-M4SB	M4CS-M4WB	M6CS-M6SB	M6CS-M6WB
■ 50 mm incr(%)	7.56	2.13	6.12	4.03	4.37	2.37	6.49	3.96	4.01	2.55	10.09	3.81
■ 40 mm, incr(%)	3.29	1.10	14.08	12.55	2.74	1.24	16.75	4.18	6.17	4.33	12.52	8.65
■ 30 mm, incr(%)	3.04	0.83	5.80	4.58	6.35	4.99	4.75	3.83	3.57	2.55	3.06	1.15

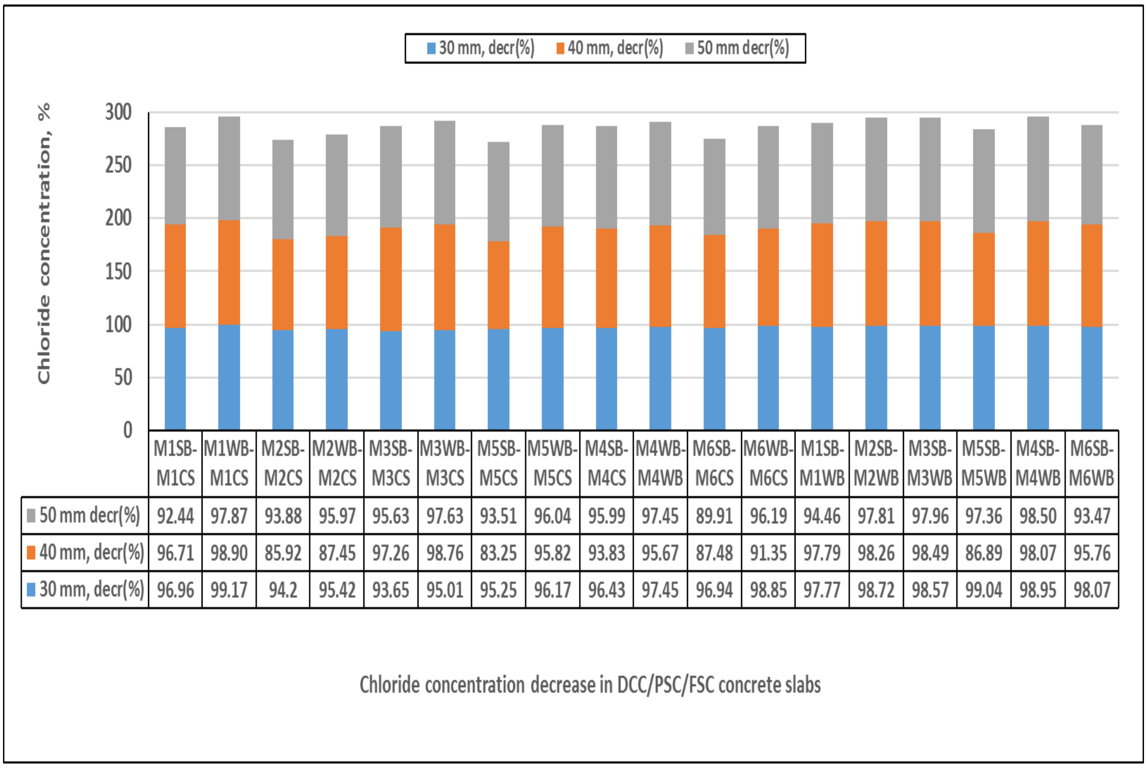
Figure 4-101 Chloride solution penetration in control PCC (CS/SB/WB) concrete slabs



	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M5WB-M5SB	M4WB-M4SB	M6WB-M6SB
■ 50 mm incr(%)	5.54	2.19	2.04	2.64	1.50	6.53
■ 40 mm, incr(%)	2.21	1.74	1.51	13.11	1.93	4.24
■ 30 mm, incr(%)	2.23	1.28	1.43	0.96	1.05	1.93

Figure 4-102 Chloride solution penetration in PCC (WB/SB) concrete slabs

The chloride solution penetration was increase in impregnation DCC (WB) concrete slabs as against the impregnation concrete slabs DCC (SB). It is also more in chloride solution penetration as when compare to the chloride solution penetration for in the case of FSC (WB/SB). The chloride solution penetration was decrease in impregnation concrete slabs (SB/WB) as when compared to the control concrete slabs (M1CS-M6CS) as against impregnation concrete slabs (SB/WB). In addition to that, the chloride solution penetration was also decrease in impregnation concrete slabs (SB) as against the impregnation concrete slabs (WB) as shown in (Figure 4-103).



	M1SB-M1CS	M1WB-M1CS	M2SB-M2CS	M2WB-M2CS	M3SB-M3CS	M3WB-M3CS	M5SB-M5CS	M5WB-M5CS	M4SB-M4CS	M4WB-M4WB	M6SB-M6CS	M6WB-M6CS	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
■ 50 mm decr(%)	92.44	97.87	93.88	95.97	95.63	97.63	93.51	96.04	95.99	97.45	89.91	96.19	94.46	97.81	97.96	97.36	98.50	93.47
■ 40 mm, decr(%)	96.71	98.90	85.92	87.45	97.26	98.76	83.25	95.82	93.83	95.67	87.48	91.35	97.79	98.26	98.49	86.89	98.07	95.76
■ 30 mm, decr(%)	96.96	99.17	94.2	95.42	93.65	95.01	95.25	96.17	96.43	97.45	96.94	98.85	97.77	98.72	98.57	99.04	98.95	98.07

Figure 4-103 Chloride solution penetration in PCC (SB/WB/CS) concrete slabs

4.6.3 Chloride solution penetration in pre-conditioned control concrete slabs/cubes

The assessment of corrosion risk of the reinforcement steel in the concrete structures expose to marine or de-icing salt environments is required in order to determine the chloride concentration profile in concrete from the exposed surface. Due to the cost and limitations of the methods of sampling for obtaining chloride concentration profiles in concrete, continuous improvement of existing methods and development of novel approaches are required. The variation of chloride concentration in control concrete slabs/cubes is to be evaluate in pre-conditions such as dry/partially/fully saturated condition as shown in (Figure 4-104). In which, the average chloride concentration in DCC control concrete slabs were increased (23.40%) at different drill depths (30-50) mm for in case of mixture type (M1) as when compared to concrete cubes average chloride concentration. But, an average chloride concentration was predominantly decreased (13.77%) in

DCC control concrete slabs as when compared to DCC control concrete cubes due to variation in chloride concentration for in case of mixture type (M2). Also, the average chloride concentration in PSC control concrete slabs were decreased (2.41%) at different drill depths (30-50) mm for in case of mixture type (M3) as when compared to concrete cubes average chloride concentration. But, the average chloride concentration was predominantly increased (6.94%) in PSC control concrete slabs as when compared to PSC control concrete cubes due to variation in chloride concentration for in case of mixture type (M5). In addition to that, the average chloride concentration in FSC control concrete slabs were predominantly increased (20.76%) at different drill depths (30-50) mm for in case of mixture type (M4) as when compared to concrete cubes average chloride concentration. But, the average chloride concentration was more decreased (3.31%) in FSC control concrete slabs as when compared to FSC control concrete cubes due to variation in chloride concentration for in case of mixture type (M6) at different drill depths (30-50) mm.

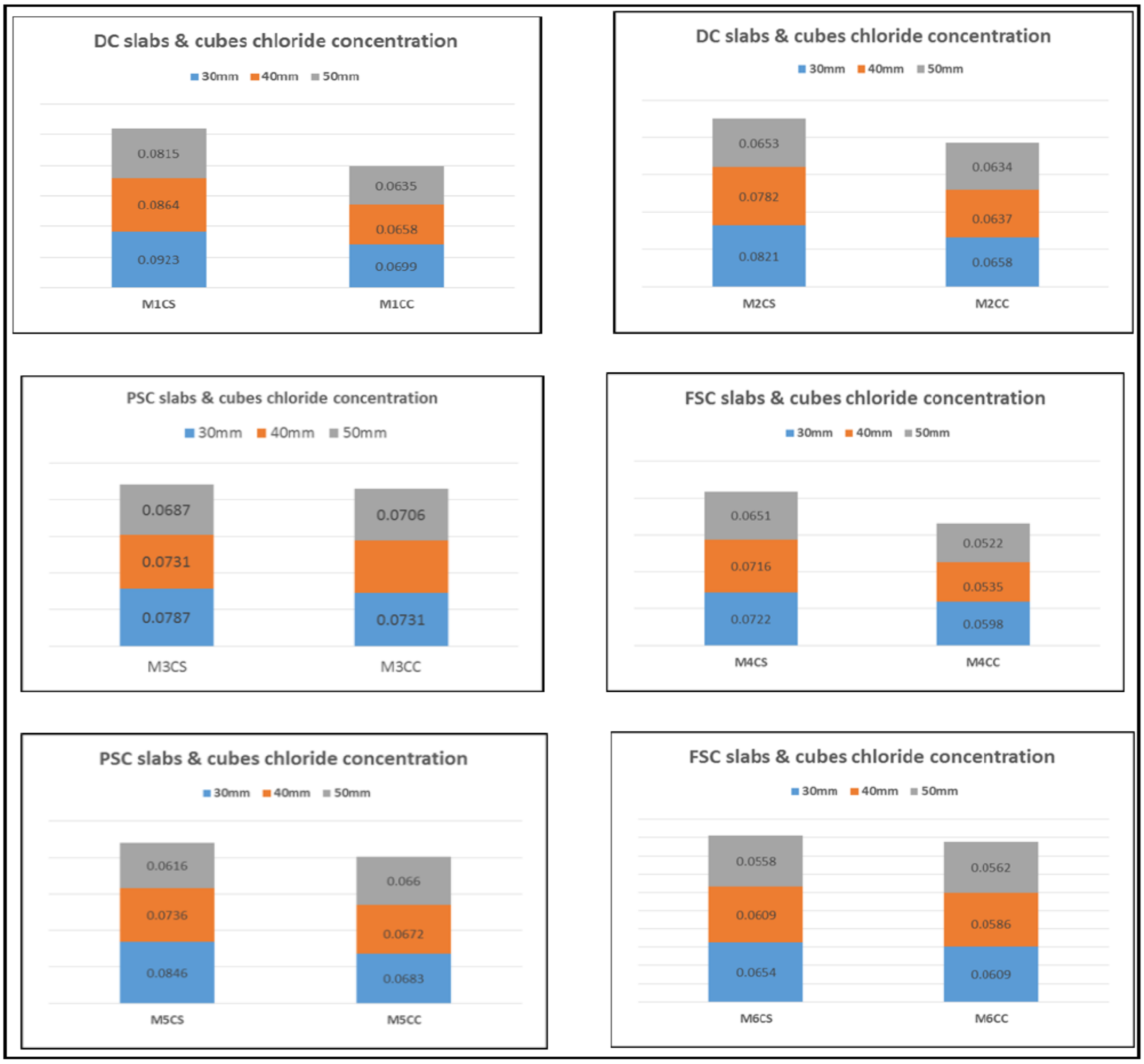


Figure 4-104 Chloride solution penetration in control PCC concrete slabs/cubes

The variation of chloride concentration in solvent based (SB) impregnation concrete slabs/cubes were interpreted in pre-conditions such as dry/partially/fully saturated condition at different drill depths (30-40-50) mm for designed concrete mixtures type as shown (Figure 4-105). In which, an average chloride concentration in DCC (SB) concrete slabs were increased (33.19%) at different drill depths (30-50) mm for in case of mixture type (M1) as when compared to concrete cubes average chloride concentration. But, an average chloride concentration was predominantly decreased (14.45%) in DCC (SB) concrete slabs as when compared to DCC impregnation concrete cubes due to variation in chloride concentration for in case of mixture type (M2) as against mixture type (M1). In addition, the average chloride concentration in PSC (SB) concrete slabs were increased (5.95%) at different drill depths (30-50) mm for in case of mixture type (M3) as when compared to concrete cubes average chloride concentration. But, an average chloride concentration was predominantly increased (10.56%) in PSC (SB) impregnation concrete slabs as when compared to PSC (SB) impregnation concrete cubes due to variation in chloride concentration for in case of mixture type (M5). In addition to that, an average chloride concentration in FSC (SB) impregnation concrete slabs were predominantly increased (22.30%) at different drill depths (30-50) mm for in case of mixture type (M4) as when compared to concrete cubes average chloride concentration. But, an average chloride concentration was more decreased (5.02%) in FSC (SB) impregnation concrete slabs as when compared to FSC (SB) impregnation concrete cubes due to variation in chloride concentration for in case of mixture type (M6) at different drill depths (30-50) mm.

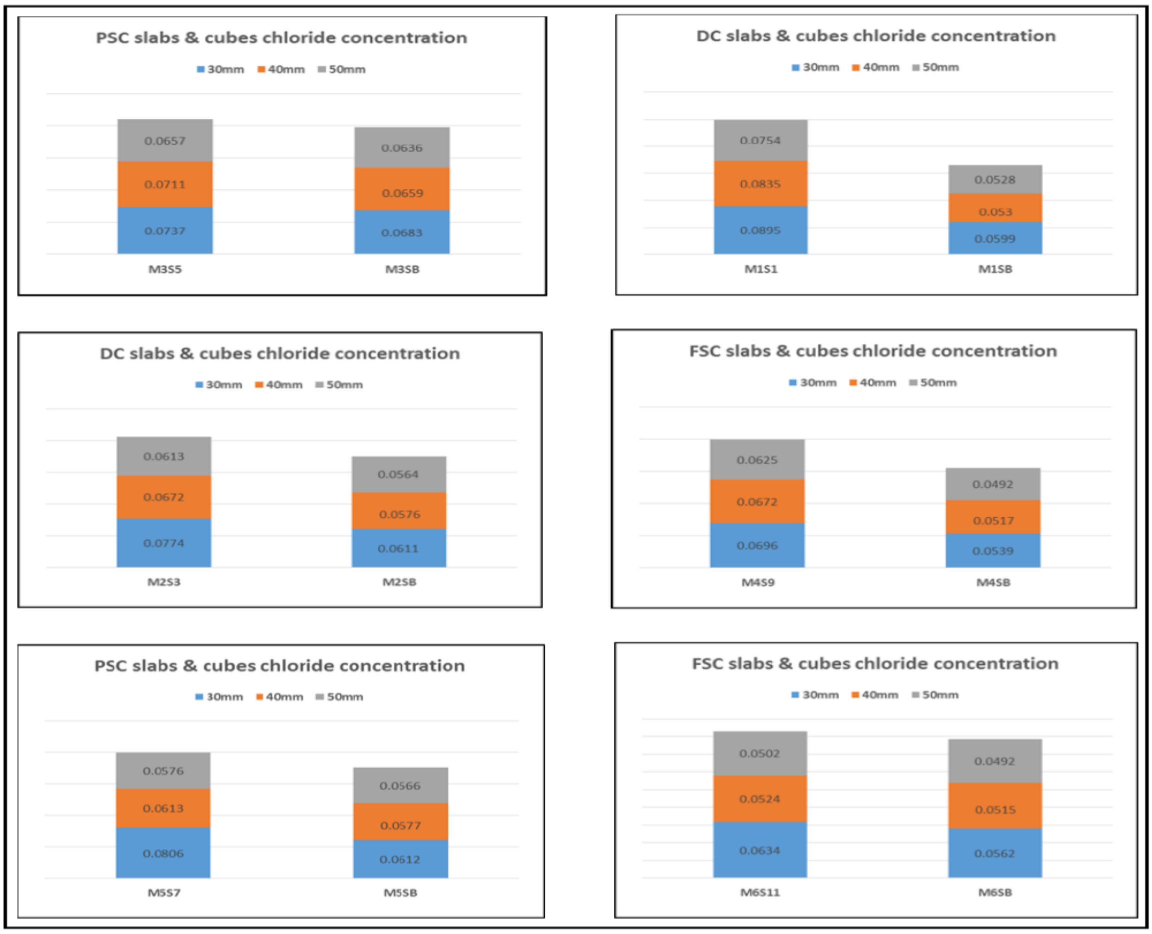


Figure 4-105 Chloride solution penetration in pre-conditioned IC (SB) slabs/cubes

The variation of chloride concentration in water based (WB) impregnation concrete slabs/cubes were interpreted in pre-conditions such as dry/partially/fully saturated condition at different drill depths (30-40-50) mm for designed concrete mixtures type as shown (Figure 4-106). In which, the average chloride concentration in DCC (WB) impregnation concrete slabs were increased (26.28%) at different drill depths (30-50) mm for in case of mixture type (M1) as when compared to concrete cubes average chloride concentration. But, the average chloride concentration was predominantly decreased (12%) in DCC (WB) impregnation concrete slabs as when compared to DCC impregnation concrete cubes due to variation in chloride concentration for in case of mixture type (M2). Also, the average chloride concentration in PSC (WB) impregnation concrete slabs were lesser decreased (4.18%) at different drill depths (30-50) mm for in case of mixture type (M3) as when compared to concrete cubes average chloride concentration. But, an average chloride concentration was predominantly increased reduction (9.82%) in PSC (WB) impregnation concrete slabs as when compared to PSC (WB) impregnation concrete cubes due to variation in chloride concentration for in case of mixture type (M5). In addition to that, an average chloride concentration in FSC (WB) impregnation concrete slabs were predominantly increased reduction (21.68%) at different drill depths (30-50) mm for in case of mixture type (M4) as when compared to concrete cubes average chloride concentration. But, an average chloride concentration was more lesser decreased (2%) in FSC (WB) impregnation concrete slabs as when compared to FSC (WB) impregnation concrete cubes due to variation in chloride concentration for in case of mixture type (M6) at different drill depths (30-50) mm.

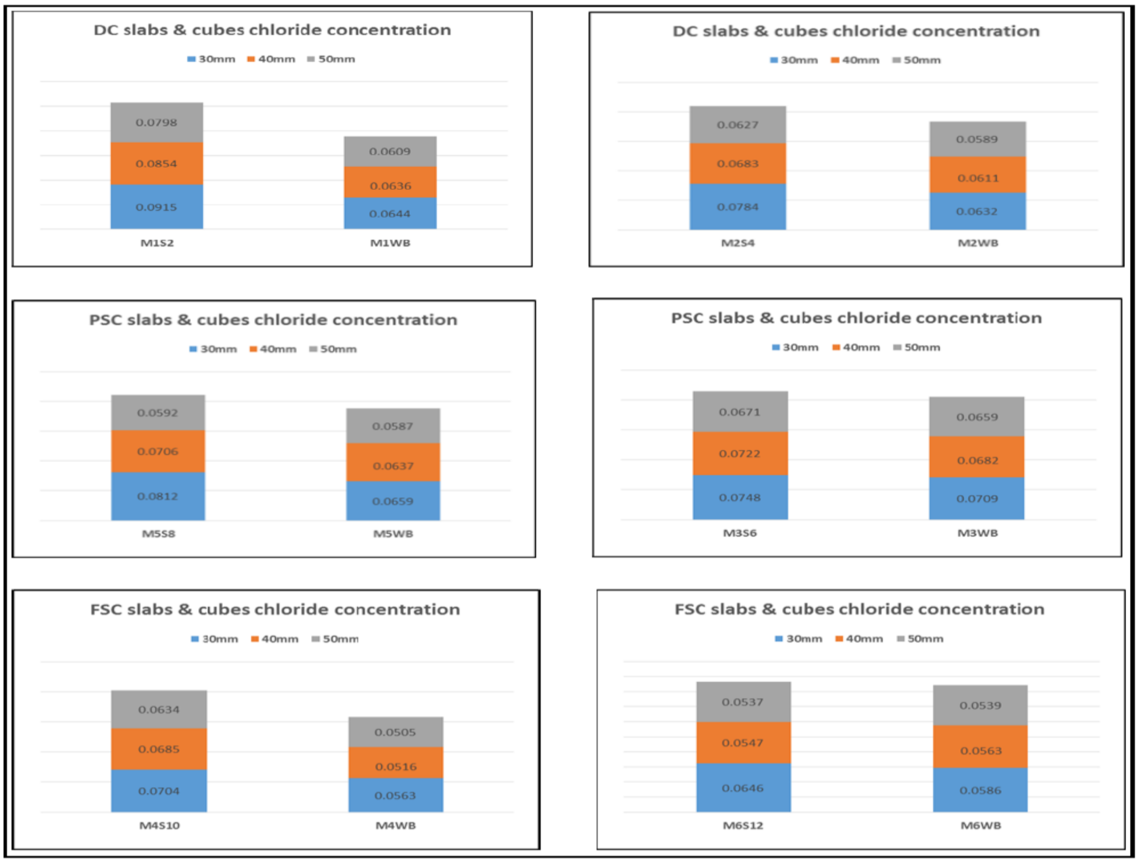


Figure 4-106 Chloride solution penetration in pre-conditioned IC (WB) slabs/cubes

The interpretation of chloride concentration in solvent based (SB) and water based (WB) impregnation concrete cubes were interpreted in pre-conditions such as dry/partially/fully saturated condition at different drill depths (30-40-50) mm for designed concrete mixtures type as shown (Figure 4-107, Figure 4-108, and Figure 4-109). In which, an average chloride concentration in DCC (SB) impregnation concrete cubes was decreased as when compared to (WB) impregnation concrete cubes at different drill depths for designed mixtures type (M1-M6). As concerned to PSC (SB) impregnation concrete cubes, an average chloride concentration at different drill depths was also decreased as when compared to (WB) impregnation concrete cubes for in case of different mixtures type (M1-M6). But, an average chloride concentration for in case of PSC (SB/WB) impregnation concrete cubes was slightly decreased as when compared to DCC (SB/WB) impregnation concrete cubes as well as somewhat higher in average chloride concentration as when compared to FSC (SB/WB) impregnation concrete cubes. Similarly, an average chloride concentration in FSC (SB) impregnation concrete cubes was decrease as when compared to (WB) impregnation concrete cubes for in case of designed mixtures type (M1-M6).

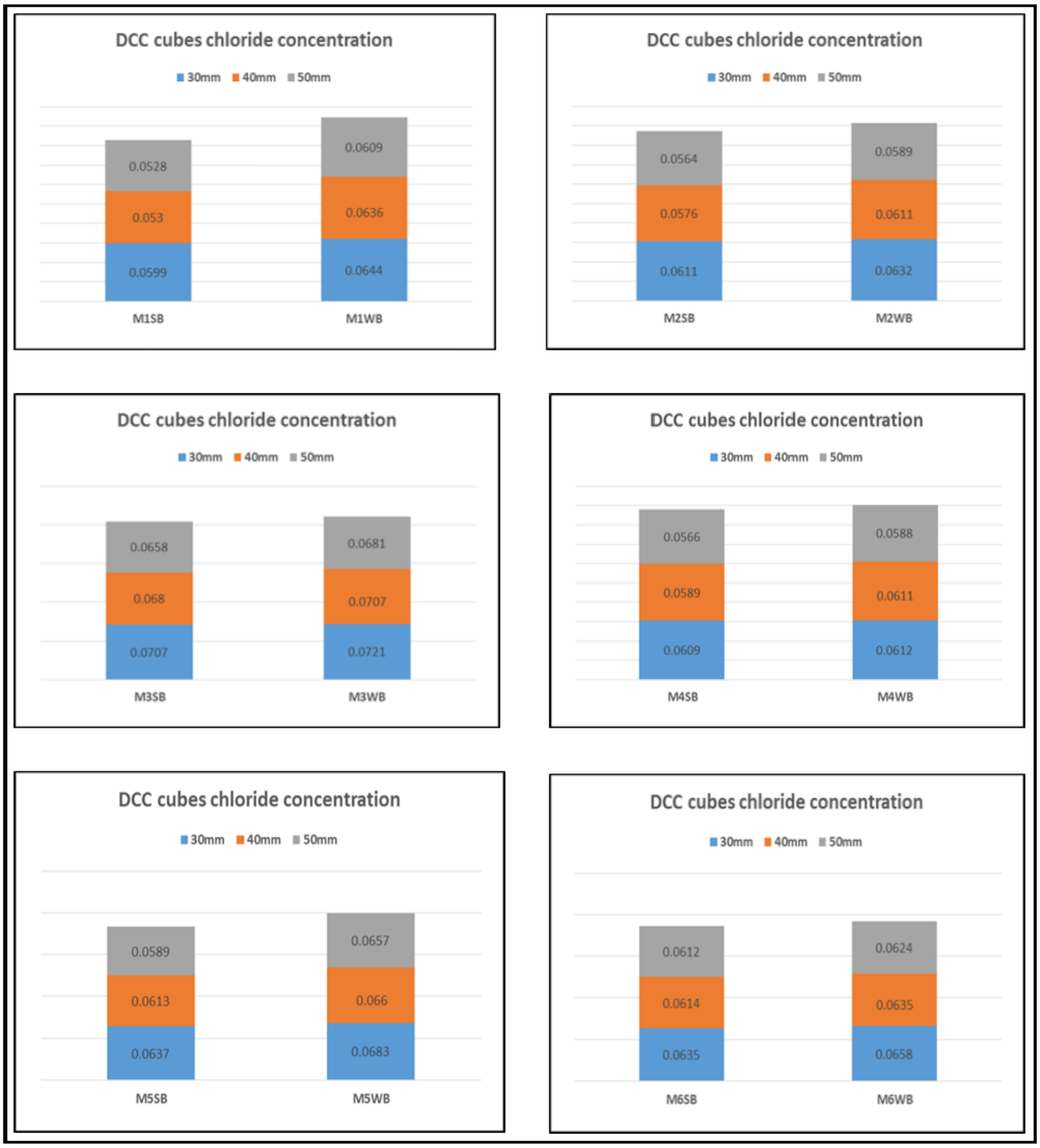


Figure 4-107 Chloride solution penetration in DCC (SB/WB) impregnation concrete cubes

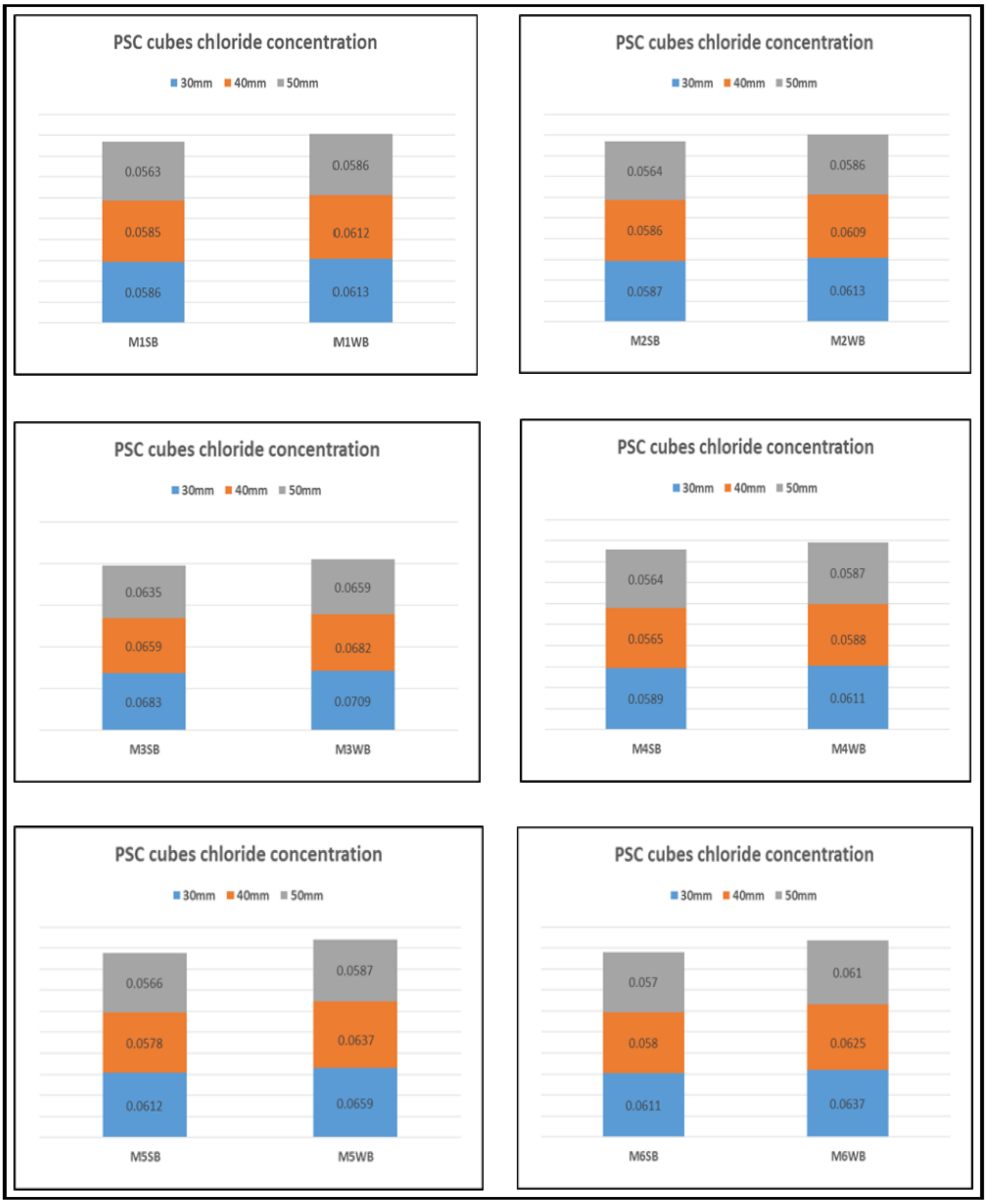


Figure 4-108 Chloride solution penetration in PSC (SB/WB) impregnation concrete cubes

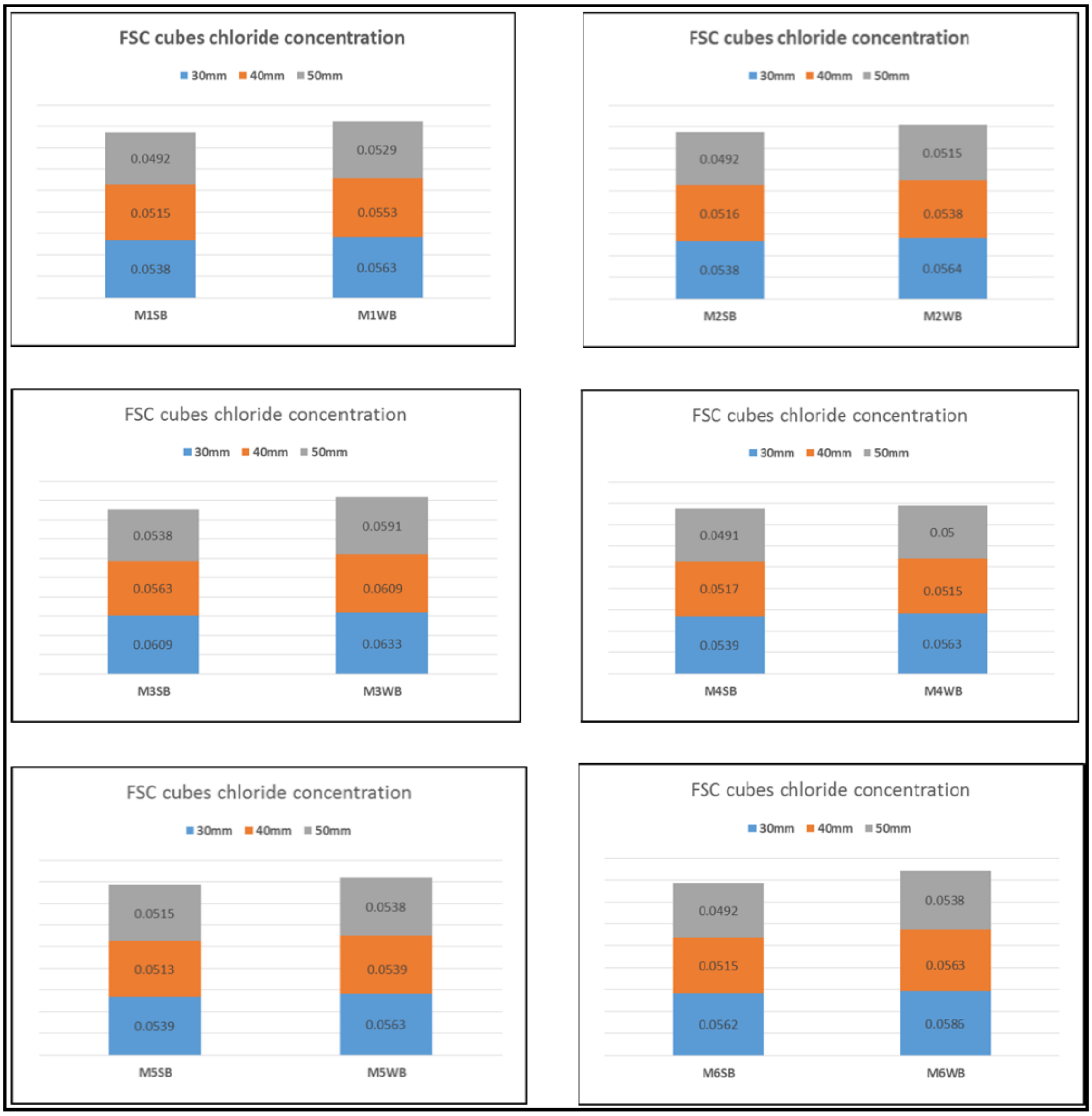


Figure 4-109 Chloride solution penetration in FSC (SB/WB) impregnation concrete cubes

4.7 Chloride diffusion coefficient in concrete cubes

4.7.1 Chloride diffusion coefficient in control PCC/IC concrete cubes

The variation of chloride diffusion coefficient in DCC concrete cubes in for different mixtures type (M1-M6) is as shown in Figure 4-110. The chloride diffusion coefficient was increase in control concrete cubes as compared to (SB/WB) impregnation concrete cubes, (M1CC-M1SB:28.26%, M2CC-M2SB:18.54%, M3CC-M3SB:18.67%, M1CC-M1WB:4.75%, M2CC-M2WB:14.86%, M3CC-M3WB:27.26%) for in the case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also increase in control concrete cubes as compared to solvent-based (SB)/water based (WB) impregnation concrete cubes (M4CC-M4SB:11.30%, M5CC-M2SB:15.32%, M6CC-M6SB:13.55%, M4CC-M4WB:4.57%, M5CC-M5WB:10.24%, M6CC-M6WB:10.76%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride diffusion coefficient was increase in water based (WB) impregnation concrete cubes as when compared to solvent-based (SB) impregnation concrete cubes (M1WB-M1SB:24.69%, M2WB-M2SB:4.33%, M3WB-M3SB:11.81%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also increase in water based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:7.05%, M5WB-M2SB:5.66%, M6WB-M6SB:3.12%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. The chloride diffusion coefficient was decrease in solvent based (SB) impregnation concrete cubes as when compared to control concrete cubes (M1SB-M1CC:71.74%, M2SB-M2CC:81.46%, M3SB-M3CC:81.33%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in solvent based (SB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4CC:88.70%, M5SB-M2CC:84.68%, M6SB-M6CC:86.45%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. The chloride diffusion coefficient was decrease in water based (WB) impregnation concrete cubes as when compared to control concrete cubes (M1WB-M1CC:95.25%, M2WB-M2CC:85.14%, M3WB-M3CC:72.74%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in water based (SB) impregnation concrete cubes as compared to control concrete cubes (M4WB-M4CC:95.43%, M5WB-M2CC:89.76%, M6WB-M6CC:89.24%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride diffusion coefficient was decrease in solvent based (SB) impregnation concrete cubes as when compared to water based impregnation (WB) concrete cubes (M1SB-M1WB:75.31%, M2SB-M2WB:95.67%, M3SB-M3WB:111.81%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in solvent based (SB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4WB:92.95%, M5SB-M2WB:94.34%, M6SB-M6WB:96.88%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

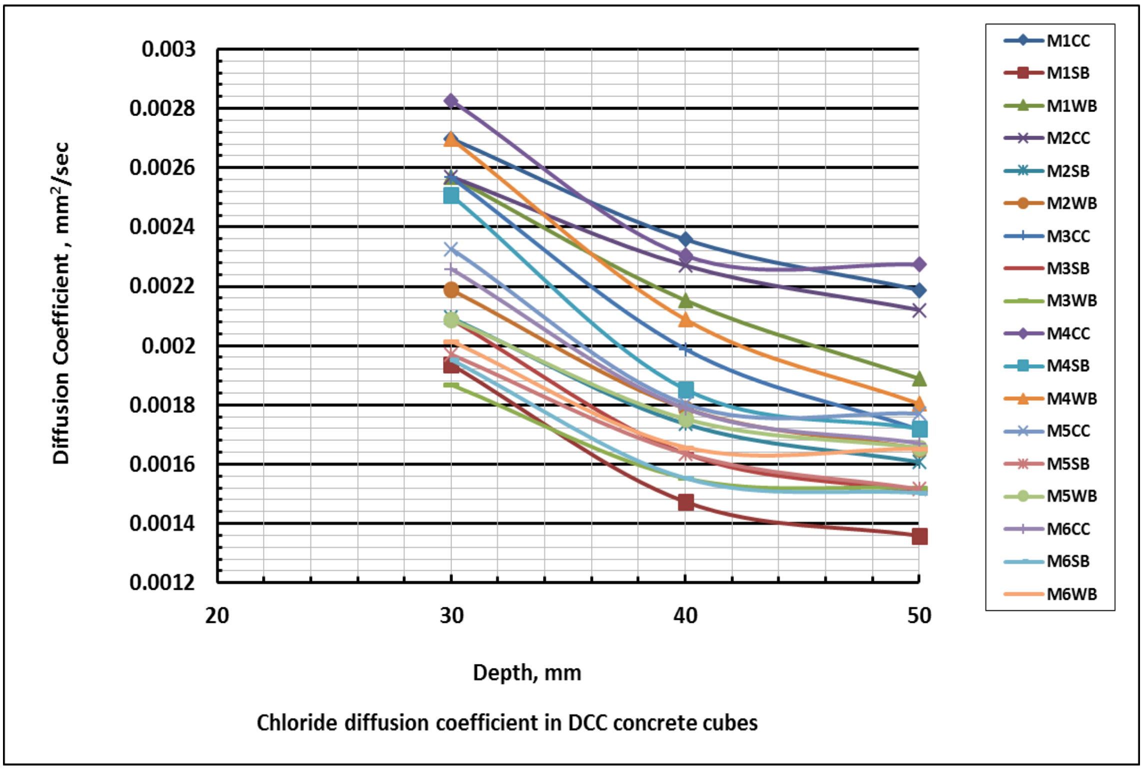


Figure 4-110 Chloride diffusion coefficient in DCC concrete cubes

The variation of chloride diffusion coefficient in PSC concrete cubes in for different mixtures type (M1-M6) is as shown in Figure 4-111. The chloride diffusion coefficient was increase in control concrete cubes as when compared to (SB/WB) impregnation concrete cubes (M1CC-M1SB:24.18%, M2CC-M2SB:30.83%, M3CC-M3SB:18.64%, M1CC-M1WB:20.15%, M2CC-M2WB:31.60%, M3CC-M3WB:23.19%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also increase in control concrete cubes as compared to (SB/WB) impregnation concrete cubes (M4CC-M4SB:20.67%, M5CC-M2SB:13.48%, M6CC-M6SB:20.42%, M4CC-M4WB:20.90%, M5CC-M5WB:10.71%, M6CC-M6WB:12.62%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride diffusion coefficient was increase in water based (WB) impregnation concrete cubes as when compared to solvent-based (SB) impregnation concrete cubes (M1WB-M1SB:5.05%, M2WB-M2SB:1.14%, M3WB-M3SB:5.91%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also increase in water based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:0.28%, M5WB-M2SB:3.10%, M6WB-M6SB:8.93%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. The chloride diffusion coefficient was decrease in solvent based (SB) impregnation concrete cubes as when compared to control concrete cubes (M1SB-M1CC:75.82%, M2SB-M2CC:69.17%, M3SB-M3CC:81.36%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in solvent based (SB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4CC:79.33%, M5SB-M2CC:86.52%, M6SB-M6CC:79.58%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. The chloride diffusion coefficient was decrease in water based (WB) impregnation concrete cubes as when compared to control concrete cubes (M1WB-M1CC:79.85%, M2WB-M2CC:68.40%, M3WB-M3CC:76.81%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in water based (SB) impregnation concrete cubes as compared to control concrete cubes (M4WB-M4CC:79.10%, M5WB-M2CC:89.29%, M6WB-M6CC:87.38%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride diffusion coefficient was decrease in solvent based (SB) impregnation concrete cubes as when compared to water based impregnation (WB) concrete cubes (M1SB-M1WB:95%, M2SB-M2WB:101.10%, M3SB-M3WB:105.90%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in water based (SB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4WB:100.30%, M5SB-M2WB:96.9%, M6SB-M6WB:91.10%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

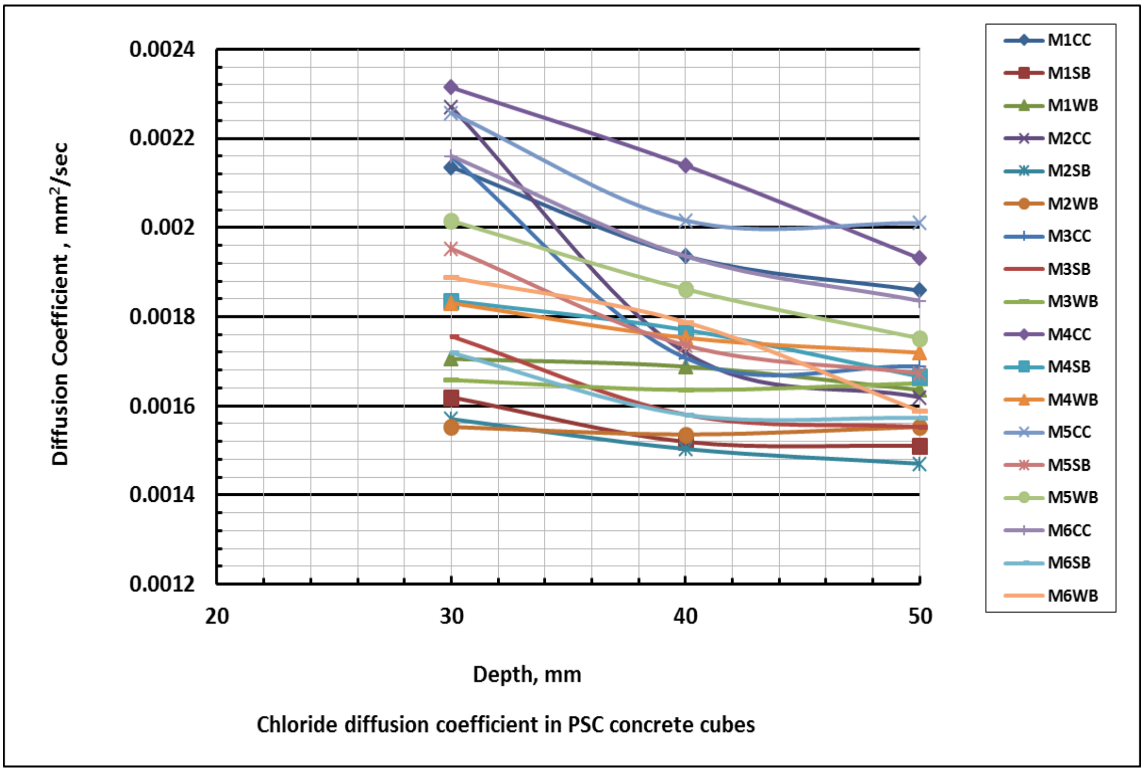


Figure 4-111 Chloride diffusion coefficient in PSC cubes

The variation of chloride diffusion coefficient in FSC concrete cubes in for different mixtures type (M1-M6) is as shown in Figure 4-112. The chloride diffusion coefficient was increase in control concrete cubes as when compared to (SB/WB) impregnation concrete cubes (M1CC-M1SB:1.66%, M2CC-M2SB:5.54%, M3CC-M3SB:6.71%, M1CC-M1WB:1.57%, M2CC-M2WB:1.78%, M3CC-M3WB:4%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also increase in control concrete cubes as compared to (SB/WB) impregnation concrete cubes (M4CC-M4SB:1.07%, M5CC-M2SB:6.41%, M6CC-M6SB:5.50%, M4CC-M4WB:0.32%, M5CC-M5WB:6.71%, M6CC-M6WB:4.88%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride diffusion coefficient was increase in water based (WB) impregnation concrete cubes as when compared to solvent-based (SB) impregnation concrete cubes (M1WB-M1SB:0.10%, M2WB-M2SB:3.82%, M3WB-M3SB:2.82%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also increase in water based (WB) impregnation concrete cubes as compared to solvent-based (SB) impregnation concrete cubes (M4WB-M4SB:0.74%, M5WB-M2SB:0.31%, M6WB-M6SB:0.65%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. The chloride diffusion coefficient was decrease in solvent based (SB) impregnation concrete cubes as when compared to control concrete cubes (M1SB-M1CC:98.34%, M2SB-M2CC:94.46%, M3SB-M3CC:93.29%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in solvent based (SB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4CC:98.93%, M5SB-M2CC:93.59%, M6SB-M6CC:94.50%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. The chloride diffusion coefficient was decrease in water based (WB) impregnation concrete cubes as when compared to control concrete cubes (M1WB-M1CC:98.43%, M2WB-M2CC:98.22%, M3WB-M3CC:96%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in water based (SB) impregnation concrete cubes as compared to control concrete cubes (M4WB-M4CC:99.68%, M5WB-M2CC:93.29%, M6WB-M6CC:96.12%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride diffusion coefficient was decrease in solvent based (SB) impregnation concrete cubes as when compared to water based impregnation (WB) concrete cubes (M1SB-M1WB:99.90%, M2SB-M2WB:96.18%, M3SB-M3WB:97.18%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in water based (SB) impregnation concrete cubes as compared to control concrete cubes (M4SB-M4WB:99.26.30%, M5SB-M2WB:100.31%, M6SB-M6WB:99.35%) for lower compressive strength (25 N/mm^2)and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

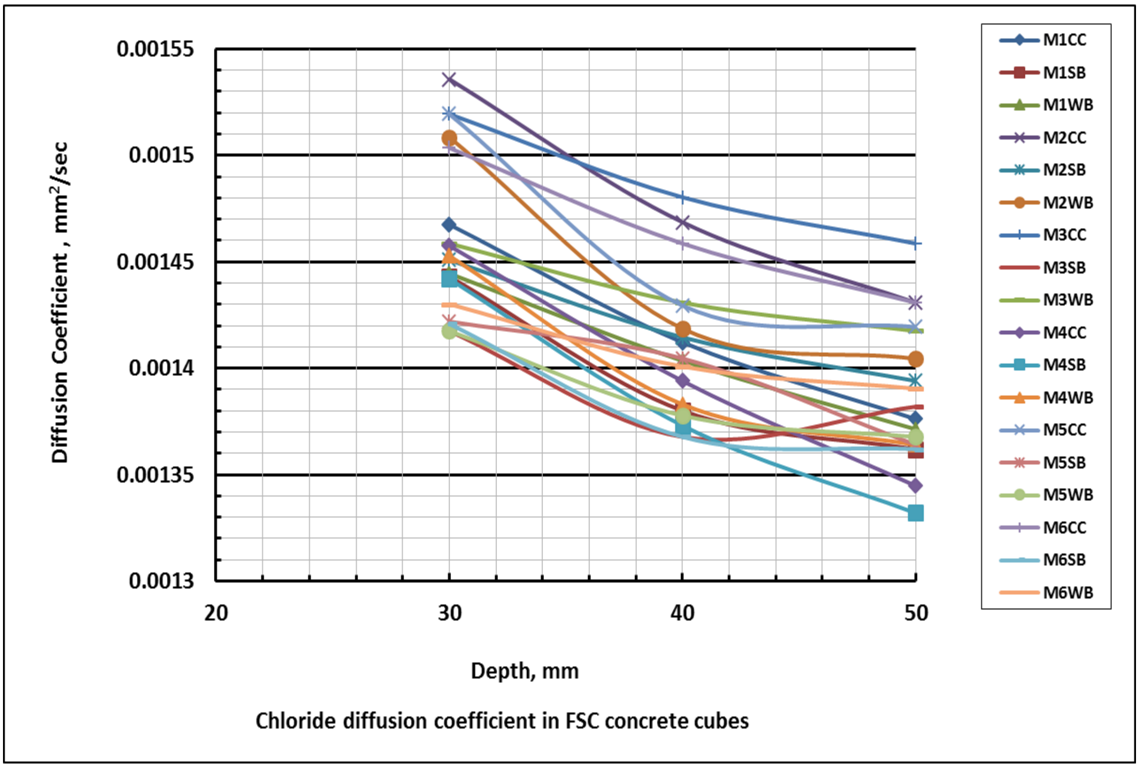
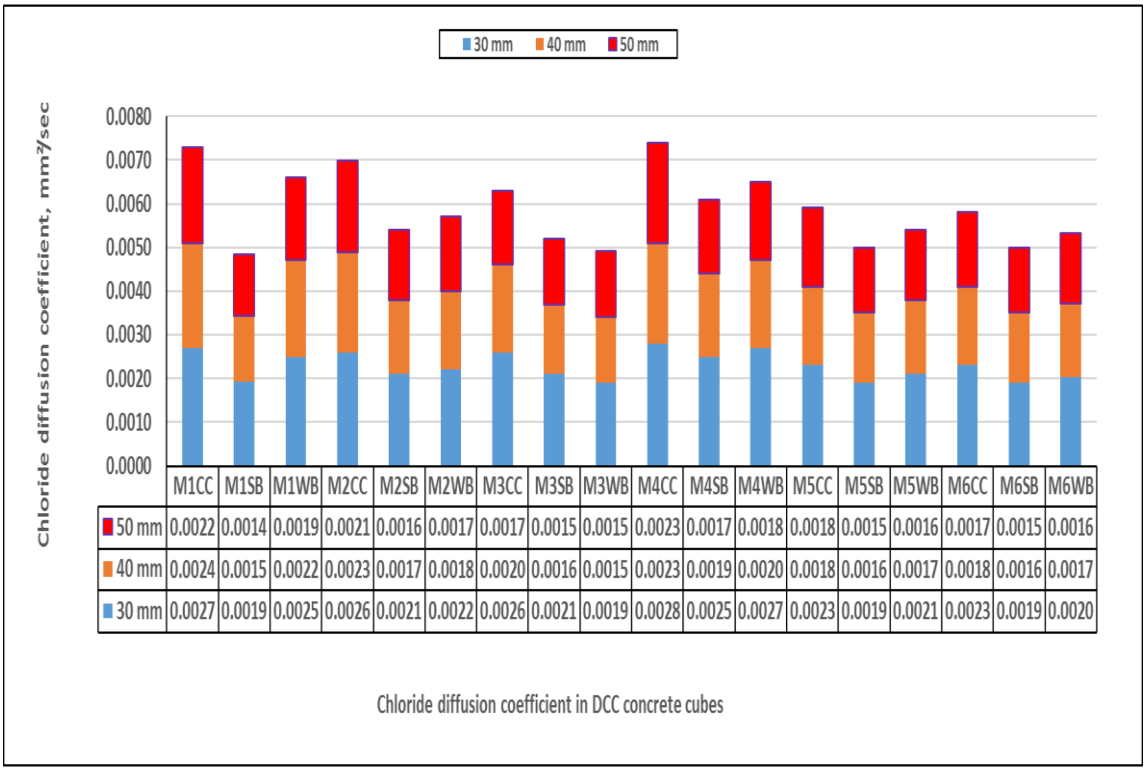


Figure 4-112 Chloride diffusion coefficient in FSC cubes

4.7.2 Comparison of chloride diffusion coefficient in control PCC/IC concrete cubes

The chloride diffusion coefficient was assess in pre-conditioned concrete cubes (DCC/PSC/FSC) at different drill depths (30, 40, and 50) mm for in the case of different control (M1CC-M6CC), and impregnation (M1SB-M6SB, and M1WB-M6WB) concrete cubes as shown in (Figure 4-113, Figure 4-114, and Figure 4-115). The chloride diffusion coefficient was higher in DCC control concrete cubes (M1-0.0024, M2-0.0023, and M3-0.0021) mm^2/sec as against the DCC impregnation concrete cubes (M1SB-0.0016, M2SB-0.0018, and M3SB-0.0017) as well as (M1WB-0.0022, M2WB-0.0019, and M3WB-0.0016) for in the case of higher compressive strength with varied slump values. Chloride diffusion coefficient was also higher in control concrete cubes (M4-0.0025, M5-0.0020, and M6-0.0019) as when compare to an impregnation concrete cubes (M1SB-0.0020, M2SB-0.0017, and M3SB-0.0017) and (M4WB-0.0022, M5WB-0.0018, and M6WB-0.0018) for in the case of varied compressive strength with constant slump values respectively. Chloride diffusion coefficient was higher in PSC control concrete cubes (M1-0.0019, M2-0.0018, and M3-0.0018) mm^2/sec as against the PSC impregnation concrete cubes

(M1SB-0.0015, M2SB-0.0015, and M3SB-0.0016) as well as (M1WB-0.0016, M2WB-0.0015, and M3WB-0.0016) mm^2/sec for in the case of higher compressive strength with varied slump values. Chloride diffusion coefficient was also higher in control concrete cubes (M4-0.0021, M5-0.0021, and M6-0.0019) as when compare to an impregnation concrete cubes (M4SB-0.0017, M5SB-0.0017, and M6SB-0.0016) and (M4WB-0.0018, M5WB-0.0018, and M6WB-0.0017) mm^2/sec for in the case of varied compressive strength with constant slump values respectively.



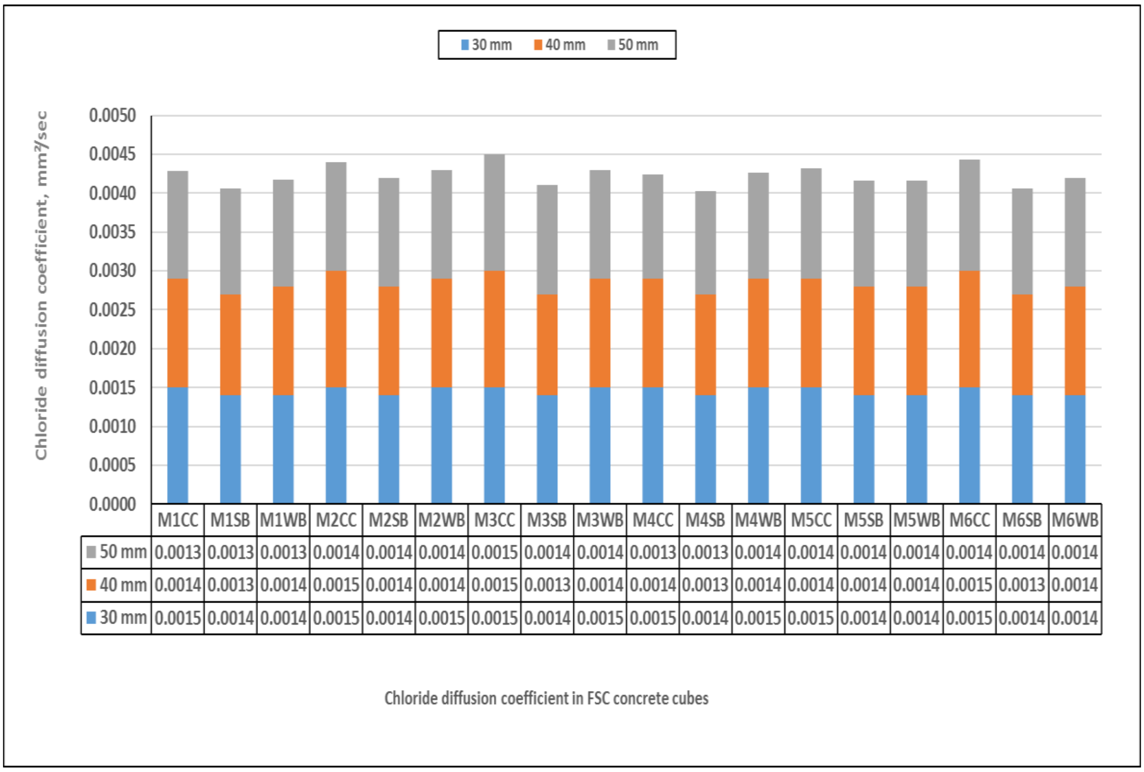
	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
🟥 50 mm	0.0022	0.0014	0.0019	0.0021	0.0016	0.0017	0.0017	0.0015	0.0015	0.0023	0.0017	0.0018	0.0018	0.0015	0.0016	0.0017	0.0015	0.0016
🟧 40 mm	0.0024	0.0015	0.0022	0.0023	0.0017	0.0018	0.0020	0.0016	0.0015	0.0023	0.0019	0.0020	0.0018	0.0016	0.0017	0.0018	0.0016	0.0017
🟦 30 mm	0.0027	0.0019	0.0025	0.0026	0.0021	0.0022	0.0026	0.0021	0.0019	0.0028	0.0025	0.0027	0.0023	0.0019	0.0021	0.0023	0.0019	0.0020

Figure 4-113 Chloride diffusion coefficient in DCC (CC/SB/WB) concrete cubes

	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
🟩 50 mm	0.0018	0.0015	0.0016	0.0016	0.0014	0.0015	0.0016	0.0015	0.0016	0.0019	0.0016	0.0017	0.0020	0.0016	0.0017	0.0018	0.0015	0.0016
🟧 40 mm	0.0019	0.0015	0.0016	0.0017	0.0015	0.0015	0.0017	0.0015	0.0016	0.0021	0.0017	0.0018	0.0020	0.0017	0.0018	0.0019	0.0015	0.0017
🟨 30 mm	0.0021	0.0016	0.0017	0.0022	0.0015	0.0016	0.0022	0.0017	0.0017	0.0023	0.0018	0.0018	0.0023	0.0019	0.0020	0.0021	0.0017	0.0018

Figure 4-114 Chloride diffusion coefficient in PSC (CC/SB/WB) concrete cubes

Chloride diffusion coefficient was higher in FSC control concrete cubes (M1-0.0014, M2-0.0015, and M3-0.0015) mm^2/sec as against the FSC impregnation concrete cubes (M1SB-0.0014, M2SB-0.0014, and M3SB-0.0014) as well as (M1WB-0.0014, M2WB-0.0015, and M3WB-0.0014) mm^2/sec for in the case of higher compressive strength with varied slump values. Chloride diffusion coefficient was also higher in control concrete cubes (M4-0.0014, M5-0.0014, and M6-0.0015) as when compare to an impregnation concrete cubes (M4SB-0.0013, M5SB-0.0014, and M6SB-0.0014) and (M4WB-0.0014, M5WB-0.0013, and M6WB-0.0014) mm^2/sec for in the case of varied compressive strength with constant slump values respectively.



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
50 mm	0.0013	0.0013	0.0013	0.0014	0.0014	0.0014	0.0015	0.0014	0.0014	0.0013	0.0013	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014
40 mm	0.0014	0.0013	0.0014	0.0015	0.0014	0.0014	0.0015	0.0013	0.0014	0.0014	0.0013	0.0014	0.0014	0.0014	0.0014	0.0015	0.0013	0.0014
30 mm	0.0015	0.0014	0.0014	0.0015	0.0014	0.0015	0.0015	0.0014	0.0015	0.0015	0.0014	0.0015	0.0015	0.0014	0.0014	0.0015	0.0014	0.0014

Figure 4-115 Chloride diffusion coefficient in FSC (CC/SB/WB) concrete cubes

It is possible to determine the variations in the (DCC/PSC/FSC) chloride diffusion coefficient at different drill depths (30, 40, and 50 mm) and compare chloride diffusion coefficient increase at different drill depths (30-40) mm, (30-50) mm, as well as (40-50) mm as shown in (

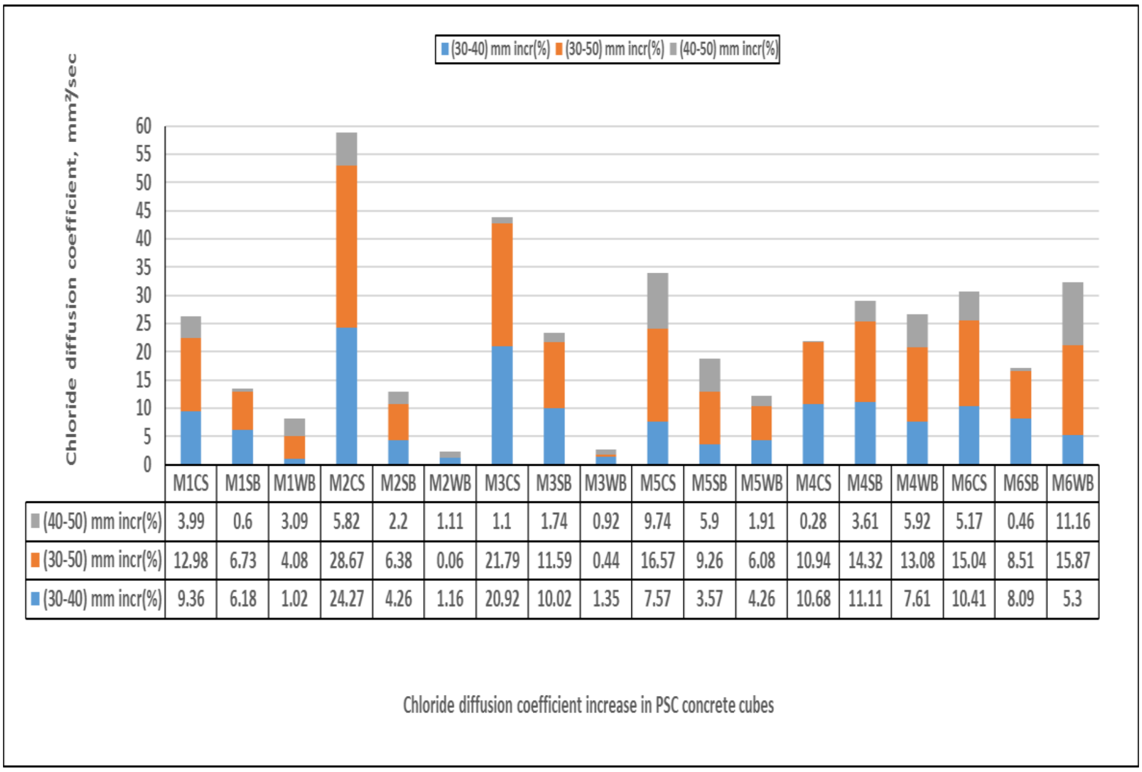
Figure *4-116*,

Figure *4-117*, and

Figure *4-118*). In the DCC, concrete cubes that, the chloride diffusion coefficient was to be more as when compare to the PSC and FCC conditioned concrete cubes.

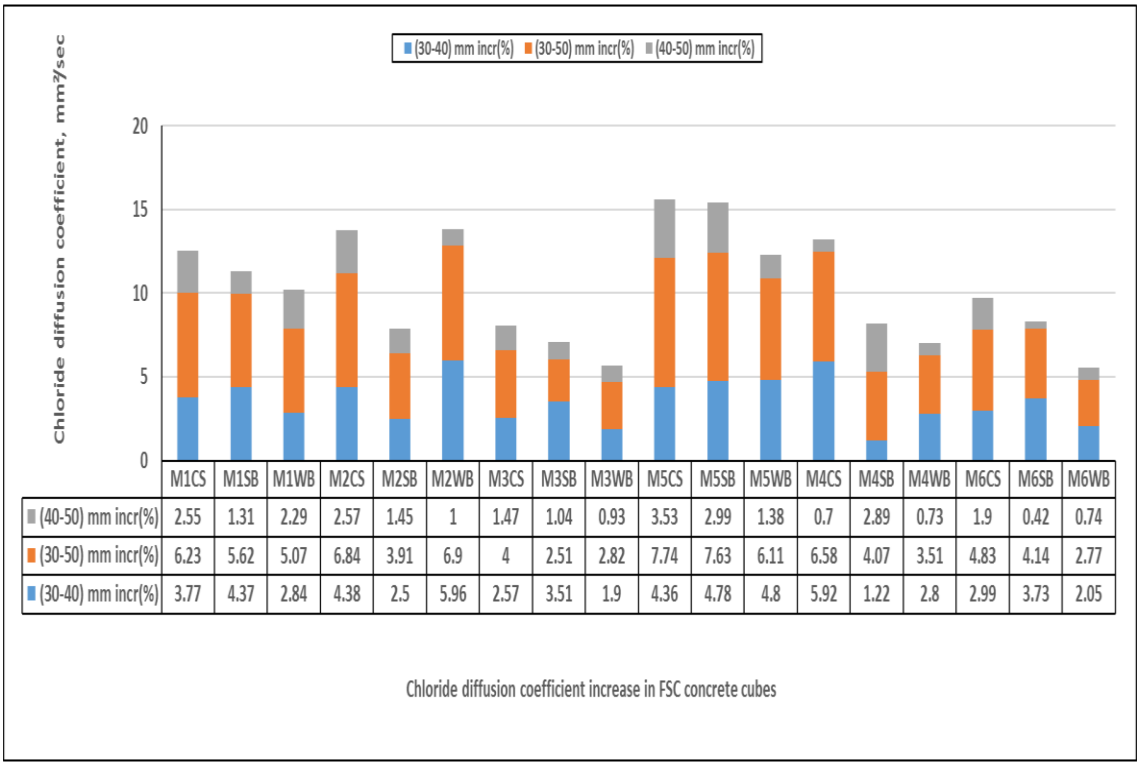
	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
🟨 (40-50) mm incr(%)	7.23	7.77	12.28	6.61	7.4	7.57	13.68	7.95	2.15	1.32	7.2	13.65	1.84	7.34	5.56	6.61	3.22	0.31
🟧 (30-50) mm incr(%)	18.92	29.82	26.53	17.51	23.23	24.48	33.16	27.9	18.66	19.59	31.42	33.14	23.91	23.07	20.74	26.05	23.04	18.05
🟩 (30-40) mm incr(%)	12.6	23.9	16.24	11.67	17.1	18.3	22.57	21.67	16.87	18.51	26.1	22.58	22.49	16.98	16.07	20.82	20.48	17.79

Figure 4-116 Chloride diffusion coefficient in DCC (CS/SB/WB) concrete cubes



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
⬜ (40-50) mm incr(%)	3.99	0.6	3.09	5.82	2.2	1.11	1.1	1.74	0.92	9.74	5.9	1.91	0.28	3.61	5.92	5.17	0.46	11.16
🟧 (30-50) mm incr(%)	12.98	6.73	4.08	28.67	6.38	0.06	21.79	11.59	0.44	16.57	9.26	6.08	10.94	14.32	13.08	15.04	8.51	15.87
🟦 (30-40) mm incr(%)	9.36	6.18	1.02	24.27	4.26	1.16	20.92	10.02	1.35	7.57	3.57	4.26	10.68	11.11	7.61	10.41	8.09	5.3

Figure 4-117 Chloride diffusion coefficient in PSC (CS/SB/WB) concrete cubes



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
(40-50) mm incr(%)	2.55	1.31	2.29	2.57	1.45	1	1.47	1.04	0.93	3.53	2.99	1.38	0.7	2.89	0.73	1.9	0.42	0.74
(30-50) mm incr(%)	6.23	5.62	5.07	6.84	3.91	6.9	4	2.51	2.82	7.74	7.63	6.11	6.58	4.07	3.51	4.83	4.14	2.77
(30-40) mm incr(%)	3.77	4.37	2.84	4.38	2.5	5.96	2.57	3.51	1.9	4.36	4.78	4.8	5.92	1.22	2.8	2.99	3.73	2.05

Figure 4-118 Chloride diffusion coefficient in FSC (CS/SB/WB) concrete cubes

Chloride diffusion coefficient was increase in DCC impregnation concrete cubes (M1WB-M6WB) as when compare to the impregnation concrete cubes (M1SB-M6SB) as shown in (

Figure *4-119*). Chloride diffusion coefficient (average) was increase for in the case of impregnation DCC impregnation concrete cubes (M1WB-M1SB-28.11%, M2WB-M2SB-3.33%, and M3WB-M3SB-6.02%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) increase for in the case of impregnation concrete cubes (M4WB-M4SB-7.67%, M5WB-M5SB-6.92%, and M6SB-M6WB-6.14%) with varied compressive strength and constant slump values (10-30) mm.

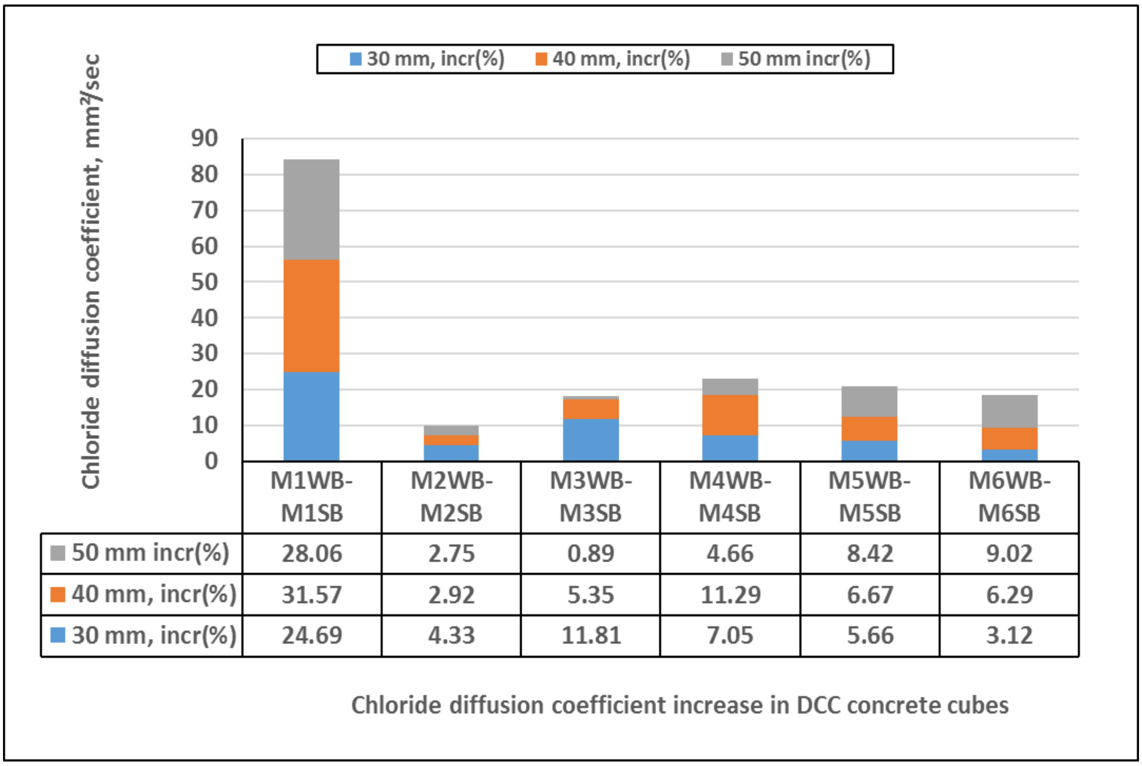
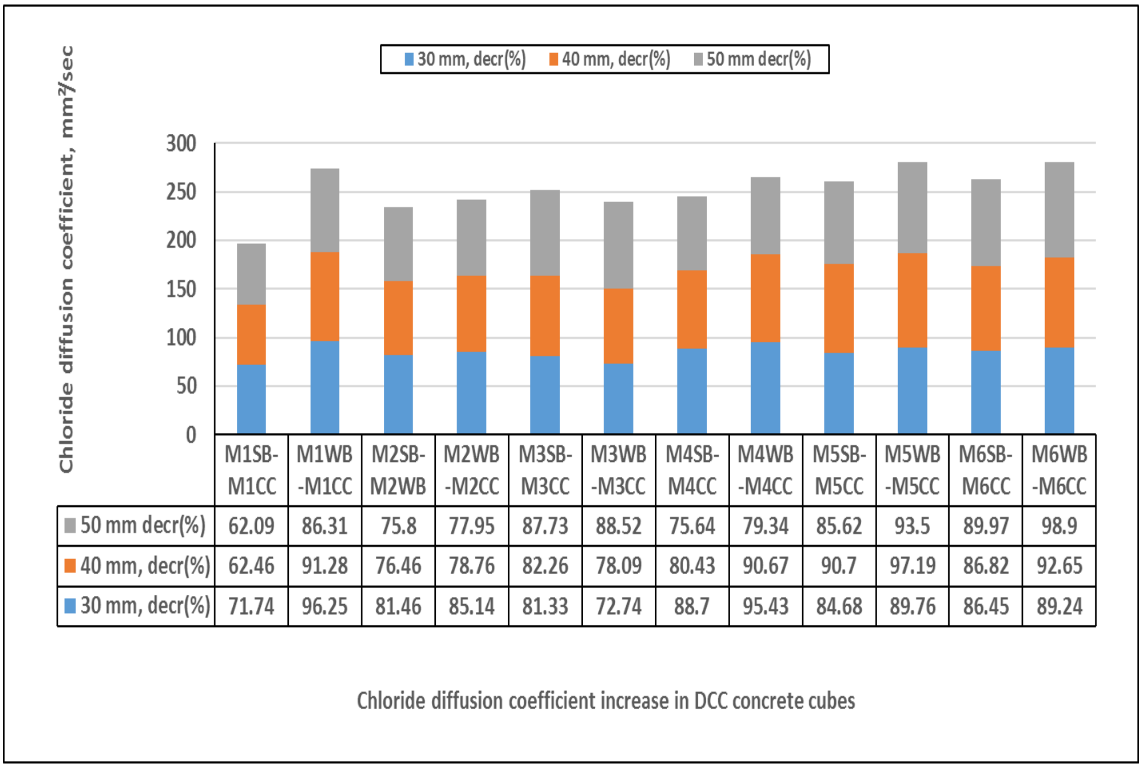


Figure 4-119 Chloride diffusion coefficient in DCC (WB/SB) concrete cubes

Chloride diffusion coefficient was decrease in DCC impregnation concrete cubes (M1SB-M6SB, and M1WB-M6WB) as when compare to the control concrete cubes (M1CC-M6CC) at different drill depths as shown in (

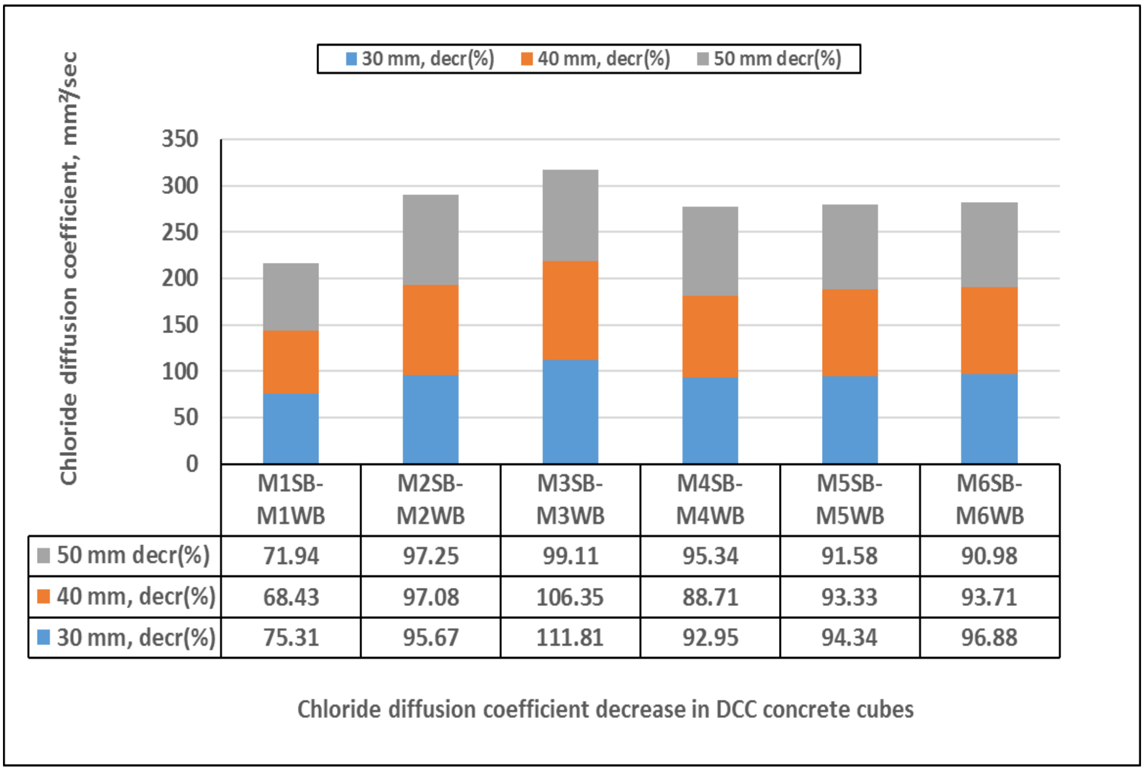
Figure *4-120*). Chloride diffusion coefficient (average) was decrease for in the case of impregnation DCC concrete cubes as when compare to control concrete cubes (M1SB-M1CC-65.43%, M2SB-M2CC-77.91%, and M3SB-M3CC-83.77%) and (M1WB-M1CC-91.28%, M2WB-M2CC-80.62%, and M3WB-M3CC-79.78%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) decrease for in the case of control concrete cubes as against impregnation concrete cubes (M4SB-M4CC-81.59%, M5SB-M5CC-87%, and M6SB-M6CC-87.75%) as well as (M4WB-M4CC-88.48%, M5WB-M5CC-93.48%, and M6WB-M6CC-93.60%) with varied compressive strength and constant slump values (10-30) mm respectively.



	M1SB-M1CC	M1WB-M1CC	M2SB-M2WB	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC
■ 50 mm decr(%)	62.09	86.31	75.8	77.95	87.73	88.52	75.64	79.34	85.62	93.5	89.97	98.9
■ 40 mm, decr(%)	62.46	91.28	76.46	78.76	82.26	78.09	80.43	90.67	90.7	97.19	86.82	92.65
■ 30 mm, decr(%)	71.74	96.25	81.46	85.14	81.33	72.74	88.7	95.43	84.68	89.76	86.45	89.24

Figure 4-120 Chloride diffusion coefficient in DCC (SB/CC) cubes

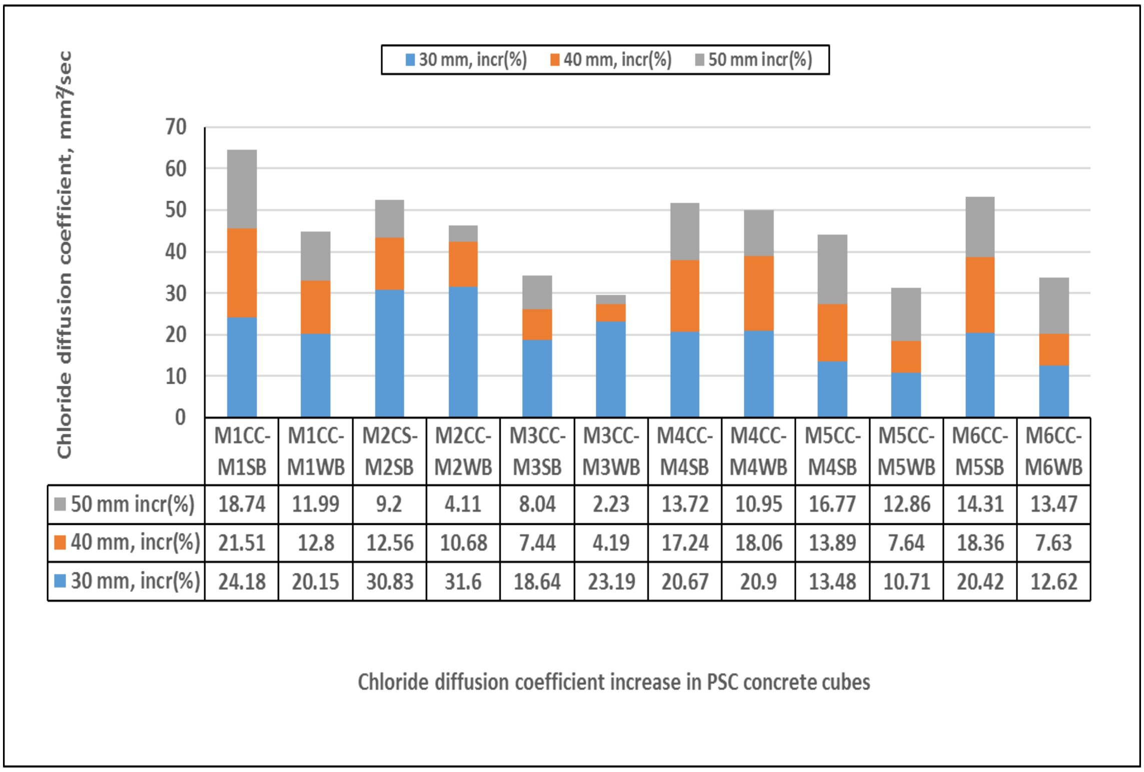
Chloride diffusion coefficient was decrease in DCC impregnation concrete cubes (M1SB-M6SB) as when compare to the control concrete cubes (M1WB-M6WB) at different drill depths as shown in (Figure 4-121). As observe from the results that, the chloride diffusion coefficient (average) was decrease for in the case of impregnation DCC concrete cubes (M1SB-M1WB-71.89%, M2SB-M2WB-96.67%, and M3SB-M3WB-105.76%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) decrease for in the case of impregnation concrete cubes (M4SB-M4WB-92.33%, M5SB-M5WB-93.08%, and M6SB-M6WB-93.86%) with varied compressive strength and constant slump values (10-30) mm.



	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M4SB-M4WB	M5SB-M5WB	M6SB-M6WB
50 mm decr(%)	71.94	97.25	99.11	95.34	91.58	90.98
40 mm, decr(%)	68.43	97.08	106.35	88.71	93.33	93.71
30 mm, decr(%)	75.31	95.67	111.81	92.95	94.34	96.88

Figure 4-121 Chloride diffusion coefficient in DCC (SB/WB) concrete cubes

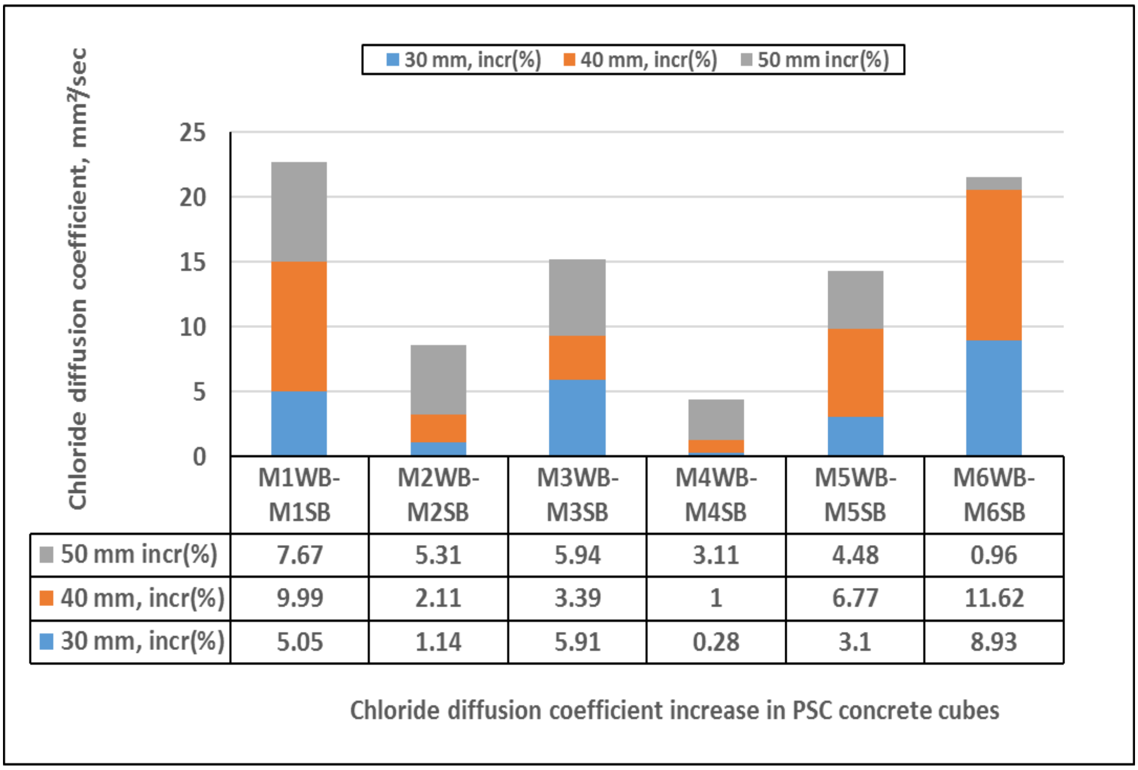
Chloride diffusion coefficient was increase in PSC control concrete cubes (M1CC-M6CC) as when compare to the impregnation concrete cubes (M1SB-M6SB, and M1WB-M6WB) at different drill depths as shown in (Figure 4-122). Chloride diffusion coefficient (average) was increase for in the case of control PSC concrete cubes as when compare to impregnation concrete cubes (M1CC-M1SB-21.48%, M2CC-M2SB-17.53%, and M3CC-M3SB-11.37%) and (M1CC-M1WB-14.98%, M2CC-M2WB-15.46%, and M3CC-M3WB-9.87%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Chloride diffusion coefficient (average) was increase for in the case of PSC control concrete cubes as against impregnation concrete cubes (M4CC-M4SB-17.21%, M5CC-M5SB-14.71%, and M6CC-M6SB-17.70%) as well as (M4CC-M4WB-16.64%, M5CC-M5WB-10.40%, and M6CC-M6WB-11.24%) with varied compressive strength and constant slump values (10-30) mm.



	M1CC-M1SB	M1CC-M1WB	M2CS-M2SB	M2CC-M2WB	M3CC-M3SB	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M4SB	M5CC-M5WB	M6CC-M5SB	M6CC-M6WB
50 mm incr(%)	18.74	11.99	9.2	4.11	8.04	2.23	13.72	10.95	16.77	12.86	14.31	13.47
40 mm, incr(%)	21.51	12.8	12.56	10.68	7.44	4.19	17.24	18.06	13.89	7.64	18.36	7.63
30 mm, incr(%)	24.18	20.15	30.83	31.6	18.64	23.19	20.67	20.9	13.48	10.71	20.42	12.62

Figure 4-122 Chloride diffusion coefficient in PSC (CC/SB) concrete cubes

Chloride diffusion coefficient was increase in PSC impregnation concrete cubes (M1WB-M6WB) as when compare to the impregnation concrete cubes (M1SB-M6SB) at different drill depths as shown in (Figure 4-123).

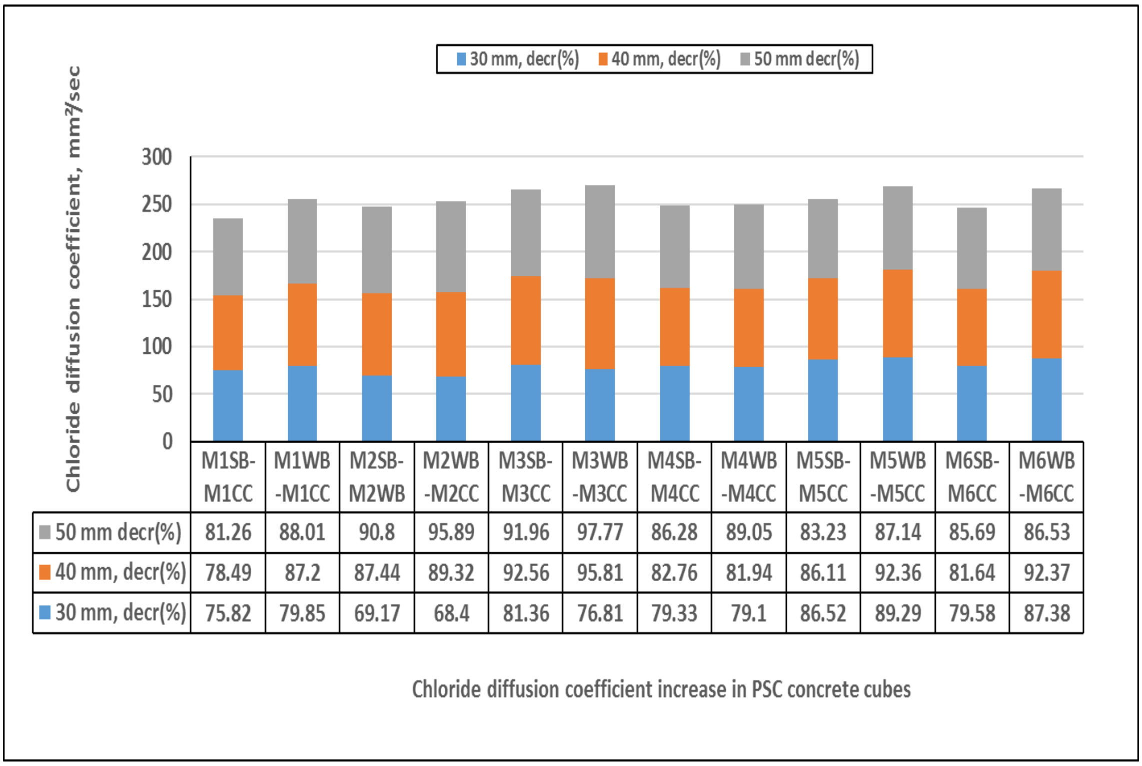


	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
50 mm incr(%)	7.67	5.31	5.94	3.11	4.48	0.96
40 mm, incr(%)	9.99	2.11	3.39	1	6.77	11.62
30 mm, incr(%)	5.05	1.14	5.91	0.28	3.1	8.93

Figure 4-123 Chloride diffusion coefficient in PSC (WB/SB) concrete cubes

As observe from the (Figure *4-123*), the chloride diffusion coefficient (average) was increase for in the case of impregnation PSC concrete cubes (M1WB-M1SB-7.57%, M2WB-M2SB-2.85%, and M3WB-M3SB-5.08%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) increase for in the case of impregnation concrete cubes (M4WB-M4SB-1.46%, M5WB-M5SB-4.78%, and M6WB-M6SB-7.17%) with varied compressive strength and constant slump values (10-30) mm.

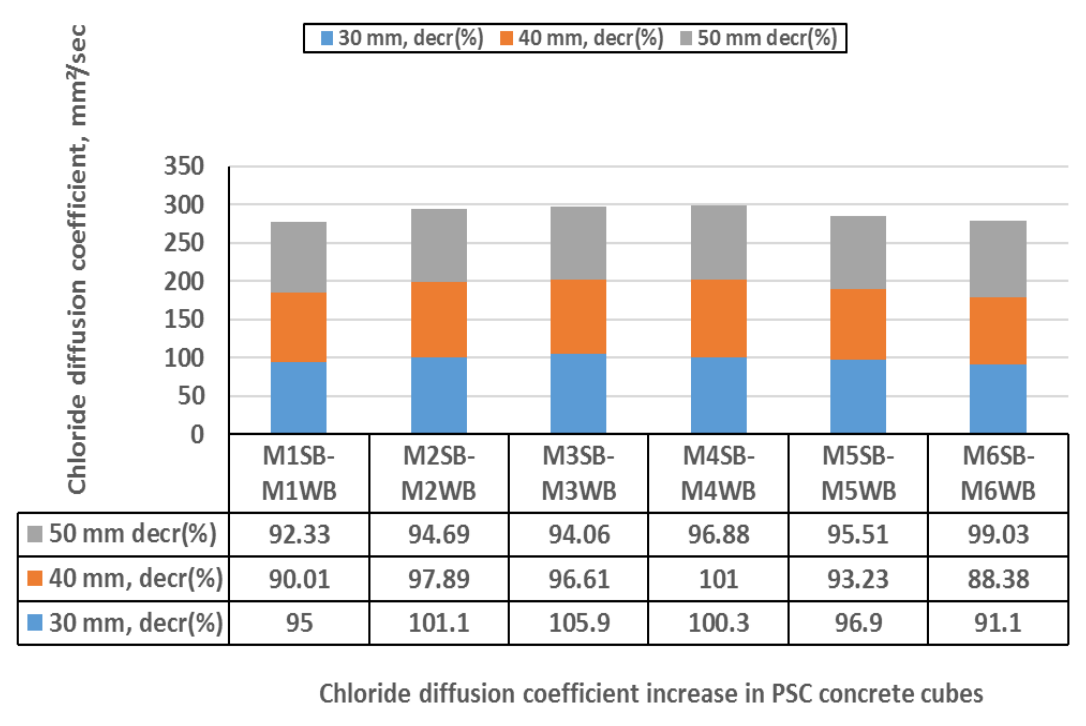
Chloride diffusion coefficient was decrease in PSC impregnation concrete cubes (M1SB-M6SB) as when compare to the control as well as impregnation concrete cubes (M1CC-M6CC), and (M1WB-M6WB) at different drill depths (30, 40, and 40) mm as shown in (Figure 4-124). Chloride diffusion coefficient (average) was decrease for in the case of impregnation concrete cubes as when compare to control PSC concrete cubes (M1SB-M1CC-78.52%, M2SB-M2CC-82.47%, and M3SB-M3CC-88.63%) and (M1WB-M1CC-85.02%, M2WB-M2CC-84.54%, and M3WB-M3CC-90.13%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) also decrease for in the case of impregnation concrete cubes as against control concrete cubes (M4SB-M4CC-82.79%, M5SB-M5CC-85.29%, and M6SB-M6CC-82.30%) as well as (M4WB-M4CC-83.36%, M5WB-M5CC-89.60%, and M6WB-M6CC-88.76%) with varied compressive strength and constant slump values (10-30) mm. It’s also confirm from results that, the chloride diffusion coefficient was decrease in PSC impregnation concrete cubes (M1SB-M6SB) as when compare to the impregnation concrete cubes (M1WB-M6WB) as shown in (Figure 4-125).



	M1SB-M1CC	M1WB-M1CC	M2SB-M2WB	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC
■ 50 mm decr(%)	81.26	88.01	90.8	95.89	91.96	97.77	86.28	89.05	83.23	87.14	85.69	86.53
■ 40 mm, decr(%)	78.49	87.2	87.44	89.32	92.56	95.81	82.76	81.94	86.11	92.36	81.64	92.37
■ 30 mm, decr(%)	75.82	79.85	69.17	68.4	81.36	76.81	79.33	79.1	86.52	89.29	79.58	87.38

Figure 4-124 Chloride diffusion coefficient in PSC (SB/WB/CC) cubes

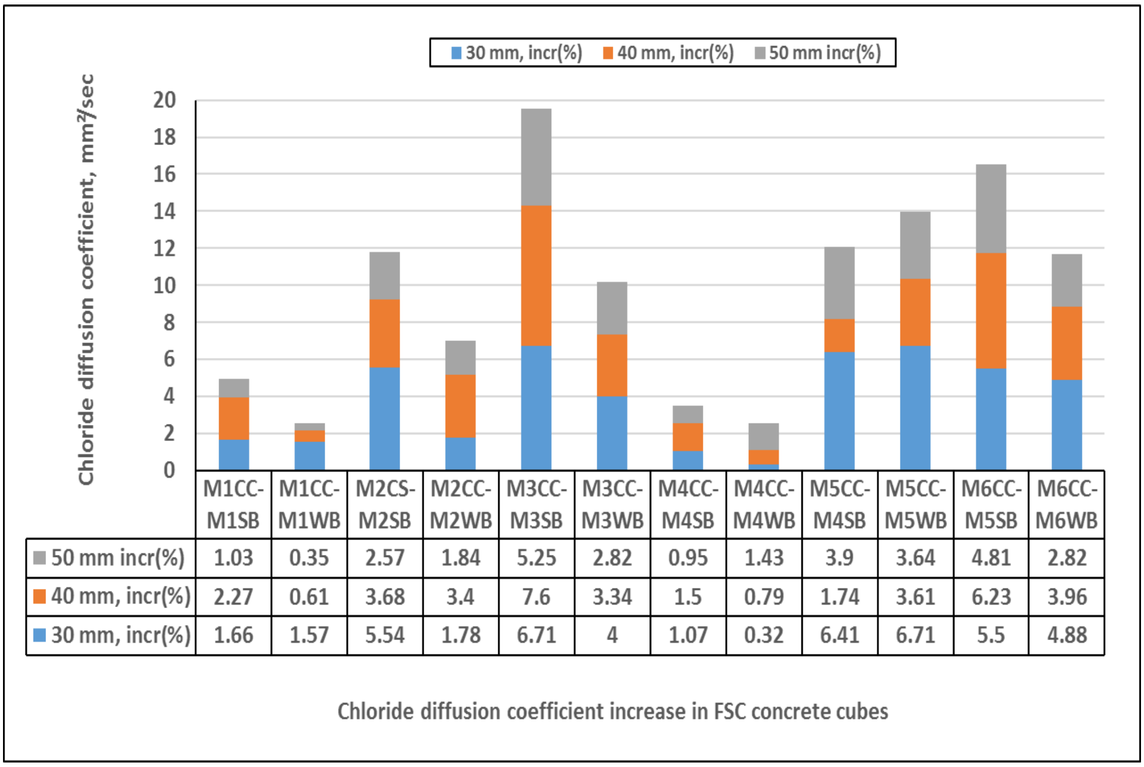
Chloride diffusion coefficient (average) was decrease for in the case of impregnation PSC concrete cubes (M1SB-M1WB-92.45%, M2SB-M2WB-97.89%, and M3SB-M3WB-98.86%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) also decrease for in the case of impregnation concrete cubes (M4SB-M4WB-99.39%, M5SB-M5WB-95.21%, and M6SB-M6WB-92.84%) with varied compressive strength and constant slump values (10-30) mm.



	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M4SB-M4WB	M5SB-M5WB	M6SB-M6WB
⬜ 50 mm decr(%)	92.33	94.69	94.06	96.88	95.51	99.03
🟧 40 mm, decr(%)	90.01	97.89	96.61	101	93.23	88.38
🟦 30 mm, decr(%)	95	101.1	105.9	100.3	96.9	91.1

Figure 4-125 Chloride diffusion coefficient in PSC (SB/WB) concrete cubes

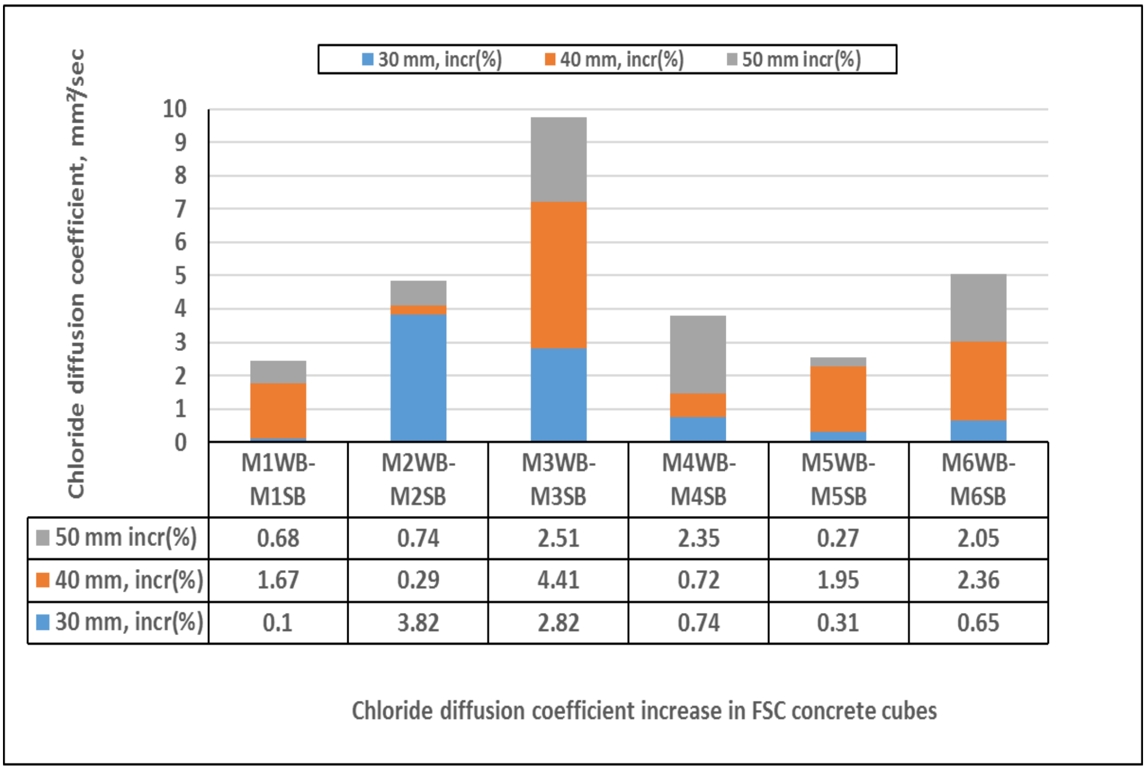
Its confirm from results that, the chloride diffusion coefficient was increase in FSC control concrete cubes (M1CC-M6CC) as when compare to the impregnation concrete cubes (M1SB-M6SB, and M1WB-M6WB) as shown in (Figure 4-126). Chloride diffusion coefficient (average) was increase for in the case of control concrete cubes as when compare to an impregnation FSC concrete cubes (M1CC-M1SB-1.65%, M2CC-M2SB-3.93%, and M3CC-M3SB-6.52%) and (M1CC-M1WB-0.84%, M2CC-M2WB-2.34%, and M3CC-M3WB-3.39%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) also increase for in the case of control concrete cubes as against impregnation concrete cubes (M4CC-M4SB-1.17%, M5CC-M5SB-4.02%, and M6CC-M6SB-5.51%) as well as (M4CC-M4WB-0.85%, M5CC-M5WB-4.65%, and M6CC-M6WB-3.89%) with varied compressive strength and constant slump values (10-30) mm. It’s also increase in the FSC impregnation concrete cubes (M1WB-M6WB) as when compare to the impregnation concrete cubes (M1SB-M6SB) as shown in (Figure 4-127).



	M1CC-M1SB	M1CC-M1WB	M2CS-M2SB	M2CC-M2WB	M3CC-M3SB	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M4SB	M5CC-M5WB	M6CC-M5SB	M6CC-M6WB
▨ 50 mm incr(%)	1.03	0.35	2.57	1.84	5.25	2.82	0.95	1.43	3.9	3.64	4.81	2.82
🟧 40 mm, incr(%)	2.27	0.61	3.68	3.4	7.6	3.34	1.5	0.79	1.74	3.61	6.23	3.96
🟦 30 mm, incr(%)	1.66	1.57	5.54	1.78	6.71	4	1.07	0.32	6.41	6.71	5.5	4.88

Figure 4-126 Chloride diffusion coefficient in FSC (CC/SB/WB) concrete cubes

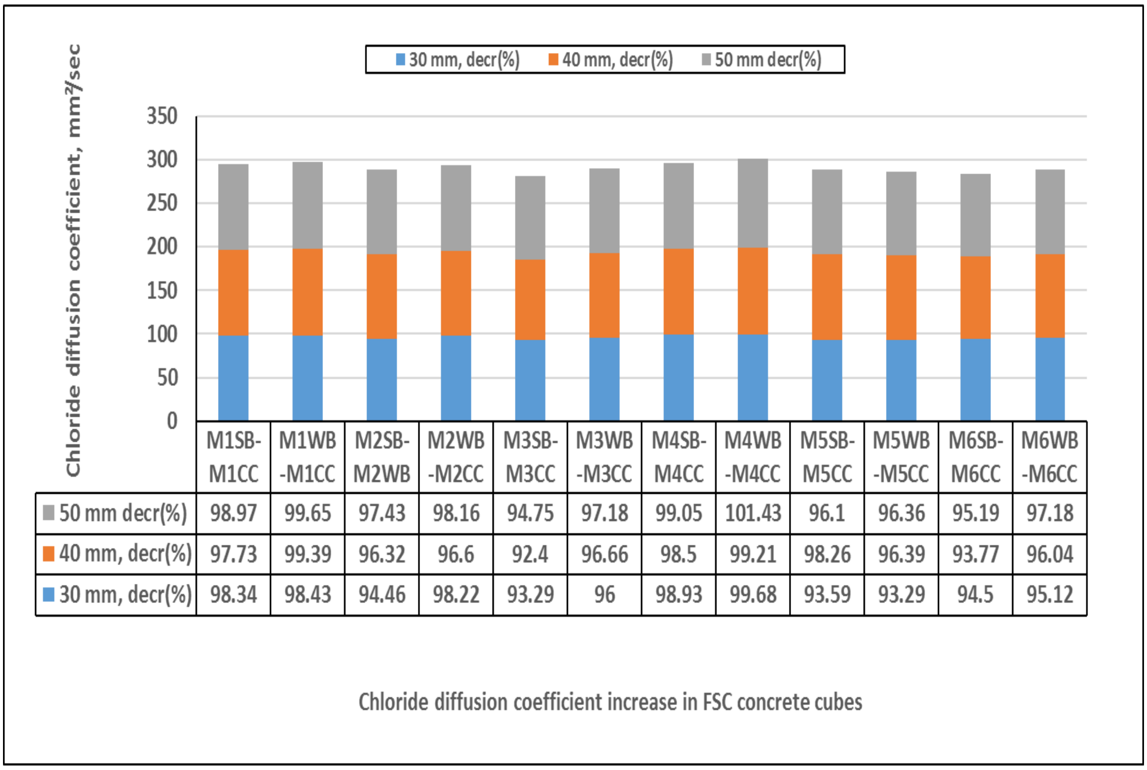
Chloride diffusion coefficient (average) was increase for in the case of impregnation FSC concrete cubes (M1WB-M1SB-0.82%, M2WB-M2SB-1.62%, and M3WB-M3SB-3.25%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Its (average) increase for in the case of impregnation concrete cubes (M4WB-M4SB-1.27%, M5WB-M5SB-0.84%, and M6WB-M6SB-1.69%) with varied compressive strength and constant slump values (10-30) mm.



	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
■ 50 mm incr(%)	0.68	0.74	2.51	2.35	0.27	2.05
■ 40 mm, incr(%)	1.67	0.29	4.41	0.72	1.95	2.36
■ 30 mm, incr(%)	0.1	3.82	2.82	0.74	0.31	0.65

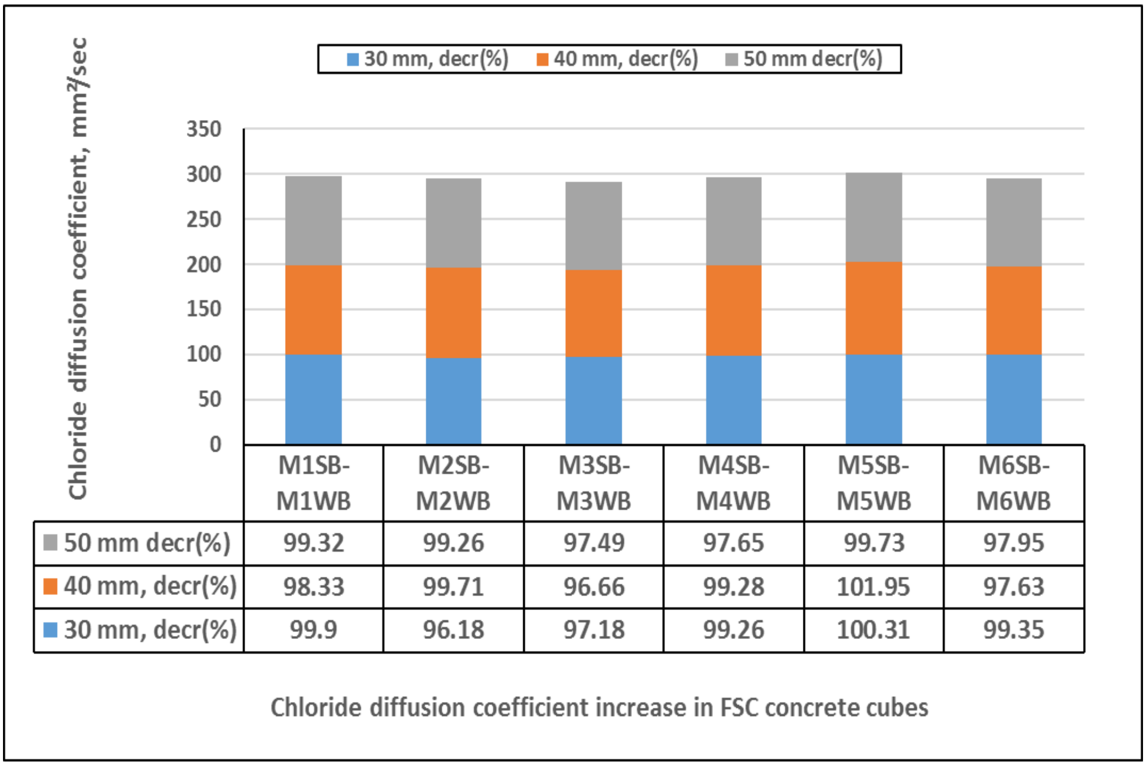
Figure 4-127 Chloride diffusion coefficient in FSC (WB/SB) concrete cubes

Chloride diffusion coefficient was decrease in the FSC impregnation concrete cubes (M1SB-M6SB, and M1WB-M6WB) as when compare to the control concrete cubes (M1CC-M6CC) as shown in (Figure 4-128). Chloride diffusion coefficient (average) was decrease in the range for in the case impregnation concrete cubes (M1SB-M1CC-98.35%, M2SB-M2CC-98.35%, and M3SB-M3CC-98.35%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Chloride diffusion coefficient (average) was also decrease in the range for in the case impregnation concrete cubes (M4SB-M4CC-98.83%., M5SB-M5CC-98.98%, and M6SB-M6CC-94.49%) with varied compressive strength and constant slump values (10-30) mm. As observe from the (Figure 4-129) that, the chloride diffusion coefficient was predominantly decrease in the FSC impregnation concrete cubes (M1SB-M6SB) as when compare to the impregnation concrete cubes (M1WB-M6WB). Chloride diffusion coefficient (average) was decrease in the range for in the case of impregnation FSC concrete cubes (M1SB-M1WB-98.18%., M2SB-M2WB-98.38%, and M3SB-M3WB-97.11%) with higher compressive strength and varied slump values (0-10, 10-30, 60-180 mm). Chloride diffusion coefficient (average) was also decrease in the range for in the case impregnation concrete cubes (M4SB-M4WB-98.73%., M5SB-M5WB-100.66%, and M6SB-M6WB-98.31%) with varied compressive strength and constant slump values (10-30) mm.



	M1SB-M1CC	M1WB-M1CC	M2SB-M2WB	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC
▨ 50 mm decr(%)	98.97	99.65	97.43	98.16	94.75	97.18	99.05	101.43	96.1	96.36	95.19	97.18
■ 40 mm, decr(%)	97.73	99.39	96.32	96.6	92.4	96.66	98.5	99.21	98.26	96.39	93.77	96.04
■ 30 mm, decr(%)	98.34	98.43	94.46	98.22	93.29	96	98.93	99.68	93.59	93.29	94.5	95.12

Figure 4-128 Chloride diffusion coefficient in FSC (SB/WB/CC) concrete cubes



	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M4SB-M4WB	M5SB-M5WB	M6SB-M6WB
▨ 50 mm decr(%)	99.32	99.26	97.49	97.65	99.73	97.95
■ 40 mm, decr(%)	98.33	99.71	96.66	99.28	101.95	97.63
■ 30 mm, decr(%)	99.9	96.18	97.18	99.26	100.31	99.35

Figure 4-129 Chloride diffusion coefficient in FSC (SB/WB) concrete cubes

The variation of chloride diffusion coefficient in solvent based and water based impregnation concrete cubes were interpreted in pre-conditions such as dry/partially/fully saturated condition as shown (Figure 4-130, Figure 4-131, and Figure 4-132). In which, the average chloride diffusion coefficient in DCC solvent based impregnation was more decreased as when compared to water based impregnation concrete cubes at different drill depths (30-50) mm with higher compressive strength and varied slump value for in case of designed mixture type (M1-M3). Whereas the average chloride diffusion coefficient in DCC solvent based impregnation concrete cubes was predominantly decreased as when compared to water based impregnation concrete cubes with lower compressive strength and constant slump value and goes on reduced in chloride diffusion coefficient value with increased compressive strength for in case of mixtures type (M4-M6).

The average chloride diffusion coefficient in PSC solvent based impregnation was more decreased as when compared to water based impregnation concrete cubes at different drill depths (30-50) mm with higher compressive strength and varied slump value for in case of designed mixture type (M1-M3). Whereas the average chloride diffusion coefficient in PSC solvent based impregnation concrete cubes was lesser decreased as when compared to water based impregnation concrete cubes with lower compressive strength and constant slump value and goes on increased in chloride diffusion coefficient reduction value with increased compressive strength for in case of mixture type (M4-M6). Similary the average chloride diffusion coefficient in FSC solvent based impregnation was predominantly lesser decreased as when compared to water based impregnation concrete cubes at different drill depths (30-50) mm with higher compressive strength and varied slump value for in case of designed mixture type (M1-M3). Whereas the average chloride diffusion coefficient in FSC solvent based impregnation concrete cubes was somewhat increased as when compared to water based impregnation concrete cubes with lower compressive strength and constant slump value and goes on reduced/increased in chloride diffusion coefficient value with increased compressive strength for in case of mixtures type (M4-M6). Thus the average chloride diffusion coefficient in DCC solvent-based impregnation concrete cubes was more decreased as when compared to water based impregnation concrete cubes as when compared to PSC and FSC concrete cubes diffusion coefficient for in case of designed mixtures type(M1-M6).

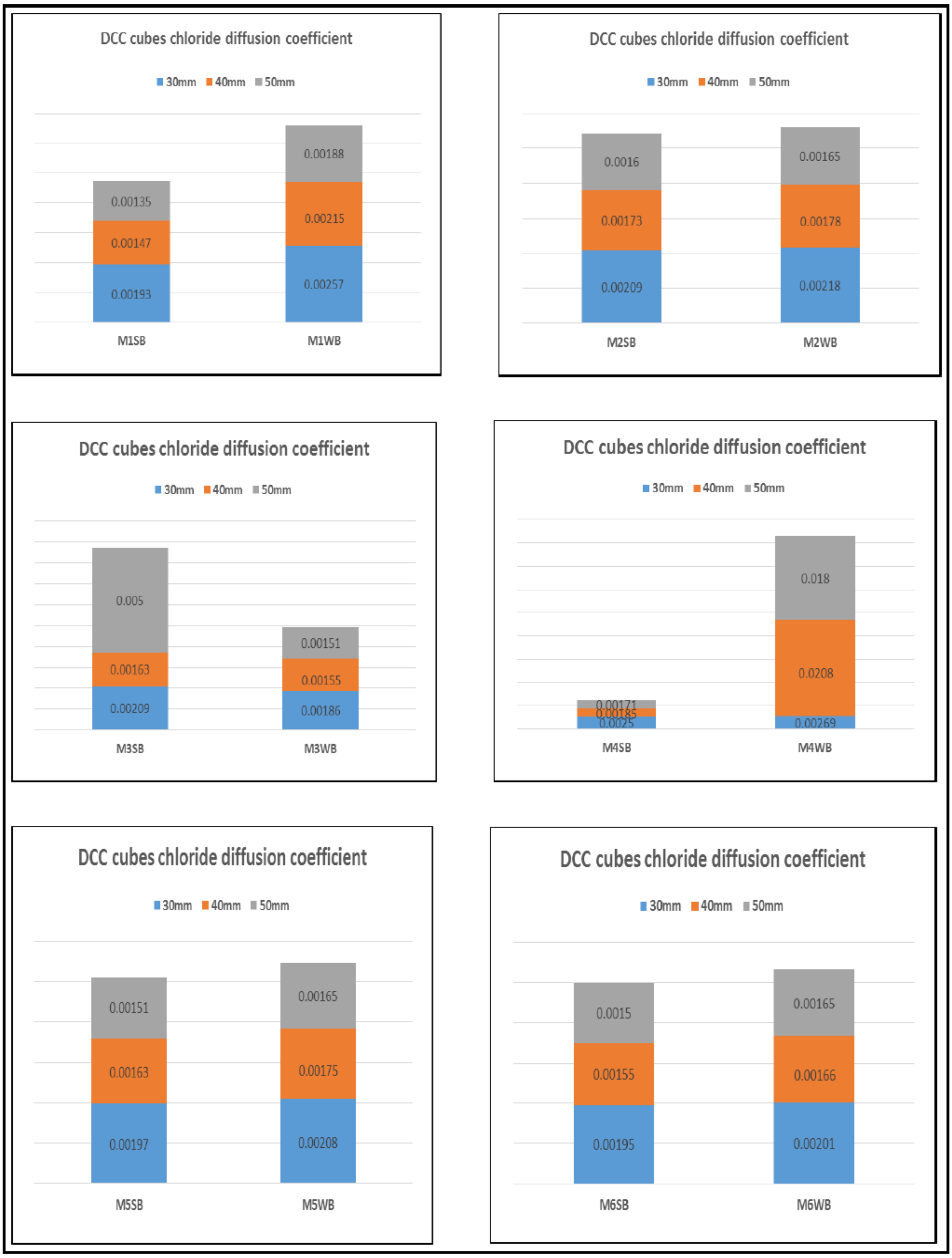


Figure 4-130 Chloride diffusion coefficient in DCC (SB/WB) concrete cubes

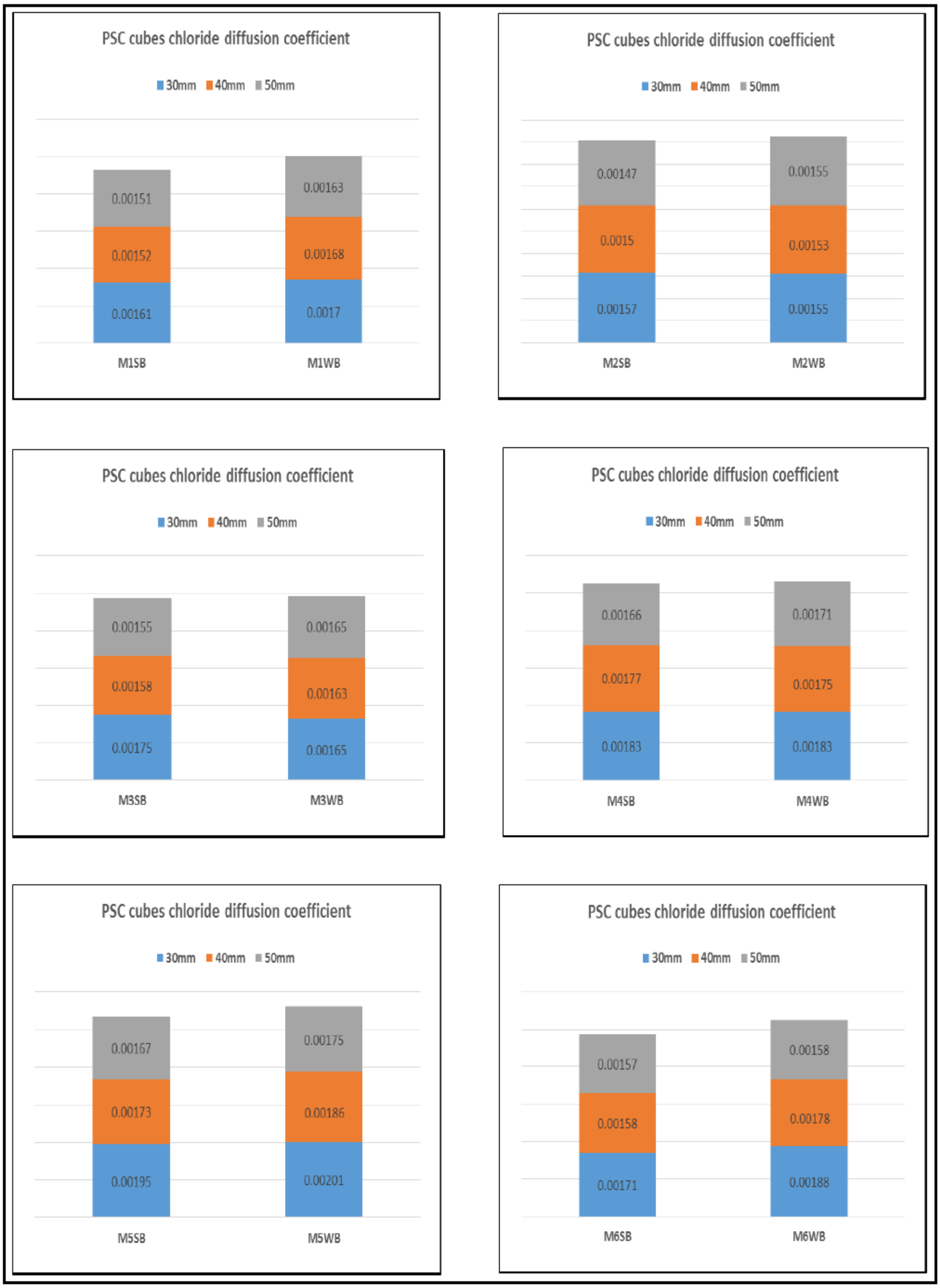


Figure 4-131 Chloride diffusion coefficient in PSC (SB/WB) concrete cubes

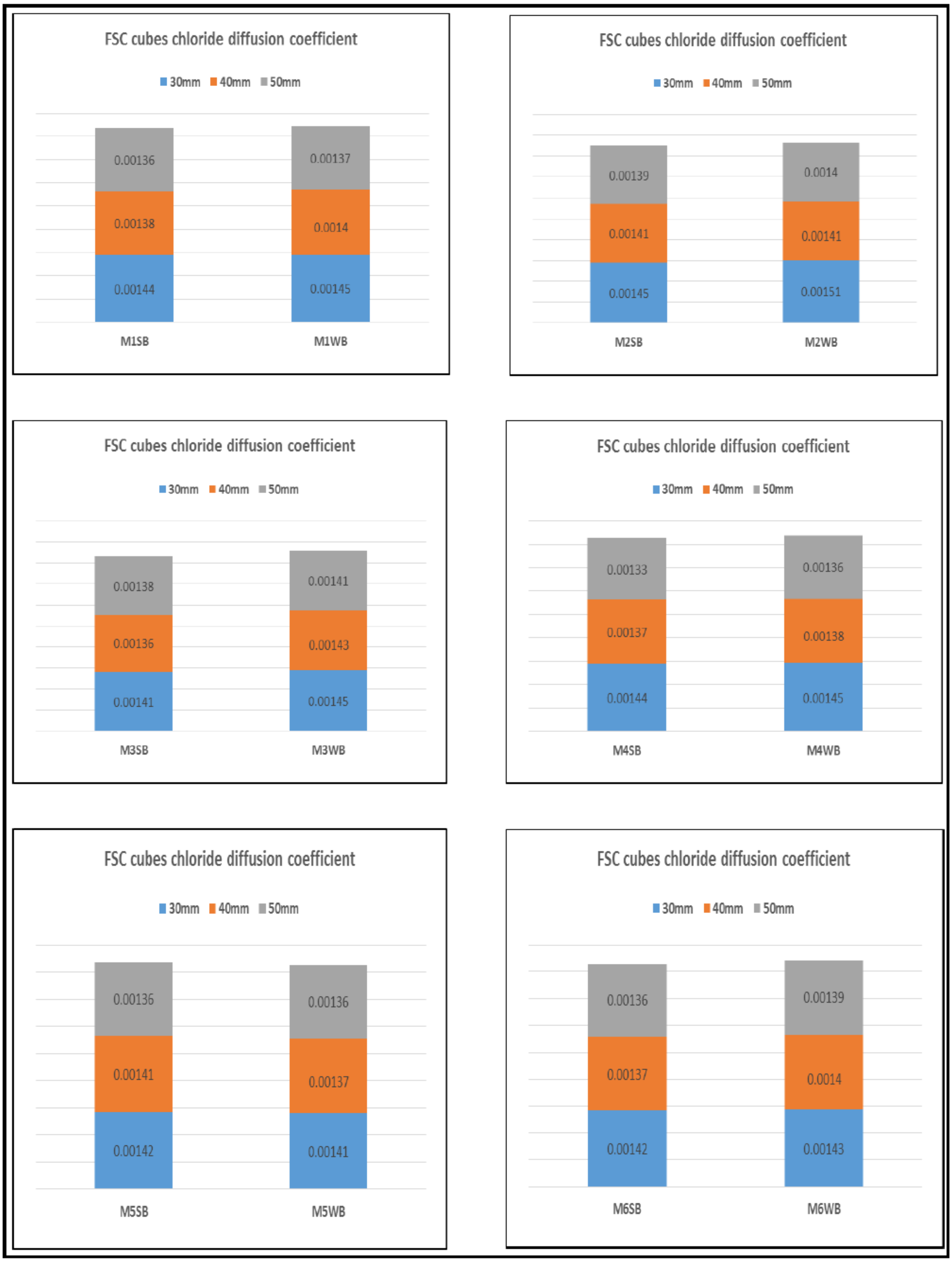


Figure 4-132 Chloride diffusion coefficient in FSC (SB/WB) concrete cubes

4.8 Chloride diffusion coefficient in concrete slabs

4.8.1 Chloride diffusion coefficient in control/IC concrete slabs

The variation of chloride diffusion coefficient in DCC/PSC/FSC concrete slabs for different mixtures type (M1-M2) is as shown in (Figure 4-133, Figure 4-134, and Figure 4-135). Chloride diffusion coefficient was increase in control concrete slabs as compared to (SB/WB) impregnation concrete slabs, (M1CS-M1SB:6.75%, M2CS-M2SB:6.60%, M1CS-M1WB:4.08%, M2CS-M2WB:4.23%) for in the case of constant higher compressive strength and varied slump value at different drill depth respectively. Chloride diffusion coefficient was also increase in control PSC concrete slabs as compared to solvent-based (SB)/water based (WB) impregnation concrete slabs (M3CS-M3SB:4.62%, M5CS-M5SB:5%, M3CS-M3WB:1.65%, M5CS-M5WB:4.73%) for lower compressive strength and constant slump value. Whereas the chloride diffusion coefficient was also increase in control FSC concrete slabs as compared to solvent-based (SB)/water based (WB) impregnation concrete slabs (M4CS-M4SB:12.70%, M6CS-M6SB:10.78%, M4CS-M4WB:10.83%, M4CS-M6WB:8.19%) for higher compressive strength and constant slump value.

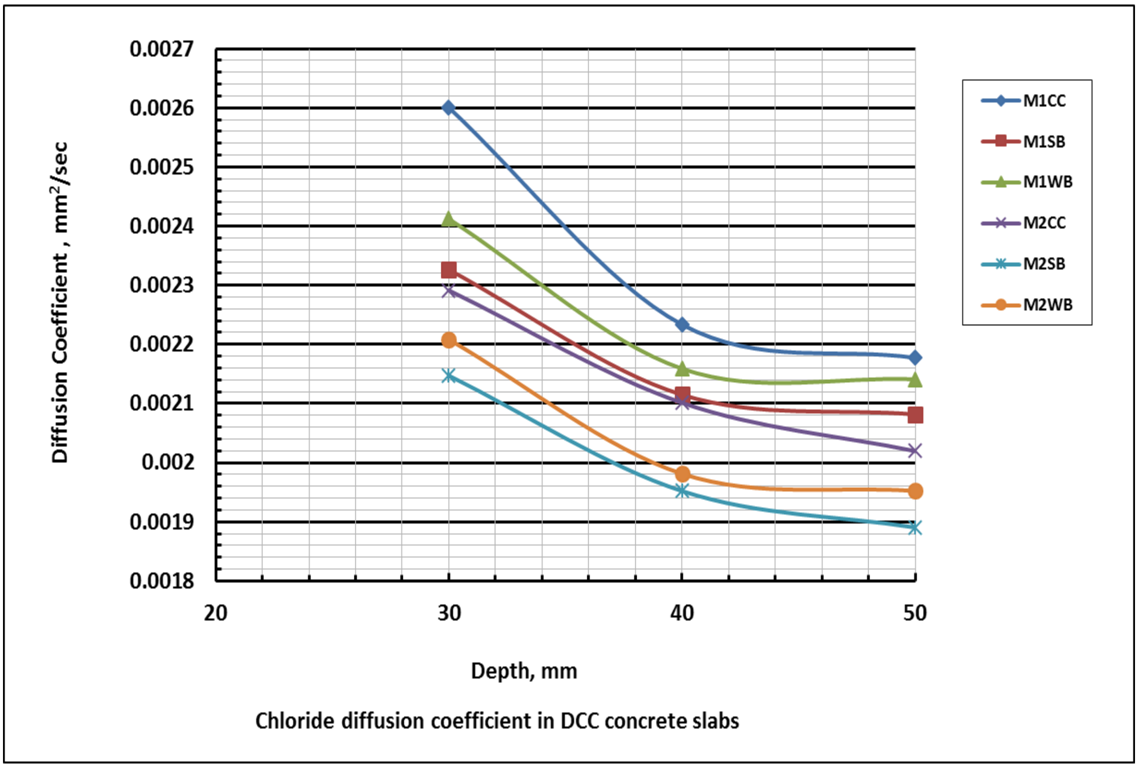


Figure 4-133 Chloride diffusion coefficient in DCC concrete slabs

The chloride diffusion coefficient was increase in DCC water based (WB) impregnation concrete slabs as when compared to DCC solvent-based (SB) impregnation concrete slabs (M1WB-M1SB:2.79%, M2WB-M2SB:2.46%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm) at different drill depth respectively. Chloride diffusion coefficient was also increase in PSC water based (WB) impregnation concrete slabs as compared to PSC solvent-based (SB) impregnation concrete slabs (M3WB-M3SB:3.07%, M5WB-M5SB:2.50%) for lower compressive strength (30 N/mm^2) and constant slump value (10-30 mm). Chloride diffusion coefficient was also increase (M4WB-M4SB:5.01%, M6WB-M6SB:2.76% in the FSC impregnation concrete slabs (WB) as when compare to an impregnation concrete cubes (SB) for in the case of higher compressive strength.

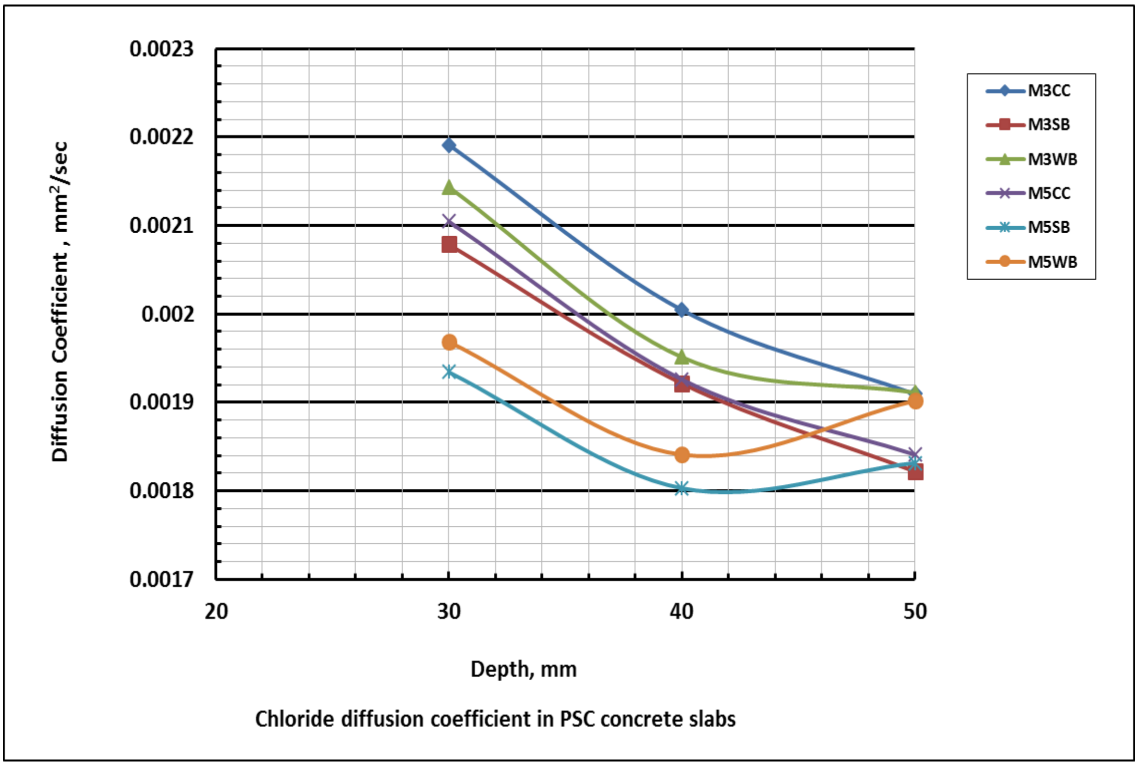


Figure 4-134 Chloride diffusion coefficient in PSC concrete slabs

The chloride diffusion coefficient was decrease in DCC solvent based (SB) impregnation concrete slabs as when compared to control DCC concrete slabs (M1SB-M1CS:93.25%, M2SB-M2CS:93.40%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm) at different drill depths respectively. Chloride diffusion coefficient was also decrease in PSC solvent based (SB) impregnation concrete slabs as compared to PSC control concrete slabs (M3SB-M3CS:95.38%, M5SB-M5CC:95%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Whereas the chloride diffusion coefficient was also decrease in the FSC solvent based impregnation concrete slabs (M4SB-M4CS:87.30%, M6SB-M6CC:89.22%) as against the FSC control concrete slabs.

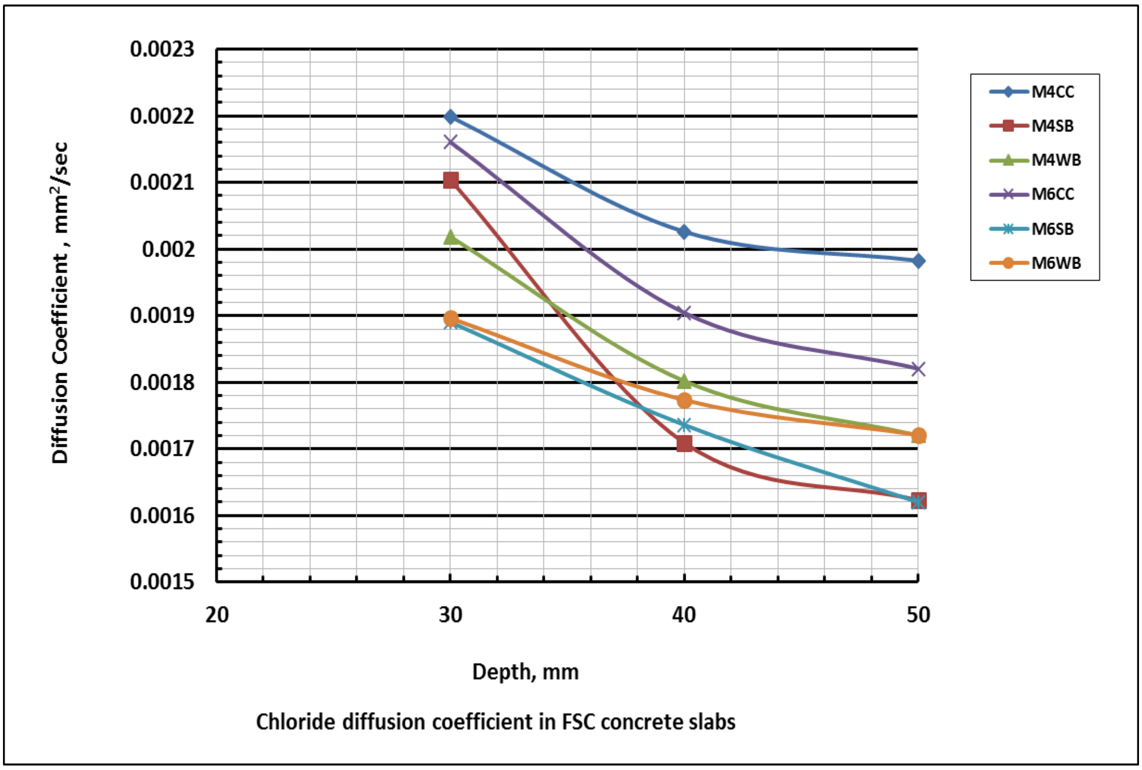


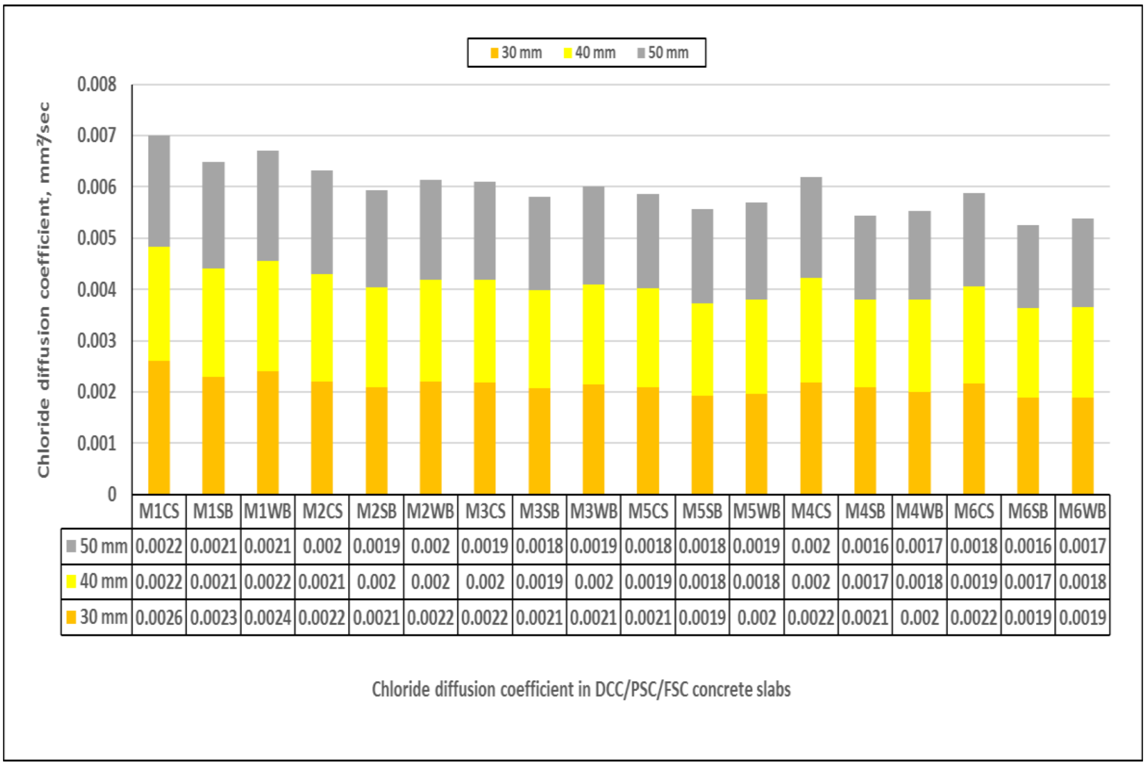
Figure 4-135 Chloride diffusion coefficient in FSC concrete slabs

The chloride diffusion coefficient was decrease in DCC water based (WB) impregnation concrete slabs as when compared to DCC control concrete slabs (M1WB-M1CS:95.92%, M2WB-M2CS:95.77%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, 10-30 mm, and 60-180 mm) at drill depth (30 mm) respectively. Chloride diffusion coefficient was also decrease in PSC water based (WB) impregnation concrete slabs as compared to PSC control concrete slabs (M3WB-M3CS:98.41%, M5WB-M5CS:97.47%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Chloride diffusion coefficient was also decrease in FSC water based (WB) impregnation concrete slabs as compared to FSC control concrete slabs (M4WB-M4CS:89.17%, M6WB-M6CS:91.81%) for lower compressive strength (25 N/mm^2) and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively.

The chloride diffusion coefficient was decrease in DCC solvent based (SB) impregnation concrete slabs as when compared to DCC water based impregnation (WB) concrete slabs (M1SB-M1WB:97.21%, M2SB-M2WB:97.54%) for in case of constant higher compressive strength (40 N/mm^2) and varied slump value (0-10 mm, and 10-30 mm) at different drill depths respectively. Chloride diffusion coefficient was also decrease in PSC solvent based (SB) impregnation concrete slabs as compared to PSC control concrete slabs (M3SB-M3WB:96.93%, M5SB-M5WB:97.36%,) for lower compressive strength and constant slump value (10-30 mm) and goes on decreases with increased compressive strength (30-40 N/mm^2) respectively. Chloride diffusion coefficient was also decrease in FSC solvent based (SB) impregnation concrete slabs as compared to FSC control concrete slabs (M4SB-M4WB:97.81%, M6SB-M6WB:97.24%,) for higher compressive strength (40 N/mm^2) and constant slump value (10-30 mm) respectively.

4.8.2 Comparison of chloride diffusion coefficient in control/IC concrete slabs

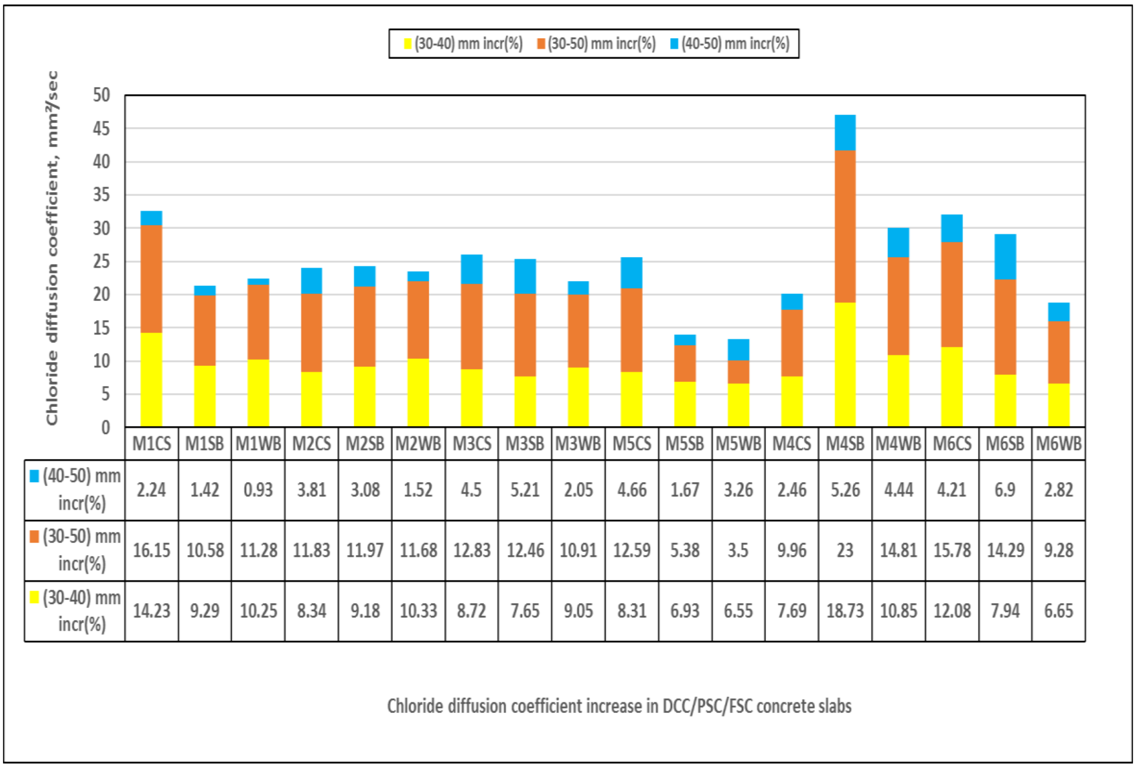
The chloride diffusion coefficient was interpret in pre-conditioned concrete slabs (DCC/PSC/FSC) at different drill depths (30, 40, and 50) mm for in the case of different control (M1CC-M6CC), and impregnation (M1SB-M6SB, and M1WB-M6WB) concrete slabs as shown in (Figure 4-136).



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
■ 50 mm	0.0022	0.0021	0.0021	0.002	0.0019	0.002	0.0019	0.0018	0.0019	0.0018	0.0018	0.0019	0.002	0.0016	0.0017	0.0018	0.0016	0.0017
■ 40 mm	0.0022	0.0021	0.0022	0.0021	0.002	0.002	0.002	0.0019	0.002	0.0019	0.0018	0.0018	0.002	0.0017	0.0018	0.0019	0.0017	0.0018
■ 30 mm	0.0026	0.0023	0.0024	0.0022	0.0021	0.0022	0.0022	0.0021	0.0021	0.0021	0.0019	0.002	0.0022	0.0021	0.002	0.0022	0.0019	0.0019

Figure 4-136 Chloride diffusion coefficient in PCC (CS/SB/WB) concrete slabs

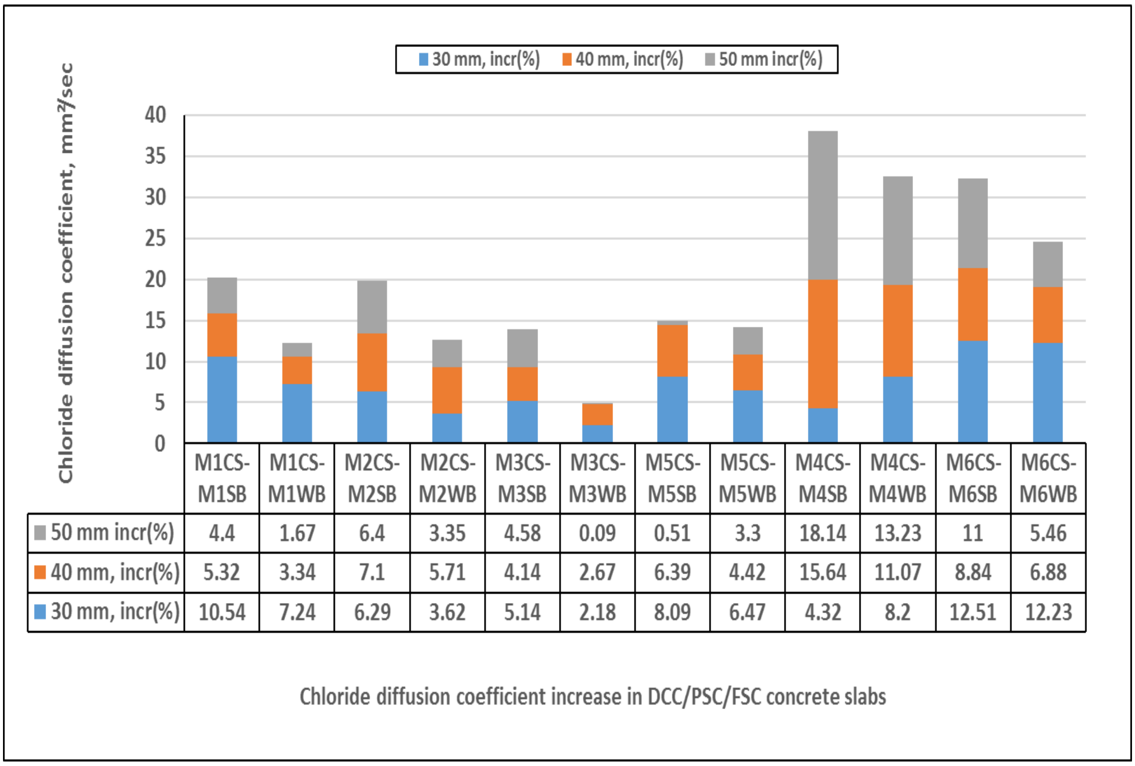
The chloride diffusion coefficient was higher in DCC control concrete slabs (M1CS-0.0023, and M2CS-0.0021) mm^2/sec as against the DCC impregnation concrete slabs (M1SB-0.0021, and M2SB-0.0019) as well as (M1WB-0.0022, and M2WB-0.0020) mm^2/sec for in the case of higher compressive strength with varied slump values. Chloride diffusion coefficient was also higher in PSC control concrete slabs (M3CS-0.0020, M5CS-0.0019) as when compare to PSC impregnation concrete slabs (M3SB-0.0019, M5SB-0.0018) and (M3WB-0.0020, M5WB-0.0019) for in the case of varied compressive strength with constant slump values respectively. Chloride diffusion coefficient was higher in FSC control concrete slabs (M4CS-0.0021, and M6CS-0.0019) mm^2/sec as against the FSC impregnation concrete slabs (M4SB-0.0018, and M6SB-0.0017) as well as (M4WB-0.0018, and M6WB-0.0017) mm^2/sec for in the case of higher compressive strength with varied slump values. It is possible to determine an effectiveness of impregnation material under various exposure conditions (DCC/PSC/FSC) in concrete slabs and compare chloride diffusion coefficient increase at different drill depths (30-40) mm, (30-50) mm, and (40-50) mm as shown in (Figure 4-137). Chloride diffusion coefficient was predominantly increase for in the case of DCC control concrete slabs (M1CS and M2CS) as when compare to the impregnation concrete slabs (M1SB, M2SB, M1WB, and M2WB).



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
(40-50) mm incr(%)	2.24	1.42	0.93	3.81	3.08	1.52	4.5	5.21	2.05	4.66	1.67	3.26	2.46	5.26	4.44	4.21	6.9	2.82
(30-50) mm incr(%)	16.15	10.58	11.28	11.83	11.97	11.68	12.83	12.46	10.91	12.59	5.38	3.5	9.96	23	14.81	15.78	14.29	9.28
(30-40) mm incr(%)	14.23	9.29	10.25	8.34	9.18	10.33	8.72	7.65	9.05	8.31	6.93	6.55	7.69	18.73	10.85	12.08	7.94	6.65

Figure 4-137 Comparison of chloride diffusion coefficient in(CS/SB/WB) concrete slabs

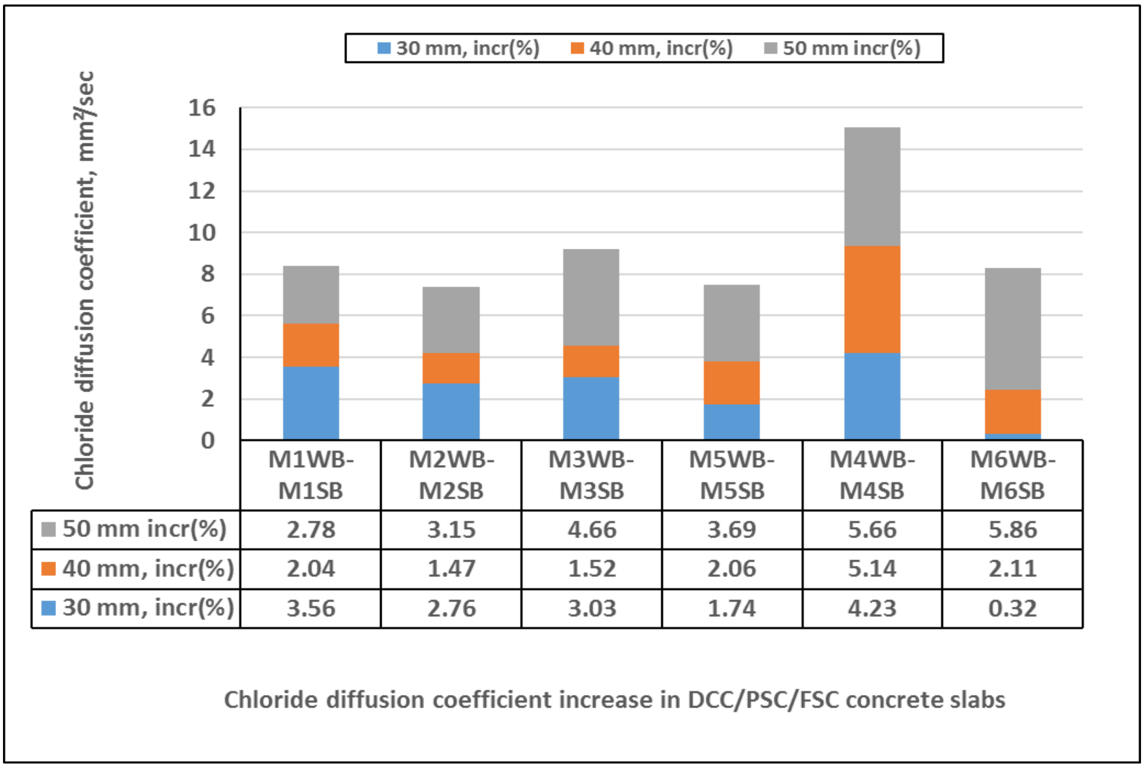
Its slightly decrease in chloride diffusion coefficient for in the case of PSC control concrete slabs (M3CS, and M5CS) as against the DCC concrete slabs. Similarly, the chloride diffusion coefficient was vary in FSC control concrete slabs (M4CS, and M6CS) as when compare to the impregnation concrete slabs (M4SB, M6SB, M4WB, and M6WB). It's confirm from the results that (Figure 4-138), the chloride diffusion coefficient was increase in the control DCC concrete slabs as when compare to the impregnation concrete slabs (M1CS-M1SB-6.75%, M2CS-M2SB-6.60%, M1CS-M1WB-4.08%, and M2CS-M2WB-4.23%). Chloride diffusion coefficient was increase in the control PSC concrete slabs as when compare to the impregnation concrete slabs (M3CS-M3SB-4.62%, M5CS-M5SB-5%, M3CS-M3WB-1.65%, and M5CS-M5WB-4.73%). Whereas in the case of FSC concrete slabs, the chloride diffusion coefficient was predominantly increase in the control FSC concrete slabs as when compare to the FSC impregnation concrete cubes (M4CS-M4SB-12.70%, M6CS-M6SB-10.78%, M4CS-M4WB-10.83%, and M6CS-M6WB-8.19% at different drill depths respectively.



	M1CS-M1SB	M1CS-M1WB	M2CS-M2SB	M2CS-M2WB	M3CS-M3SB	M3CS-M3WB	M5CS-M5SB	M5CS-M5WB	M4CS-M4SB	M4CS-M4WB	M6CS-M6SB	M6CS-M6WB
■ 50 mm incr(%)	4.4	1.67	6.4	3.35	4.58	0.09	0.51	3.3	18.14	13.23	11	5.46
■ 40 mm, incr(%)	5.32	3.34	7.1	5.71	4.14	2.67	6.39	4.42	15.64	11.07	8.84	6.88
■ 30 mm, incr(%)	10.54	7.24	6.29	3.62	5.14	2.18	8.09	6.47	4.32	8.2	12.51	12.23

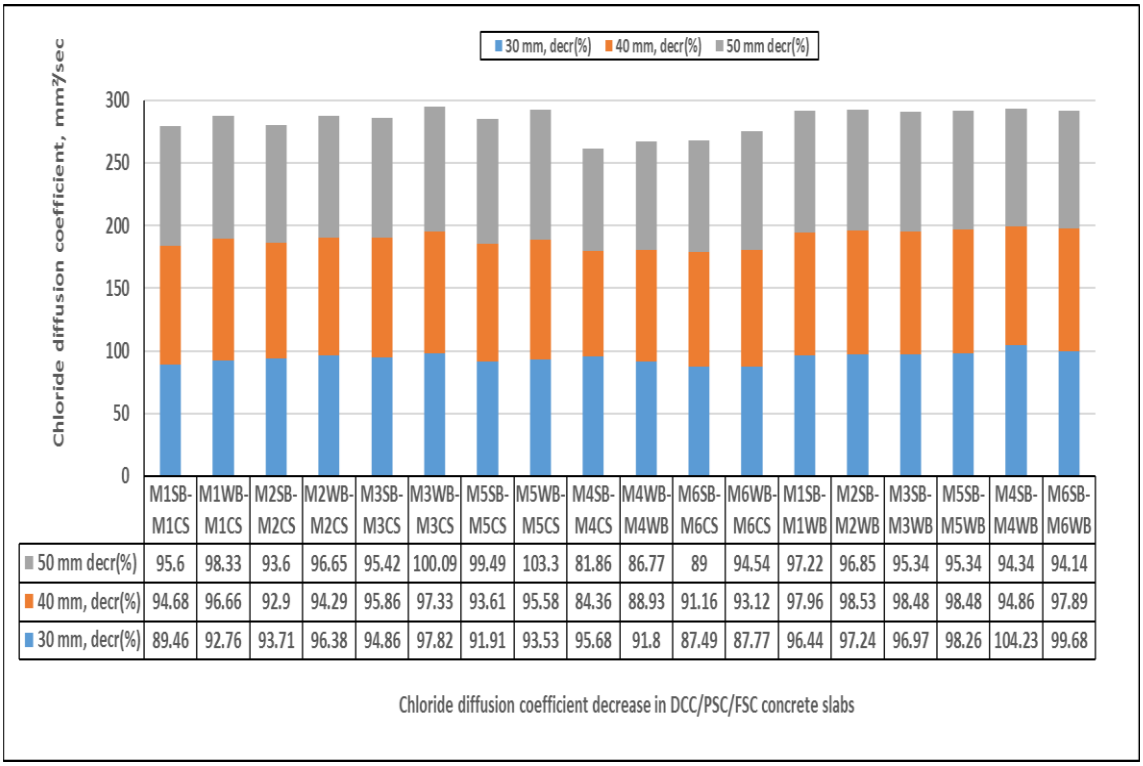
Figure 4-138 Chloride diffusion coefficient in (CS/SB/WB) concrete slabs

Chloride diffusion coefficient was increase in the impregnation DCC concrete slabs (Figure *4-139*) as when compare to the impregnation concrete slabs (M1WB-M1SB-2.79%, M2WB-M2SB-2.46%). Its increase in the control PSC concrete slabs as when compare to the impregnation concrete slabs (M3WB-M3SB-3.07%, M5WB-M5SB-2.50%).



	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M5WB-M5SB	M4WB-M4SB	M6WB-M6SB
▨ 50 mm incr(%)	2.78	3.15	4.66	3.69	5.66	5.86
■ 40 mm, incr(%)	2.04	1.47	1.52	2.06	5.14	2.11
■ 30 mm, incr(%)	3.56	2.76	3.03	1.74	4.23	0.32

Figure 4-139 Chloride diffusion coefficient in PCC (WB/SB) concrete slabs



	M1SB-M1CS	M1WB-M1CS	M2SB-M2CS	M2WB-M2CS	M3SB-M3CS	M3WB-M3CS	M5SB-M5CS	M5WB-M5CS	M4SB-M4CS	M4WB-M4WB	M6SB-M6CS	M6WB-M6CS	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M5SB-M5WB	M4SB-M4WB	M6SB-M6WB
▨ 50 mm decr(%)	95.6	98.33	93.6	96.65	95.42	100.09	99.49	103.3	81.86	86.77	89	94.54	97.22	96.85	95.34	95.34	94.34	94.14
■ 40 mm, decr(%)	94.68	96.66	92.9	94.29	95.86	97.33	93.61	95.58	84.36	88.93	91.16	93.12	97.96	98.53	98.48	98.48	94.86	97.89
■ 30 mm, decr(%)	89.46	92.76	93.71	96.38	94.86	97.82	91.91	93.53	95.68	91.8	87.49	87.77	96.44	97.24	96.97	98.26	104.23	99.68

Figure 4-140 Chloride diffusion coefficient in (SB/CS/WB) concrete slabs

Whereas in the case of FSC concrete slabs, the chloride diffusion coefficient was predominantly increase in the control FSC concrete slabs as when compare to the FSC impregnation concrete cubes (M4WB-M4SB-5.01%, M6WB-M6SB-2.76%) at different drill depths respectively. Chloride diffusion coefficient was decrease in an impregnation DCC concrete slab (Figure *4-140*) as when compare to the control concrete slabs (M1SB-M1CS-93.25%, M2SB-M2CS-93.40%, M1WB-M1CS-95.92%, M2WB-M2CS-95.77%, M1SB-M1WB-97.21%, and M2SB-M2WB-97.54%). It's also decrease in an impregnation PSC concrete slabs as when compare to the control concrete slabs (M3SB-M3CS-95.38%, M5SB-M5CS-95%, M3WB-M3CS-98.41%, M5WB-M5CS-97.47%, M3SB-M3WB-96.93%, and M5SB-M5WB-97.36%). Chloride diffusion coefficient was less decrease in an FSC impregnation concrete slab as against FSC control concrete slabs (M4SB-M4CS-87.30%, M6SB-M6CS-89.22%, M4WB-M4CS-89.17%, M6WB-M6CS-91.81%, M4SB-M4WB-97.81%, and M6SB-M6WB-97.24%)

An extensive growing interest in the effect of chloride diffusion into the concrete has resulted in a number of studies, both in the laboratory and in the field. In fact, an important and often expensive decisions regarding design or maintenance of structures were carry out based on such studies. Thus, a thorough consideration of the methodologies used to obtain and to interpret the data is important. However, in the search for minimum chloride diffusion models, the main issue, structural lifetime, sometimes appears to have been lost. In practice, the diffusion of chlorides into concrete will be important in one aspect only such as when it causes initiation and growth of critical corrosion in such a way that the lifetime of the structure is severely impaired. The chloride diffusion coefficient through concrete is an important parameter related with reinforced concrete durability. It could be measure with different test methods based on natural diffusion, in which a water saturated concrete specimen is place in contact with a chloride solution, and a chloride profile is obtain after a time. Diffusion is the main transport mechanism and data fitting to the error function solution of Fick's second law, is use to determine the chloride diffusion coefficient value. A fully water saturated sample is needed in order to assure a diffusion transport mechanism, otherwise other transport mechanisms as capillary sorption or wick action could act.

Thus in the present research work, the variation of chloride diffusion coefficient in control concrete slabs/cubes were interpreted in pre-conditions such as dry/partially/fully saturated condition as shown (Figure 4-141). In which, an average chloride diffusion coefficient in DCC control concrete slabs were decreased (3.52%) at different drill depths (30-50) mm for in case of mixture type (M1) as when compared to concrete cubes average chloride diffusion coefficient. But, the average chloride diffusion coefficient was predominantly decreased (8.61%) in DCC control concrete slabs as when compared to DCC control concrete cubes due to variation in chloride diffusion coefficient for in case of mixture type (M2). Also, the average chloride diffusion coefficient in PSC control concrete slabs were increased (9.62%) at different drill depths (30-50) mm for in case of mixture type (M3) as when compared to concrete cubes average diffusion coefficient. But, the average chloride diffusion coefficient was predominantly decreased (6.97%) in PSC control concrete slabs as when compared to PSC control concrete cubes due to variation in chloride diffusion coefficient for in case of mixture type (M5). In addition to that, the average chloride diffusion coefficient in FSC control concrete slabs were predominantly increased (32.38%) at different drill depths (30-50) mm for in case of mixture type (M4) as when compared to concrete cubes average chloride diffusion coefficient. But, the average chloride diffusion coefficient was somewhat increased (25.01%) in FSC control concrete slabs as when compared to FSC control concrete cubes due to variation in chloride diffusion coefficient for in case of mixture type (M6) at different drill depths (30-50) mm.

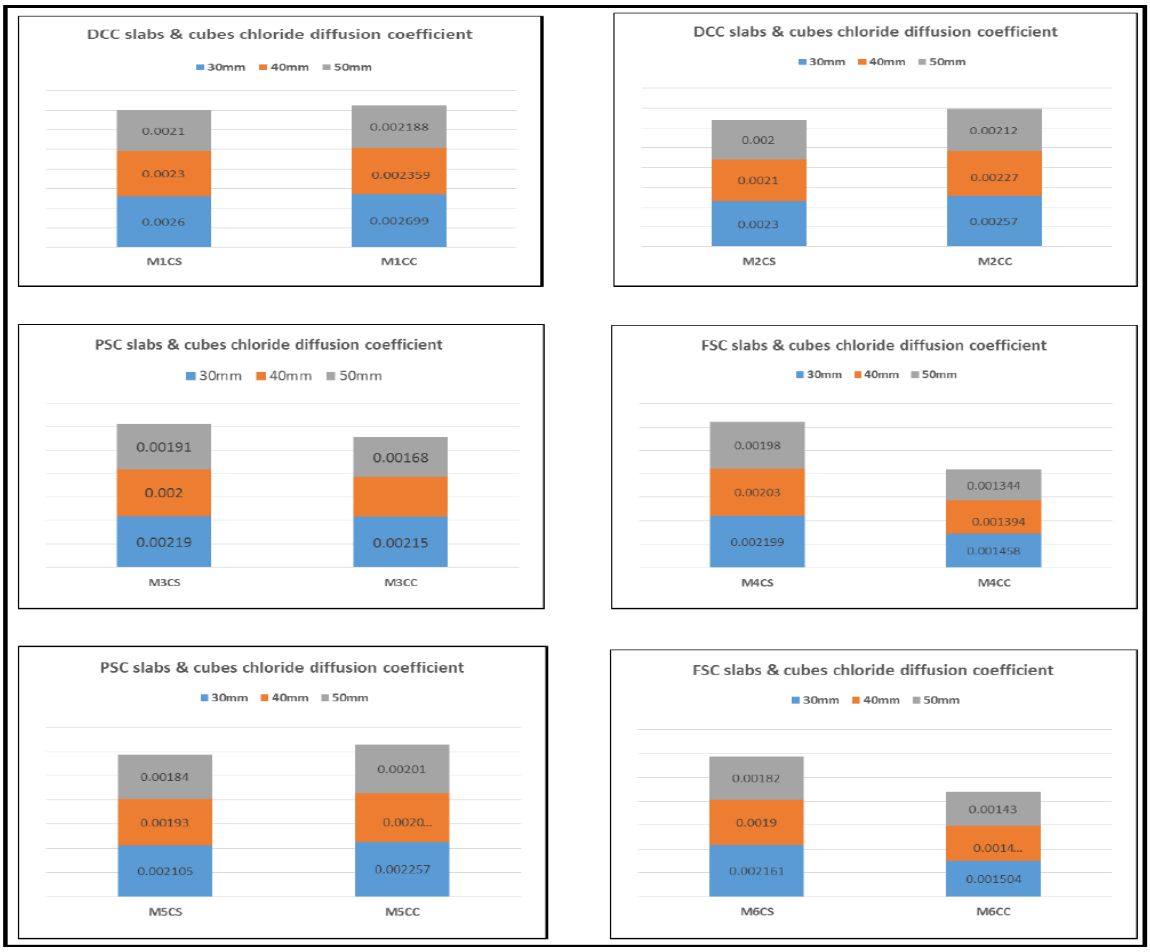


Figure 4-141 Chloride diffusion coefficient in pre-conditioned control concrete slabs/cubes

The variation of chloride diffusion coefficient in solvent-based impregnation concrete slabs/cubes were interpret in pre-conditions such as dry/partially/fully saturated condition as shown

(Figure 4-142). In which, the average chloride diffusion coefficient in DCC solvent based impregnation concrete slabs were increased (27.06%) at different drill depths (30-50) mm for in case of mixture type (M1) as when compared to concrete cubes average chloride diffusion coefficient. Also, the average chloride diffusion coefficient was increased (9.03%) in DCC solvent based impregnation concrete slabs as when compared to DCC solvent based impregnation cubes due to variation in chloride diffusion coefficient for in case of mixture type (M2). Similarly, the average chloride diffusion coefficient in PSC solvent based impregnation concrete slabs were increased (16%) at different drill depths (30-50) mm for in case of mixture type (M3) as when compared to concrete cubes average diffusion coefficient. But, the average chloride diffusion coefficient was slightly increased (3.87%) in PSC control concrete slabs as when compared to PSC solvent based impregnation concrete cubes due to variation in chloride diffusion coefficient for in case of mixture type (M5). In addition to that, the average chloride diffusion coefficient in FSC solvent based impregnation concrete slabs were predominantly increased (23.07%) at different drill depths (30-50) mm for in case of mixture type (M4) as when compared to concrete cubes average chloride diffusion coefficient. But, the average chloride diffusion coefficient was somewhat decreased (20.73%) in FSC solvent based impregnation concrete slabs as when compared to FSC solvent based impregnation concrete cubes due to variation in chloride diffusion coefficient for in case of mixture type (M6) at different drill depths (30-50) mm.

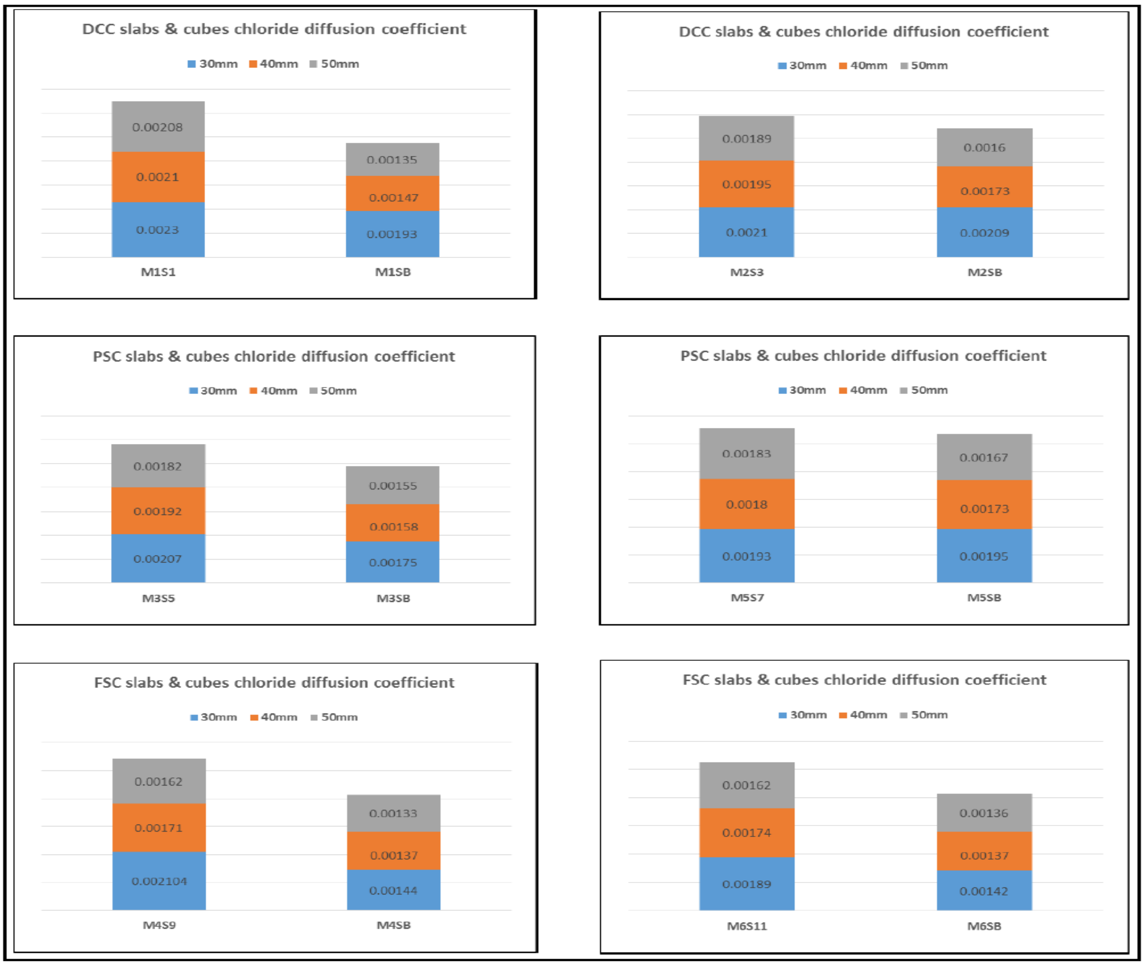


Figure 4-142 Chloride diffusion coefficient in pre-conditioned IC (SB) slabs/cubes

The variation of chloride diffusion coefficient in impregnation (WB) concrete slabs/cubes was determined in pre-conditions such as dry/partially/fully saturated condition as shown (Figure 4-143). In which, the average chloride diffusion coefficient in DCC water based impregnation concrete slabs were increased (1.84%) at different drill depths (30-50) mm for in case of mixture type (M1) as when compared to concrete cubes average chloride diffusion coefficient. Also, the average chloride diffusion coefficient was increased (8.80%) in DCC water based impregnation concrete slabs as when compared to DCC water based impregnation cubes due to variation in chloride diffusion coefficient for in case of mixture type (M2). Similarly, the average chloride diffusion coefficient in PSC water based impregnation concrete slabs were increased (17.48%) at different drill depths (30-50) mm for in case of mixture type (M3) as when compared to concrete cubes average diffusion coefficient. But, the average chloride diffusion coefficient was more decreased (1.42%) in PSC water based impregnation concrete slabs as when compared to PSC water based impregnation concrete cubes due to variation in chloride diffusion coefficient for in case of mixture type (M5). In addition to that, the average chloride diffusion coefficient in FSC water based impregnation concrete slabs were predominantly increased (23.89%) at different drill depths (30-50) mm for in case of mixture type (M4) as when compared to concrete cubes average chloride diffusion coefficient. But, the average chloride diffusion coefficient was somewhat decreased (21.48%) in FSC water based impregnation concrete slabs as when compared to FSC water based impregnation concrete cubes due to variation in chloride diffusion coefficient for in case of mixture type (M6) at different drill depths (30-50) mm.

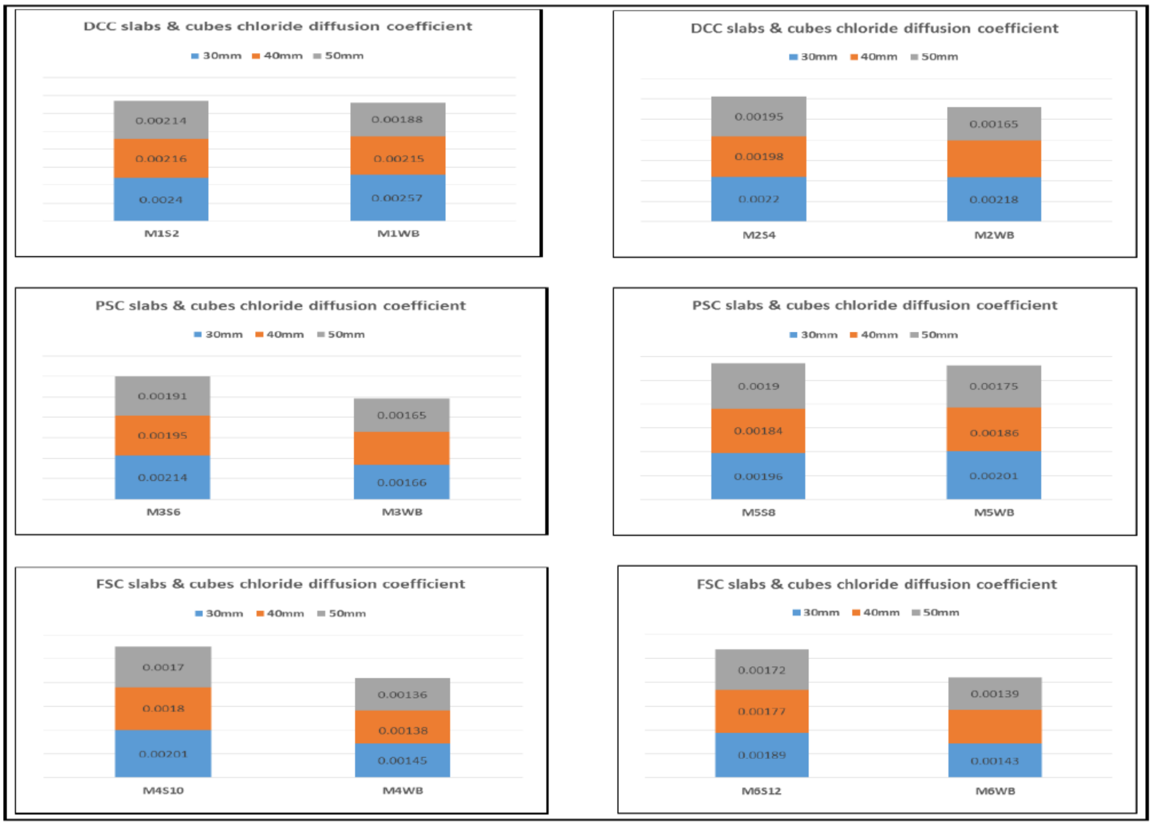


Figure 4-143 Chloride diffusion coefficient in pre-conditioned IC (WB) slabs/cubes

4.9 Salt ponding test with finite moisture content in concrete cubes

4.9.1 Chloride solution absorption in control PCC/IC in concrete cubes

The variation of chloride solution absorption in control (M1-0%-M6-0%) and impregnation (M1SB-0%-M6SB-0%) DCC concrete cubes for in the case of different mixtures type is as shown in Figure 4-144. The chloride solution absorption (average) at different time interval up to 160 days was increase in control concrete cubes (M1-0%-1.13%, M2-0%-1.11%, M3-0%-1.09%, M4-0%-1.03%, M5-0%-1.04%, and M6-0%-1%) as when compared to an solvent-based impregnation (M1SB-0%-0.57%, M2SB-0%-0.58%, M3SB-0%-0.56%, M4SB-0%-0.58%, M5SB-0%-0.57%, and M6SB-0%-0.57%) concrete cube. Chloride solution absorption (average) at different time interval up to 160 days was also increase in control DCC concrete cubes as against the water-based impregnation concrete cubes (M1WB-0%-0.63%, M2WB-0%-0.59%, M3WB-0%-0.60%, M4WB-0%-0.59%, M5WB-0%-0.58%, and M6WB-0%-0.58%).

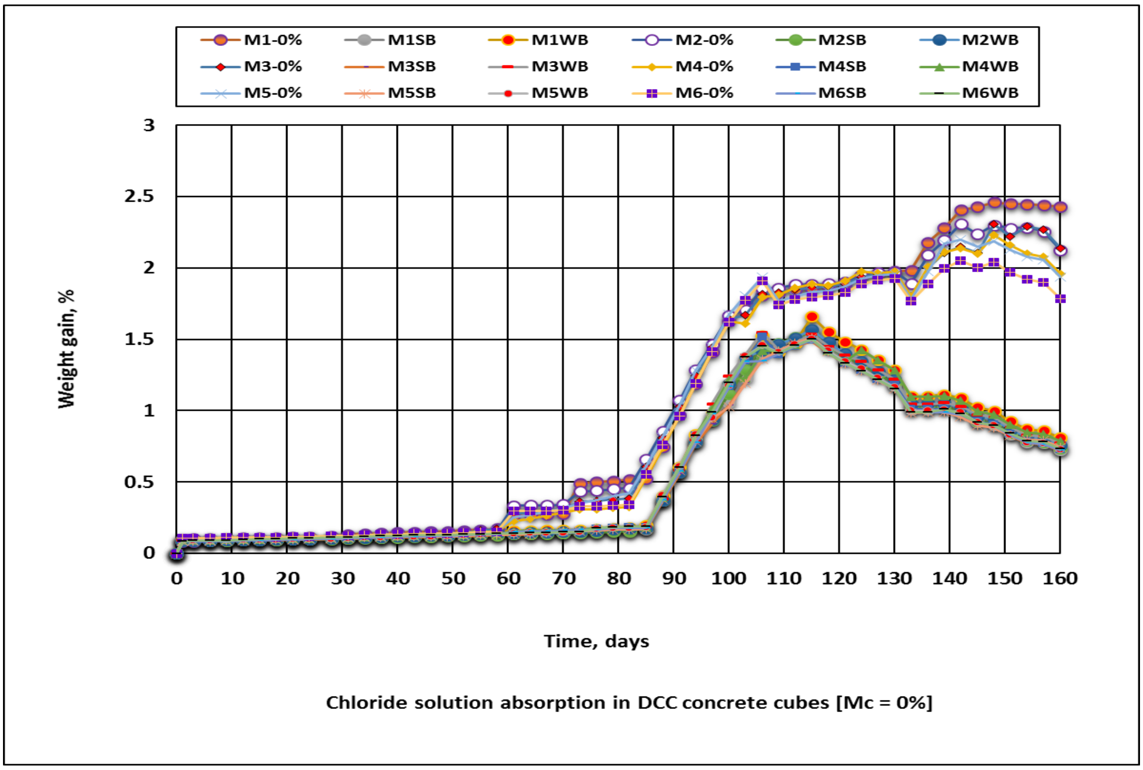


Figure 4-144 Chloride solution absorption in DCC concrete cubes

The variation of chloride solution absorption in PSC concrete cubes for different mixtures type (M1-M6) at different time interval is as shown in Figure 4-145. Chloride solution absorption (average) at different time interval up to 160 days was decrease (M1SB-0.21%, M2SB-0.12%, M3SB-0.19%, M4SB-0.11%, M5SB-0.18%, M6SB-0.10%) in PSC impregnation (SB) concrete cubes as when compared to PSC control concrete cubes (M1-2%-0.40%, M2-2%-0.17%, M3-2%-0.28%, M4-2%-0.15%, M5-2%-0.24%, M6-2%-0.13%). Chloride solution absorption in FSC concrete cubes for different mixtures type (M1-M6) is as shown in Figure 4-146. Chloride solution absorption (average) at different time interval up to 160 days was predominantly decrease (M1SB-0.13%, M2SB-0.07%, M3SB-0.11%, M4SB-0.06%, M5SB-0.04%, M6SB-0.03%) in FSC impregnation (SB) concrete cubes as when compared to FSC control concrete cubes (M1-3%-0.22%, M2-3%-0.09%, M3-3%-0.16%, M4-3%-0.095%, M5-3%-0.16%, M6-3%-0.08%).

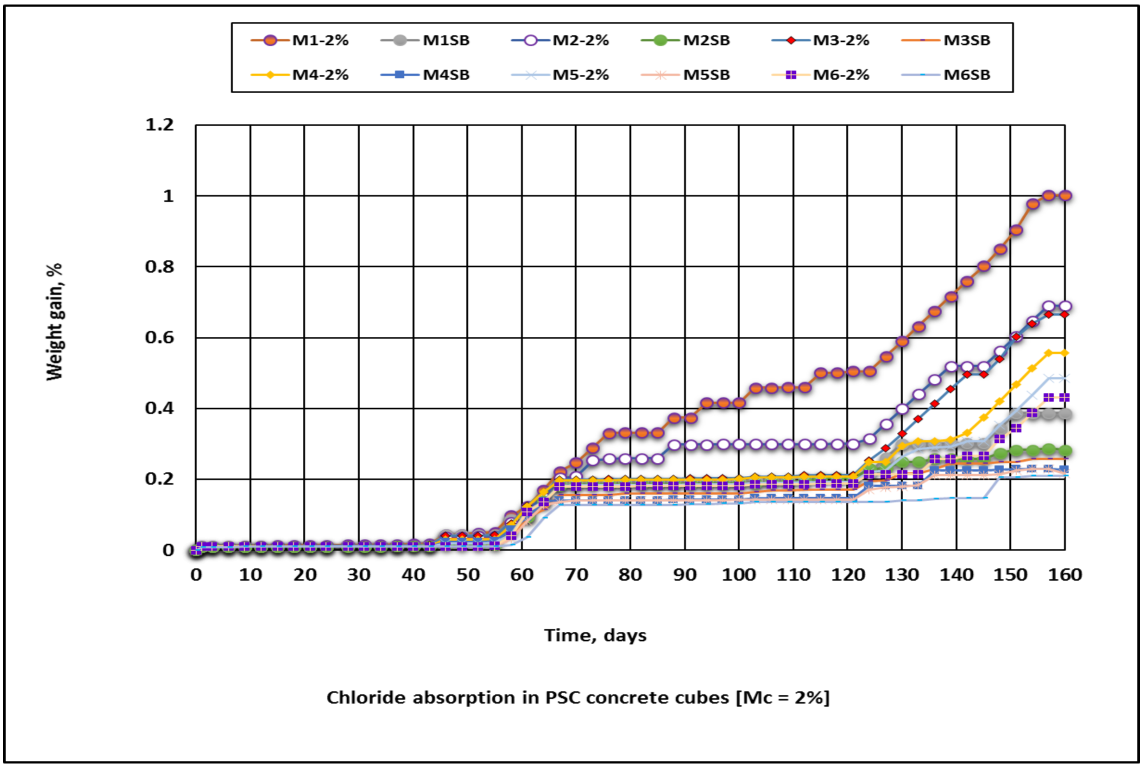


Figure 4-145 Chloride solution absorption in PSC concrete cubes

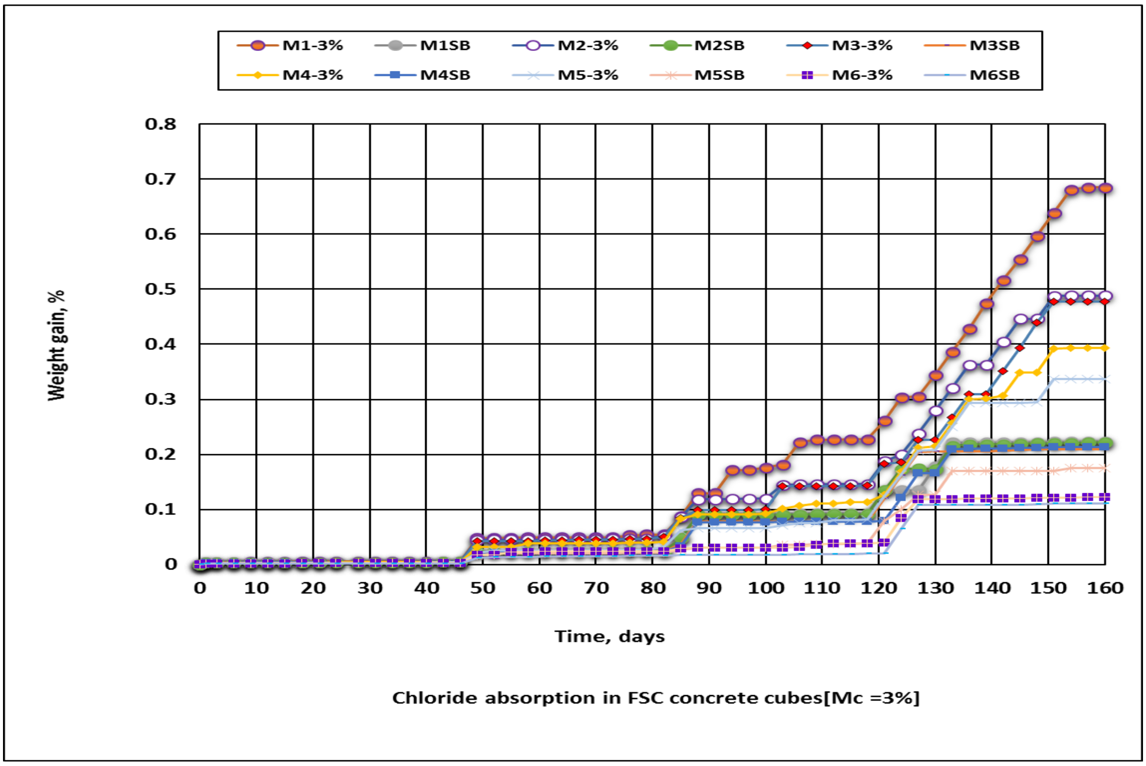


Figure 4-146 Chloride solution absorption in FSC concrete cubes

The chloride solution absorption (average) variation in the PSC water based impregnation concrete cubes in different mixtures type (M1-M6) at different time interval up to 160 days is as shown in

Figure 4-147 respectively. Chloride solution absorption (average) at different time interval up to 160 days, was predominantly decrease (M1WB-0.15%, M2WB-0.073%, M3WB-0.13%, M4WB-0.063%, M5WB-0.11%, M6WB-0.05%) in PSC impregnation (SB) concrete cubes as when compared to FSC control concrete cubes (M1-2%-0.29%, M2-2%-0.10%, M3-2%-0.19%, M4-2%-0.08%, M5-2%-0.17%, M6-2%-0.07%). The chloride solution absorption in FSC water based impregnation concrete cubes in different mixtures type (M1-M6) is as shown in Figure 4-148.

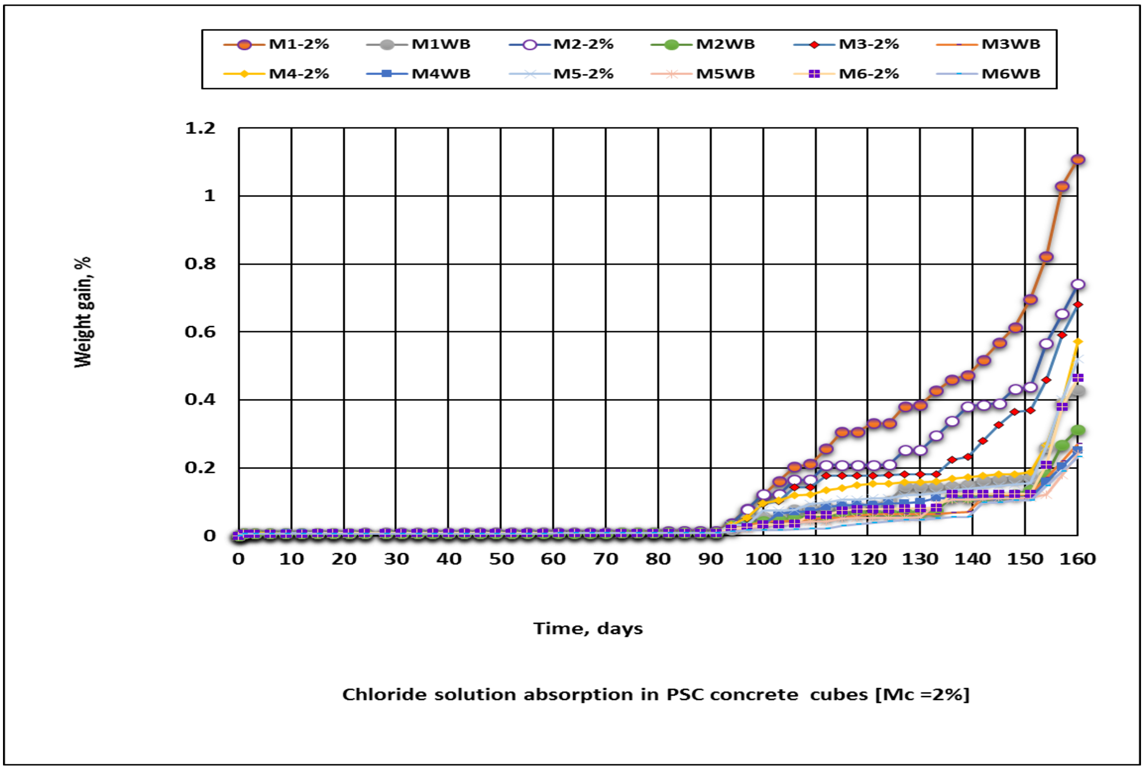


Figure 4-147 Chloride solution absorption in PSC concrete cubes

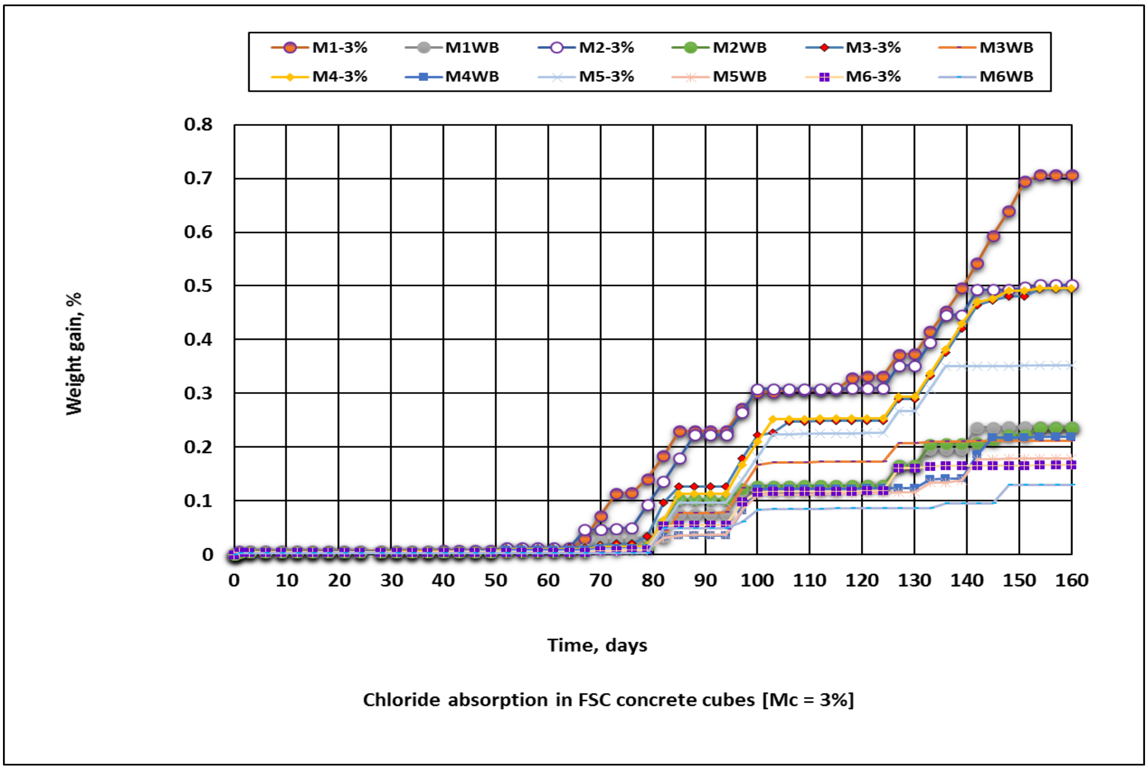


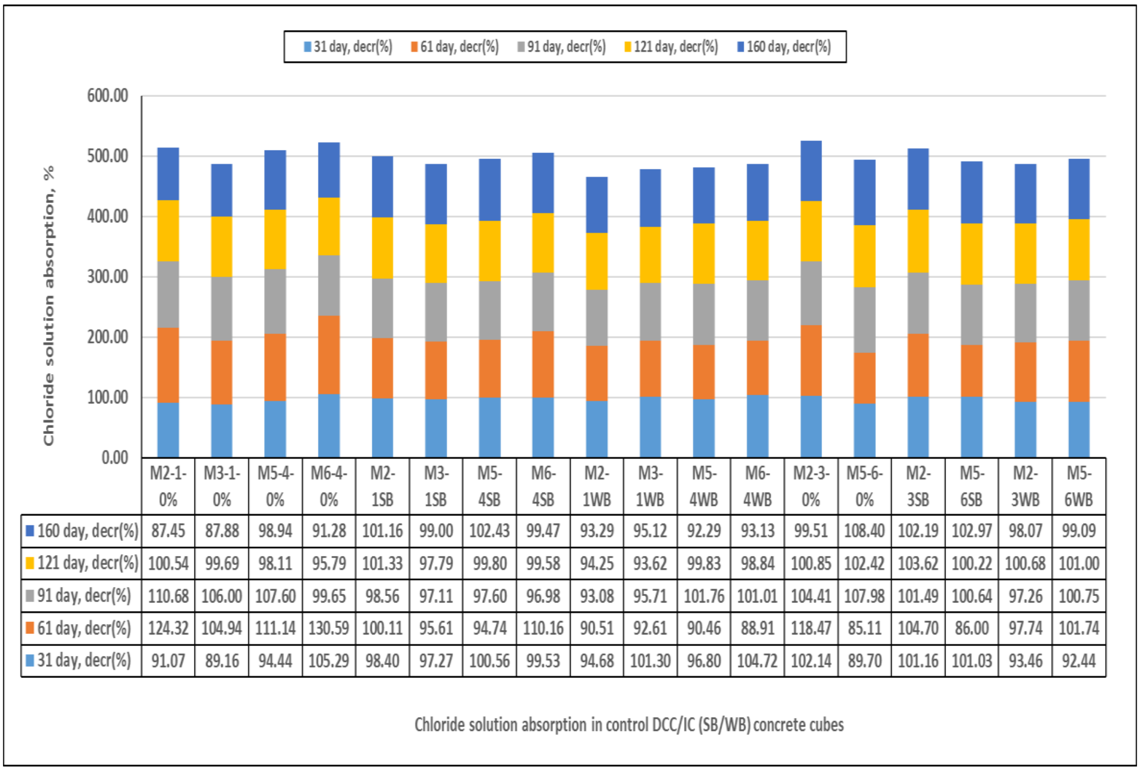
Figure 4-148 Chloride solution absorption in FSC concrete cubes

Chloride solution absorption (average) at different time interval up to 160 days, was decrease (M1WB-0.17%, M2WB-0.077%, M3WB-0.14%, M4WB-0.067%, M5WB-0.069%, M6WB-0.053%) in FSC impregnation (SB) concrete cubes as when compared to FSC control concrete cubes (M1-2%-0.25%, M2-2%-0.09%, M3-2%-0.21%, M4-2%-0.09%, M5-2%-0.18%, M6-2%-0.09%).

4.9.2 Comparison of chloride solution absorption in control PCC/IC concrete cubes

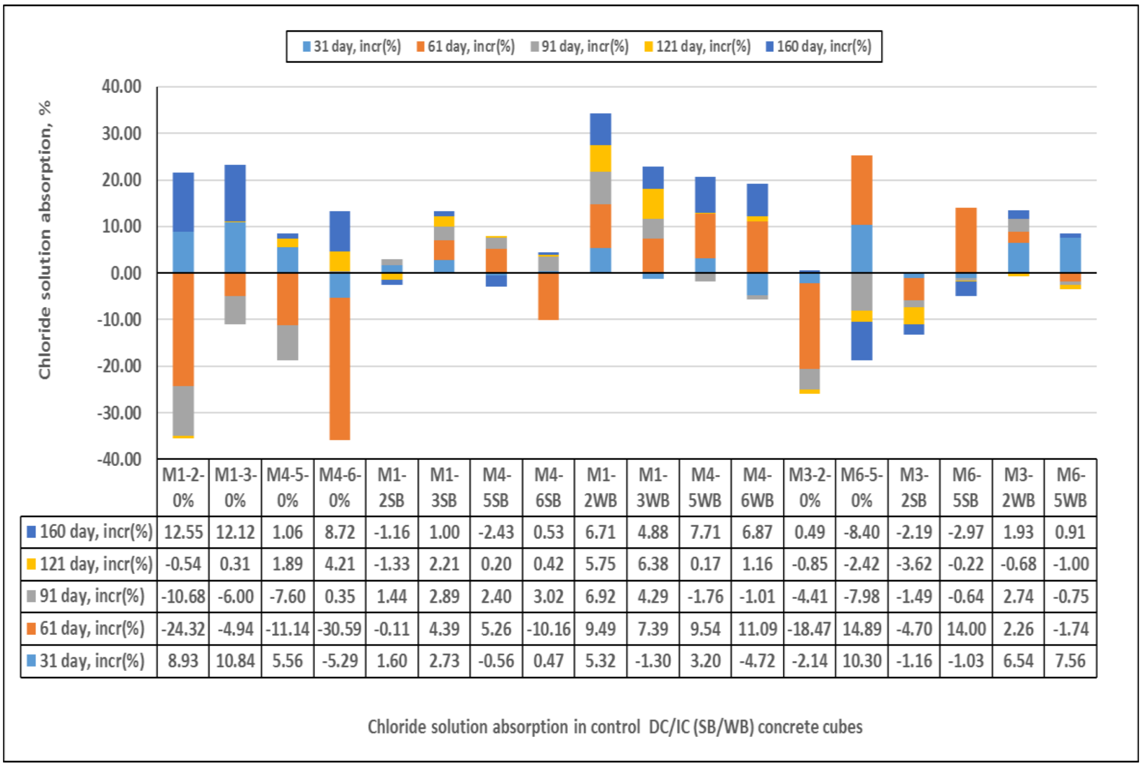
An effectiveness of impregnation against chloride solution absorption in DCC designed control and impregnation concrete cubes at different time interval (31th, 61th, 91th, 121th, and 1601th day) was assessed as shown in (Figure 4-149). Chloride solution absorption (average) at different time interval up to 160 days was decrease for in the case of impregnation concrete cubes in designed concrete mix (M2-1SB-99.91% , M3-1SB-95.67%, M5-4SB-99.03%, M6-4SB-101.15%, M2-1WB-93.16% , M3-1WB-95.67%, M5-4WB-96.23%, M6-4WB-97.32%, M2-3SB-102.63%, M5-6SB-98.17%, M2-3WB-97.44%, M5-6WB-99%). Chloride solution absorption (average) at different time interval was also decrease for in the case of DCC control concrete cubes (M2-1-0%-102.81%, M3-1-0%-97.53%, M5-4-0%-102.05%, M6-4-0%-104.52%, M2-3-0%-105.08%, and M5-6-0%-98.72%) as when compare to various concrete mix designs.

Furthermore, the chloride solution absorption (average) was higher (positive sign) and lower (negative sign) as when compare to different concrete mix designs for in the case of impregnation cubes (M1SB-M6SB and M4WB-M6WB) and control concrete cubes (M1-0%-M6-0%) at different time interval (31th, 61th, 91th, 121th, and 1601th) day was as shown in (Figure 4-150). Chloride solution absorption (average) at time interval 160th day was increase for in the case of impregnation concrete cubes in designed concrete mix (M1-2SB-1.16% , M1-3SB-1%, M4-5SB-2.43%, M4-6SB-0.53%, M1-2WB-6.71%, M1-3WB-4.88%, M4-5WB-7.71%, M4-6WB-6.87%, M3-2SB-2.19%, M6-5SB-2.97%, M3-2WB-1.93%, M6-5WB-0.91%). Chloride solution absorption (average) at different time interval was also decrease for in the case of DCC control concrete cubes (M1-2-0%-12.55%, M1-3-0%-12.12%, M4-5-0%-1.06%, M4-6-0%-8.72%, M3-2-0%-0.49%, and M6-5-0%-8.40%) as when compare to various concrete mix designs.



	M2-1-0%	M3-1-0%	M5-4-0%	M6-4-0%	M2-1SB	M3-1SB	M5-4SB	M6-4SB	M2-1WB	M3-1WB	M5-4WB	M6-4WB	M2-3-0%	M5-6-0%	M2-3SB	M5-6SB	M2-3WB	M5-6WB
■ 160 day, decr(%)	87.45	87.88	98.94	91.28	101.16	99.00	102.43	99.47	93.29	95.12	92.29	93.13	99.51	108.40	102.19	102.97	98.07	99.09
■ 121 day, decr(%)	100.54	99.69	98.11	95.79	101.33	97.79	99.80	99.58	94.25	93.62	99.83	98.84	100.85	102.42	103.62	100.22	100.68	101.00
■ 91 day, decr(%)	110.68	106.00	107.60	99.65	98.56	97.11	97.60	96.98	93.08	95.71	101.76	101.01	104.41	107.98	101.49	100.64	97.26	100.75
■ 61 day, decr(%)	124.32	104.94	111.14	130.59	100.11	95.61	94.74	110.16	90.51	92.61	90.46	88.91	118.47	85.11	104.70	86.00	97.74	101.74
■ 31 day, decr(%)	91.07	89.16	94.44	105.29	98.40	97.27	100.56	99.53	94.68	101.30	96.80	104.72	102.14	89.70	101.16	101.03	93.46	92.44

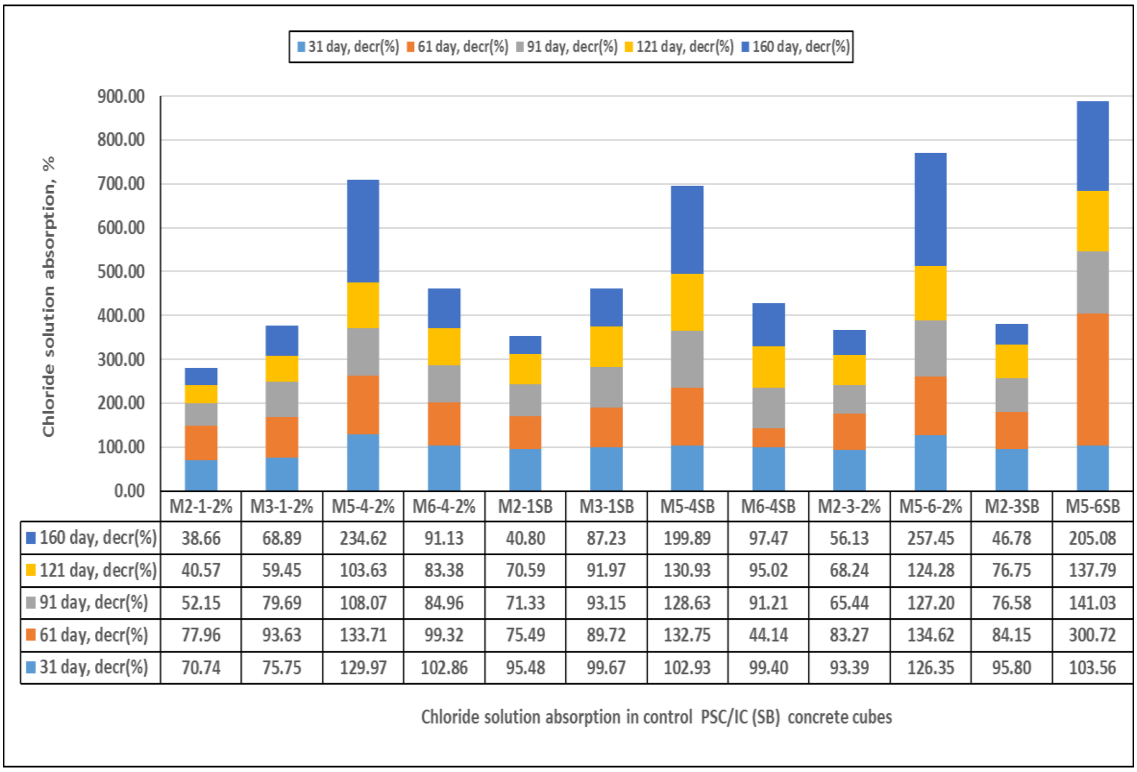
Figure 4-149 Chloride solution absorption decrase in DCC concrete cubes



	M1-2-0%	M1-3-0%	M4-5-0%	M4-6-0%	M1-2SB	M1-3SB	M4-5SB	M4-6SB	M1-2WB	M1-3WB	M4-5WB	M4-6WB	M3-2-0%	M6-5-0%	M3-2SB	M6-5SB	M3-2WB	M6-5WB
■ 160 day, incr(%)	12.55	12.12	1.06	8.72	-1.16	1.00	-2.43	0.53	6.71	4.88	7.71	6.87	0.49	-8.40	-2.19	-2.97	1.93	0.91
■ 121 day, incr(%)	-0.54	0.31	1.89	4.21	-1.33	2.21	0.20	0.42	5.75	6.38	0.17	1.16	-0.85	-2.42	-3.62	-0.22	-0.68	-1.00
■ 91 day, incr(%)	-10.68	-6.00	-7.60	0.35	1.44	2.89	2.40	3.02	6.92	4.29	-1.76	-1.01	-4.41	-7.98	-1.49	-0.64	2.74	-0.75
■ 61 day, incr(%)	-24.32	-4.94	-11.14	-30.59	-0.11	4.39	5.26	-10.16	9.49	7.39	9.54	11.09	-18.47	14.89	-4.70	14.00	2.26	-1.74
■ 31 day, incr(%)	8.93	10.84	5.56	-5.29	1.60	2.73	-0.56	0.47	5.32	-1.30	3.20	-4.72	-2.14	10.30	-1.16	-1.03	6.54	7.56

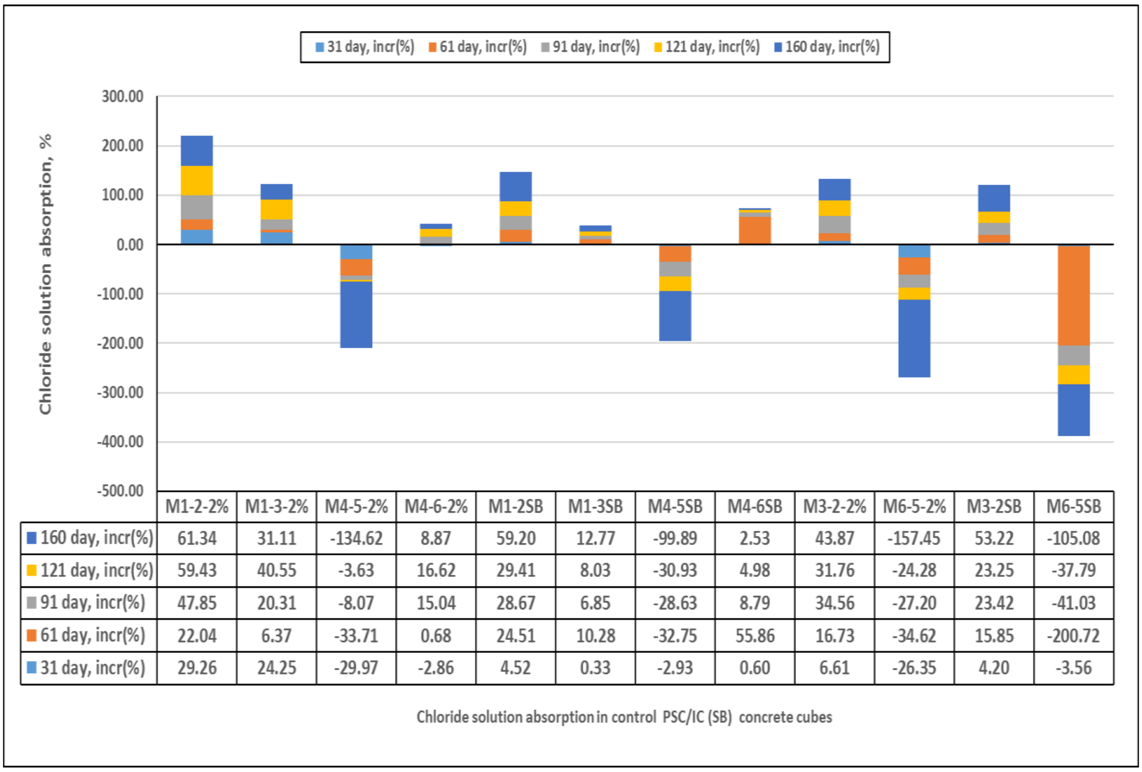
Figure 4-150 Chloride solution absorption increase in DCC concrete cubes

The performance of impregnation against chloride solution absorption in PSC designed control and impregnation concrete cubes at different time interval (31th, 61th, 91th, 121th, and 1601th day) was interpret as shown in (Figure 4-151). Chloride solution absorption (average) at different time interval up to 160 days was decrease for in the case of PSC impregnation concrete cubes in designed concrete mix (M2-1SB-70.74%, M3-1SB-92.35%, M5-4SB-139.03%, M6-4SB-85.45%, M2-3SB-76.01%, M5-6SB-177.64%).



	M2-1-2%	M3-1-2%	M5-4-2%	M6-4-2%	M2-1SB	M3-1SB	M5-4SB	M6-4SB	M2-3-2%	M5-6-2%	M2-3SB	M5-6SB
■ 160 day, decr(%)	38.66	68.89	234.62	91.13	40.80	87.23	199.89	97.47	56.13	257.45	46.78	205.08
■ 121 day, decr(%)	40.57	59.45	103.63	83.38	70.59	91.97	130.93	95.02	68.24	124.28	76.75	137.79
■ 91 day, decr(%)	52.15	79.69	108.07	84.96	71.33	93.15	128.63	91.21	65.44	127.20	76.58	141.03
■ 61 day, decr(%)	77.96	93.63	133.71	99.32	75.49	89.72	132.75	44.14	83.27	134.62	84.15	300.72
■ 31 day, decr(%)	70.74	75.75	129.97	102.86	95.48	99.67	102.93	99.40	93.39	126.35	95.80	103.56

Figure 4-151 Chloride solution absorption decrease in PSC concrete cubes



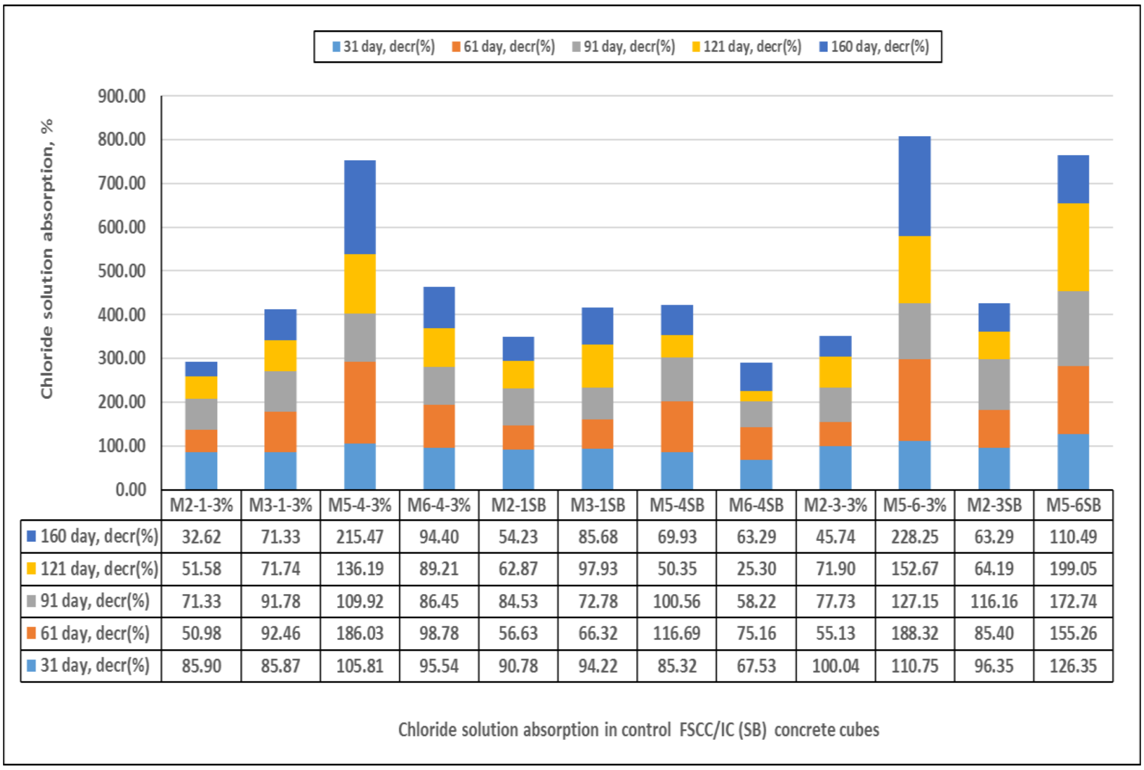
	M1-2-2%	M1-3-2%	M4-5-2%	M4-6-2%	M1-2SB	M1-3SB	M4-5SB	M4-6SB	M3-2-2%	M6-5-2%	M3-2SB	M6-5SB
■ 160 day, incr(%)	61.34	31.11	-134.62	8.87	59.20	12.77	-99.89	2.53	43.87	-157.45	53.22	-105.08
■ 121 day, incr(%)	59.43	40.55	-3.63	16.62	29.41	8.03	-30.93	4.98	31.76	-24.28	23.25	-37.79
■ 91 day, incr(%)	47.85	20.31	-8.07	15.04	28.67	6.85	-28.63	8.79	34.56	-27.20	23.42	-41.03
■ 61 day, incr(%)	22.04	6.37	-33.71	0.68	24.51	10.28	-32.75	55.86	16.73	-34.62	15.85	-200.72
■ 31 day, incr(%)	29.26	24.25	-29.97	-2.86	4.52	0.33	-2.93	0.60	6.61	-26.35	4.20	-3.56

Figure 4-152 Chloride solution absorption increase in PSC concrete cubes

Chloride solution absorption (average) at different time interval was also decrease for in the case of PSC control concrete cubes (M2-1-2%-56.02%, M3-1-2%-75.48%, M5-4-2%-142%, M6-4-

2%-92.33%, M2-3-2%-73.29%, and M5-6-2%-153.98%) as when compare to various concrete mix designs. Whereas the chloride solution absorption (average) was higher (positive sign) and lower (negative sign) as when compare to different concrete mix designs for in the case of PSC impregnation cubes (M1SB-M6SB) and control concrete cubes (M1-2%-M6-2%) at different time interval (31th, 61th, 91th, 121th, and 160th) day was as shown in (Figure 4-152). Chloride solution absorption (average) at time interval 160th day was increase for in the case of impregnation concrete cubes in designed concrete mix (M1-2SB-59.20%, M1-3SB-12.77%, M4-5SB-99.89%, M4-6SB-2.53%, M3-2SB-53.22%, M6-5SB-105.08%). Chloride solution absorption (average) at different time interval was also increase for in the case of PSC control concrete cubes (M1-2-2%-61.34%, M1-3-2%-31.11%, M4-5-2%-134.62%, M4-6-2%-8.87%, M3-2-2%-43.87%, and M6-5-2%-157.45%) as when compare to various concrete mix designs.

An effective performance of impregnation materials against chloride solution absorption in FSC designed control and impregnation concrete cubes at different time interval (31th, 61th, 91th, 121th, and 1601th day) was assessed as shown in (Figure *4-153*).

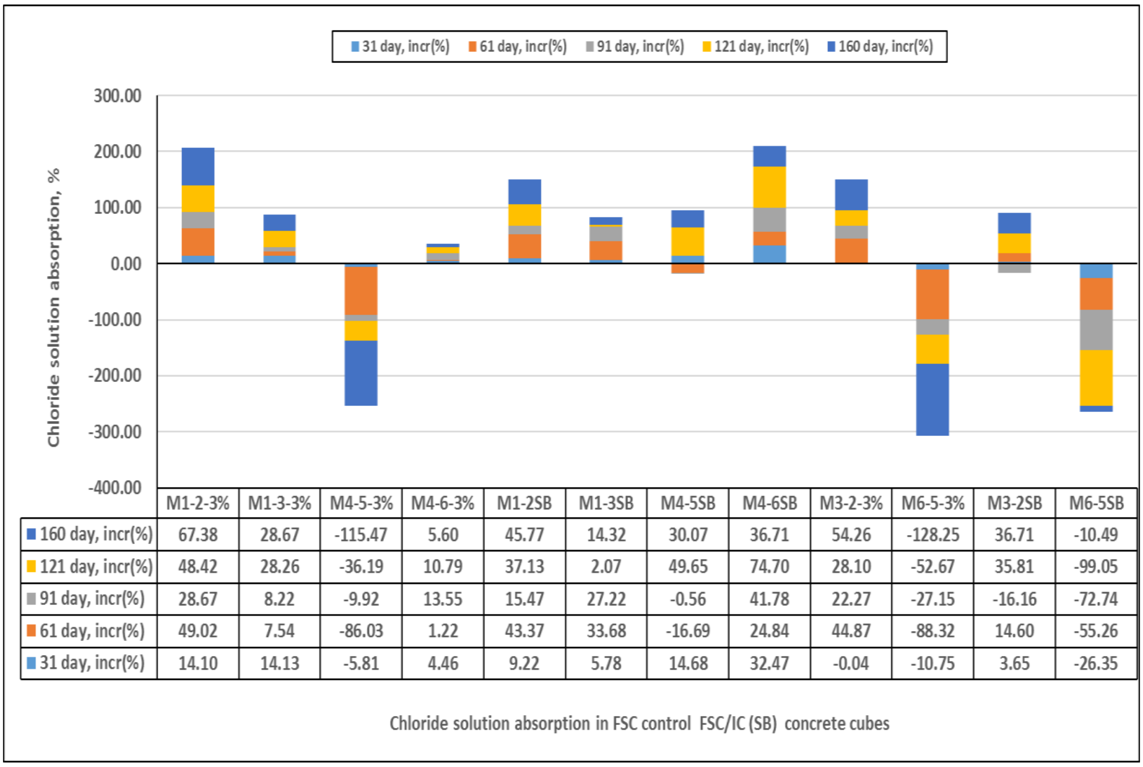


	M2-1-3%	M3-1-3%	M5-4-3%	M6-4-3%	M2-1SB	M3-1SB	M5-4SB	M6-4SB	M2-3-3%	M5-6-3%	M2-3SB	M5-6SB
■ 160 day, decr(%)	32.62	71.33	215.47	94.40	54.23	85.68	69.93	63.29	45.74	228.25	63.29	110.49
■ 121 day, decr(%)	51.58	71.74	136.19	89.21	62.87	97.93	50.35	25.30	71.90	152.67	64.19	199.05
■ 91 day, decr(%)	71.33	91.78	109.92	86.45	84.53	72.78	100.56	58.22	77.73	127.15	116.16	172.74
■ 61 day, decr(%)	50.98	92.46	186.03	98.78	56.63	66.32	116.69	75.16	55.13	188.32	85.40	155.26
■ 31 day, decr(%)	85.90	85.87	105.81	95.54	90.78	94.22	85.32	67.53	100.04	110.75	96.35	126.35

Figure 4-153 Chloride solution absorption decrease in FSC concrete cubes

Chloride solution absorption (average) at different time interval up to 160 days was decrease for in the case of FSC (SB) impregnation concrete cubes in designed concrete mix as compare to the different concrete design mixes (M2-1SB-69.81% , M3-1SB-83.38%, M5-4SB-84.57%, M6-4SB-57.90%, M2-3SB-85.08%, M5-6SB-152.78%).

Chloride solution absorption (average) at different time interval up to 160 days was also decrease for in the case of FSC control concrete cubes (M2-1-3%-58.48%, M3-1-3%-82.63%, M5-4-3%-150.68%, M6-4-3%-92.88%, M2-3-3%-70.11%, and M5-6-3%-161.43%) as when compare to various concrete mix designs. Chloride solution absorption (average) was higher (positive sign) and lower (negative sign) as when compare to different concrete mix designs for in the case of impregnation cubes (M1SB-M6SB) and control concrete cubes (M1-0%-M6-0%) at different time interval (31th, 61th, 91th, 121th, and 160th) day was as shown in (Figure *4-154*). Chloride solution absorption (average) at time interval 160th day was increase for in the case of FSC (SB) impregnation concrete cubes in designed concrete mix (M1-2SB-45.77%, M1-3SB-14.32%, M4-5SB-30.07%, M4-6SB-36.71%, M3-2SB-36.71%, M6-5SB-10.49%). Chloride solution absorption (average) at different time interval was also decrease for in the case of FSC control concrete cubes (M1-2-3%-67.38%, M1-3-3%-28.67%, M4-5-3%-115.47%, M4-6-3%-5.60%, M3-2-3%-54.26%, and M6-5-3%-128.25%) as when compare to various concrete mix designs.

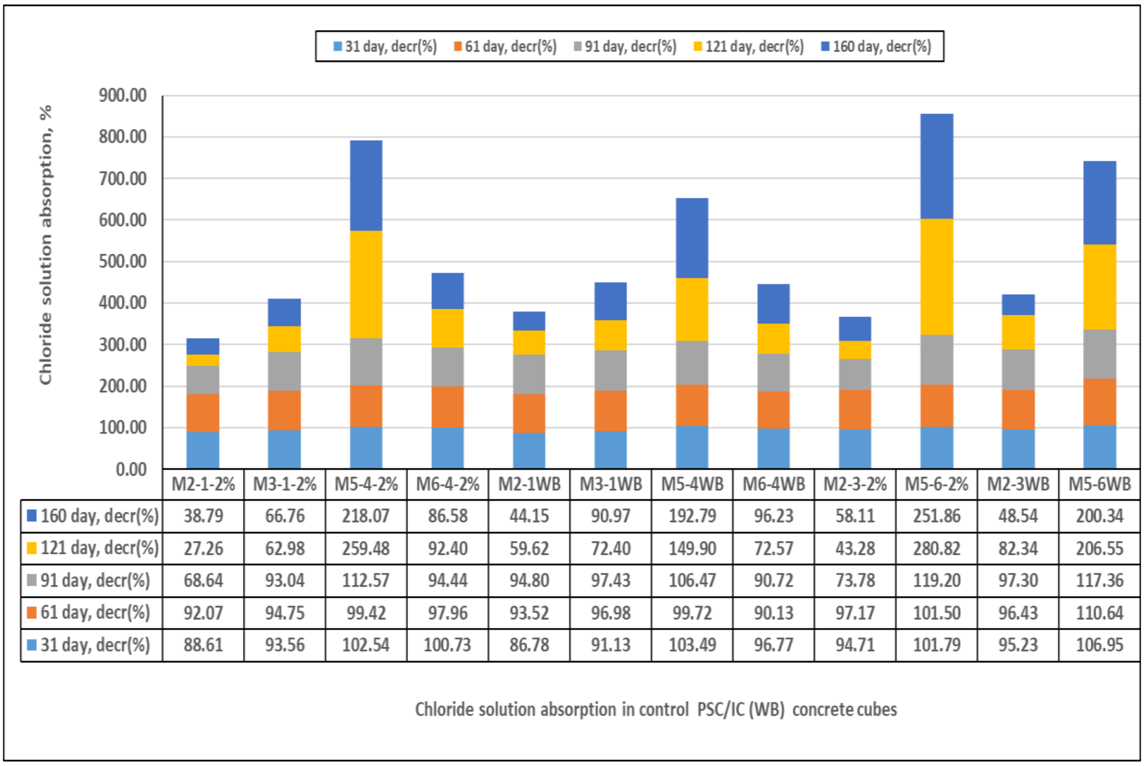


	M1-2-3%	M1-3-3%	M4-5-3%	M4-6-3%	M1-2SB	M1-3SB	M4-5SB	M4-6SB	M3-2-3%	M6-5-3%	M3-2SB	M6-5SB
■ 160 day, incr(%)	67.38	28.67	-115.47	5.60	45.77	14.32	30.07	36.71	54.26	-128.25	36.71	-10.49
■ 121 day, incr(%)	48.42	28.26	-36.19	10.79	37.13	2.07	49.65	74.70	28.10	-52.67	35.81	-99.05
■ 91 day, incr(%)	28.67	8.22	-9.92	13.55	15.47	27.22	-0.56	41.78	22.27	-27.15	-16.16	-72.74
■ 61 day, incr(%)	49.02	7.54	-86.03	1.22	43.37	33.68	-16.69	24.84	44.87	-88.32	14.60	-55.26
■ 31 day, incr(%)	14.10	14.13	-5.81	4.46	9.22	5.78	14.68	32.47	-0.04	-10.75	3.65	-26.35

Figure 4-154 Chloride solution absorption increase in FSC concrete cubes

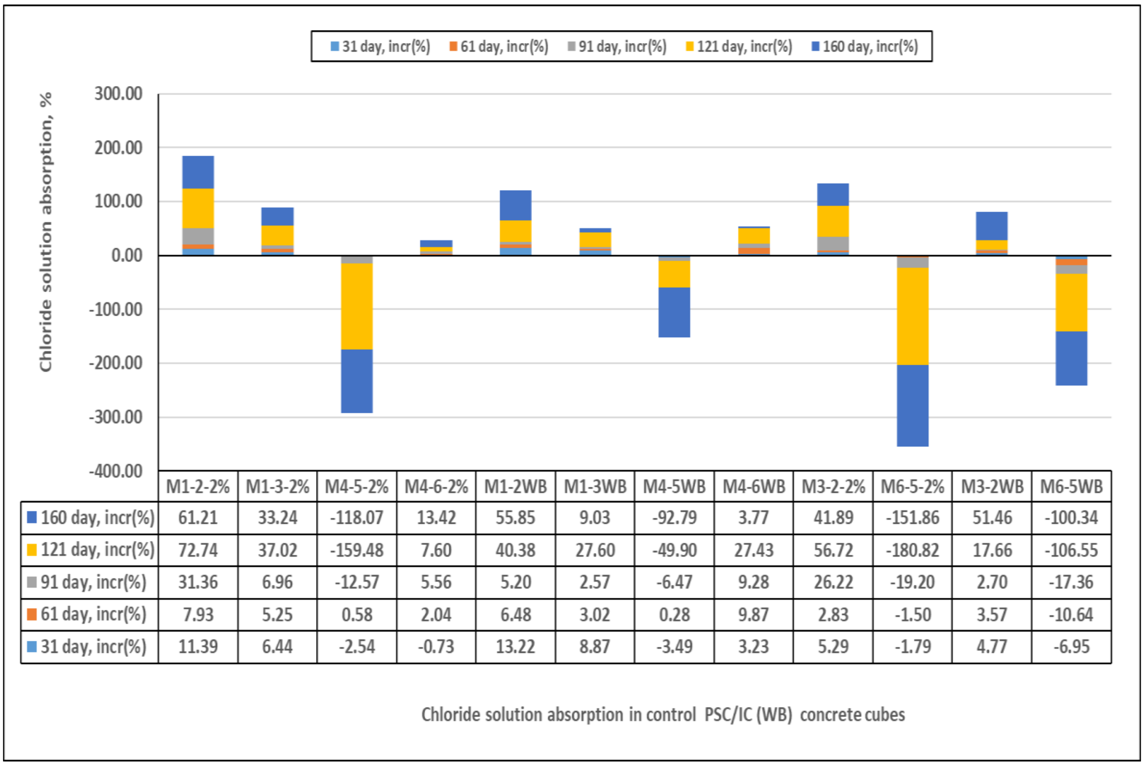
The performance of impregnation materials against chloride solution absorption in PSC designed control and impregnation concrete cubes at different time interval (31th, 61th, 91th, 121th, and 160th day) was assessed as shown in (Figure 4-155). Chloride solution absorption (average) at different time interval up to 160 days was decrease for in the case of PSC (WB) impregnation concrete cubes in designed concrete mix as compare to the different concrete design mixes (M2-1WB-75.78% , M3-1WB-89.78%, M5-4WB-130.47%, M6-4WB-89.28%, M2-3WB-83.97%, M5-6WB-148.37%). Chloride solution absorption (average) at different time interval up to 160 days was also decrease for in the case of PSC control concrete cubes (M2-1-2%-63.07%, M3-1-2%-82.22%, M5-4-2%-158.42%, M6-4-2%-94.42%, M2-3-2%-73.41%, and M5-6-2%-171.03%) as when compare to various concrete mix designs.

Chloride solution absorption (average) was higher (positive sign) and lower (negative sign) as when compare to different concrete mix designs for in the case of PSC impregnation cubes (M1WB-M6WB) and control concrete cubes (M1-2%-M6-2%) at different time interval (31th, 61th, 91th, 121th, and 160th) day was as shown in (Figure 4-156). Chloride solution absorption (average) at time interval 160th day was increase for in the case of PSC (WB) impregnation concrete cubes in designed concrete mix (M1-2WB-55.85%, M1-3WB-9.03%, M4-5WB-92.79%, M4-6WB-3.77%, M3-2WB-51.46%, M6-5WB-100.34%). Chloride solution absorption (average) at different time interval was also increase for in the case of PSC control concrete cubes (M1-2-2%-61.21%, M1-3-2%-33.24%, M4-5-2%-118.07%, M4-6-2%-13.42%, M3-2-2%-41.89%, and M6-5-2%-151.86%) as when compare to various concrete mix designs.



	M2-1-2%	M3-1-2%	M5-4-2%	M6-4-2%	M2-1WB	M3-1WB	M5-4WB	M6-4WB	M2-3-2%	M5-6-2%	M2-3WB	M5-6WB
■ 160 day, decr(%)	38.79	66.76	218.07	86.58	44.15	90.97	192.79	96.23	58.11	251.86	48.54	200.34
■ 121 day, decr(%)	27.26	62.98	259.48	92.40	59.62	72.40	149.90	72.57	43.28	280.82	82.34	206.55
■ 91 day, decr(%)	68.64	93.04	112.57	94.44	94.80	97.43	106.47	90.72	73.78	119.20	97.30	117.36
■ 61 day, decr(%)	92.07	94.75	99.42	97.96	93.52	96.98	99.72	90.13	97.17	101.50	96.43	110.64
■ 31 day, decr(%)	88.61	93.56	102.54	100.73	86.78	91.13	103.49	96.77	94.71	101.79	95.23	106.95

Figure 4-155 Chloride solution absorption in PSC concrete cubes

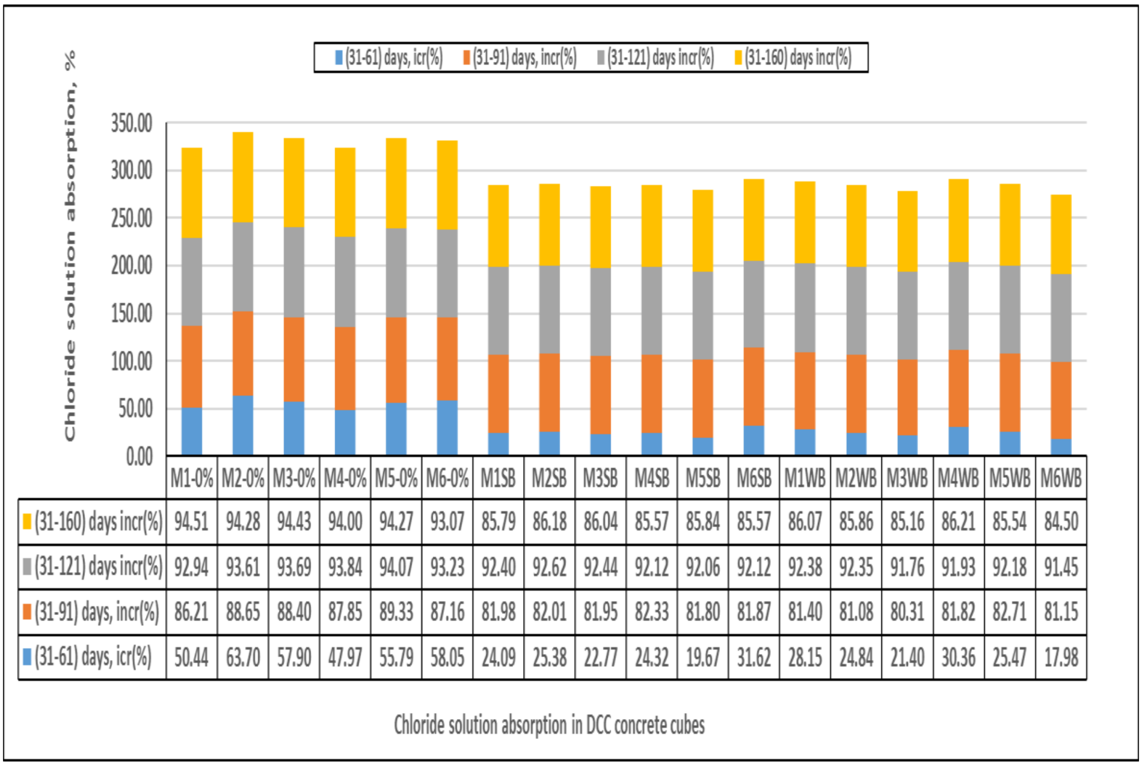


	M1-2-2%	M1-3-2%	M4-5-2%	M4-6-2%	M1-2WB	M1-3WB	M4-5WB	M4-6WB	M3-2-2%	M6-5-2%	M3-2WB	M6-5WB
■ 160 day, incr(%)	61.21	33.24	-118.07	13.42	55.85	9.03	-92.79	3.77	41.89	-151.86	51.46	-100.34
■ 121 day, incr(%)	72.74	37.02	-159.48	7.60	40.38	27.60	-49.90	27.43	56.72	-180.82	17.66	-106.55
■ 91 day, incr(%)	31.36	6.96	-12.57	5.56	5.20	2.57	-6.47	9.28	26.22	-19.20	2.70	-17.36
■ 61 day, incr(%)	7.93	5.25	0.58	2.04	6.48	3.02	0.28	9.87	2.83	-1.50	3.57	-10.64
■ 31 day, incr(%)	11.39	6.44	-2.54	-0.73	13.22	8.87	-3.49	3.23	5.29	-1.79	4.77	-6.95

Figure 4-156 Chloride solution absorption in PSC concrete cubes

It is possible to compare the variations in chloride solution absorption with moisture content (Mc = 0%) for in the case of DCC control/IC (SB/WB) concrete cubes at different time interval (31-

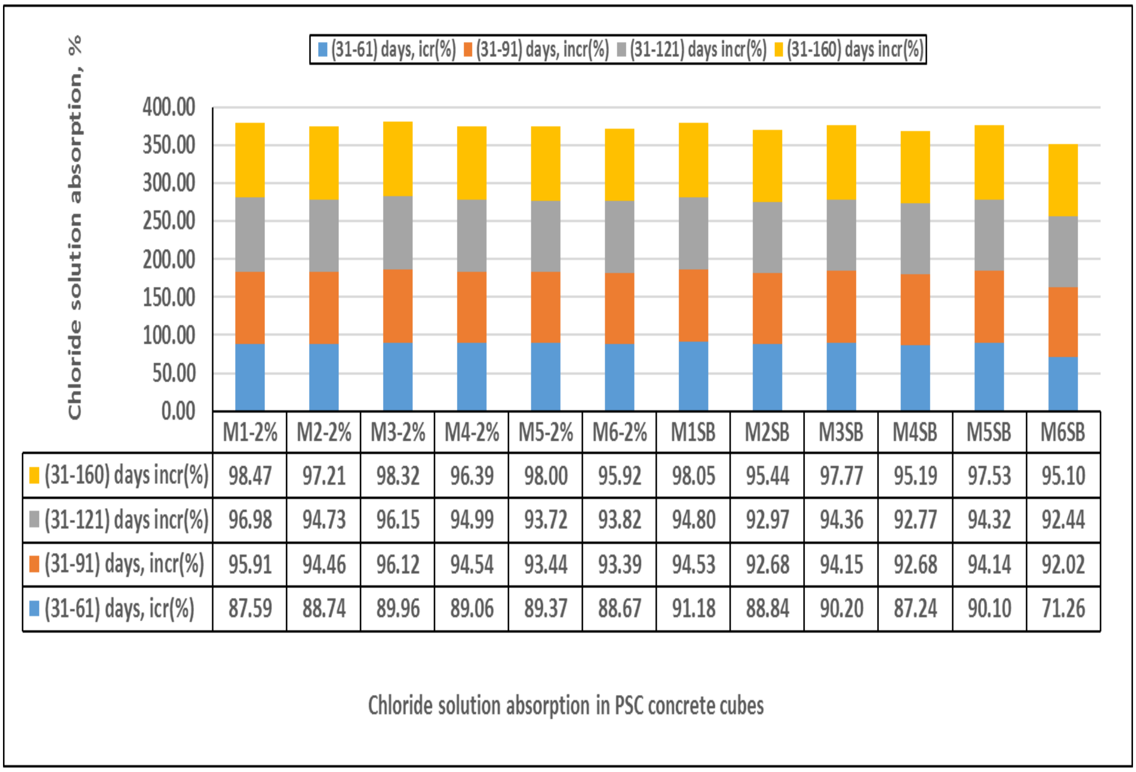
61th), (31-91th), (31-121th), and (31-160th) day as shown in (Figure 4-157) respectively. It is clear from the results that, the chloride solution absorption was increase at an initial time interval (31-61th) for in the case of DCC control concrete cubes (M1-0%-50.44%, M2-0%-63.70%, M3-0%-57.90%, M4-0%-47.97%, M5-0%-55.79%, and M6-0%-58.05%), as when compare to solvent-based impregnation concrete cubes (M1SB-24.09%, M2SB-25.38%, M3SB-22.77%, M4SB-24.32%, M5SB-19.67%, and M6SB-31.62%). It’s also increase in chloride solution absorption in control DCC concrete cubes as against water-based impregnation concrete cubes (M1WB-28.15%, M2WB-24.84%, M3WB-21.40%, M4WB-30.36%, M5WB-25.47%, and M6WB-17.98%). Chloride solution absorption was increase at longer time interval (31-160th) for in the case of DCC control concrete cubes (M1-0%-94.51%, M2-0%-94.28%, M3-0%-94.43%, M4-0%-94%, M5-0%-94.27%, and M6-0%-93.07%), as when compare to solvent-based impregnation concrete cubes (M1SB-85.79%, M2SB-86.18%, M3SB-86.04%, M4SB-85.57%, M5SB-85.84%, and M6SB-85.57%). Its also increase in chloride solution absorption in control DCC concrete cubes as against water-based impregnation concrete cubes (M1WB-86.07%, M2WB-85.86%, M3WB-85.16%, M4WB-86.21%, M5WB-85.54%, and M6WB-84.50%) as when compare to an initial time duration (31-61th) days respectively.



	M1-0%	M2-0%	M3-0%	M4-0%	M5-0%	M6-0%	M1SB	M2SB	M3SB	M4SB	M5SB	M6SB	M1WB	M2WB	M3WB	M4WB	M5WB	M6WB
🟨 (31-160) days incr(%)	94.51	94.28	94.43	94.00	94.27	93.07	85.79	86.18	86.04	85.57	85.84	85.57	86.07	85.86	85.16	86.21	85.54	84.50
◼ (31-121) days incr(%)	92.94	93.61	93.69	93.84	94.07	93.23	92.40	92.62	92.44	92.12	92.06	92.12	92.38	92.35	91.76	91.93	92.18	91.45
🟧 (31-91) days, incr(%)	86.21	88.65	88.40	87.85	89.33	87.16	81.98	82.01	81.95	82.33	81.80	81.87	81.40	81.08	80.31	81.82	82.71	81.15
🟦 (31-61) days, icr(%)	50.44	63.70	57.90	47.97	55.79	58.05	24.09	25.38	22.77	24.32	19.67	31.62	28.15	24.84	21.40	30.36	25.47	17.98

Figure 4-157 Chloride solution absorption in DCC (M1-M6-0%/SB/WB) concrete cubes

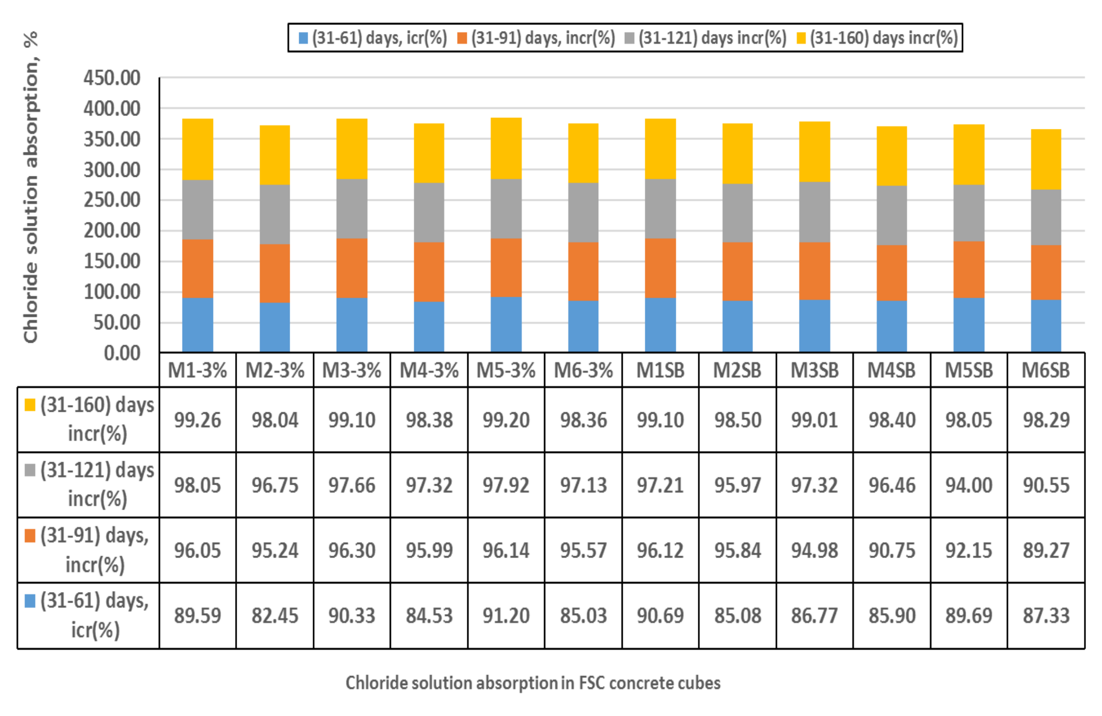
It is possible to interpret the variations in chloride solution absorption with moisture content (Mc = 2%) for in the case of PSC control/IC (SB) concrete cubes at different time interval (31-61th), (31-91th), (31-121th), and (31-160th) day as shown in (Figure 4-158) respectively.



	M1-2%	M2-2%	M3-2%	M4-2%	M5-2%	M6-2%	M1SB	M2SB	M3SB	M4SB	M5SB	M6SB
■ (31-160) days incr(%)	98.47	97.21	98.32	96.39	98.00	95.92	98.05	95.44	97.77	95.19	97.53	95.10
■ (31-121) days incr(%)	96.98	94.73	96.15	94.99	93.72	93.82	94.80	92.97	94.36	92.77	94.32	92.44
■ (31-91) days, incr(%)	95.91	94.46	96.12	94.54	93.44	93.39	94.53	92.68	94.15	92.68	94.14	92.02
■ (31-61) days, icr(%)	87.59	88.74	89.96	89.06	89.37	88.67	91.18	88.84	90.20	87.24	90.10	71.26

Figure 4-158 Chloride solution absorption in PSC (M1-M6-2%/SB) concrete cubes

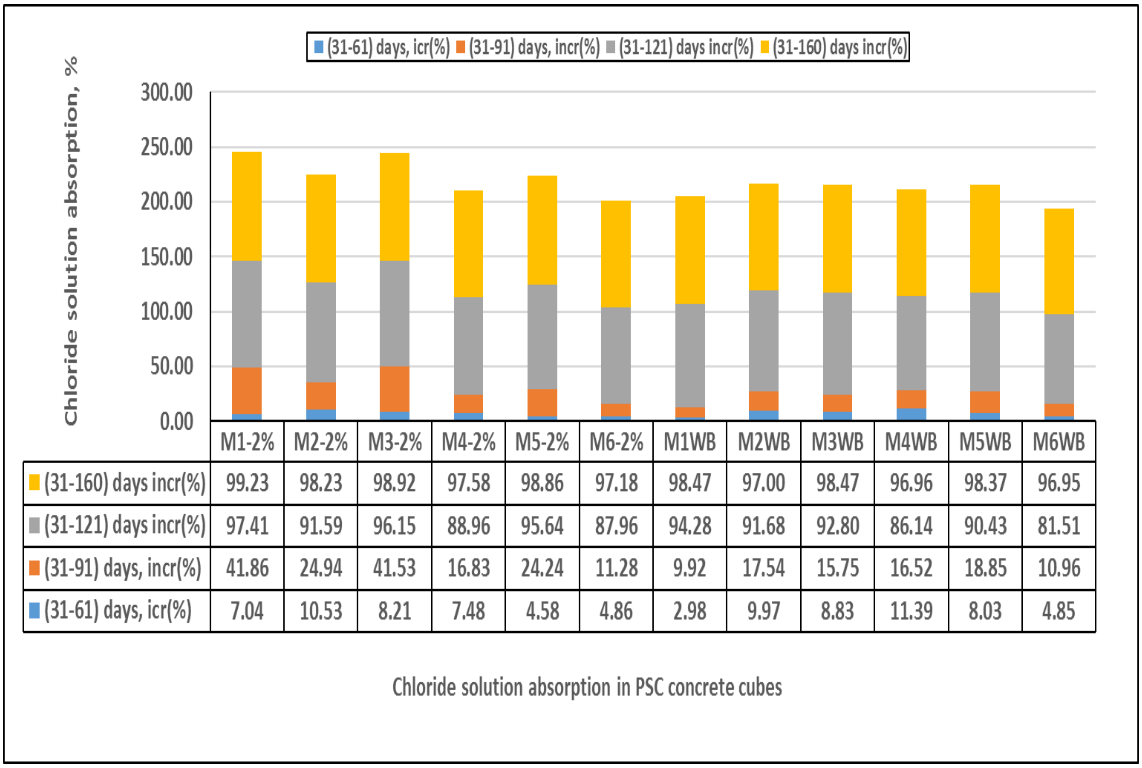
It is clear from the results that, the chloride solution absorption was increase at an initial time interval (31-61th) for in the case of PSC control concrete cubes (M1-2%-87.59%, M2-2%-88.74%, M3-2%-89.96%, M4-2%-89.06%, M5-2%-89.37%, and M6-2%-88.67%), as when compare to solvent-based impregnation concrete cubes (M1SB-91.18%, M2SB-88.84%, M3SB-90.20%, M4SB-87.24%, M5SB-90.10%, and M6SB-71.26%). Chloride solution absorption was increase at longer time interval (31-160th) for in the case of PSC control concrete cubes (M1-2%-98.47%, M2-2%-97.21%, M3-2%-98.32%, M4-2%-96.39%, M5-2%-98%, and M6-2%-95.92%), as when compare to solvent-based impregnation concrete cubes (M1SB-98.05%, M2SB-95.44%, M3SB-97.77%, M4SB-95.19%, M5SB-97.53%, and M6SB-95.10%) as when compare to an initial time duration (31-61th) day respectively. It is possible to interpret the variations in chloride solution absorption with moisture content (Mc = 3%) for in the case of FSC control/IC (SB) concrete cubes at different time interval (31-61th), (31-91th), (31-121th), and (31-160th) day as shown in (Figure 4-159) respectively.



	M1-3%	M2-3%	M3-3%	M4-3%	M5-3%	M6-3%	M1SB	M2SB	M3SB	M4SB	M5SB	M6SB
(31-160) days incr(%)	99.26	98.04	99.10	98.38	99.20	98.36	99.10	98.50	99.01	98.40	98.05	98.29
(31-121) days incr(%)	98.05	96.75	97.66	97.32	97.92	97.13	97.21	95.97	97.32	96.46	94.00	90.55
(31-91) days, incr(%)	96.05	95.24	96.30	95.99	96.14	95.57	96.12	95.84	94.98	90.75	92.15	89.27
(31-61) days, icr(%)	89.59	82.45	90.33	84.53	91.20	85.03	90.69	85.08	86.77	85.90	89.69	87.33

Figure 4-159 Chloride solution absorption in FSC (M1-M6-3%/SB) concrete cubes

It is clear from the results that, the chloride solution absorption was increase at an initial time interval (31-61th) for in the case of FSC control concrete cubes (M1-3%-89.59%, M2-3%-82.45%, M3-3%-90.33%, M4-3%-84.53%, M5-3%-91.20%, and M6-3%-85.03%), as when compare to solvent-based impregnation concrete cubes (M1SB-90.69%, M2SB-85.08%, M3SB-86.77%, M4SB-85.90%, M5SB-89.69%, and M6SB-87.33%). Chloride solution absorption was increase at longer time interval (31-160th) for in the case of FSC control concrete cubes (M1-3%-99.26%, M2-3%-98.04%, M3-3%-99.10%, M4-3%-98.38%, M5-3%-99.20%, and M6-3%-98.36%), as when compare to solvent-based impregnation concrete cubes (M1SB-99.10%, M2SB-98.50%, M3SB-99.01%, M4SB-98.40%, M5SB-98.05%, and M6SB-98.29%) as when compare to an initial time duration (31-61th) day respectively. It is possible to interpret the variations in chloride solution absorption with moisture content (Mc = 2%) for in the case of PSC control/IC (WB) concrete cubes at different time interval (31-61th), (31-91th), (31-121th), and (31-160th) day as shown in (Figure 4-160) respectively.



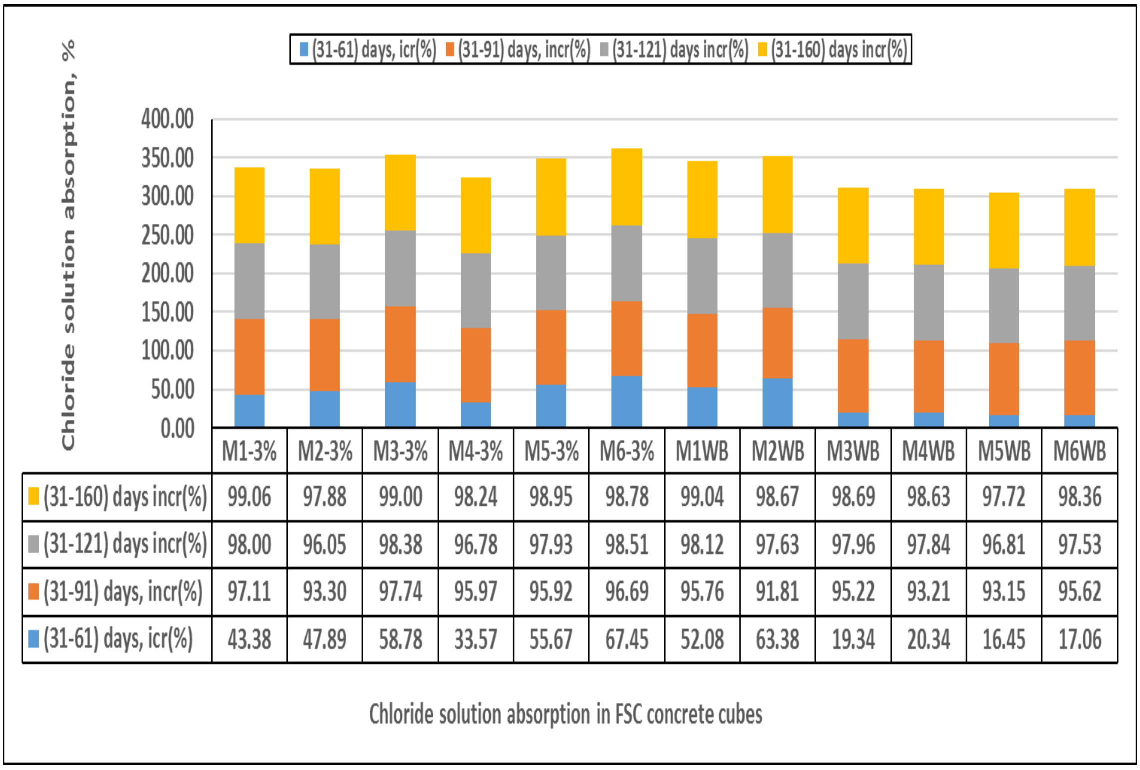
	M1-2%	M2-2%	M3-2%	M4-2%	M5-2%	M6-2%	M1WB	M2WB	M3WB	M4WB	M5WB	M6WB
🟨 (31-160) days incr(%)	99.23	98.23	98.92	97.58	98.86	97.18	98.47	97.00	98.47	96.96	98.37	96.95
⬜ (31-121) days incr(%)	97.41	91.59	96.15	88.96	95.64	87.96	94.28	91.68	92.80	86.14	90.43	81.51
🟧 (31-91) days, incr(%)	41.86	24.94	41.53	16.83	24.24	11.28	9.92	17.54	15.75	16.52	18.85	10.96
🟦 (31-61) days, icr(%)	7.04	10.53	8.21	7.48	4.58	4.86	2.98	9.97	8.83	11.39	8.03	4.85

Figure 4-160 Chloride solution absorption in PSC (M1-M6-2%/WB) concrete cubes

It is clear from the results that, the chloride solution absorption was increase at an initial time interval (31-61th) for in the case of PSC control concrete cubes (M1-2%-7.04%, M2-2%-10.53%, M3-2%-8.21%, M4-2%-7.48%, M5-2%-4.58%, and M6-2%-4.86%), as when compare to solvent-based impregnation concrete cubes (M1WB-2.98%, M2WB-9.97%, M3WB-8.83%, M4WB-11.39%, M5WB-8.03%, and M6WB-4.85%). Chloride solution absorption was increase at longer time interval (31-160th) for in the case of PSC control concrete cubes (M1-2%-99.23%, M2-2%-98.23%, M3-2%-98.92%, M4-2%-97.58%, M5-2%-98.86%, and M6-2%-97.18%), as when compare to solvent-based impregnation concrete cubes (M1WB-98.47%, M2WB-97%, M3WB-98.47%, M4WB-96.96%, M5WB-98.37%, and M6WB-96.95%) as when compare to an initial time duration (31-61th) day respectively.

The variations in chloride solution absorption with moisture content (Mc = 3%) for in the case of FSC control/IC (WB) concrete cubes at different time interval (31-61th), (31-91th), (31-121th), and (31-160th) day as shown in (Figure 4-161) respectively. It is clear from the results that, the chloride solution absorption was increase at an initial time interval (31-61th) for in the case of FSC control concrete cubes (M1-3%-43.38%, M2-3%-47.89%, M3-3%-58.78%, M4-3%-33.57%, M5-3%-55.67%, and M6-3%-67.45%), as when compare to solvent-based impregnation concrete cubes (M1WB-52.08%, M2WB-63.38%, M3WB-19.34%, M4WB-20.34%, M5WB-16.45%, and

M6WB-17.06%). Chloride solution absorption was increase at longer time interval (31-160th) for in the case of PSC control concrete cubes (M1-3%-99.06%, M2-3%-97.88%, M3-3%-99%, M4-3%-98.24%, M5-3%-98.95%, and M6-3%-98.78%), as when compare to solvent-based impregnation concrete cubes (M1WB-99.04%, M2WB-98.67%, M3WB-98.69%, M4WB-98.63%, M5WB-97.72%, and M6WB-98.36%) as when compare to an initial time duration (31-61th) day respectively.



	M1-3%	M2-3%	M3-3%	M4-3%	M5-3%	M6-3%	M1WB	M2WB	M3WB	M4WB	M5WB	M6WB
🟨 (31-160) days incr(%)	99.06	97.88	99.00	98.24	98.95	98.78	99.04	98.67	98.69	98.63	97.72	98.36
▨ (31-121) days incr(%)	98.00	96.05	98.38	96.78	97.93	98.51	98.12	97.63	97.96	97.84	96.81	97.53
🟧 (31-91) days, incr(%)	97.11	93.30	97.74	95.97	95.92	96.69	95.76	91.81	95.22	93.21	93.15	95.62
🟦 (31-61) days, icr(%)	43.38	47.89	58.78	33.57	55.67	67.45	52.08	63.38	19.34	20.34	16.45	17.06

Figure 4-161 Chloride solution absorption in FSC (M1-M6-3%/WB) concrete cubes

4.9.3 Summary

This chapter summarises the main results and discussion about results from the present research work. From this present research work, it is possible to interpret the variations in hardness value, near surface characteristics, rate of absorption capacity, chloride solution absorption and penetration under various exposure conditions at different drill depths in the concrete cubes/slabs. It is also possible to interpret chloride solution absorption in the concrete cubes with finite moisture content as per present research work.

- The concrete cube hardness was vary exponentially with an increased concrete compressive strength in the designed concrete mix.

- It is confirm from the results that, the concrete hardness value of the concrete cubes was increase with lower w/c ratio, and higher compressive strength.

- The concrete cube was also characterize by an ultrasonic pulse velocity, which is vary linearly with an increased concrete compressive strength in the designed concrete mix.

- From the present research work, it is clear from the results that, an ultrasonic pulse velocity was higher at lower w/c ratio, and higher concrete compressive strength.

- The sorptivity coefficient in the concrete cubes was increases with lower cumulative absorption in the designed concrete mix.

- The water diffusion coefficient was lesser at lower sorptivity coefficient, it goes on increases with an increased sorptivity coefficient up to certain time duration, and after that, it reaches equilibrium state in the concrete cubes.

- The ratio of sorptivity-desorptivity coefficient was vary linearly and proportional to each other with time duration in the concrete cubes.

- The near surface characteristics assess by an ISAT was higher in DCC concrete cubes as when compare to PSC/FSC concrete cubes with higher concrete compressive strength and varied slump value.

- ISAT was higher in the concrete cubes with lower concrete compressive strength, and goes on decreases with higher concrete compressive strength and constant slump value under various exposures condition.

- For lower w/c ratio, ISAT was decrease in the concrete cubes with higher concrete compressive strength, and goes on increases with lower concrete compressive strength and higher w/c ratio under various exposures condition.

- The chloride solution absorption was higher in the DCC control concrete and an impregnation concrete cubes (SB/WB) as when compare to PSC/FSC concrete cubes.

- The chloride solution absorption was predominantly decrease for in case of impregnation concrete cubes (SB) as when compare to an impregnation concrete cubes (WB) under various exposures condition.

- The chloride solution penetration/chloride diffusion coefficient was higher at different drill depths for in the case of control DCC and an impregnation concrete cubes/slabs (SB/WB) as when compare to PSC/FSC control and an impregnation concrete cubes/slabs (SB/WB) under various exposures condition.

- From an extensive present research work, its confirm that, the chloride solution absorption was higher for in the case of control DCC and an impregnation concrete cubes (SB/WB) with finite moisture content (Mc = 0%) as when compare to PSC (Mc = 2%)/FSC (Mc = 3%) control and an impregnation concrete cubes (SB/WB) under various exposures condition.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objectives of this research was to investigate the performance of impregnation material on concrete cubes/slabs under pre-conditioning such as dry/partially/fully saturated condition. The cyclic wetting and drying tests can be view for the most part as a test of sorption cycles. At any partially saturated condition, sorption is the governing mechanism until a state of saturation has occurred, at which time diffusion becomes the controlling mechanism in the surface layers of the concrete. For different types of concrete, varying time lengths are required to achieve a state of saturation. Although in reality for low w/c concretes, a true state of saturation is difficult to obtain. The rate of sorption, in turn the sorptivity is govern by the pore structure of the concrete and its moisture content. The conclusions based on the investigations presented in this thesis are present as follows.

- The concrete cube hardness was vary exponentially with an increased concrete compressive strength and varied slump value in the designed concrete mix.

- It is confirm from the results that, the concrete hardness value of the concrete cubes was increase with lower w/c ratio, and higher compressive strength with varied slump value.

- The concrete cube was also characterize by an ultrasonic pulse velocity, which is vary linearly with an increased concrete compressive strength in the designed concrete mix.

- It is clear from the results that, an ultrasonic pulse velocity was higher at lower w/c ratio, and higher concrete compressive strength.

- The sorptivity coefficient in the concrete cubes was increases with lower cumulative absorption in the designed concrete mix. It is possible to establish power type of an equation between sorptivity coefficient and square root of time/water diffusion coefficient for designed concrete mix.

- The water diffusion coefficient was lesser at lower sorptivity coefficient, it goes on increases with an increased sorptivity coefficient up to certain time duration, and after that, it reaches equilibrium state in the concrete cubes. In fact from this research work that, it is possible to establish logarithmic relationship between water diffusion coefficient and square root of time.

- The ratio of sorptivity-desorptivity coefficient was vary linearly and proportional to each other with time duration in the concrete cubes.

- The near surface characteristics assess by an ISAT was higher in DCC concrete cubes as when compare to PSC/FSC concrete cubes with higher concrete compressive strength and varied slump value. In fact, the moisture content can have negative influence on measured results of various types of concrete. The moisture content was reduced water absorption capacity and thus it is advisable to dry test specimens prior to testing in the ISAT.

- ISAT was higher in the concrete cubes with lower concrete compressive strength, and goes on decreases with higher concrete compressive strength and constant slump value under various exposures condition.

- For lower w/c ratio, ISAT was decrease in the concrete cubes with higher concrete compressive strength, and goes on increases with lower concrete compressive strength and higher w/c ratio under various exposures condition.

- The chloride solution absorption was higher in the DCC control concrete and an impregnation concrete cubes (SB/WB) as when compare to PSC/FSC concrete cubes.

- The chloride solution absorption was predominantly decrease for in case of impregnation concrete cubes (SB) as when compare to an impregnation concrete cubes (WB) under various exposures condition.

- The chloride solution penetration/chloride diffusion coefficient was higher at different drill depths for in the case of control DCC and an impregnation concrete cubes/slabs (SB/WB) as when compare to PSC/FSC control and an impregnation concrete cubes/slabs (SB/WB) under various exposures condition.

- From an extensive present research work, its confirm that, the chloride solution absorption was higher for in the case of control DCC and an impregnation concrete cubes (SB/WB) with finite moisture content (Mc = 0%) as when compare to PSC (Mc = 2%)/FSC (Mc = 3%) control and an impregnation concrete cubes (SB/WB) under various exposures condition.

5.2 Recommendation for the future research work

The sodium chloride (road salt) is use throughout the winter months in order to clear iced roads. Road salt can be an effective and economical choice for de-icing when applied correctly as part of a comprehensive highway de-icing management system. However, numerous studies have documented the negative effects of road salt on forest and aquatic ecosystems, drinking water, vehicles, and infrastructure. When considering these negative effects, the effectiveness and economical arguments for road salt are call into question, as these often hidden, chronic, and cumulative costs may outweigh the short-term benefits. Due to that, maintenance costs of reinforced concrete infrastructure (bridges, tunnels, harbours, parking structures) are increasing due to aging of structures under aggressive exposure. Corrosion of reinforcement due to chloride ingress is the main problem for existing structures in marine and de-icing salt environments. Corrosion cannot be rule out completely for new infrastructure, even with today’s emphasis on design for long service life.

- The proper evaluation of concrete ingredient material were necessary in order to interpret an exact magnitude of sorptivity in pre-conditioned concrete structure.

- An extensive research work is need to investigate the size effect in salt ponding test for long-term duration in concrete structure.

- There is need to study the near surface characteristics of concrete structure for in the case of different designed concrete mix under various exposures condition.

- There is an extensive research work is needed in the field of absorption characteristics of water/chloride solution in pre-conditioned concrete structure.

- An extensive investigation should be carry out in the field of water/chloride diffusion coefficient and surface chloride concentration for in the case of different mixtures type.

- There is a need to understand the effectiveness of the performance of impregnation material on concrete structure in different exposure condition such as dry/partially/fully saturated condition.

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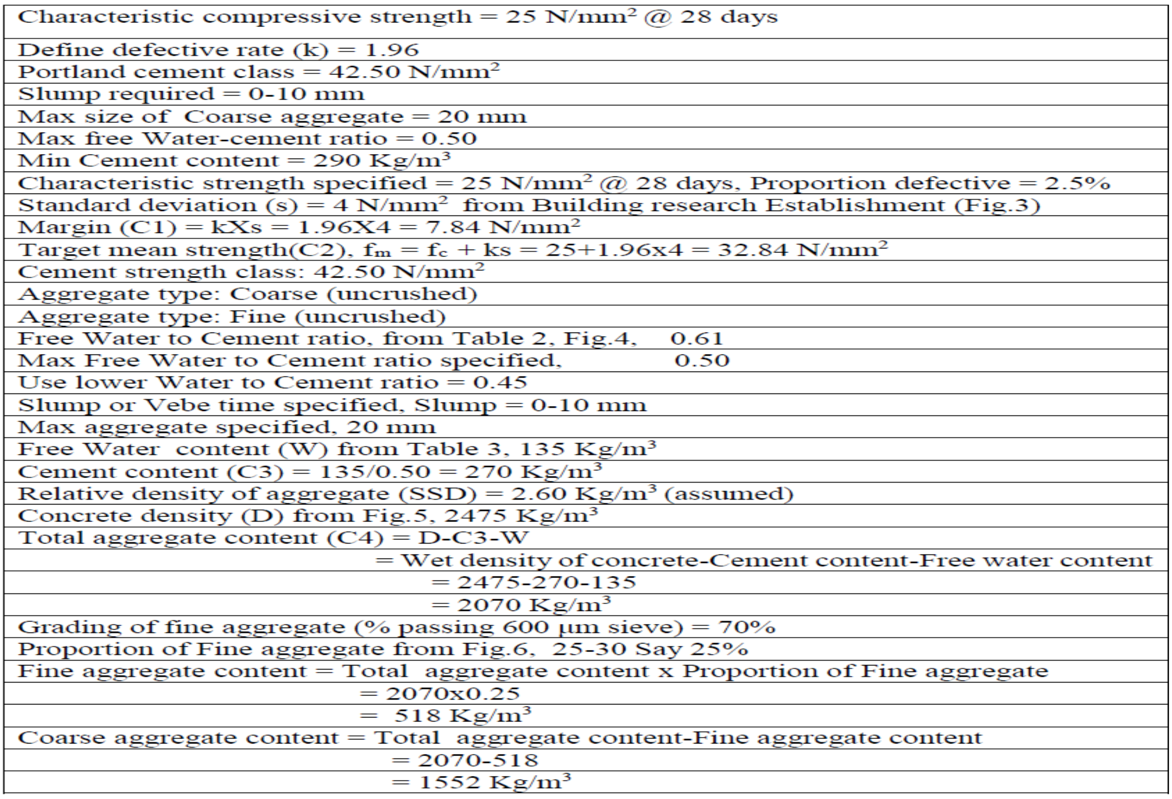
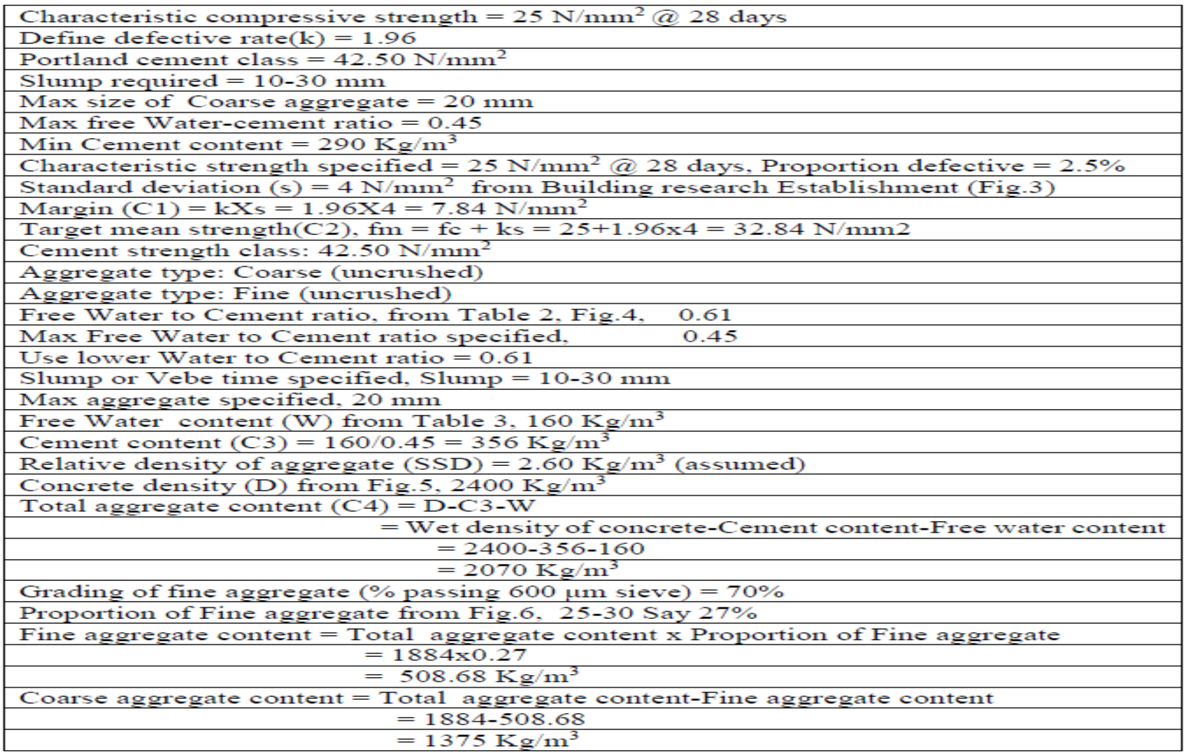
APPENDIX 1 Concrete mixes design

Table 1 Concrete mixes design for characteristic compressive strength (25 N/mm^2)



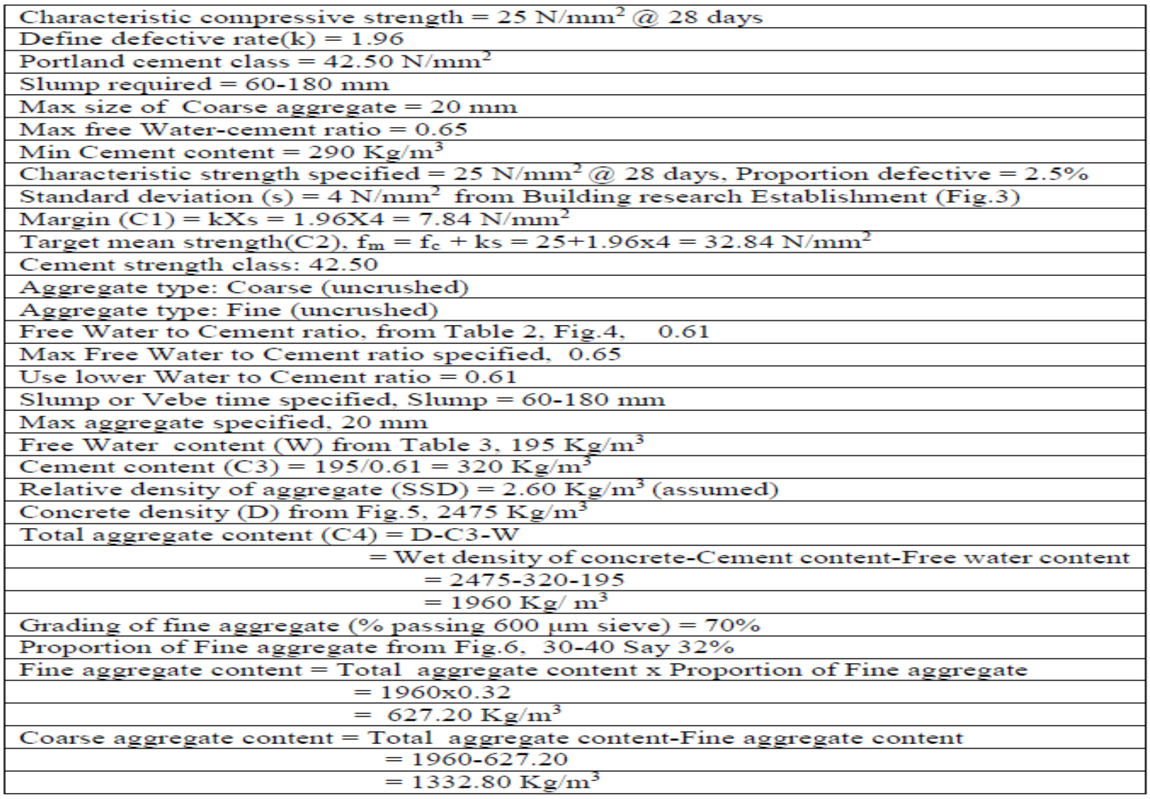
Characteristic compressive strength = 25 N/mm^2 @ 28 days
Define defective rate (k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 0-10 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.50
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 25 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks = 25+1.96x4 = 32.84$ N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.61
Max Free Water to Cement ratio specified, 0.50
Use lower Water to Cement ratio = 0.45
Slump or Vebe time specified, Slump = 0-10 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 135 Kg/m^3
Cement content (C3) = 135/0.50 = 270 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2475 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2475-270-135
= 2070 Kg/m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 25%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 2070x0.25
= 518 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 2070-518
= 1552 Kg/m^3

Table 2 Concrete mixes design for characteristic compressive strength (25 N/mm^2)



Characteristic compressive strength = 25 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 10-30 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.45
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 25 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), fm = fc + ks = 25+1.96x4 = 32.84 N/mm2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.61
Max Free Water to Cement ratio specified, 0.45
Use lower Water to Cement ratio = 0.61
Slump or Vebe time specified, Slump = 10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 160 Kg/m^3
Cement content (C3) = 160/0.45 = 356 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2400 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-356-160
= 2070 Kg/m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 27%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1884x0.27
= 508.68 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1884-508.68
= 1375 Kg/m^3

Table 3 Concrete mixes design for characteristic compressive strength (25 N/mm^2)



Characteristic compressive strength = 25 N/mm^2 @ 28 days

Define defective rate(k) = 1.96

Portland cement class = 42.50 N/mm^2

Slump required = 60-180 mm

Max size of Coarse aggregate = 20 mm

Max free Water-cement ratio = 0.65

Min Cement content = 290 Kg/m^3

Characteristic strength specified = 25 N/mm^2 @ 28 days, Proportion defective = 2.5%

Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)

Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2

Target mean strength(C2), $f_m = f_c + ks$ = 25+1.96x4 = 32.84 N/mm^2

Cement strength class: 42.50

Aggregate type: Coarse (uncrushed)

Aggregate type: Fine (uncrushed)

Free Water to Cement ratio, from Table 2, Fig.4, 0.61

Max Free Water to Cement ratio specified, 0.65

Use lower Water to Cement ratio = 0.61

Slump or Vebe time specified, Slump = 60-180 mm

Max aggregate specified, 20 mm

Free Water content (W) from Table 3, 195 Kg/m^3

Cement content (C3) = 195/0.61 = 320 Kg/m^3

Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)

Concrete density (D) from Fig.5, 2475 Kg/m^3

Total aggregate content (C4) = D-C3-W

= Wet density of concrete-Cement content-Free water content

= 2475-320-195

= 1960 Kg/ m^3

Grading of fine aggregate (% passing 600 μm sieve) = 70%

Proportion of Fine aggregate from Fig.6, 30-40 Say 32%

Fine aggregate content = Total aggregate content x Proportion of Fine aggregate

= 1960x0.32

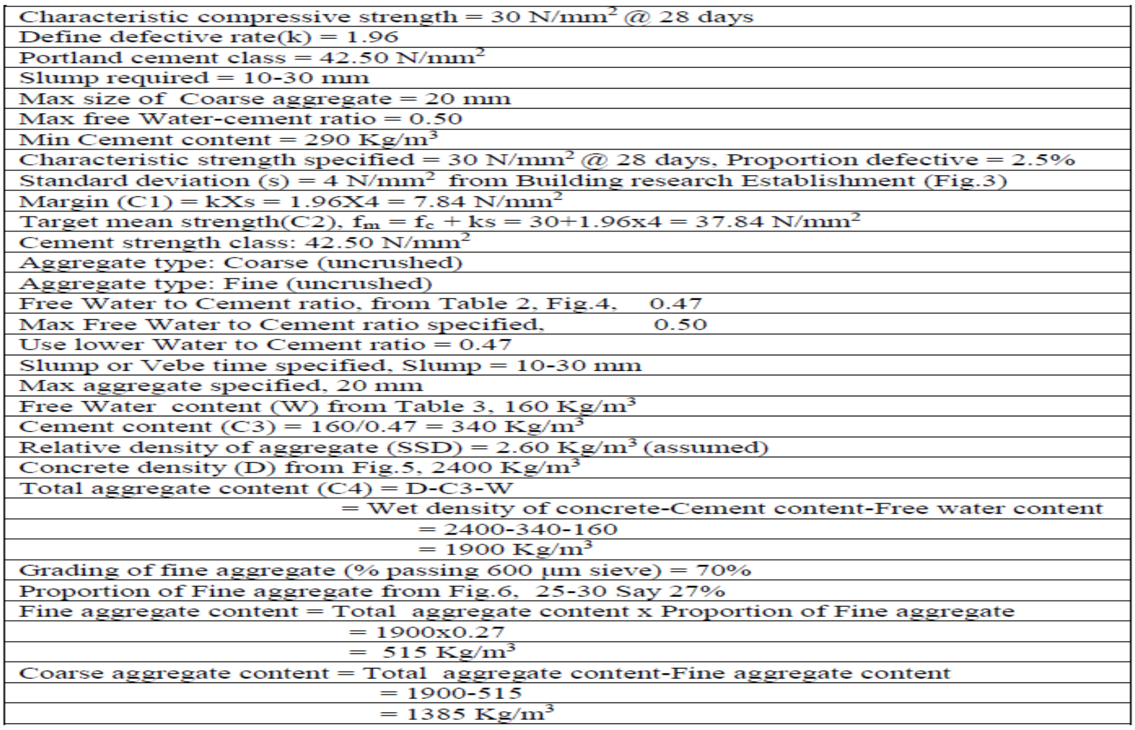
= 627.20 Kg/m^3

Coarse aggregate content = Total aggregate content-Fine aggregate content

= 1960-627.20

= 1332.80 Kg/m^3

Table 4 Concrete mixes design for characteristic compressive strength (30 N/mm^2)



Characteristic compressive strength = 30 N/mm^2 @ 28 days

Define defective rate(k) = 1.96

Portland cement class = 42.50 N/mm^2

Slump required = 10-30 mm

Max size of Coarse aggregate = 20 mm

Max free Water-cement ratio = 0.50

Min Cement content = 290 Kg/m^3

Characteristic strength specified = 30 N/mm^2 @ 28 days, Proportion defective = 2.5%

Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)

Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2

Target mean strength(C2), $f_m = f_c + ks$ = 30+1.96x4 = 37.84 N/mm^2

Cement strength class: 42.50 N/mm^2

Aggregate type: Coarse (uncrushed)

Aggregate type: Fine (uncrushed)

Free Water to Cement ratio, from Table 2, Fig.4, 0.47

Max Free Water to Cement ratio specified, 0.50

Use lower Water to Cement ratio = 0.47

Slump or Vebe time specified, Slump = 10-30 mm

Max aggregate specified, 20 mm

Free Water content (W) from Table 3, 160 Kg/m^3

Cement content (C3) = 160/0.47 = 340 Kg/m^3

Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)

Concrete density (D) from Fig.5, 2400 Kg/m^3

Total aggregate content (C4) = D-C3-W

= Wet density of concrete-Cement content-Free water content

= 2400-340-160

= 1900 Kg/m^3

Grading of fine aggregate (% passing 600 μm sieve) = 70%

Proportion of Fine aggregate from Fig.6, 25-30 Say 27%

Fine aggregate content = Total aggregate content x Proportion of Fine aggregate

= 1900x0.27

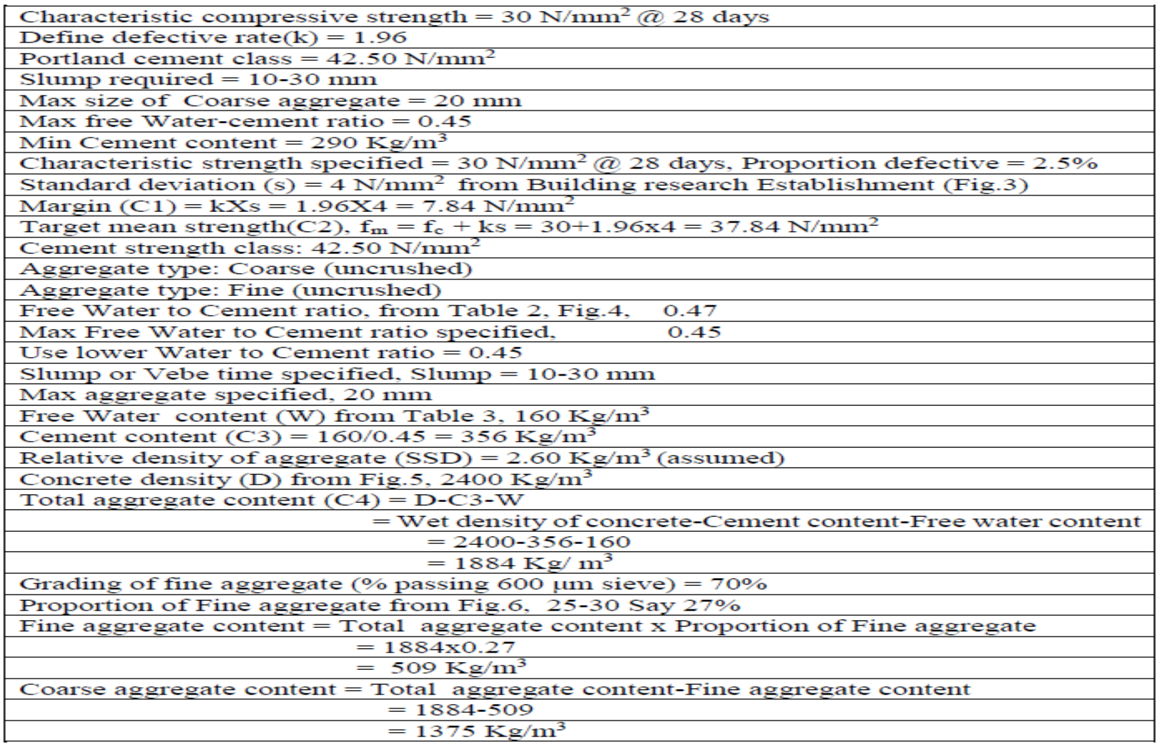
= 515 Kg/m^3

Coarse aggregate content = Total aggregate content-Fine aggregate content

= 1900-515

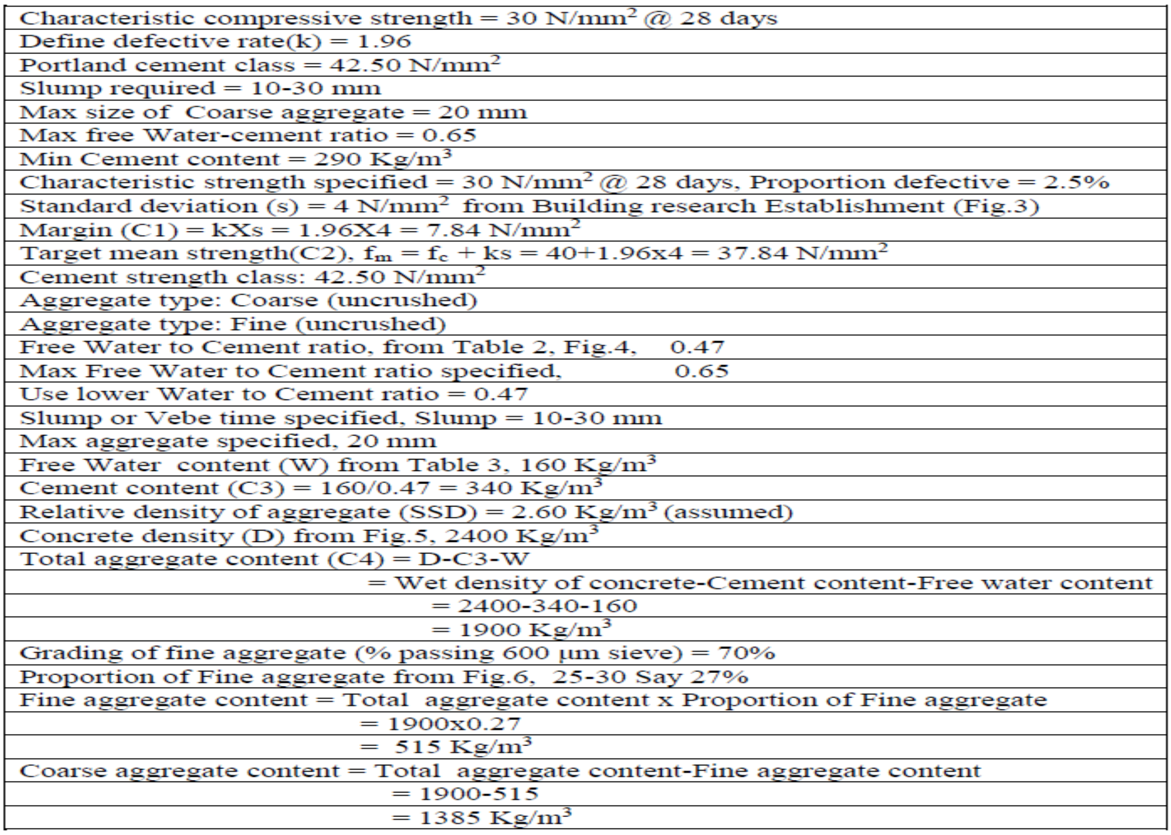
= 1385 Kg/m^3

Table 5 Concrete mixes design for characteristic compressive strength (30 N/mm^2)



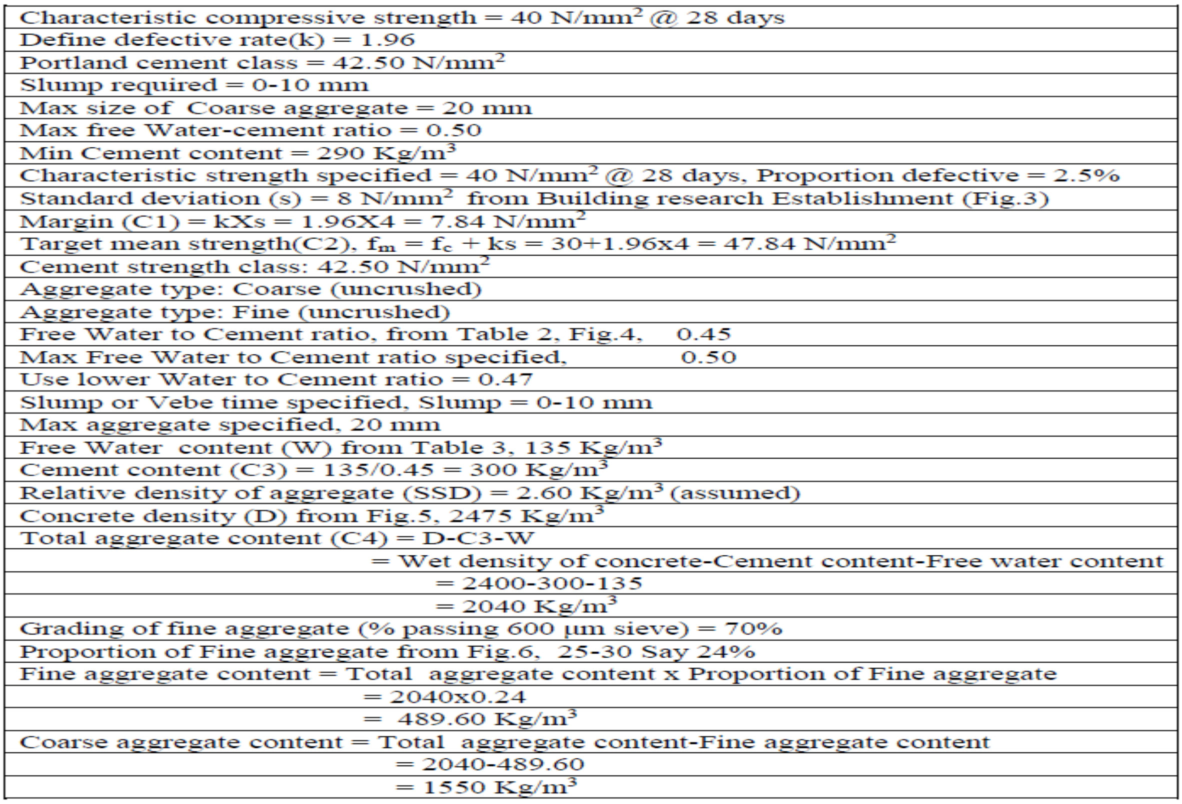
Characteristic compressive strength = 30 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 10-30 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.45
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 30 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks = 30+1.96x4 = 37.84$ N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.47
Max Free Water to Cement ratio specified, 0.45
Use lower Water to Cement ratio = 0.45
Slump or Vebe time specified, Slump = 10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 160 Kg/m^3
Cement content (C3) = 160/0.45 = 356 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2400 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-356-160
= 1884 Kg/ m^3
Grading of fine aggregate (% passing 600 μm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 27%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1884x0.27
= 509 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1884-509
= 1375 Kg/m^3

Table 6 Concrete mixes design for characteristic compressive strength (30 N/mm^2)



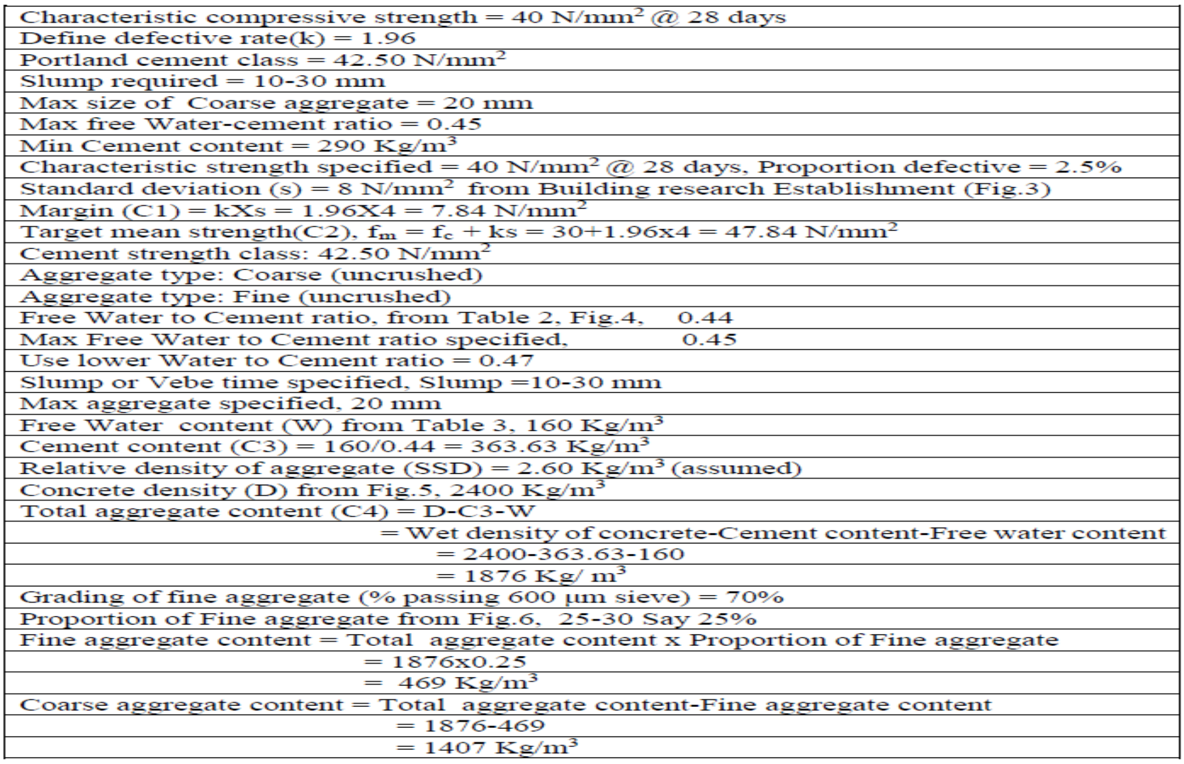
Characteristic compressive strength = 30 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 10-30 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.65
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 30 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks = 40+1.96x4 = 37.84$ N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.47
Max Free Water to Cement ratio specified, 0.65
Use lower Water to Cement ratio = 0.47
Slump or Vebe time specified, Slump = 10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 160 Kg/m^3
Cement content (C3) = 160/0.47 = 340 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2400 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-340-160
= 1900 Kg/m^3
Grading of fine aggregate (% passing 600 μm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 27%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1900x0.27
= 515 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1900-515
= 1385 Kg/m^3

Table 7 Concrete mixes design for characteristic compressive strength (40 N/mm^2)



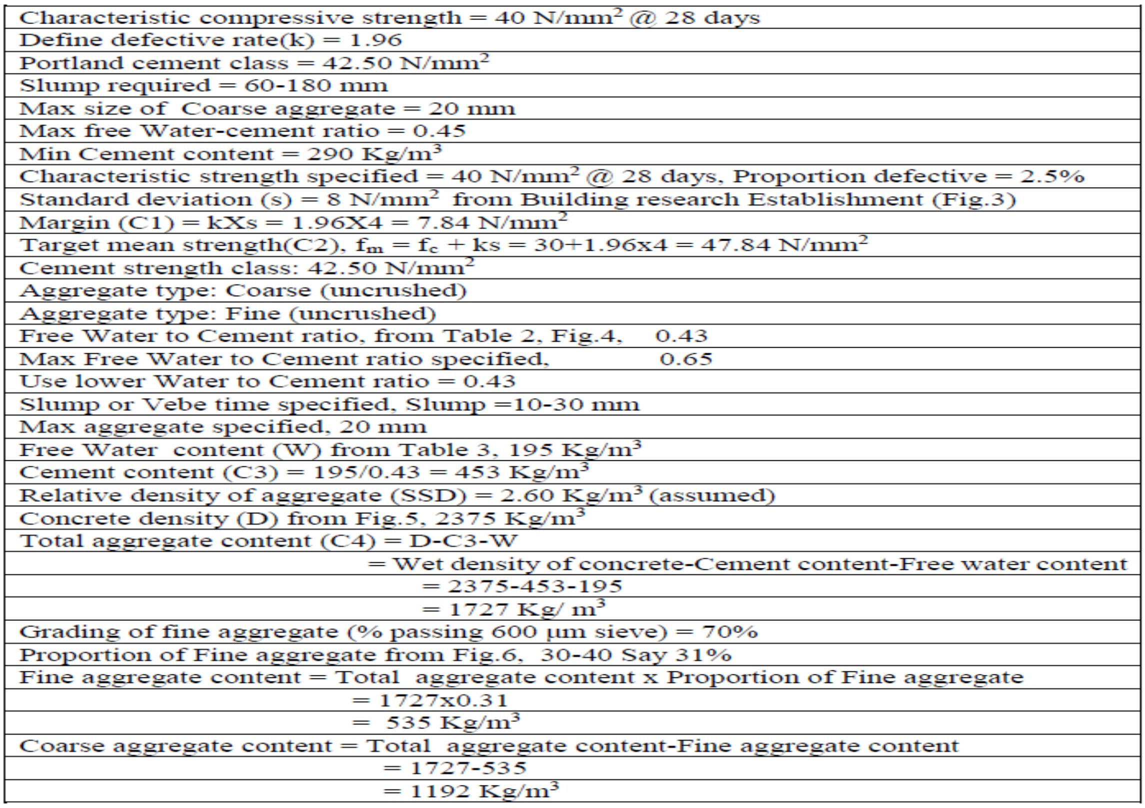
Characteristic compressive strength = 40 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 0-10 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.50
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 40 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 8 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 30+1.96x4 = 47.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.45
Max Free Water to Cement ratio specified, 0.50
Use lower Water to Cement ratio = 0.47
Slump or Vebe time specified, Slump = 0-10 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 135 Kg/m^3
Cement content (C3) = 135/0.45 = 300 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2475 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-300-135
= 2040 Kg/m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 24%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 2040x0.24
= 489.60 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 2040-489.60
= 1550 Kg/m^3

Table 8 Concrete mixes design for characteristic compressive strength (40 N/mm^2)



Characteristic compressive strength = 40 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 10-30 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.45
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 40 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 8 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 30+1.96x4 = 47.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.44
Max Free Water to Cement ratio specified, 0.45
Use lower Water to Cement ratio = 0.47
Slump or Vebe time specified, Slump =10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 160 Kg/m^3
Cement content (C3) = 160/0.44 = 363.63 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2400 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-363.63-160
= 1876 Kg/ m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 25%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1876x0.25
= 469 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1876-469
= 1407 Kg/m^3

Table 9 Concrete mixes design for characteristic compressive strength (40 N/mm^2)



Characteristic compressive strength = 40 N/mm^2 @ 28 days

Define defective rate(k) = 1.96

Portland cement class = 42.50 N/mm^2

Slump required = 60-180 mm

Max size of Coarse aggregate = 20 mm

Max free Water-cement ratio = 0.45

Min Cement content = 290 Kg/m^3

Characteristic strength specified = 40 N/mm^2 @ 28 days, Proportion defective = 2.5%

Standard deviation (s) = 8 N/mm^2 from Building research Establishment (Fig.3)

Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2

Target mean strength(C2), $f_m = f_c$ + ks = 30+1.96x4 = 47.84 N/mm^2

Cement strength class: 42.50 N/mm^2

Aggregate type: Coarse (uncrushed)

Aggregate type: Fine (uncrushed)

Free Water to Cement ratio, from Table 2, Fig.4, 0.43

Max Free Water to Cement ratio specified, 0.65

Use lower Water to Cement ratio = 0.43

Slump or Vebe time specified, Slump =10-30 mm

Max aggregate specified, 20 mm

Free Water content (W) from Table 3, 195 Kg/m^3

Cement content (C3) = 195/0.43 = 453 Kg/m^3

Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)

Concrete density (D) from Fig.5, 2375 Kg/m^3

Total aggregate content (C4) = D-C3-W

= Wet density of concrete-Cement content-Free water content

= 2375-453-195

= 1727 Kg/ m^3

Grading of fine aggregate (% passing 600 μm sieve) = 70%

Proportion of Fine aggregate from Fig.6, 30-40 Say 31%

Fine aggregate content = Total aggregate content x Proportion of Fine aggregate

= 1727x0.31

= 535 Kg/m^3

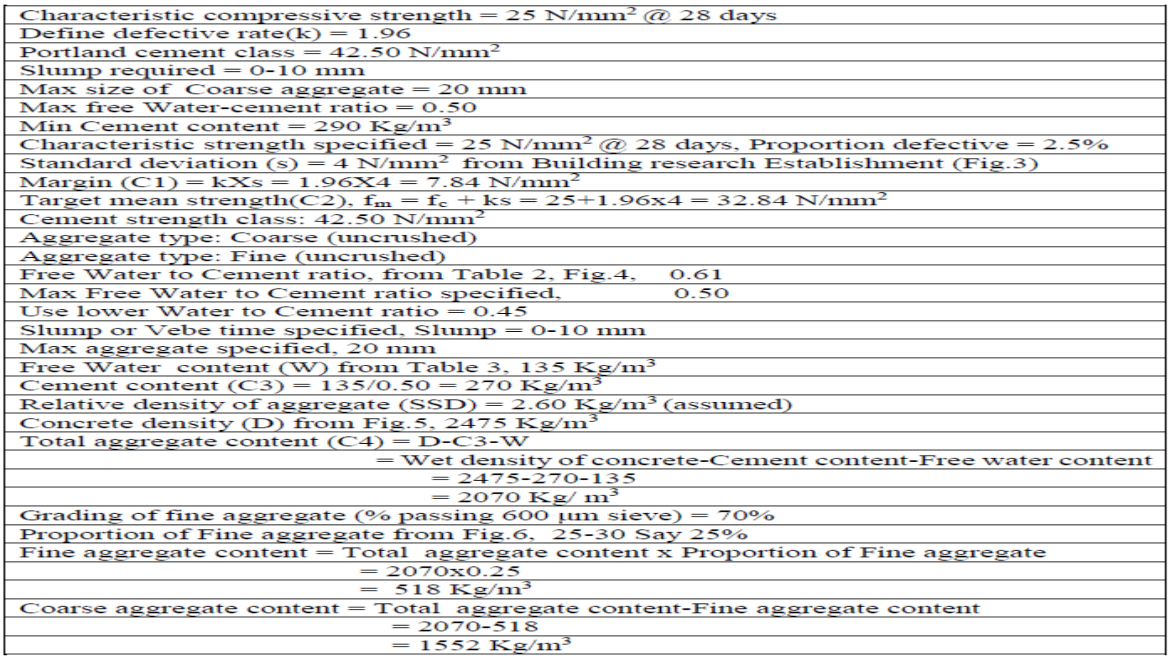
Coarse aggregate content = Total aggregate content-Fine aggregate content

= 1727-535

= 1192 Kg/m^3

Note: In all cases $^+$ indicates in which Variables (Slump value & Water-cement ratio), and Constant (Compressive strength)

Table 10 Concrete mixes design$^+$ for characteristic compressive strength (25 N/mm^2)



Characteristic compressive strength = 25 N/mm^2 @ 28 days

Define defective rate(k) = 1.96

Portland cement class = 42.50 N/mm^2

Slump required = 0-10 mm

Max size of Coarse aggregate = 20 mm

Max free Water-cement ratio = 0.50

Min Cement content = 290 Kg/m^3

Characteristic strength specified = 25 N/mm^2 @ 28 days, Proportion defective = 2.5%

Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)

Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2

Target mean strength(C2), $f_m = f_c$ + ks = 25+1.96x4 = 32.84 N/mm^2

Cement strength class: 42.50 N/mm^2

Aggregate type: Coarse (uncrushed)

Aggregate type: Fine (uncrushed)

Free Water to Cement ratio, from Table 2, Fig.4, 0.61

Max Free Water to Cement ratio specified, 0.50

Use lower Water to Cement ratio = 0.45

Slump or Vebe time specified, Slump = 0-10 mm

Max aggregate specified, 20 mm

Free Water content (W) from Table 3, 135 Kg/m^3

Cement content (C3) = 135/0.50 = 270 Kg/m^3

Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)

Concrete density (D) from Fig.5, 2475 Kg/m^3

Total aggregate content (C4) = D-C3-W

= Wet density of concrete-Cement content-Free water content

= 2475-270-135

= 2070 Kg/ m^3

Grading of fine aggregate (% passing 600 μm sieve) = 70%

Proportion of Fine aggregate from Fig.6, 25-30 Say 25%

Fine aggregate content = Total aggregate content x Proportion of Fine aggregate

= 2070x0.25

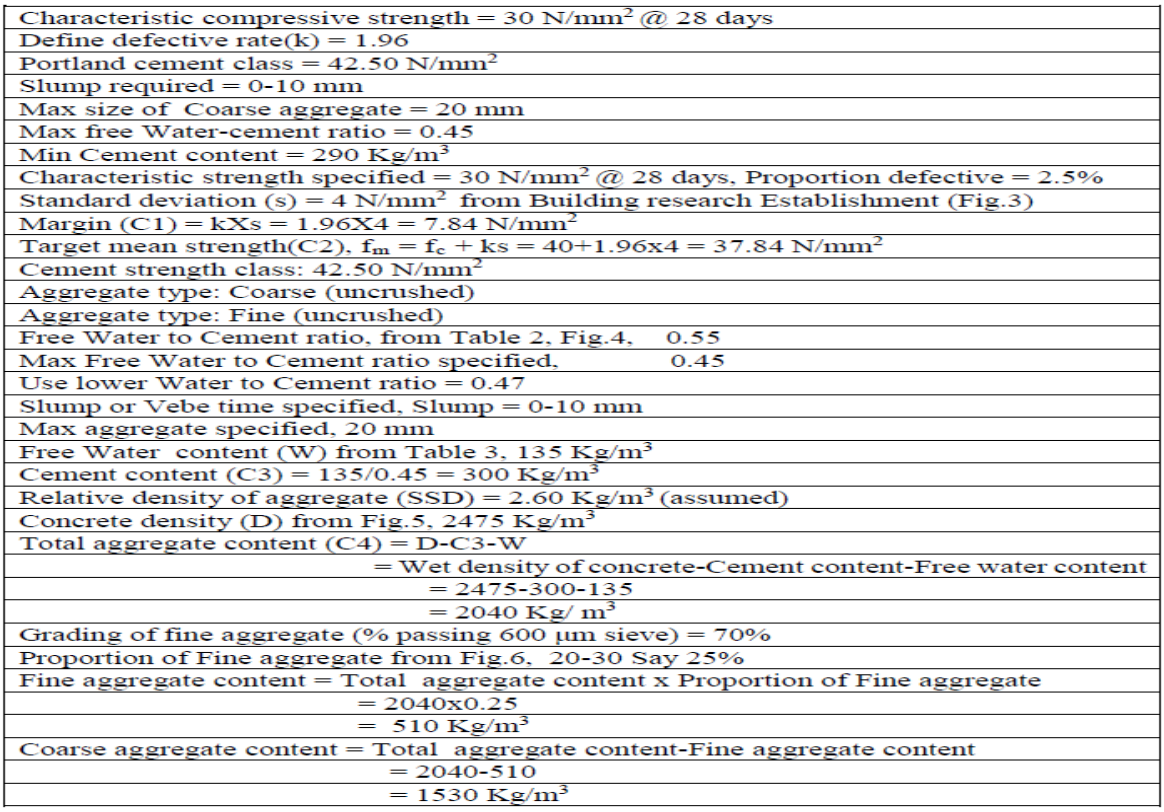
= 518 Kg/m^3

Coarse aggregate content = Total aggregate content-Fine aggregate content

= 2070-518

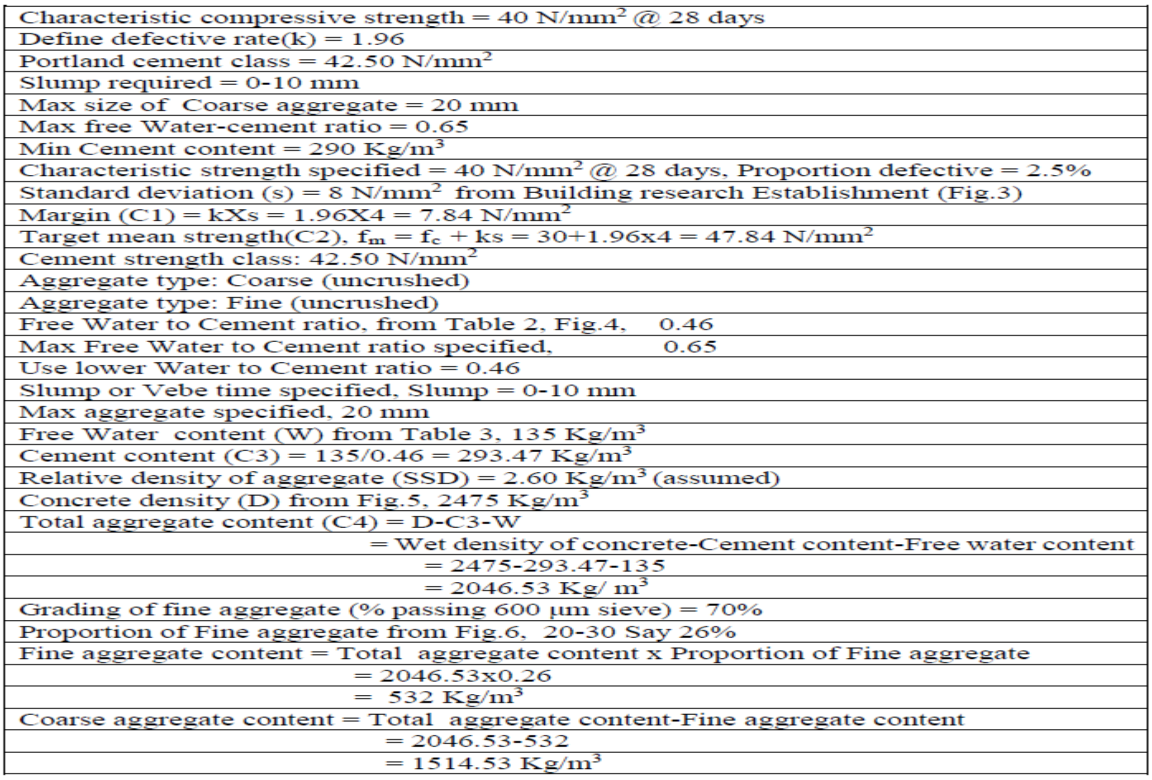
= 1552 Kg/m^3

Table 11 Concrete mixes design$^+$ for characteristic compressive strength (30 N/mm^2)



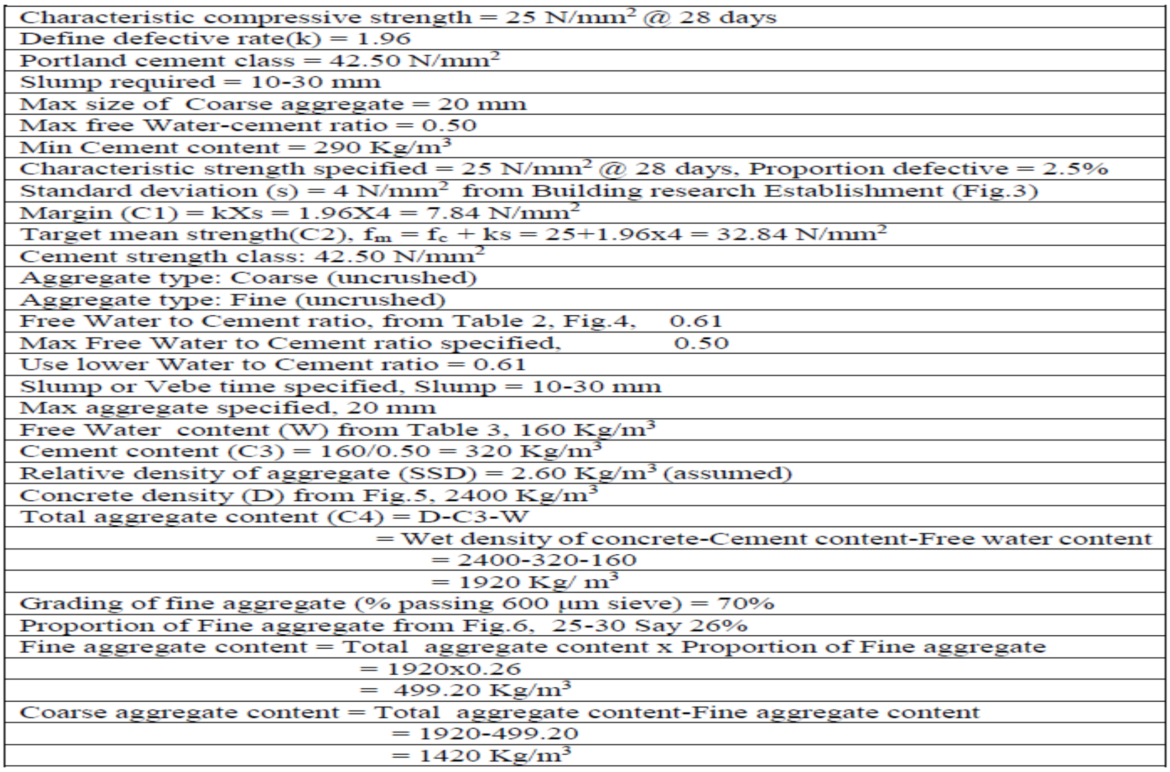
Characteristic compressive strength = 30 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 0-10 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.45
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 30 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), f_m = f_c + ks = 40+1.96x4 = 37.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.55
Max Free Water to Cement ratio specified, 0.45
Use lower Water to Cement ratio = 0.47
Slump or Vebe time specified, Slump = 0-10 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 135 Kg/m^3
Cement content (C3) = 135/0.45 = 300 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2475 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2475-300-135
= 2040 Kg/ m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 20-30 Say 25%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 2040x0.25
= 510 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 2040-510
= 1530 Kg/m^3

Table 12 Concrete mixes design$^+$ for characteristic compressive strength (40 N/mm^2)



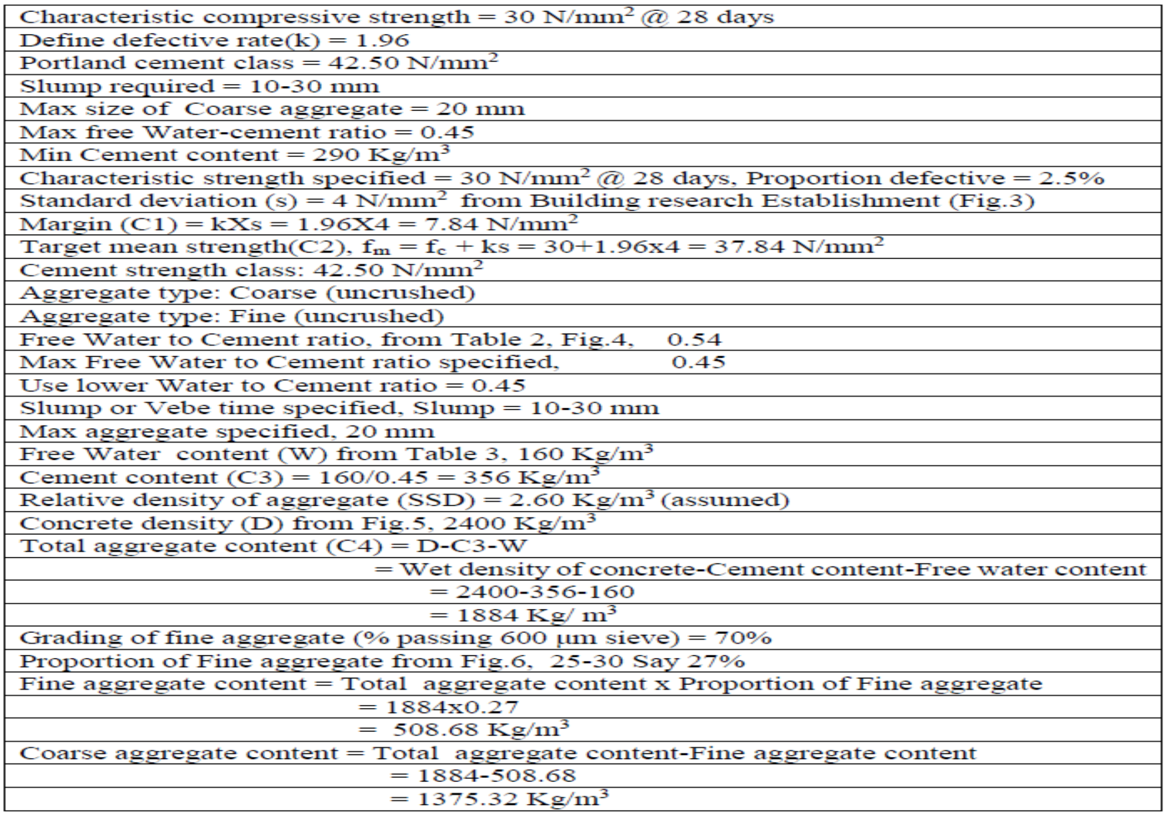
Characteristic compressive strength = 40 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 0-10 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.65
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 40 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 8 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), f_m = f_c + ks = 30+1.96x4 = 47.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.46
Max Free Water to Cement ratio specified, 0.65
Use lower Water to Cement ratio = 0.46
Slump or Vebe time specified, Slump = 0-10 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 135 Kg/m^3
Cement content (C3) = 135/0.46 = 293.47 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2475 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2475-293.47-135
= 2046.53 Kg/ m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 20-30 Say 26%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 2046.53x0.26
= 532 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 2046.53-532
= 1514.53 Kg/m^3

Table 13 Concrete mixes design$^+$ for characteristic compressive strength (25 N/mm^2)



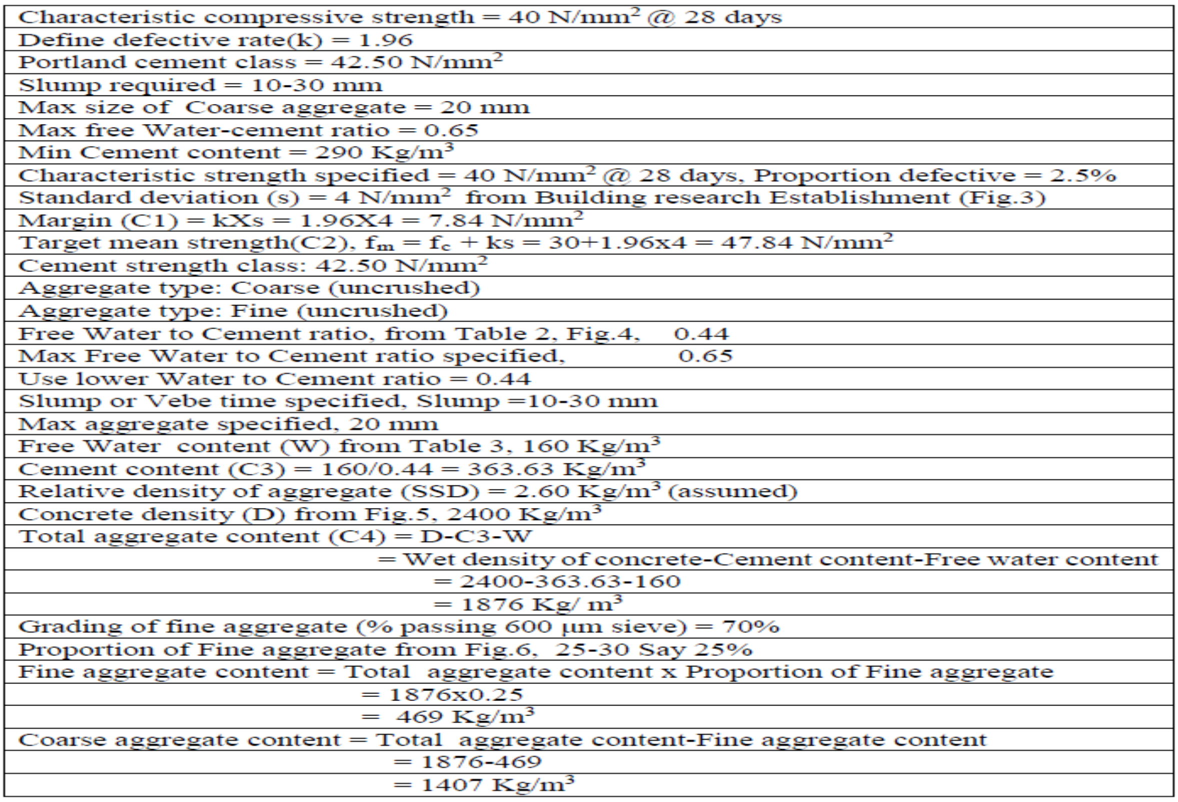
Characteristic compressive strength = 25 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 10-30 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.50
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 25 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 25+1.96x4 = 32.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.61
Max Free Water to Cement ratio specified, 0.50
Use lower Water to Cement ratio = 0.61
Slump or Vebe time specified, Slump = 10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 160 Kg/m^3
Cement content (C3) = 160/0.50 = 320 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2400 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-320-160
= 1920 Kg/ m^3
Grading of fine aggregate (% passing 600 μm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 26%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1920x0.26
= 499.20 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1920-499.20
= 1420 Kg/m^3

Table 14 Concrete mixes design$^+$ for characteristic compressive strength (30 N/ mm^2)



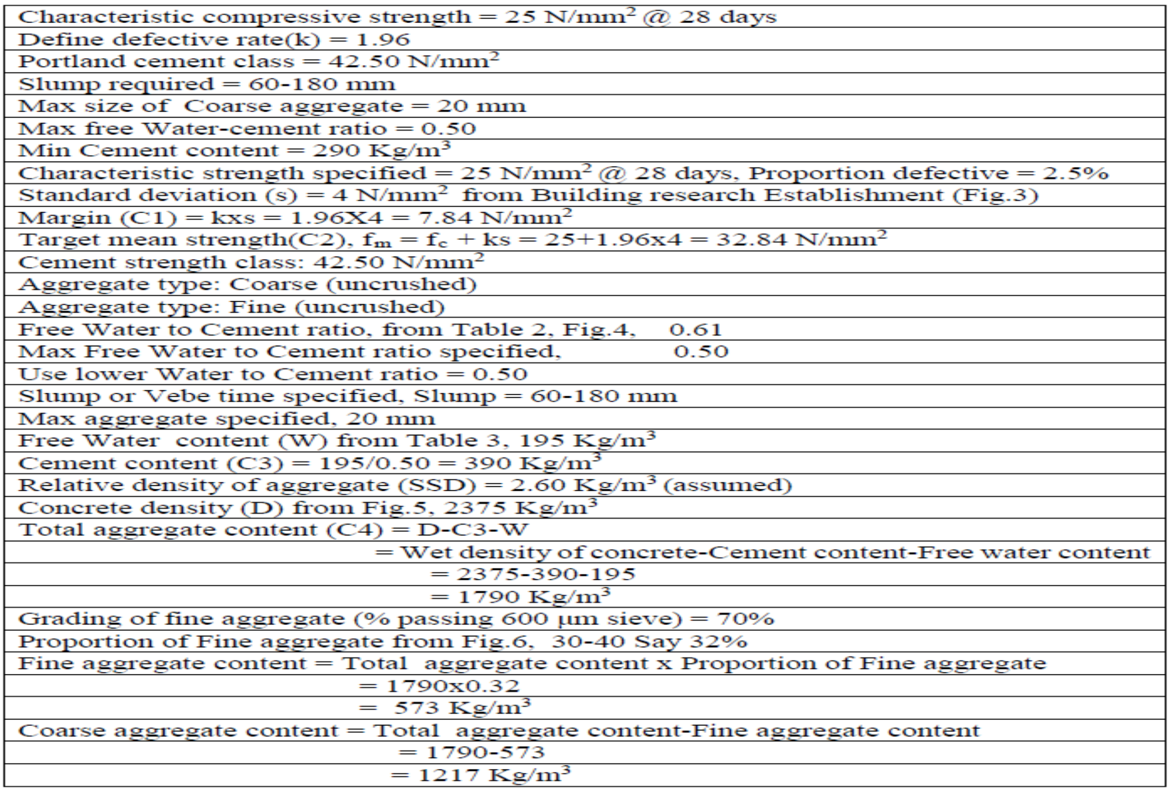
Characteristic compressive strength = 30 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 10-30 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.45
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 30 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 30+1.96x4 = 37.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.54
Max Free Water to Cement ratio specified, 0.45
Use lower Water to Cement ratio = 0.45
Slump or Vebe time specified, Slump = 10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 160 Kg/m^3
Cement content (C3) = 160/0.45 = 356 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2400 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-356-160
= 1884 Kg/ m^3
Grading of fine aggregate (% passing 600 μm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 27%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1884x0.27
= 508.68 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1884-508.68
= 1375.32 Kg/m^3

Table 15 Concrete mixes design^{+} for characteristic compressive strength (40 N/mm^2)



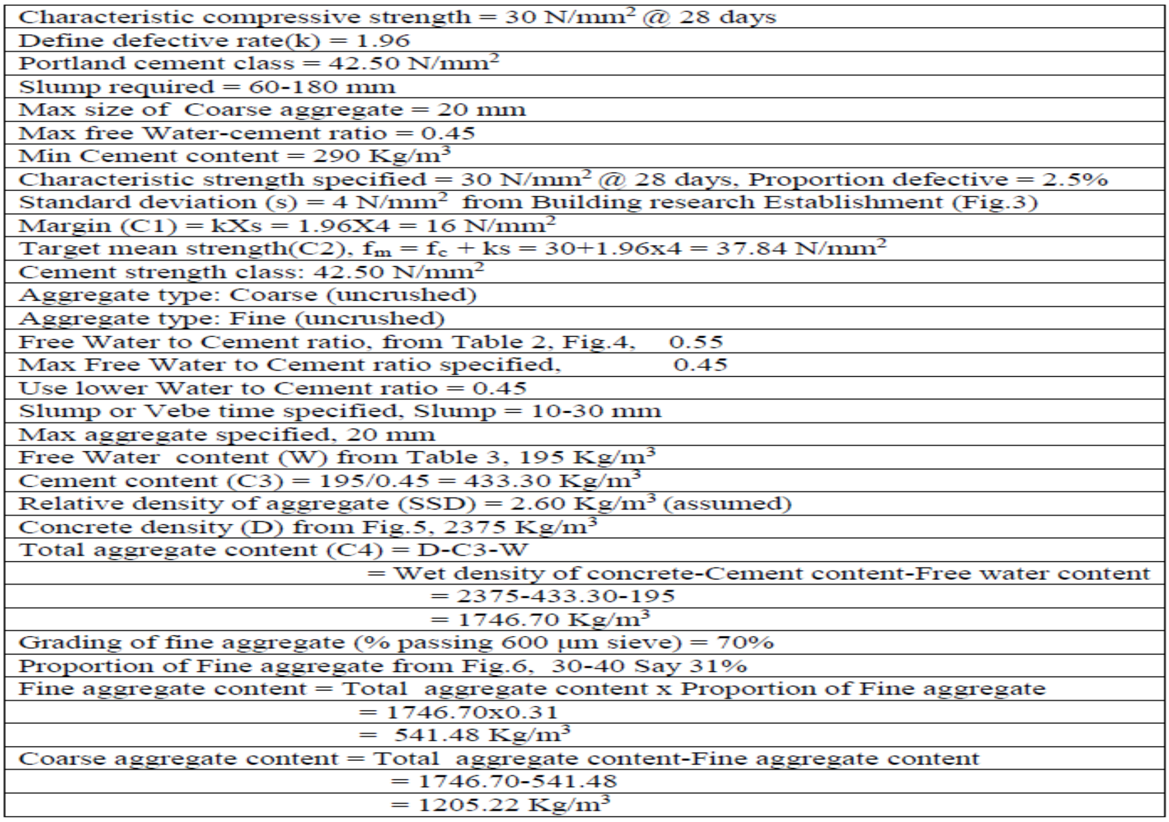
Characteristic compressive strength = 40 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 10-30 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.65
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 40 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 30+1.96x4 = 47.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.44
Max Free Water to Cement ratio specified, 0.65
Use lower Water to Cement ratio = 0.44
Slump or Vebe time specified, Slump =10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 160 Kg/m^3
Cement content (C3) = 160/0.44 = 363.63 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2400 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2400-363.63-160
= 1876 Kg/ m^3
Grading of fine aggregate (% passing 600 μm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 25-30 Say 25%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1876x0.25
= 469 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1876-469
= 1407 Kg/m^3

Table 16 Concrete mixes design^{+} for characteristic compressive strength (25 N/mm^2)



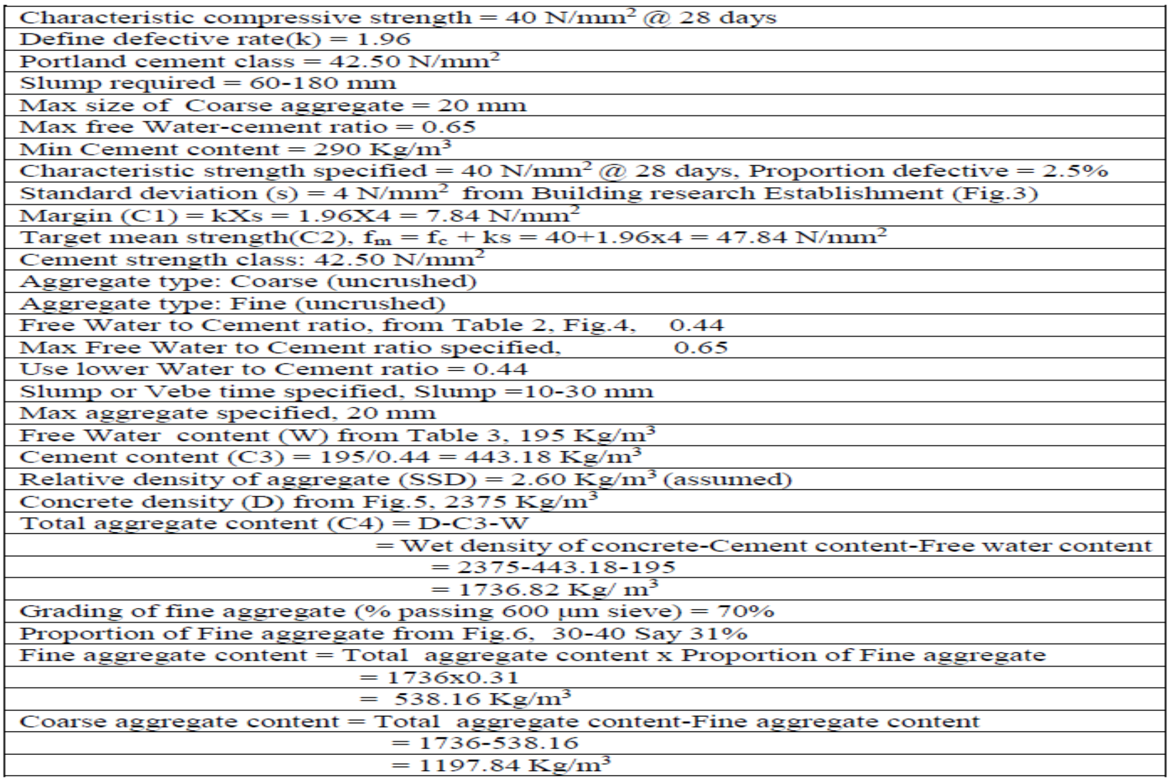
Characteristic compressive strength = 25 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 60-180 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.50
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 25 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kxs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 25+1.96x4 = 32.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.61
Max Free Water to Cement ratio specified, 0.50
Use lower Water to Cement ratio = 0.50
Slump or Vebe time specified, Slump = 60-180 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 195 Kg/m^3
Cement content (C3) = 195/0.50 = 390 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2375 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2375-390-195
= 1790 Kg/m^3
Grading of fine aggregate (% passing 600 μm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 30-40 Say 32%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1790x0.32
= 573 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1790-573
= 1217 Kg/m^3

Table 17 Concrete mixes design$^+$ for characteristic compressive strength (30 N/mm^2)



Characteristic compressive strength = 30 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 60-180 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.45
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 30 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 16 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 30+1.96x4 = 37.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.55
Max Free Water to Cement ratio specified, 0.45
Use lower Water to Cement ratio = 0.45
Slump or Vebe time specified, Slump = 10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 195 Kg/m^3
Cement content (C3) = 195/0.45 = 433.30 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2375 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2375-433.30-195
= 1746.70 Kg/m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 30-40 Say 31%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1746.70x0.31
= 541.48 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1746.70-541.48
= 1205.22 Kg/m^3

Table 18 Concrete mixes design$^+$ for characteristic compressive strength (30 N/mm^2)



Characteristic compressive strength = 40 N/mm^2 @ 28 days
Define defective rate(k) = 1.96
Portland cement class = 42.50 N/mm^2
Slump required = 60-180 mm
Max size of Coarse aggregate = 20 mm
Max free Water-cement ratio = 0.65
Min Cement content = 290 Kg/m^3
Characteristic strength specified = 40 N/mm^2 @ 28 days, Proportion defective = 2.5%
Standard deviation (s) = 4 N/mm^2 from Building research Establishment (Fig.3)
Margin (C1) = kXs = 1.96X4 = 7.84 N/mm^2
Target mean strength(C2), $f_m = f_c + ks$ = 40+1.96x4 = 47.84 N/mm^2
Cement strength class: 42.50 N/mm^2
Aggregate type: Coarse (uncrushed)
Aggregate type: Fine (uncrushed)
Free Water to Cement ratio, from Table 2, Fig.4, 0.44
Max Free Water to Cement ratio specified, 0.65
Use lower Water to Cement ratio = 0.44
Slump or Vebe time specified, Slump =10-30 mm
Max aggregate specified, 20 mm
Free Water content (W) from Table 3, 195 Kg/m^3
Cement content (C3) = 195/0.44 = 443.18 Kg/m^3
Relative density of aggregate (SSD) = 2.60 Kg/m^3 (assumed)
Concrete density (D) from Fig.5, 2375 Kg/m^3
Total aggregate content (C4) = D-C3-W
= Wet density of concrete-Cement content-Free water content
= 2375-443.18-195
= 1736.82 Kg/ m^3
Grading of fine aggregate (% passing 600 µm sieve) = 70%
Proportion of Fine aggregate from Fig.6, 30-40 Say 31%
Fine aggregate content = Total aggregate content x Proportion of Fine aggregate
= 1736x0.31
= 538.16 Kg/m^3
Coarse aggregate content = Total aggregate content-Fine aggregate content
= 1736-538.16
= 1197.84 Kg/m^3

Note: In all cases $^+$ indicates in which variables (Compressive strength & Water-cement ratio), and Constant (Slump value)

Table:19 (Variable: Slump & W/C value; Constant: Compressive strength)$^+$

Item No	Comp/Mean Target strength (N/mm^2)	Slump (mm)	w/c	Cement (Kg)	Water (Kg/lt)	FA (Kg)	CA(Kg)	
							10 mm	20 mm
1	25/32.84	0-10	0.50	270	135	518	517	1035
2	25/32.84	10-30	0.45	356	160	508	458	917
3	25/32.84	60-180	0.61	320	195	627	444	888
4	30/37.84	0-10	0.45	300	135	510	510	1020
5	30/37.84	10-30	0.45	356	160	508	458	916
6	30/37.84	60-180	0.45	433	195	541	401	803
7	40/47.84	0-10	0.45	300	135	489	516	1033
8	40/47.84	10-30	0.44	363	160	469	469	938
9	40/47.84	60-180	0.43	453	195	535	397	794

Table:20 (Variable: Compressive strength & W/C value; Constant: Slump)$^+$

Item No	Comp/Mean target strength (N/mm^2)	Slump (mm)	w/c	Cement (Kg)	Water (Kg/lt	FA (Kg)	CA(Kg)	
							10 mm	20 mm
1	25/32.84	0-10	0.50	270	135	518	517	1035
2	30/37.84	0-10	0.45	300	135	510	510	1020
3	40/47.84	0-10	0.46	293	135	532	504	1009
4	25/32.84	10-30	0.50	320	160	499	473	946
5	30/37.84	10-30	0.45	356	160	508	458	916
6	40/47.84	10-30	0.44	363	160	469	469	938
7	25/32.84	60-180	0.50	390	195	573	406	811
8	30/37.84	60-180	0.45	433	195	541	401	803
9	40/47.84	60-180	0.44	443	195	538	399	798

Table:21 Summary of aggregate property used for this research work

Aggregate property summary and Declared values (CEMEX company)										
Source Name		Attenborough Quarry								
Source Address		Long Lane, Attenborough, Nottingham, Nottinghamshire, NG9 6BL								
Size		4/20		10/20		4/10		0/4		
Test		Result	Report No	Result	Report No	Result	Report No	Result	Report No	Test method
LA				18	20448					BS EN 1097-2
Micro Deval										BS EN 1097-1
Total Sulfur*										BS EN 1744-1
Particle Density	APP	2.66	20450	2.64	20449	2.64	20447	2.69	20445	BS EN 1097-6
	OD	2.59	20450	2.60	20449	2.58	20447	2.64	20445	BS EN 1097-6
	SSD	2.62	20450	2.62	20449	2.61	20447	2.66	20445	BS EN 1097-6
Water absorption		0.90	20450	0.60	20449	0.90	20447	0.70	20445	BS EN 1097-6
Acid soluble sulfate						<0.1	326095	<0.1	326093	BS EN 1744-1
Water soluble* chloride						<0.001	326094	<0.001	312195	BS EN 1744-1
Magnesium sulphate		2	20505							BS EN 1367-2
Bulk density		1.50	20450	1.45	20449	1.50	20447	1.65	20445	BS EN 1097-3
Petrographic		Normal	4463/T 2					Normal	4463/T 1	BS812-104
Drying shrinkage				0.039	50111 862					BS EN 1367-4
Shell content										BS EN933-7
Ph value										BS EN1377-3
Aggregate impact value-Dry										BS812 Pt 112
Aggregate Abrasion value**										BS EN 1097-8
10% Fines-Oven dry										BS812 Pt 111
*Testing carried out by our competent subcontractor						**Indicates Non UKAS Accredited test				

APPENDIX 2 Non-destructive test

Table 1 Interpretation of compressive strength by RHT on DCC concrete cubes

Rebound hammer test on dry concrete cubes for different mixtures type																	
Cube ID	RHN	Comp Stg, N/mm²	Cube ID	RHN	Comp Stg, N/mm²	Cube ID	RHN	Comp Stg, N/mm²	Cube ID	RHN	Comp Stg, N/mm²	Cube ID	RHN	Comp Stg, N/mm²	Cube ID	RHN	Comp Stg, N/mm²
A1	52.58	34.5	B1	55.25	37.4	C1	53.3	34.2	D1	26.1	47.9	E1	54.1	35.6	F1	48	27.3
A2	52.08	31.6	B2	51.25	29.1	C2	52.8	33.1	D2	26.7	48.4	E2	51.4	31.3	F2	53.0	33.3
A3	50.33	29.3	B3	52.80	33.1	C3	55	36.9	D3	27.3	48.3	E3	51.7	31.5	F3	45.3	22.9
A4	51.08	32.5	B4	52.60	33.0	C4	51.5	31.2	D4	29.2	50.1	E4	52.9	33.4	F4	53.2	34.3
A5	52.08	30.0	B5	51.00	30.2	C5	52.4	32.4	D5	23.3	45.3	E5	54.2	35.9	F5	51	30.3
A6	55.08	37.5	B6	55.60	39.0	C6	52.2	32.3	D6	24.6	46.6	E6	48.7	27.4	F6	52.3	32.5
A7	51.16	30.2	B7	54.40	35.8	C7	49.5	28.8	D7	20.5	42.4	E7	51.7	31.5	F7	53.1	33.4
A8	48.5	26.9	B8	50.30	29.8	C8	56	39	D8	26.3	47.9	E8	50.6	29.8	F8	53.6	35.0
A9	52.16	35.3	B9	50.90	33.9	C9	54.6	38.3	D9	26.2	48.1	E9	51.8	32.4	F9	53.4	34.5
A10	54.58	35.4	B10	49.90	29.0	C10	53.5	34.3	D10	26	47.7	E10	52.1	31.8	F10	51.6	32.0
A11	53	34.2	B11	48.90	27.7	C11	53.7	34.7	D11	28.1	49.0	E11	52.7	32.9	F11	53.5	34.8
A12	40.58	18.7	B12	50.60	31.1	C12	55.7	38.5	D12	21.5	44.0	E12	50.3	29.4	F12	54	35.2

Table 2 Comparison of compressive strength by UPVT on DC concrete cubes

Ultrasonic pulse velocity test on dry concrete cubes for different mixtures type																	
Cube ID	UPV, m/s	Comp Stg, N/mm²	Cube ID	UPV, m/s	Comp Stg, N/mm²	Cube ID	UPV, m/s	Comp Stg, N/mm²	Cube ID	UPV, m/s	Comp Stg, N/mm²	Cube ID	UPV, m/s	Comp Stg, N/mm²	Cube ID	UPV, m/s	Comp Stg, N/mm²
A1	4276	33.5	B1	4490	36.3	C1	4367	35.4	D1	3000	23.9	E1	4400	34.9	F1	3284	31.3
A2	4368	31	B2	4274	31.2	C2	4180	33.06	D2	3788	26.7	E2	3464	32.3	F2	4060	33.1
A3	3600	29.7	B3	4274	32.6	C3	4574	36.5	D3	3600	29.3	E3	3267	31.42	F3	3464	31.5
A4	4270	32.1	B4	4470	35	C4	4150	33.2	D4	3690	29.2	E4	4367	33.1	F4	4274	34.1
A5	4360	30.7	B5	4180	30.2	C5	4474	36.4	D5	3191	25.1	E5	4500	34.9	F5	3200	30.4
A6	4900	36.9	B6	4700	36.8	C6	4274	34.1	D6	3225	27	E6	3264	31.4	F6	4300	33.5
A7	4366	30.4	B7	4200	35	C7	4267	32.8	D7	3259	26.5	E7	3100	31.5	F7	4184	33.4
A8	4365	31.3	B8	4360	31.2	C8	4974	40	D8	3016	26.5	E8	3367	31.4	F8	4374	34.8
A9	4568	33.5	B9	4700	37.6	C9	4184	33.3	D9	3900	27.2	E9	4274	32.55	F9	4464	34.5
A10	4485	34.8	B10	4174	30.8	C10	4464	34.4	D10	3950	28	E10	3200	31.7	F10	4300	33
A11	4675	34	B11	4367	31.7	C11	4574	36.7	D11	3930	28.9	E11	3364	32.7	F11	4474	34.8
A12	3934	32.1	B12	4274	34.7	C12	4874	37.7	D12	3791	27.7	E12	3184	31.4	F12	4584	36.5

APPENDIX 3 Sorptivity test

Table 1 water absorption in concrete cubes for different mixtures type

Mix ID	Average,%	Min,value(%)	Max,value(%)	STD
M1	2.52	1.34	0.44	4.02
M2	3.02	1.64	0.58	4.96
M3	2.43	1.32	0.49	3.91
M4	3.77	2.05	0.63	6.08
M5	2.64	1.43	0.55	4.24
M6	2.53	1.32	0.45	4.00

Table 2 sorptivity coefficient in concrete cubes for different mixtures type

Mix ID	Average	Min,value	Max,value	STD
M1	0.00029	0.00027	0.00092	0.00004
M2	0.00035	0.00033	0.00113	0.00005
M3	0.00027	0.00026	0.00089	0.00004
M4	0.00043	0.00041	0.00148	0.00007
M5	0.00030	0.00027	0.00092	0.00005
M6	0.00029	0.00027	0.00091	0.00004

Table 3 moisture content in concrete cubes for different mixtures type

Mix ID	Average,%	Min,value(%)	Max,value(%)	STD
M1	2.61	1.41	4.19	0.44
M2	3.15	1.75	5.23	0.59
M3	2.52	1.41	4.10	0.50
M4	3.97	2.22	6.48	0.64
M5	2.75	1.53	4.45	0.55
M6	2.63	1.40	4.20	0.45

Table 4 Cumulative absorption in concrete cubes for different mixtures type

Mix ID	Average,%	Min,value(%)	Max,value(%)	STD
M1	0.0058	0.0031	0.0093	0.0010
M2	0.0069	0.0038	0.0115	0.0013
M3	0.0054	0.0030	0.0088	0.0011
M4	0.0084	0.0047	0.0137	0.0013
M5	0.0060	0.0033	0.0097	0.0012
M6	0.0057	0.0030	0.0091	0.0010

Table 5 Water diffusion coefficient in concrete cubes for different mixtures type

Mix ID	Average	Min,value	Max,value	STD
M1	1.09	0.47	2.20	0.56
M2	1.17	0.47	2.37	0.61

M3	1.15	0.47	2.27	0.56
M4	1.20	0.47	2.44	0.57
M5	1.13	0.47	2.20	0.55
M6	1.05	0.47	2.07	0.54

Table 6 Desorptivity coefficient in concrete cubes for different mixtures type

Mix ID	Average	Min,value	Max,value	STD
M1	8.41	0.24	41.74	11.55
M2	9.98	0.31	46.69	13.20
M3	8.80	0.31	41.10	11.60
M4	12.86	0.36	60.38	17.09
M5	8.04	0.30	36.46	10.49
M6	7.95	0.21	37.44	10.59

APPENDIX 4 Initial surface absorption test

Table.1 ISAT on dry concrete cubes at various time interval in different mixtures type

ISAT, ml/m²/s on dry concrete cubes at various time interval in different mixtures type											
CUBE ID	10 min	30 min	60 min	CUBE ID	10 min	30 min	60 min	CUBE ID	10 min	30 min	60 min
A1	2.1	1.45	1.15	B1	2.90	1.95	1.45	C1	2.00	1.90	1.20
A2	2.1	1.45	1.20	B2	2.80	1.95	1.45	C2	2.40	1.80	1.20
A3	2.00	1.40	1.15	B3	1.70	1.65	1.00	C3	3.50	2.85	2.40
A4	2.25	1.45	1.00	B4	1.65	1.65	0.95	C4	1.95	1.80	1.20
A5	2.40	1.50	1.00	B5	2.70	1.25	0.95	C5	2.70	2.35	1.80
A6	2.05	1.35	1.10	B6	2.85	1.30	0.95	C6	3.40	2.95	2.60
A7	1.80	1.40	1.05	B7	3.15	1.90	1.85	C7	2.80	2.15	1.35
A8	2.20	1.50	1.00	B8	3.05	1.85	1.85	C8	3.40	3.00	2.65
A9	2.05	1.70	1.10	B9	2.75	1.30	0.60	C9	2.25	1.50	1.25
A10	2.75	1.75	1.45	B10	2.50	1.10	0.70	C10	1.90	1.25	1.10
A11	2.85	1.55	1.45	B11	2.55	1.50	1.85	C11	2.80	2.15	1.35
A12	2.60	1.50	1.40	B12	1.60	0.90	0.70	C12	3.00	2.00	2.40
Average	2.26	1.50	1.17	Average	2.52	1.53	1.19	Average	2.68	2.14	1.71
STD	0.32	0.12	0.17	STD	0.55	0.36	0.47	STD	0.58	0.56	0.62
Min,av	1.80	1.35	1.00	Min,av	1.60	0.90	0.60	Min,av	1.90	1.25	1.10
Max,av	2.85	1.75	1.45	Max,av	3.15	1.95	1.85	Max,av	3.50	3.00	2.65
CUBE ID	10 min	30 min	60 min	CUBE ID	10 min	30 min	60 min	CUBE ID	10 min	30 min	60 min
D1	2.00	1.90	1.20	E1	2.80	2.25	1.95	F1	3.30	2.50	2.05
D2	2.40	1.80	1.20	E2	2.95	2.10	1.85	F2	3.20	2.50	2.00
D3	3.50	2.85	2.40	E3	2.75	2.20	1.75	F3	3.30	2.00	2.25
D4	1.95	1.80	1.20	E4	2.80	2.00	1.85	F4	3.25	2.60	2.00
D5	2.70	2.35	1.80	E5	2.90	2.05	1.55	F5	3.10	2.70	1.95
D6	3.40	2.95	2.60	E6	2.50	2.10	1.85	F6	3.45	2.60	2.20
D7	2.80	2.15	1.35	E7	2.55	1.95	1.85	F7	3.45	2.70	2.20
D8	3.40	3.00	2.65	E8	2.95	2.10	1.85	F8	3.25	2.70	2.05
D9	2.25	1.50	1.25	E9	2.50	2.25	1.6	F9	3.35	2.55	2.15
D10	1.90	1.25	1.10	E10	3.10	2.20	1.75	F10	3.35	2.25	2.05
D11	2.80	2.15	1.35	E11	3.20	2.15	1.65	F11	3.25	2.90	2.10
D12	3.00	2.00	2.40	E12	3.00	2.15	1.65	F12	3.00	2.80	2.00
Average	2.68	2.14	1.71	Average	2.83	2.13	1.76	Average	3.27	2.57	2.08
STD	0.58	0.56	0.62	STD	0.23	0.09	0.12	STD	0.13	0.24	0.10
Min,av	1.90	1.25	1.10	Min,av	2.50	1.95	1.55	Min,av	3.00	2.00	1.95
Max,av	3.50	3.00	2.65	Max,av	3.20	2.25	1.95	Max,av	3.45	2.90	2.25

Table.2 ISAT on wet concrete cubes at various time interval in different mixtures type

ISAT, ml/m²/s on wet concrete cubes at various time interval in different mixtures type											
CUBE ID	10 min	30 min	60 min	CUBE ID	10 min	30 min	60 min	CUBE ID	10 min	30 min	60 min
A1	0.40	0.30	0.24	B1	0.35	0.30	0.24	C1	0.35	0.3	0.24
A2	0.30	0.23	0.20	B2	0.35	0.30	0.24	C2	0.35	0.3	0.24
A3	0.30	0.23	0.15	B3	0.30	0.23	0.24	C3	0.30	0.23	0.24
A4	0.45	0.40	0.30	B4	0.30	0.24	0.20	C4	0.35	0.3	0.24
A5	0.40	0.30	0.20	B5	0.35	0.30	0.24	C5	0.30	0.23	0.2
A6	0.35	0.30	0.15	B6	0.35	0.30	0.24	C6	0.30	0.24	0.2
Average	0.37	0.29	0.21	Average	0.33	0.28	0.23	Average	0.33	0.27	0.23
STD	0.06	0.06	0.06	STD	0.03	0.04	0.02	STD	0.03	0.04	0.02
Min,av	0.30	0.23	0.15	Min,av	0.30	0.23	0.20	Min,av	0.30	0.23	0.2
Max,av	0.45	0.40	0.30	Max,av	0.35	0.30	0.24	Max,av	0.35	0.3	0.24
A7	0.30	0.23	0.15	B7	0.35	0.30	0.20	C7	0.30	0.23	0.2
A8	0.20	0.15	0.10	B8	0.30	0.225	0.20	C8	0.20	0.15	0.12
A9	0.20	0.18	0.15	B9	0.30	0.24	0.20	C9	0.25	0.23	0.2
A10	0.20	0.15	0.12	B10	0.25	0.23	0.12	C10	0.25	0.24	0.2
A11	0.30	0.23	0.15	B11	0.20	0.15	0.12	C11	0.20	0.15	0.12
A12	0.20	0.18	0.15	B12	0.30	0.25	0.15	C12	0.25	0.2	0.15
Average	0.23	0.19	0.14	Average	0.28	0.23	0.17	Average	0.24	0.20	0.17
STD	0.05	0.03	0.02	STD	0.05	0.05	0.04	STD	0.04	0.04	0.04
Min,av	0.20	0.15	0.10	Min,av	0.20	0.15	0.12	Min,av	0.20	0.15	0.12
Max,av	0.30	0.23	0.15	Max,av	0.35	0.30	0.20	Max,av	0.30	0.24	0.2

Note: Cube ID from A1-A6-B1-B6-C1-C6-Mc = 2.5%;

Cube ID from A7-A12- B7-B12-C7-C12-Mc = 5%

Table.3 ISAT on wet concrete cubes at various time interval in different mixtures type

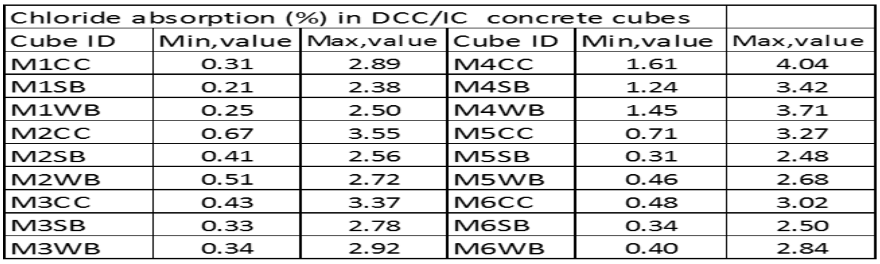
ISAT, ml/m²/s on wet concrete cubes at various time interval in different mixtures type											
CUBE ID	10 min	30 min	60 min	CUBE NO	10 min	30 min	60 min	CUBE ID	10 min	30 min	60 min
D1	0.30	0.23	0.20	E1	0.25	0.23	0.2	F1	0.20	0.18	0.15
D2	0.25	0.23	0.20	E2	0.20	0.18	0.15	F2	0.20	0.18	0.15
D3	0.35	0.3	0.24	E3	0.30	0.23	0.15	F3	0.25	0.23	0.20
D4	0.25	0.24	0.20	E4	0.20	0.18	0.15	F4	0.20	0.12	0.10
D5	0.30	0.25	0.20	E5	0.30	0.23	0.15	F5	0.25	0.12	0.15
D6	0.30	0.24	0.20	E6	0.25	0.15	0.12	F6	0.20	0.12	0.10
Average	0.29	0.25	0.21	Average	0.25	0.20	0.15	Average	0.22	0.16	0.14
STD	0.04	0.03	0.02	STD	0.04	0.03	0.03	STD	0.03	0.04	0.04
Min,av	0.25	0.23	0.20	Min,av	0.20	0.15	0.12	Min,av	0.20	0.12	0.10
Max,av	0.35	0.3	0.24	Max,av	0.30	0.23	0.2	Max,av	0.25	0.23	0.20
D7	0.25	0.23	0.24	E7	0.25	0.20	0.15	F7	0.13	0.12	0.10
D8	0.25	0.23	0.10	E8	0.20	0.15	0.1	F8	0.15	0.12	0.10
D9	0.20	0.18	0.15	E9	0.25	0.20	0.15	F9	0.20	0.15	0.12
D10	0.30	0.23	0.20	E10	0.20	0.23	0.15	F10	0.15	0.12	0.10
D11	0.20	0.18	0.10	E11	0.25	0.23	0.15	F11	0.20	0.12	0.10
D12	0.20	0.15	0.12	E12	0.25	0.20	0.15	F12	0.20	0.15	0.12
Average	0.23	0.20	0.15	Average	0.23	0.20	0.14	Average	0.17	0.13	0.11
STD	0.04	0.03	0.06	STD	0.03	0.03	0.02	STD	0.03	0.02	0.01
Min,av	0.20	0.15	0.10	Min,av	0.20	0.15	0.1	Min,av	0.13	0.12	0.10
Max,av	0.30	0.225	0.24	Max,av	0.25	0.23	0.15	Max,av	0.20	0.15	0.12

Note: Cube ID from D1-D6-E1-E6-F1-F6-Mc = 2.5%;

Cube ID from D7-D12- E7-E12-F7-F12-Mc = 5%

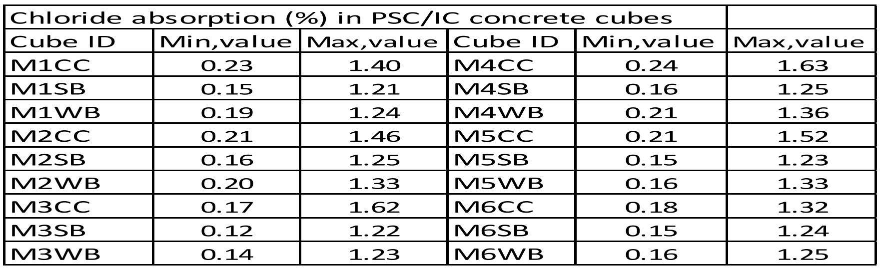
APPENDIX 5 Salt ponding test on concrete cubes

Table.1 Chloride absorption in DCC cubes for different mixtures type



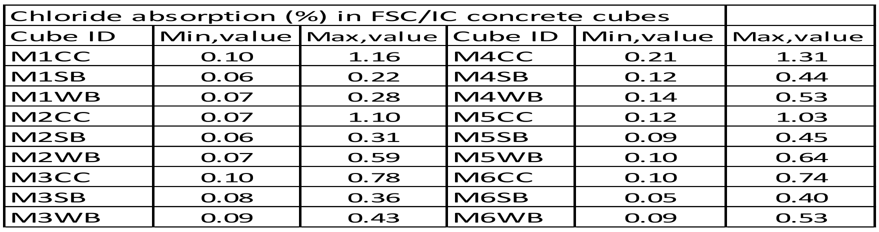
Chloride absorption (%) in DCC/IC concrete cubes					
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1CC	0.31	2.89	M4CC	1.61	4.04
M1SB	0.21	2.38	M4SB	1.24	3.42
M1WB	0.25	2.50	M4WB	1.45	3.71
M2CC	0.67	3.55	M5CC	0.71	3.27
M2SB	0.41	2.56	M5SB	0.31	2.48
M2WB	0.51	2.72	M5WB	0.46	2.68
M3CC	0.43	3.37	M6CC	0.48	3.02
M3SB	0.33	2.78	M6SB	0.34	2.50
M3WB	0.34	2.92	M6WB	0.40	2.84

Table.2 Chloride absorption in PSC cubes for different mixtures type



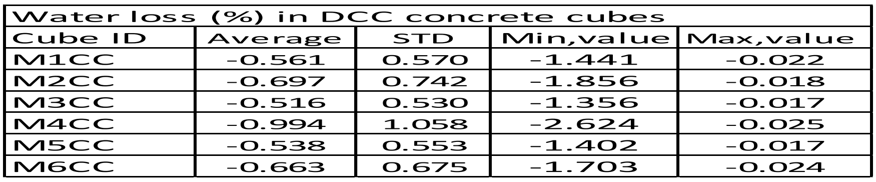
Chloride absorption (%) in PSC/IC concrete cubes					
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1CC	0.23	1.40	M4CC	0.24	1.63
M1SB	0.15	1.21	M4SB	0.16	1.25
M1WB	0.19	1.24	M4WB	0.21	1.36
M2CC	0.21	1.46	M5CC	0.21	1.52
M2SB	0.16	1.25	M5SB	0.15	1.23
M2WB	0.20	1.33	M5WB	0.16	1.33
M3CC	0.17	1.62	M6CC	0.18	1.32
M3SB	0.12	1.22	M6SB	0.15	1.24
M3WB	0.14	1.23	M6WB	0.16	1.25

Table.3 Chloride absorption in FSC cubes for different mixtures type



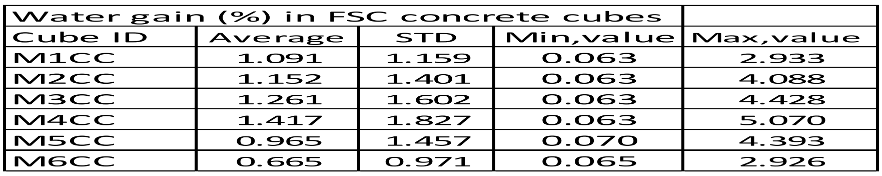
Chloride absorption (%) in FSC/IC concrete cubes					
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1CC	0.10	1.16	M4CC	0.21	1.31
M1SB	0.06	0.22	M4SB	0.12	0.44
M1WB	0.07	0.28	M4WB	0.14	0.53
M2CC	0.07	1.10	M5CC	0.12	1.03
M2SB	0.06	0.31	M5SB	0.09	0.45
M2WB	0.07	0.59	M5WB	0.10	0.64
M3CC	0.10	0.78	M6CC	0.10	0.74
M3SB	0.08	0.36	M6SB	0.05	0.40
M3WB	0.09	0.43	M6WB	0.09	0.53

Table.4 Variation of water loss in pre-conditioned DCC cubes



Water loss (%) in DCC concrete cubes				
Cube ID	Average	STD	Min,value	Max,value
M1CC	-0.561	0.570	-1.441	-0.022
M2CC	-0.697	0.742	-1.856	-0.018
M3CC	-0.516	0.530	-1.356	-0.017
M4CC	-0.994	1.058	-2.624	-0.025
M5CC	-0.538	0.553	-1.402	-0.017
M6CC	-0.663	0.675	-1.703	-0.024

Table.5 Variation of water gain in pre-conditioned FSC cubes



Water gain (%) in FSC concrete cubes				
Cube ID	Average	STD	Min,value	Max,value
M1CC	1.091	1.159	0.063	2.933
M2CC	1.152	1.401	0.063	4.088
M3CC	1.261	1.602	0.063	4.428
M4CC	1.417	1.827	0.063	5.070
M5CC	0.965	1.457	0.070	4.393
M6CC	0.665	0.971	0.065	2.926

Table.6 Variation of water gain in pre-conditioned PSC cubes

Water gain (%) in PSC concrete cubes				
Cube ID	Average	STD	Min,value	Max,value
M1CC	0.617	0.712	0.049	1.817
M2CC	0.567	0.625	0.050	1.445
M3CC	0.565	0.622	0.050	1.397
M4CC	0.657	0.749	0.051	1.856
M5CC	0.138	0.101	0.050	0.334
M6CC	0.113	0.064	0.050	0.236

Table.7 Variation of average chloride concentration in pre-conditioned concrete cubes

Interpretation of average chloride concentration at different drill depths in concrete cubes											
CUBE ID	DCCav	PSCav	%incr	%decr	FSCav	%incr	%decr	PSCav	FSCav	%incr	%decr
M1CC	0.0664	0.0636	4.24	95.76	0.0563	11.06	88.94	0.0636	0.0563	11.5543	88.45
M1SB	0.0553	0.0578	-4.62	104.62	0.0515	11.35	88.65	0.0578	0.0515	10.8471	89.15
M1WB	0.0630	0.0603	4.14	95.86	0.0548	8.81	91.19	0.0603	0.0548	9.18582	90.81
M2CC	0.0643	0.0621	3.43	96.57	0.0563	8.98	91.02	0.0621	0.0563	9.30347	90.70
M2SB	0.0584	0.0579	0.80	99.20	0.0516	10.86	89.14	0.0579	0.0516	10.9518	89.05
M2WB	0.0611	0.0603	1.25	98.75	0.054	10.40	89.60	0.0603	0.0540	10.5356	89.46
M3CC	0.0727	0.0716	1.48	98.52	0.0657	8.10	91.90	0.0716	0.0657	8.2219	91.78
M3SB	0.0682	0.0659	3.30	96.70	0.057	13.04	86.96	0.0659	0.0570	13.481	86.52
M3WB	0.0703	0.0684	2.77	97.23	0.0611	10.30	89.70	0.0684	0.0611	10.591	89.41
M4CC	0.0684	0.0596	12.90	87.10	0.0552	6.43	93.57	0.0596	0.0552	7.37985	92.62
M4SB	0.0588	0.0572	2.69	97.31	0.0516	9.62	90.38	0.0572	0.0516	9.88704	90.11
M4WB	0.0604	0.0596	1.35	98.65	0.0528	11.22	88.78	0.0596	0.0528	11.3779	88.62
M5CC	0.0688	0.0672	2.35	97.65	0.0622	7.23	92.77	0.0672	0.0622	7.40336	92.60
M5SB	0.0613	0.0585	4.58	95.42	0.0523	10.19	89.81	0.0585	0.0523	10.6787	89.32
M5WB	0.0667	0.0628	5.87	94.13	0.0547	12.17	87.83	0.0628	0.0547	12.9306	87.07
M6CC	0.0659	0.0643	2.46	97.54	0.0586	8.67	91.33	0.0643	0.0586	8.88964	91.11
M6SB	0.0620	0.0587	5.35	94.65	0.0523	10.36	89.64	0.0587	0.0523	10.9434	89.06
M6WB	0.0639	0.0624	2.33	97.67	0.0563	9.63	90.37	0.0624	0.0563	9.85637	90.14

Table.8 Chloride concentration in pre-conditioned control concrete slabs/cubes

Comparison of chloride concentration in concrete slabs/cubes							
Depth	M1CS	M1CC	PCC	Depth	M4CS	M4CC	PCC
30	0.0923	0.070		30	0.0722	0.0598	
40	0.0864	0.066	DC	40	0.0716	0.0535	FSC
50	0.0815	0.064		50	0.0651	0.0522	
Depth	M2CS	M2CC		Depth	M5CS	M5CC	
30	0.0821	0.066		30	0.0846	0.0683	
40	0.0782	0.064	DC	40	0.0736	0.0672	PSC
50	0.0653	0.063		50	0.0616	0.066	
Depth	M3CS	M3CC		Depth	M6CS	M6CC	
30	0.0787	0.073		30	0.0654	0.0609	
40	0.0731	0.071	PSC	40	0.0609	0.0586	FSC
50	0.0687	0.071		50	0.0558	0.0562	
M1CS-M6CS- control slabs				M1CC-M6CC- control cubes			

Table.9 Chloride concentration in pre-conditioned impregnation concrete slabs/cubes

Comparison of chloride concentration in concrete slabs/cubes							
Depth	M1S1	M1SB	PCC	Depth	M4S9	M4SB	PCC
30	0.0895	0.0599		30	0.0696	0.0539	
40	0.0835	0.053	DC	40	0.0672	0.0517	FSC
50	0.0754	0.0528		50	0.0625	0.0492	
Depth	M2S3	M2SB		Depth	M5S7	M5SB	
30	0.0774	0.0611		30	0.0806	0.0612	
40	0.0672	0.0576	DC	40	0.0613	0.0577	PSC
50	0.0613	0.0564		50	0.0576	0.0566	
Depth	M3S5	M3SB		Depth	M6S11	M6SB	
30	0.0737	0.0683		30	0.0634	0.0562	
40	0.0711	0.0659	PSC	40	0.0524	0.0515	FSC
50	0.0657	0.0636		50	0.0502	0.0492	
M1S1-M6S11- impregnation slabs				M1SB-M6SB- impregnation cubes			

APPENDIX 6 Chloride diffusion coefficient in pre-conditioned concrete cubes

Table.1 Comparison of chloride diffusion coefficient (average) in PCC concrete cubes

Interpretation of chloride diffusion coefficient in control/impregnation concrete cubes at different drill depths											
CUBE ID	DCCAver	PSCAver	%incr	%decr	FSCAver	%incr	%decr	PSCAver	FSCAver	%incr	%decr
	(30-50) mm	(30-50) mm			(30-50) mm			(30-50) mm	(30-50) mm		
M1CC	0.00242	0.00198	18.15	81.85	0.00142	41.26	58.74	0.00198	0.00142	28.24	71.76
M1SB	0.00159	0.00155	2.48	97.52	0.00140	12.22	87.78	0.00155	0.00140	9.98	90.02
M1WB	0.00220	0.00168	23.93	76.07	0.00141	36.18	63.82	0.00168	0.00141	16.11	83.89
M2CC	0.00232	0.00187	19.42	80.58	0.00148	36.28	63.72	0.00187	0.00148	20.93	79.07
M2SB	0.00181	0.00151	16.42	83.58	0.00142	21.66	78.34	0.00151	0.00142	6.27	93.73
M2WB	0.00188	0.00155	17.55	82.45	0.00144	23.05	76.95	0.00155	0.00144	6.68	93.32
M3CC	0.00209	0.00185	11.45	88.55	0.00149	28.93	71.07	0.00185	0.00149	19.74	80.26
M3SB	0.00174	0.00163	6.51	93.49	0.00139	20.32	79.68	0.00163	0.00139	14.77	85.23
M3WB	0.00165	0.00165	-0.10	100.10	0.00144	12.82	87.18	0.00165	0.00144	12.90	87.10
M4CC	0.00247	0.00213	13.77	86.23	0.00140	43.32	56.68	0.00213	0.00140	34.27	65.73
M4SB	0.00203	0.00176	13.28	86.72	0.00138	31.79	68.21	0.00176	0.00138	21.34	78.66
M4WB	0.00220	0.00177	19.52	80.48	0.00140	36.26	63.74	0.00177	0.00140	20.80	79.20
M5CC	0.00197	0.00209	-6.48	106.48	0.00146	25.97	74.03	0.00209	0.00146	30.48	69.52
M5SB	0.00171	0.00179	-4.68	104.68	0.00140	18.19	81.81	0.00179	0.00140	21.84	78.16
M5WB	0.00183	0.00188	-2.41	102.41	0.00139	24.26	75.74	0.00188	0.00139	26.04	73.96
M6CC	0.00191	0.00198	-3.75	103.75	0.00146	23.17	76.83	0.00198	0.00146	25.95	74.05
M6SB	0.00167	0.00162	2.71	97.29	0.00138	17.13	82.87	0.00162	0.00138	14.82	85.18
M6WB	0.00177	0.00175	1.13	98.87	0.00141	20.72	79.28	0.00175	0.00141	19.82	80.18

APPENDIX 7 Chloride diffusion coefficient in pre-conditioned concrete slabs

Table.1 Variation of average chloride concentration in pre-conditioned concrete slabs

Interpretation of average chloride concentration at different drill depths in concrete slabs											
Cube ID	DCCav	PSCav	%incr	%decr	FSCav	%incr	%decr	PSCav	FSCav	%incr	%decr
M1CS	0.0867	0.0735	15.24	84.76	0.0696	19.73	80.27	0.074	0.07	5.30	94.70
M1S1	0.0828	0.0702	15.23	84.77	0.0664	19.78	80.22	0.07	0.066	5.37	94.63
M1S2	0.0856	0.0714	16.62	83.38	0.0674	21.22	78.78	0.071	0.067	5.52	94.48
M2CS	0.0752	0.0733	2.553	97.45	0.0604	19.75	80.25	0.073	0.06	17.64	82.36
M2S3	0.0686	0.0665	3.085	96.92	0.0553	19.39	80.61	0.066	0.055	16.83	83.17
M2S4	0.0698	0.0704	-0.80	100.8	0.0577	17.39	82.61	0.07	0.058	18.04	81.96

Table.2 Comparison of chloride diffusion coefficient (average) in pre-conditioned concrete slabs

Interpretation of chloride diffusion coefficient in control/impregnation concrete slabs at different drill depths											
Cube ID	DCCAver	PSCAver	%incr	%decr	FSCAver	%incr	%decr	PSCAver	FSCAver	%incr	%decr
	(30-50) mm	(30-50) mm			(30-50) mm			(30-50) mm	(30-50) mm		
M1CC	0.00234	0.00204	12.92	87.08	0.0021	11.45	88.546	0.00204	0.00207	-1.68	101.7
M1SB	0.00217	0.00194	10.74	89.26	0.0018	16.65	83.349	0.00194	0.00181	6.63	93.4
M1WB	0.00224	0.00200	10.52	89.48	0.0018	17.44	82.555	0.00200	0.00185	7.74	92.3
M2CC	0.00214	0.00196	8.43	91.57	0.0020	8.21	91.79	0.00196	0.00196	-0.24	100.2
M2SB	0.00200	0.00186	7.03	92.97	0.0017	12.40	87.597	0.00186	0.00175	5.78	94.2
M2WB	0.00205	0.00190	7.01	92.99	0.0018	12.22	87.779	0.00190	0.00180	5.61	94.4

APPENDIX 8 Comparison of chloride concentration in concrete slabs/cubes

Table.1 Interpretation of chloride concentration in control concrete slabs/cubes

Chloride concentration in control concrete slabs/cubes					
			M1CS-M1CC		
Depth	M1CS	M1CC	Incr (%)	decr (%)	Pre-condition
30	0.0923	0.0699	24.27	75.7313	
40	0.0864	0.0658	23.84	76.1574	DC
50	0.0815	0.0635	22.09	77.9141	
Depth	M2CS	M2CC	M2CS-M2CC		
30	0.0821	0.0658	19.85	80.1462	
40	0.0782	0.0637	18.54	81.4578	DC
50	0.0653	0.0634	2.91	97.1	
Depth	M3CS	M3CC	M3CS-M3CC		
30	0.0787	0.0731	7.12	92.88	
40	0.0731	0.071	2.87	97.13	PSC
50	0.0687	0.0706	-2.77	102.77	
Depth	M4CS	M4CC	M4CS-M4CC		
30	0.0722	0.0598	17.17	82.83	
40	0.0716	0.0535	25.2793	74.7207	FSC
50	0.0651	0.0522	19.82	80.18	
Depth	M5CS	M5CC	M5CS-M5CC		
30	0.0846	0.0683	19.27	80.7329	
40	0.0736	0.0672	8.70	91.3043	PSC
50	0.0616	0.066	-7.14	107.143	
Depth	M6CS	M6CC	M6CS-M6CC		
30	0.0654	0.0609	6.88	93.12	
40	0.0609	0.0586	3.78	96.22	FSC
50	0.0558	0.0562	-0.72	100.72	

Table.2 Interpretation of chloride concentration in impregnation concrete slabs/cubes (SB)

Chloride concentration in IC (SB) slabs/cubes					
			M1S1-M1SB		
Depth	M1S1	M1SB	Incr (%)	decr (%)	Pre-condition
30	0.0895	0.0599	33.07	66.93	
40	0.0835	0.053	36.53	63.47	DC
50	0.0754	0.0528	29.97	70.03	
Depth	M2S3	M2SB	M2S3-M2SB		
30	0.0774	0.0611	21.06	78.94	
40	0.0672	0.0576	14.29	85.71	DC
50	0.0613	0.0564	7.99	92.01	
Depth	M3S5	M3SB	M3S5-M3SB		
30	0.0737	0.0683	7.33	92.67	
40	0.0711	0.0659	7.31	92.69	PSC
50	0.0657	0.0636	3.20	96.80	
Depth	M4S9	M4SB	M4S9-M4SB		
30	0.0696	0.0539	22.56	77.44	
40	0.0672	0.0517	23.0655	76.93	FSC
50	0.0625	0.0492	21.28	78.72	
Depth	M5S7	M5SB	M5S7-M5SB		
30	0.0806	0.0612	24.07	75.93	
40	0.0613	0.0577	5.87	94.13	PSC
50	0.0576	0.0566	1.74	98.26	
Depth	M6S11	M6SB	M6S11-M6SB		
30	0.0634	0.0562	11.36	88.64	
40	0.0524	0.0515	1.72	98.28	FSC
50	0.0502	0.0492	1.99	98.01	

Table.3 Interpretation of chloride concentration in impregnation concrete slabs/cubes (WB)

Chloride concetration in IC (WB) slabs/cubes					
			M1S2-M1WB		
Depth	M1S2	M1WB	Incr (%)	decr (%)	Pre-condition
30	0.0915	0.0644	29.62	70.38	
40	0.0854	0.0636	25.53	74.47	DC
50	0.0798	0.0609	23.68	76.32	
Depth	M2S4	M2WB	M2S4-M2WB		
30	0.0784	0.0632	19.39	80.61	
40	0.0683	0.0611	10.54	89.46	DC
50	0.0627	0.0589	6.06	93.94	
Depth	M3S6	M3WB	M3S6-M3WB		
30	0.0748	0.0709	5.21	94.79	
40	0.0722	0.0682	5.54	94.46	PSC
50	0.0671	0.0659	1.79	98.21	
Depth	M4S10	M4WB	M4S10-M4WB		
30	0.0704	0.0563	20.03	79.97	
40	0.0685	0.0516	24.6715	75.33	FSC
50	0.0634	0.0505	20.35	79.65	
Depth	M5S8	M5WB	M5S8-M5WB		
30	0.0812	0.0659	18.84	81.16	
40	0.0706	0.0637	9.77	90.23	PSC
50	0.0592	0.0587	0.84	99.16	
Depth	M6S12	M6WB	M6S12-M6WB		
30	0.0646	0.0586	9.29	90.71	
40	0.0547	0.0563	-2.93	102.93	FSC
50	0.0537	0.0539	-0.37	100.37	

Table.4 Interpretation of chloride concentration in impregnation concrete cubes (SB/WB)

Chloride concentration in IC (SB/WB) cubes														
	DC		M1SB-M1WB			PSC		M1SB-M1WB			FSC		M1SB-M1WB	
Depth	M1SB	M1WB	decr (%)	incr (%)	Depth	M1SB	M1WB	decr (%)	incr (%)	Depth	M1SB	M1WB	decr (%)	incr (%)
30	0.0599	0.0644	-7.51	92.49	30	0.0586	0.0613	-4.61	95.39	30	0.0538	0.0563	-4.65	95.35
40	0.053	0.0636	-20.00	80.00	40	0.0585	0.0612	-4.62	95.38	40	0.0515	0.0553	-7.38	92.62
50	0.0528	0.0609	-15.34	84.66	50	0.0563	0.0586	-4.09	95.91	50	0.0492	0.0529	-7.52	92.48
Depth	M2SB	M2WB	M2SB-M2WB		Depth	M2SB	M2WB	M2SB-M2WB		Depth	M2SB	M2WB	M2SB-M2WB	
30	0.0611	0.0632	-3.44	96.56	30	0.0587	0.0613	-4.43	95.57	30	0.0538	0.0564	-4.83	95.17
40	0.0576	0.0611	-6.08	93.92	40	0.0586	0.0609	-3.92	96.08	40	0.0516	0.0538	-4.26	95.74
50	0.0564	0.0589	-4.43	95.57	50	0.0564	0.0586	-3.90	96.10	50	0.0492	0.0515	-4.67	95.33
Depth	M3SB	M3WB	M3SB-M3WB		Depth	M3SB	M3WB	M3SB-M3WB		Depth	M3SB	M3WB	M3SB-M3WB	
30	0.0707	0.0721	-1.98	98.02	30	0.0683	0.0709	-3.81	96.19	30	0.0609	0.0633	-3.94	96.06
40	0.068	0.0707	-3.97	96.03	40	0.0659	0.0682	-3.49	96.51	40	0.0563	0.0609	-8.17	91.83
50	0.0658	0.0681	-3.50	96.50	50	0.0635	0.0659	-3.78	96.22	50	0.0538	0.0591	-9.85	90.15
Depth	M4SB	M4WB	M4SB-M4WB		Depth	M4SB	M4WB	M4SB-M4WB		Depth	M4SB	M4WB	M4SB-M4WB	
30	0.0609	0.0612	-0.49	99.51	30	0.0589	0.0611	-3.74	96.26	30	0.0539	0.0563	-4.45	95.55
40	0.0589	0.0611	-3.74	96.26	40	0.0565	0.0588	-4.07	95.93	40	0.0517	0.0515	0.39	100.39
50	0.0566	0.0588	-3.89	96.11	50	0.0564	0.0587	-4.08	95.92	50	0.0491	0.05	-1.83	98.17
Depth	M5SB	M5WB	M5SB-M5WB		Depth	M5SB	M5WB	M5SB-M5WB		Depth	M5SB	M5WB	M5SB-M5WB	
30	0.0637	0.0683	-7.22	92.78	30	0.0612	0.0659	-7.68	92.32	30	0.0539	0.0563	-4.45	95.55
40	0.0613	0.066	-7.67	92.33	40	0.0578	0.0637	-10.21	89.79	40	0.0513	0.0539	-5.07	94.93
50	0.0589	0.0657	-11.54	88.46	50	0.0566	0.0587	-3.71	96.29	50	0.0515	0.0538	-4.47	95.53
Depth	M6SB	M6WB	M6SB-M6WB		Depth	M6SB	M6WB	M6SB-M6WB		Depth	M6SB	M6WB	M6SB-M6WB	
30	0.0635	0.0658	-3.62	96.38	30	0.0611	0.0637	-4.26	95.74	30	0.0562	0.0586	-4.27	95.73
40	0.0614	0.0635	-3.42	96.58	40	0.058	0.0625	-7.76	92.24	40	0.0515	0.0563	-9.32	90.68
50	0.0612	0.0624	-1.96	98.04	50	0.057	0.061	-7.02	92.98	50	0.0492	0.0538	-9.35	90.65

APPENDIX 9 Comparison of chloride diffusion coefficient in concrete slabs/cubes

Table.1 Interpretation of chloride diffusion coefficient in control concrete slabs/cubes

Chloride diffusion coefficient in control concrete slabs/cubes					
			M1CS-M1CC		
Depth	M1CS	M1CC	Incr (%)	decr (%)	Pre-condition
30	0.0026	0.002699	-3.81	103.808	
40	0.0023	0.002359	-2.57	102.565	DC
50	0.0021	0.002188	-4.19	104.19	
Depth	M2CS	M2CC	M2CS-M2CC		
30	0.0023	0.00257	-11.74	111.739	
40	0.0021	0.00227	-8.10	108.095	DC
50	0.002	0.00212	-6.00	106.0	
Depth	M3CS	M3CC	M3CS-M3CC		
30	0.00219	0.00215	1.83	98.17	
40	0.002	0.0017	15.00	85.00	PSC
50	0.00191	0.00168	12.04	87.96	
Depth	M4CS	M4CC	M4CS-M4CC		
30	0.0022	0.001458	33.70	66.30	
40	0.00203	0.001394	31.33	68.67	FSC
50	0.00198	0.001344	32.12	67.88	
Depth	M5CS	M5CC	M5CS-M5CC		
30	0.00211	0.002257	-7.22	107.221	
40	0.00193	0.002016	-4.46	104.456	PSC
50	0.00184	0.00201	-9.24	109.239	
Depth	M6CS	M6CC	M6CS-M6CC		
30	0.00216	0.001504	30.40	69.60	
40	0.0019	0.001459	23.21	76.79	FSC
50	0.00182	0.00143	21.43	78.57	

Table.2 Interpretation of chloride diffusion coefficient in impregnation concrete slabs/cubes (SB)

Chloride diffusion coefficient in IC (SB) slabs/cubes					
			M1S1-M1SB		
Depth	M1S1	M1SB	Incr (%)	decr (%)	Pre-condition
30	0.0023	0.00193	16.09	83.91	
40	0.0021	0.00147	30.00	70.00	DC
50	0.00208	0.00135	35.10	64.90	
Depth	M2S3	M2SB	M2S3-M2SB		
30	0.0021	0.00209	0.48	99.52	
40	0.00195	0.00173	11.28	88.72	DC
50	0.00189	0.0016	15.34	84.66	
Depth	M3S5	M3SB	M3S5-M3SB		
30	0.00207	0.00175	15.46	84.54	
40	0.00192	0.00158	17.71	82.29	PSC
50	0.00182	0.00155	14.84	85.16	
Depth	M4S9	M4SB	M4S9-M4SB		
30	0.0021	0.00144	31.43	68.57	
40	0.00171	0.00137	19.883	80.12	FSC
50	0.00162	0.00133	17.90	82.10	
Depth	M5S7	M5SB	M5S7-M5SB		
30	0.00193	0.00195	-1.04	101.04	
40	0.0018	0.00173	3.89	96.11	PSC
50	0.00183	0.00167	8.74	91.26	
Depth	M6S11	M6SB	M6S11-M6SB		
30	0.00189	0.00142	24.87	75.13	
40	0.00174	0.00137	21.26	78.74	FSC
50	0.00162	0.00136	16.05	83.95	

Table.3 Interpretation of chloride diffusion coefficient in impregnation concrete slabs/cubes (WB)

Chloride diffusion coefficient in IC (WB) slabs/cubes					
			M1S2-M1WB		
Depth	M1S2	M1WB	Incr (%)	decr (%)	Pre-condition
30	0.0024	0.00257	-7.08	107.08	
40	0.00216	0.00215	0.46	99.54	DC
50	0.00214	0.00188	12.15	87.85	
Depth	M2S4	M2WB	M2S4-M2WB		
30	0.0022	0.00218	0.91	99.09	
40	0.00198	0.00178	10.10	89.90	DC
50	0.00195	0.00165	15.38	84.62	
Depth	M3S6	M3WB	M3S6-M3WB		
30	0.00214	0.00166	22.43	77.57	
40	0.00195	0.00163	16.41	83.59	PSC
50	0.00191	0.00165	13.61	86.39	
Depth	M4S10	M4WB	M4S10-M4WB		
30	0.00201	0.00145	27.86	72.14	
40	0.0018	0.00138	23.3333	76.67	FSC
50	0.00171	0.00136	20.47	79.53	
Depth	M5S8	M5WB	M5S8-M5WB		
30	0.00196	0.00201	-2.55	102.55	
40	0.00184	0.00186	-1.09	101.09	PSC
50	0.0019	0.00175	7.89	92.11	
Depth	M6S12	M6WB	M6S12-M6WB		
30	0.00189	0.00143	24.34	75.66	
40	0.00177	0.0014	20.90	79.10	FSC
50	0.00172	0.00139	19.19	80.81	

Table.4 Interpretation of chloride diffusion coefficient in impregnation concrete cubes (SB/WB)

Chloride diffusion coefficient in IC (SB/WB) cubes														
	DC		M1SB-M1WB			PSC		M1SB-M1WB			FSC		M1SB-M1WB	
Depth	M1SB	M1WB	decr (%)	incr (%)	Depth	M1SB	M1WB	decr (%)	incr (%)	Depth	M1SB	M1WB	decr (%)	incr (%)
30	0.00193	0.00257	-33.16	66.84	30	0.00161	0.0017	-5.59	94.41	30	0.00144	0.00145	-0.69	99.31
40	0.00147	0.00215	-46.26	53.74	40	0.00152	0.0017	-10.53	89.47	40	0.00138	0.0014	-1.45	98.55
50	0.00135	0.00188	-39.26	60.74	50	0.00151	0.0016	-7.95	92.05	50	0.00136	0.00137	-0.74	99.26
Depth	M2SB	M2WB	M2SB-M2WB		Depth	M2SB	M2WB	M2SB-M2WB		Depth	M2SB	M2WB	M2SB-M2WB	
30	0.00209	0.00218	-4.31	95.69	30	0.00157	0.0016	1.27	101.27	30	0.00145	0.00151	-4.14	95.86
40	0.00173	0.00178	-2.89	97.11	40	0.0015	0.0015	-2.00	98.00	40	0.00141	0.00141	0.00	100.00
50	0.0016	0.00165	-3.12	96.88	50	0.00147	0.0016	-5.44	94.56	50	0.00139	0.0014	-0.72	99.28
Depth	M3SB	M3WB	M3SB-M3WB		Depth	M3SB	M3WB	M3SB-M3WB		Depth	M3SB	M3WB	M3SB-M3WB	
30	0.00209	0.00186	11.00	111.00	30	0.00175	0.0017	5.71	105.71	30	0.00141	0.00145	-2.84	97.16
40	0.00163	0.00155	4.91	104.91	40	0.00158	0.0016	-3.16	96.84	40	0.00136	0.00143	-5.15	94.85
50	0.005	0.00151	69.80	169.80	50	0.00155	0.0017	-6.45	93.55	50	0.00158	0.00141	10.76	110.76
Depth	M4SB	M4WB	M4SB-M4WB		Depth	M4SB	M4WB	M4SB-M4WB		Depth	M4SB	M4WB	M4SB-M4WB	
30	0.0025	0.00269	-7.60	92.40	30	0.00183	0.0018	0.00	100.00	30	0.00144	0.00145	-0.69	99.31
40	0.00185	0.00208	-12.43	87.57	40	0.00177	0.0018	1.13	101.13	40	0.00137	0.00138	-0.73	99.27
50	0.00171	0.0018	-5.26	94.74	50	0.00166	0.0017	-3.01	96.99	50	0.00133	0.00136	-2.26	97.74
Depth	M5SB	M5WB	M5SB-M5WB		Depth	M5SB	M5WB	M5SB-M5WB		Depth	M5SB	M5WB	M5SB-M5WB	
30	0.00197	0.00208	-5.58	94.42	30	0.00195	0.002	-3.08	96.92	30	0.00142	0.00141	0.70	100.70
40	0.00163	0.00175	-7.36	92.64	40	0.00173	0.0019	-7.51	92.49	40	0.00141	0.00137	2.84	102.84
50	0.00151	0.00165	-9.27	90.73	50	0.00167	0.0018	-4.79	95.21	50	0.00136	0.00136	0.00	100.00
Depth	M6SB	M6WB	M6SB-M6WB		Depth	M6SB	M6WB	M6SB-M6WB		Depth	M6SB	M6WB	M6SB-M6WB	
30	0.00195	0.00201	-3.08	96.92	30	0.00171	0.0019	-9.94	90.06	30	0.00142	0.00143	-0.70	99.30
40	0.00155	0.00166	-7.10	92.90	40	0.00158	0.0018	-12.66	87.34	40	0.00137	0.0014	-2.19	97.81
50	0.0015	0.00165	-10.00	90.00	50	0.00157	0.0016	-0.64	99.36	50	0.00136	0.00139	-2.21	97.79

APPENDIX 10 Salt ponding test on concrete cubes with finite moisture content

Table.1 Chloride absorption in DCC cubes for different mixtures type [Mc=0%]

Chloride absorption (%) in DCC/IC concrete cubes								
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1-0%	0.100	2.46	M1SB	0.086	1.537	M1WB	0.094	1.659
M2-0%	0.083	2.31	M2SB	0.086	1.546	M2WB	0.088	1.569
M3-0%	0.087	2.31	M3SB	0.083	1.485	M3WB	0.093	1.549
M4-0%	0.093	2.23	M4SB	0.080	1.519	M4WB	0.090	1.505
M5-0%	0.086	2.20	M5SB	0.084	1.512	M5WB	0.092	1.503
M6-0%	0.107	2.05	M6SB	0.083	1.494	M6WB	0.087	1.501

Table.2 Chloride absorption in PSC cubes for different mixtures type [Mc=2%]

Chloride absorption (%) in PSC/IC concrete cubes					
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1-2%	0.011	1.003	M1SB	0.010	0.556
M2-2%	0.009	0.387	M2SB	0.010	0.229
M3-2%	0.010	0.690	M3SB	0.010	0.486
M4-2%	0.009	0.288	M4SB	0.010	0.229
M5-2%	0.010	0.665	M5SB	0.010	0.431
M6-2%	0.009	0.258	M6SB	0.009	0.210

Table.3 Chloride absorption in FSC cubes for different mixtures type [Mc=3%]

Chloride absorption (%) in FSC/IC concrete cubes					
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1-3%	0.004	0.685	M1SB	0.003	0.394
M2-3%	0.003	0.224	M2SB	0.003	0.214
M3-3%	0.003	0.489	M3SB	0.003	0.337
M4-3%	0.003	0.222	M4SB	0.002	0.175
M5-3%	0.003	0.478	M5SB	0.002	0.123
M6-3%	0.003	0.209	M6SB	0.001	0.111

Table.4 Chloride absorption in PSC cubes for different mixtures type [Mc=2%]

Chloride absorption (%) in PSC/IC concrete cubes					
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1-2%	0.008	1.110	M1WB	0.008	0.572
M2-2%	0.007	0.430	M2WB	0.007	0.253
M3-2%	0.008	0.741	M3WB	0.007	0.521
M4-2%	0.007	0.313	M4WB	0.007	0.241
M5-2%	0.007	0.682	M5WB	0.007	0.466
M6-2%	0.007	0.271	M6WB	0.007	0.232

Table.5 Chloride absorption in FSC cubes for different mixtures type [Mc=3%]

Chloride absorption (%) in FSC/IC concrete cubes					
Cube ID	Min,value	Max,value	Cube ID	Min,value	Max,value
M1-3%	0.006	0.706	M1WB	0.004	0.496
M2-3%	0.005	0.238	M2WB	0.002	0.219
M3-3%	0.005	0.502	M3WB	0.004	0.352
M4-3%	0.004	0.236	M4WB	0.002	0.179
M5-3%	0.004	0.495	M5WB	0.004	0.166
M6-3%	0.002	0.211	M6WB	0.002	0.129