

# INTERPRETATION OF CHLORIDE ABSORPTION IN PRE-CONDITIONED IMPREGNATION PSC CUBES

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**Abstract:** The chloride contamination will occur from the application of de-icing salts. It was confirmed that the application of de-icing salts caused a significant reduction in structural and serviceability reliabilities. The chemicals used in the snow and ice control operations (de-icers) may cause corrosion damage to the transportation infrastructure such as reinforced/pre-stressed concrete structures and steel bridge. There are many ways to manage the corrosive effects of de-icers, such as selection of high-quality concrete, adequate concrete cover and alternative reinforcement, control of the ingress and accumulation of deleterious species, injection of beneficial species into concrete, and use of non-corrosive de-icer alternatives and optimal application rates. In fact, snow and ice on streets and highways are a major threat to human life and limb. Traffic accidents and fatalities climb as snow and ice reduce traction on roadways. Lengthened emergency response times create additional risks for persons in urgent need of medical care, particularly in cases of heart attacks, burns, childbirth and poisoning. Thus the de-icing salts are necessary to provide safe winter driving conditions and save lives by preventing the freezing of a layer of ice on concrete infrastructure. However, the safety and sense of comfort provided by these salts is not without a price, as these salts can greatly contribute to the degradation and decay of reinforced concrete transportation systems. The importance of chloride concentration as a durability-based material property has received greater attention only after the revelation that chloride-induced corrosion is the major problem for concrete durability. Therefore, there is a need to quantify the chloride concentration in concrete which is of paramount importance. The present research work was made an attempt to interpret the concrete chloride absorption in order to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as partially saturated condition and salt ponded with chloride solution for about 28 days. Thus the objectives of this present research are such as: First, this research will examine the influence of conditioning such as partially saturated condition on the results of chloride concentration performed on concrete cubes with different mixtures proportion in which 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 (100 mm<sup>3</sup>) with grades of concrete ranges from 25-40 N/mm<sup>2</sup> were prepared and evaluate the chloride absorption under specified exposure condition. The wetting/drying tests can be considered for the most part as a test of sorption cycles. In fact at partially saturated condition, sorption is the controlling 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 designed mixtures type of concrete, varying time durations are required in order to achieve a desired pre-conditions such as PSC conditioned cubes.

For constant higher concrete compressive strength, varied slump values and higher/lower w/c ratio, as well as varied concrete compressive strength, constant slump value and higher/lower w/c ratio, a true state of saturation is difficult to obtain. The rate of absorption (sorptivity) is controlled by the pore structure of the concrete and its degree of saturation for in case of PSC cubes. As observed from the present research that, the variation of chloride absorption in control PSC cubes was higher as when compared to impregnation concrete cubes either in solvent based (SB) and water based (WB) impregnation material. It's possible to established relationship between rate of chloride absorption and square root of time by power type of equation in designed concrete mixtures type. The average chloride absorption in PSC control/impregnation (SB/WB) concrete cubes were slightly increased/decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned PSC control/impregnation (SB/WB) concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in PSC control/impregnation (SB/WB) concrete cubes was slightly decreased with lesser concrete compressive strength and constant slump value as when compared to pre-condition PSC control/impregnation (SB/WB) concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength.

**Keywords:** Concrete, mixture proportion, grade of concrete, pre-conditioning, slump, w/c ratio, chloride absorption, de-icer, snow and ice control, reinforcing steel, corrosion

## 1.0 Introduction

Chloride penetration in reinforced concrete structure has been regarded as a big problem in the service life design. When chloride ions reach on the steel surface in concrete, a passive film, maintained by a high alkalinity of concrete pore solution, starts to dissolve, thereby leading to corrosion of steel. Corrosion propagation accordingly imposes cover cracking of inner part of concrete, which in turn gives rise to a structure failure in the end of the deterioration process. Thus, predicting the chloride ingress in concrete structure exposed to a saline environment is essentially required to prepare a proper maintenance and thus reduce such high risk of chloride induced corrosion. Knowledge of performance of structural concrete is required for design and compliance purposes. One driving force for the use of high performance concretes (HPC) is enhanced durability yet it would be wrong to assume that all HPCs can deliver the desired performance level. In situ characterisation of the permeation properties of concrete is the most viable means for assessing durability and has become increasingly

important over the past 20 years. A variety of methods exist that provide a range of parameters (air permeability, water absorption rate, sorptivity and chloride migration coefficient). In this paper both the challenges and opportunities for assessing transport properties of high-performance concrete are highlighted [Yang *et al.* 2018]. Carbonation and chloride action are the two leading causes of degradation in reinforced concrete structures. Despite the combined action of these two mechanisms being a reality, there is little research on the effect of this combination in cementitious matrices. Incorporation of fly ash in cementitious matrices has been frequently used in order to make the matrix more resistant to the action of chlorides. It is known that  $\text{Ca}(\text{OH})_2$  existing in the matrix is consumed by the pozzolanic reactions, which makes easier the carbonation front advance. This paper presents a study of the behavior of cementitious matrices, with and without fly ash, subjected to the combined action of chlorides and carbonation. After curing, the specimens were subjected to three different wetting-drying cycles, considering NaCl solutions and  $\text{CO}_2$  atmospheres. Results show that carbonation has a direct influence on chloride penetration, decreasing it for cement mortars with 0% fly ash and increasing it for mortars with 40% cement replacement by fly ash. Moreover, the evolution of carbonation is also influenced by chloride presence, which decreases under the combined action [Raphaele Malheiro *et al.* 2018]. In the present day models for the life of concrete structures, the causes of failure have been earmarked and role of chloride ion has been placed at the top, because of comparative ease of  $\text{Cl}^-$  transport in concrete structure and its extraordinary damaging effect on the existing passivating film on the rebar surface. Therefore, diffusion of  $\text{Cl}^-$  ions through concrete media has been given pronounced recognition and various testing techniques for the measurement of 'diffusion' of  $\text{Cl}^-$  have been developed and standardized [Altaf Ahmad, and Anil Kumar, 2013]. Chloride-induced corrosion is the major durability issue of reinforced concrete structures along seacoast and in cold areas where de-icing salts are used. Various service life prediction models based on chloride induced corrosion have been developed. Temperature plays an important role in modeling chloride transport in cement-based materials. However, it is often overlooked. In this paper, the effect of temperature on non-steady-state migration and diffusion coefficients of chloride ion in concrete with w/c ratios of 0.35, 0.48 and 0.6 were investigated. Non-steady-state migration coefficient was measured at 20°C and 5°C following NT build 492. Non-steady-state diffusion coefficient was measured at 5°C, 20°C and 40°C according to NT build 443. The effect of temperature on migration/diffusion coefficient is examined by using Arrhenius Equation. The results show that higher temperatures result in higher diffusion/migration coefficients. Temperatures alter the chloride penetration depth, but not the trend of chloride profile. The activation energy obtained from non-steady-state migration coefficient is quite comparable to Samson and Marchand's results, which is around 20 kJ/mol, and independent of w/c ratio. However, the activation energy obtained from non-steady-state diffusion tests ranges from 17.9-39.9 kJ/mol, which seems dependent on w/c ratio. The surface chloride concentration is also affected by water-to-cement ratio and temperature [Qiang Yuan Ghent *et al.* 2009]. Due to environmental (low  $\text{CO}_2$  emission) and economic benefit, supplementary cementitious materials (SCMs) have been widely used in reinforced concrete structures. However, the question from engineering practice is to which extend these blended mixtures do meet the future durability criteria. Chloride ingress is nowadays considered as the main concern for reinforcement corrosion. Due to self-desiccation or drying process, cement-based materials are no longer saturated, which would greatly influence the chloride transport properties. This paper explores the effect of water saturation level on chloride diffusivity in cement-based materials by resistivity measurements. The results showed that chloride diffusivity is highly dependent on the water saturation level and water-vapour desorption isotherm of the mortar material. The dependency varies with cement type, and is significantly related to pore size distribution characteristics. In addition, the effect of water content on chloride diffusivity is more evident in blended cement mortars than reference ordinary Portland cement mortar. For the materials studied in this research, the capillary pores with diameter range of 7.1-73 nm plays dominated role in chloride diffusion under non-saturated state. Chloride penetration is a humid process, and occurs only if water is present. In saturated condition, all the pores in concrete are fulfilled with water solution. Diffusion through the water-filled porous network is believed to be the main mechanism for chloride penetration. Under non-saturated condition, water phase favours to fill the smaller pores, and the moisture profile inside porous network would be distributed in different manner from that in saturated condition. As a result, the chloride penetration becomes much more complex. Corrosion is the inevitable process that occurs when refined metals return to their more stable combined forms as oxides, carbonates and sulphides. The corrosion process may be defined as the surface wastage that occurs when metals are exposed to reactive environments. Costs associated with corrosion damage and control can be substantial, being as much as 3.5% of the GNP of some industrial countries. Reinforced concrete structures have not been immune to the ravages of corrosion despite the protection that concrete provides to embedded steel. Reasons for the increasing incidence of corrosion damage to reinforced concrete structures include the use of de-icing salts and calcium chloride set-accelerators, increased construction in aggressive environments, fast-track construction practices, changing cement composition resulting in finer grinding and lower cement contents, lower cover depths and poor construction practice including inadequate supervision. Reinforcement corrosion is particularly pernicious in that damage may occur rapidly and repairs are invariably expensive. Furthermore by the time visible corrosion damage is noticed, structural integrity may already be compromised. There is currently considerable debate about the merits of the various systems for the repair of reinforcement corrosion. This monograph attempts to clarify some of the important issues by drawing on international experience as well as local findings. Effectiveness of repair systems should be measured in terms of cost, risk of failure and long-term performance. As such no single system is appropriate for all repairs but will depend on the type of structure, service conditions, level of deterioration and financial constraints of the project [Yong Zhang, and Guang Ye, 2015]. Chloride-induced corrosion of steel in concrete structures exposed to marine environment has been identified as one of the main causes of durability deterioration and decreased service lives. The initiation period is a key element in predicting the service life of reinforced concrete structures. This paper proposes a mathematical model to predict the initial phase of steel corrosion in reinforced concrete structures in the marine environment [Dao Van Dinh, 2017]. Transport of chloride in unsaturated concrete media is largely controlled by various phenomena occurring during the kinetics of the penetration of the ions chlorides within this media. This article studies the influence of the hydric rate of cementitious material on the penetration of chlorides. This transfer test was performed which insures an optimal contact of the material with a chloride solution without perturbing the hydric state of the material during these tests and by taking into account the fixation of chlorides on the matrix material. The results showed the important effect of the rate of saturation on the chlorides transfer and fixation [Hayet Chalabia *et al.* 2017]. In order to mimic the intermittent exposure of sea water to concrete, varying environmental conditions for relative humidity and chloride concentration were considered. As for the moisture distribution in concrete, statistical permeability model based on pore size distribution was used to represent influence of material properties on moisture transport. Then, a combined chloride diffusion and convection was

modelled in variation of moisture level in concrete. As a result, smaller relative wet duration induces higher rate of chloride penetration due to enhanced moisture permeability from the surface, and also higher concentration gradient near the surface of concrete due to repeated wet/dry cycle. This implies that only diffusion analysis on chloride induced corrosion in concrete structure may underestimate the serviceability in given material performance [Sung-In Hong *et al.* 2017].

The prolonged periods of snowfall in countries with advanced infrastructure and transport systems have rendered the use of de-icing agents to a common occurrence on roads and highway structures. They are necessary in order to maintain a good level of service with respect to the transport systems, thus avoiding traffic jams and disruptions, but also to provide a high level of road safety. Today, chloride-based products, such as rock salt, are the most commonly encountered de-icers as they are easy to apply and store but mostly because they efficiently melt ice at an affordable price [TRB, 1991]. However, their widespread use over a long period has left the construction industry and the engineering community with a grave problem regarding the durability of highway reinforced concrete bridges and multi-storey parking structures [Pullar-Strecker, 2002], due mainly to the fact that they cause corrosion of the reinforcement and steel components [Pullar-Strecker, 2002]. In cold-climate regions, snow and ice control operations are crucial to maintaining highways that endure cold and snowy weather. The growing use of de-icers has raised concerns about their effects on motor vehicles, transportation infrastructure, and the environment. The deleterious effect of chloride-based de-icers on reinforcing steel bar in concrete structures is well known [Shi, *et al.* 2009]. De-icers may also pose detrimental effects on concrete infrastructure through their reactions with cement paste and/or aggregates and thus reduce concrete integrity and strength, which in turn may foster the ingress of moisture, oxygen and other aggressive agents onto the rebar surface and promote rebar corrosion. Large amounts of solid and liquid chemicals (known as de-icers) as well as abrasives are applied onto winter highways to keep them clear of ice and snow. De-icers applied on to highways often contain chlorides because of their cost-effectiveness, including mainly sodium chloride (NaCl), magnesium chloride (MgCl<sub>2</sub>), and calcium chloride (CaCl<sub>2</sub>), sometimes blended with proprietary corrosion inhibitors. The rock salt/sodium chloride (NaCl), is the most commonly used de-icing agent. It was first used to control snow and ice on roadways to improve transportation safety in the 1930s, and became widespread by the 1960s. The salt works by dissolving into precipitation on roadways and lowering the freezing point, thereby melting ice and snow. Eliminating the ice has enormous safety benefits, but depending on the amount of chemicals used, the dissolved salt can have negative effects on the surrounding environment. The melting snow and ice carries de-icing chemicals onto vegetation and into soils along the roadside where they eventually enter local waterways. Elevated salt levels in soils can inhibit the ability of vegetation to absorb both water and nutrients, which can slow plant growth and ultimately affect animal habitats. This degradation also affects the ability of these areas to act as buffers to slow the runoff of other contaminants into the watershed. Once the salt enters freshwater it can build up to concentration levels that further affect aquatic plants and other organisms. Salt deposits along roadways also attract birds, deer, and other animals which increases the chance of animal-vehicle accidents. While the major effect on public drinking water supplies for humans is merely an alteration of taste, high concentrations of sodium in drinking water can lead to increased dietary intake and possibly hypertension. Since salt is corrosive to automobiles, bridge decks, and other roadway infrastructure, de-icing chemicals are often combined with other substances to block corrosion. While eliminating ice is of great benefit to commerce and human safety, these drawbacks must be taken into consideration by communities as they plan for regular maintenance of the concrete infrastructure, as well as the health of the local ecosystem. The costs of maintaining reinforced concrete infrastructures are increasing due to aging of structures, which are being exposed to aggressive environment. Corrosion of reinforcement due to chloride ingress is the main problem for existing structures in marine and de-icing salt environments [Bertolini *et al.* 2013]. In the Netherlands 5% of motorway bridges, built predominantly between 1960 and 1980, shows cracking and spalling of the concrete cover due to chloride induced corrosion [Gaal, 2004]. This corresponds to 10% of the bridges showing corrosion initiation at an age of 40 years [Polder *et al.* 2012]. Older structures have been built according to older codes, which may not have provided sufficient protection. Moreover, for new infrastructure corrosion cannot be ruled out completely, even with today's emphasis on design for long service life (typically 100 years), either by composition requirements (Eurocodes) or based on service life modelling and performance testing [Fib, 2006]. This may be due to various factors, such as unforeseen aggressive loads, e.g. leakage of joints; or to deviations from the intended concrete quality or cover thickness; or to modelling inadequacies [Bertolini *et al.* 2011]. Repair of corrosion damage is possible, but costly, potentially disruptive and not necessarily long lived. A European study has shown that 50% of repairs fail within 10 years [Tilly, 2011]. These results were confirmed by a study in the Netherlands [Visser *et al.* 2012]. In the worst case, this means that after about 10 years the structure must again be repaired, involving more costs; and possibly this will go on until the structure is taken out of service. Thus in the present research work, an attempt was made to interpret the concrete chloride absorption in order to characterize the different concrete mixtures type for in case of 72 pre-conditioned concrete cubes (100 mm<sup>3</sup>) such as partially saturated condition and salt ponded with chloride solution for about 28 days. This research will examine the influence of conditioning such as partially saturated condition on the results of chloride absorption in concrete cubes with different mixtures proportion in which slump (0-10, 10-30, 60-180) mm, and w/c ratio value was varied with constant compressive strength (40 N/mm<sup>2</sup>) as in the first case and compressive strength (25-40 N/mm<sup>2</sup>), and w/c ratio value varied with constant slump (10-30) mm as in the second case.

## 2.0 Research objectives

The interpretation of the performance of a concrete mix is not limited to the determination of its mechanical properties since it is of paramount importance to characterize the material in terms of the parameters that rate its durability. The importance of chloride concentration as a durability-based material property has received greater attention only after the revelation that chloride-induced corrosion is the major problem for concrete durability. The present research work was made an attempt to interpret the concrete chloride absorption in order to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as partially saturated condition and salt ponded with chloride solution for about 28 days with 10% NaCl solution. Thus the objectives of this present research is to examine the influence of conditioning such as partially saturated condition on the results of chloride absorption in concrete cubes with different mixtures proportion in which 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 (100 mm<sup>3</sup>) with grades of concrete ranges from 25-40 N/mm<sup>2</sup> were prepared and evaluate the chloride absorption under specified exposure condition.

### 3.0 Experimental program

In the present research work, six different mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm<sup>3</sup>). Three of the mixtures were concrete cubes (100 mm<sup>3</sup>) with a compressive strength 40 N/mm<sup>2</sup>, slump (0-10, 10-30, and 60-180 mm), and different w/c (0.45, 0.44, and 0.43). These mixtures were designated as M1, M2, and M3. Another Three of the mixtures were concrete cubes with a compressive strength (25 N/mm<sup>2</sup>, 30 N/mm<sup>2</sup>, and 40 N/mm<sup>2</sup>), slump (10-30 mm), and different w/c (0.5 0.45, and 0.44). These mixtures were designated as M4, M5, and M6. The overall details of the mixture proportions were to be represented in Table.1-2. Twelve concrete cubes of size (100 mm<sup>3</sup>) were cast for each mixture and overall Seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crushed stone with maximum nominal size of 10 mm with grade of cement 42.5 N/mm<sup>2</sup> and fine aggregate used was 4.75 mm sieve size down 600 microns for this research work. As concern to impregnation materials, Water based (WB) and Solvent based (SB) impregnate materials were used 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 disclosed and they will be referred 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.

Table: 1 (Variable: Slump & W/C value; Constant: Compressive strength)

Mix No	Comp/mean target strength(N/mm <sup>2</sup> )	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA(Kg) 10 mm	Mixture Proportions
M1	40/47.84	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M2	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M3	40/47.84	60-180	0.43	5.43	2.34	6.42	14.30	1:1.18:2.63

Table: 2 (Variable: Compressive strength & W/C value; Constant: Slump)

Mix No	Comp/mean target strength(N/mm <sup>2</sup> )	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA(Kg) 10 mm	Mixture Proportions
M4	25/32.84	10-30	0.50	3.84	1.92	5.98	17.04	1:1.55:4.44
M5	30/37.84	10-30	0.45	4.27	1.92	6.09	16.50	1:1.42:3.86
M6	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87

### 4.0 Interpretation of chloride absorption

The primary aim of this research was to interpret the effectiveness of wetting pre-conditioned concrete cubes on chloride absorption, which was exposed to pre-determined conditions such as partially saturated condition was evaluated in control/impregnation concrete cubes for about 28 days salt ponding test in all designed six mixtures type (M1-M6). The pre-conditioned partially saturated condition was assessed in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 21 days. The chloride ingress in to the concrete can only take place if the concrete pores are totally/partly filled 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 concrete is a porous material with a wide range of pore sizes. Nano-pores are predominant in the hydration products of cements. In fact the concrete was just as other similar porous systems which have an intense interaction with moisture of its environment. If the concrete surface is in contact with liquid water or with aqueous salt solutions, significant quantities of water are absorbed by capillary suction. Under drying conditions, the moisture content is reduced again with a marked hysteresis. All changes of moisture content will induce volume changes which are at the origin of crack formation. The durability of a concrete structure depends essentially on this complex interaction between the porous material and its surrounding. It has been shown by a number of authors that, the deep impregnation of the concrete surfaces with water repellent agents forms an efficient and long lasting barrier with respect to chloride ingress [Zhao *et al.* 2006]. In this way service life of reinforced concrete structures situated in an aggressive environment such as marine climate/de-icing performance can be significantly improved in different concrete infrastructures. Thus in the present research work that, the effectiveness of impregnation materials such as solvent/water based impregnation materials was evaluated in pre-conditioned concrete cubes in ordered to reduce chloride absorption for in case of designed mixtures type. The variation of concrete chloride absorption values under pre-conditioned control (M1CC-M6CC)/impregnation (M1SB-M6SB) concrete cubes in PSC was represented in Tables.3 at different time duration (1-24) day respectively.

**Table.3 Interpretation of chloride absorption in PSC/IC cubes**

Mix ID	1 day	3 day	6 day	9 day	12 day	15 day	18 day	21 day	24 day
M1CC	3.220	3.220	3.261	3.261	3.262	3.262	3.262	3.263	3.303
M1SB	1.161	1.162	1.202	1.202	1.202	1.203	1.203	1.203	1.204
M1WB	2.438	2.438	2.480	2.480	2.480	2.484	2.485	2.485	2.485
M2CC	2.480	2.480	2.523	2.524	2.524	2.524	2.524	2.525	2.525
M2SB	1.929	1.929	1.969	1.969	1.969	1.969	1.970	1.970	1.970
M2WB	2.244	2.244	2.284	2.284	2.284	2.286	2.286	2.287	2.287
M3CC	2.152	2.153	2.193	2.193	2.193	2.193	2.194	2.194	2.195
M3SB	1.864	1.864	1.909	1.909	1.909	1.909	1.910	1.910	1.911
M3WB	1.977	1.977	2.020	2.020	2.020	2.020	2.021	2.021	2.022
M4CC	2.813	2.813	2.857	2.859	2.860	2.860	2.861	2.861	2.861
M4SB	1.878	1.879	1.924	1.925	1.925	1.925	1.925	1.926	1.926
M4WB	2.304	2.304	2.349	2.350	2.350	2.350	2.350	2.350	2.351
M5CC	2.259	2.259	2.302	2.303	2.303	2.303	2.303	2.303	2.304
M5SB	1.841	1.842	1.879	1.879	1.880	1.880	1.880	1.880	1.881
M5WB	2.003	2.003	2.047	2.047	2.048	2.048	2.049	2.049	2.050
M6CC	1.947	1.947	1.991	1.991	1.992	1.992	1.992	1.993	1.993
M6SB	1.671	1.671	1.716	1.716	1.716	1.717	1.717	1.718	1.718
M6WB	1.824	1.824	1.869	1.869	1.873	1.875	1.875	1.875	1.876

## 5.0 Discussion about Results

The dry-wet pre-condition accelerate the transport process of chloride absorption within a certain distance from the surface, beyond this distance, chloride absorption in the complete immersion specimens migrate more rapidly than those under dry-wet pre-condition [Xu Gang *et al.* 2015]. In absolute dry condition, the penetration rate of chloride ion will be much larger because of advection process than that in diffusion process in mortar with water saturated condition. Moreover, at the surface part of mortar, additional chloride content due to diffusion process can be also confirmed on distribution of chloride content due to advection process during absorption test. In order to assess the penetration of chloride ion, effects of both advection and diffusion processes depending on moisture condition of mortar should be considered. The concrete 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 absorbed by capillary suction and concentrated by evaporation of water. It was found from the researchers [Hong, and Hooton, 1999] that, the longer drying times increase the rate of chloride ingress. A good relationship exists between the depth of chloride penetration and the square root of the number of cycles. In fact several authors have shown that an effective chloride barrier can be established in pre-conditioned concrete by surface impregnation with a liquid water repellent. However, the question arises frequently as to whether chloride contaminated concrete structures with high moisture content can still be protected from further chloride penetration into the porous structure by surface impregnation. There is a need to determine the efficiency of surface impregnation of chloride-contaminated concrete before any protective treatment applied on the concrete. In the present research work, tests were run to investigate the influence of pre-condition such as PSC cubes on the efficiency of surface impregnation. It's actually confirmed from the results that, higher saturation degree reduces the efficiency of surface impregnation. Thus, pre-drying of concrete with high saturation degree is essential for the establishment of an effective, reliable, and long lasting chloride barrier. The process of wetting/drying is a major problem for concrete infrastructures which was exposed to chlorides and its effects are most severe in many concrete infrastructures locations such as marine structures, particularly in the splash and tidal zones, parking garages exposed to de-icer salts, and highway structures, such as bridges and other elevated roadways for instance the Gardner expressway. When the concrete is dry/partially dry, which was then exposed to salt water, it will imbibe the salt water by capillary suction. The concrete will continue to suck in the salt water until saturation or until there is no more reservoir of salt water. A concentration gradient of chlorides will develop in the concrete, stopping at some point in the interior of the concrete. If the external environment becomes dry, then pure water will evaporate from the pores, and salts that were originally in solution may precipitate out in the pores close to the surface. The point of highest chloride concentration may exist within the concrete. On subsequent wetting, more salt solution will enter the pores, while re-dissolving and carrying existing chlorides deeper into the concrete. The rate to which the chlorides will penetrate the concrete depends on the duration of the wetting/drying periods. If the concrete remains wet, some salts may migrate in from the concrete surface by diffusion. However, if the wetting period is short, the entry of salt water by absorption will carry the salts into the interior the concrete and be further concentrated during drying. The process of wetting/drying increases the concentrations of ions such as chlorides, by evaporation of water. The drying of the concrete also helps to increase the availability of the oxygen required for steel corrosion, as oxygen has a substantially lower diffusion coefficient in saturated concrete. As the concrete dries and the pores become less saturated, oxygen will have a better chance to diffuse into the concrete and attain the level necessary to induce and sustain corrosion. There is an

increased availability of oxygen that also contributes to the deterioration compared to the submerged part of the structure. The concrete is fully submerged, less chloride would enter the concrete as the dominant penetration mechanism is diffusion through the pore solution. There are several factors that can affect the degree that chlorides will enter concrete through wetting/drying. In fact the ingress of chlorides into concrete is strongly influenced by the sequence of wetting/drying, and on the time duration. Thus in the present research work, the effectiveness of 72 preconditioned concrete cubes of size (100) mm on chloride absorption under pre-conditions such as partially saturated condition was evaluated for in case of six designed mixtures type (M1-M6). The variation of chloride absorption in control concrete cubes for in different mixtures type (M1CC-M6CC) is as shown in Figs.1a-1f respectively. Chloride absorption is correlated with square root of time by power type of equation for in all designed control mixtures type (M1CC-M6CC).

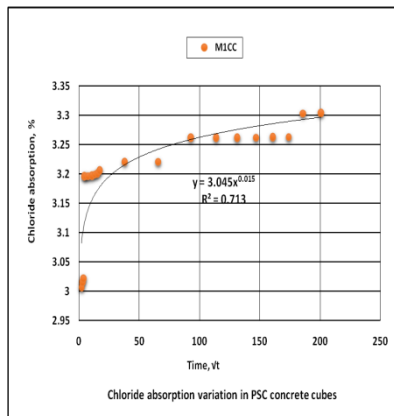


Fig.1a Cl-time in control mix M1

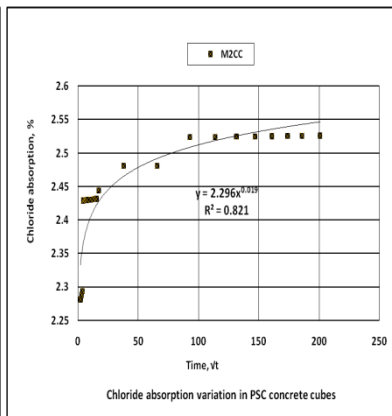


Fig.1b Cl-time in control mix M2

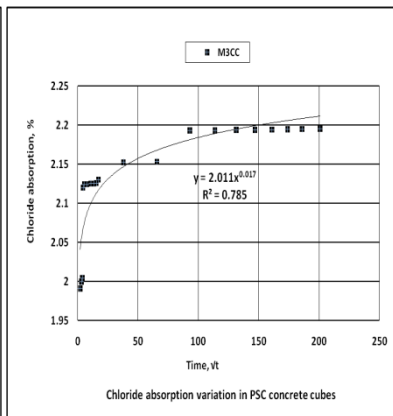


Fig.1c Cl-time in control mix M3

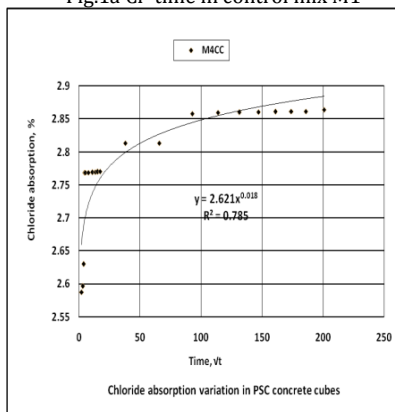


Fig.1d Cl-time in control mix M4

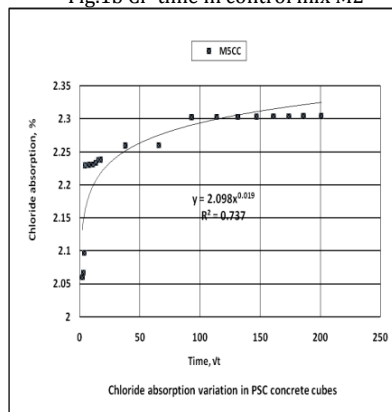


Fig.1e Cl-time in control mix M5

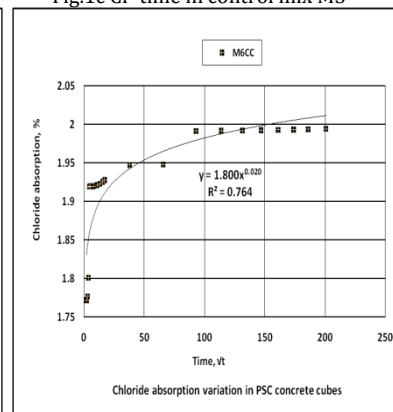


Fig.1f Cl-time in control mix M6

The chloride absorption is gradually increased at initial time duration, afterwards deviates with square root of time duration and reaches equilibrium in turn indicates that, pore structure is attained fully saturated condition. The chloride absorption is increased at time interval (1 day) as when compared to time interval (28 day) for in case of all designed control mixtures type [(M1CC-M2CC:22.98-23.55, M1CC-M3CC:33.17-33.55, M1CC-M4CC:12.66-13.32, M1CC-M5CC:29.84-30.25, M1CC-M6CC:39.54-39.64, M2CC-M3CC:13.23-13.09, M2CC-M4CC:-13.40-(-13.38), M2CC-M5CC:8.90-8.76, M2CC-M6CC:21.50-21.06, M3CC-M4CC:-30.70-(-30.46), M3CC-M5CC:-4.99-(-4.98), M3CC-M6CC:9.52-9.16, M4CC-M5CC:-19.67-19.53, M4CC-M6CC:30.78-30.37, and M5CC-M6CC:13.82-13.47]%. The chloride absorption is initially increased due to concentration gradient. Concentration gradient is more at an initial time duration, due to that the rate of absorption is also more, once the pore structure is fully saturated, the rate of chloride absorption goes on decreases with time duration. Thus the concentration gradient is more at an initial stage, goes on decreases as time passes and thus chloride absorption is reduced gradually as time in turn reaches equilibrium state.

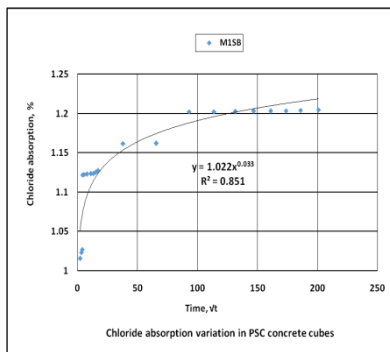


Fig.2a Cl-time in impregnation mix M1

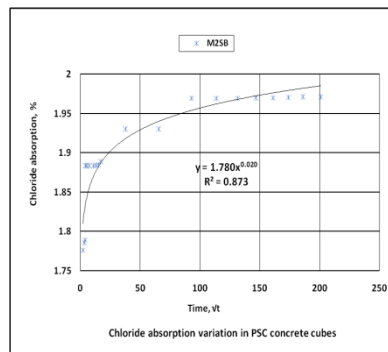


Fig.2b Cl-time in impregnation mix M2

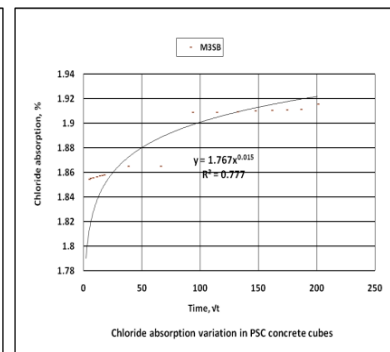


Fig.2c Cl-time in impregnation mix M3

The chloride absorption is increased at initial time duration, deviates with square root of time duration and reaches equilibrium when the concrete structure is attained fully saturated condition. The chloride absorption is increased at time interval (1 day) as when compared to time interval (28 day) for in case of all designed control mixtures type as when compared to impregnation concrete cubes [(M1CC-M1SB:63.94-63.55, M1CC-M1WB:24.29-24.75, M2CC-M2SB:22.21-21.96, M2CC-M2WB:9.51-9.43, M3CC-M3SB:13.36-12.75, M3CC-M3WB:8.13-7.88, M4CC-M4SB:33.22-32.71, M4CC-M4WB:18.07-17.89, M5CC-M5SB:18.49-18.35, M5CC-M5WB:11.33-11.03, M6CC-M6SB:14.15-13.80, M6CC-M6WB:6.31-5.90, and M1WB-M1SB:52.36-51.56, M2WB-M2SB:14.04-13.84, and M3WB-M3SB:5.69-5.29, M4WB-M4SB:18.49-18.05, M5WB-M5SB:8.07-8.23, M6WB-M6SB:8.37-8.39]%. Chloride absorption is initially increased which may be due to concentration gradient. Variation of chloride absorption in impregnation concrete cubes for in case of different mixture type (M1SB-M6SB) is as shown in Figs.2a-2f respectively. Chloride absorption is directly correlated to the square root of time by power type of equation in all designed impregnation mixtures type (M1SB-M6SB).

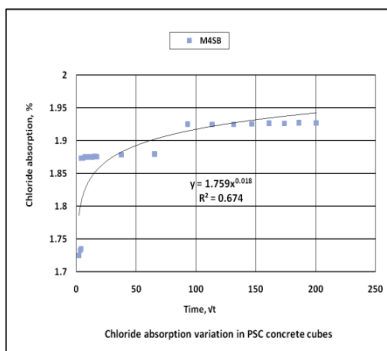


Fig.2d Cl-time in impregnation mix M4

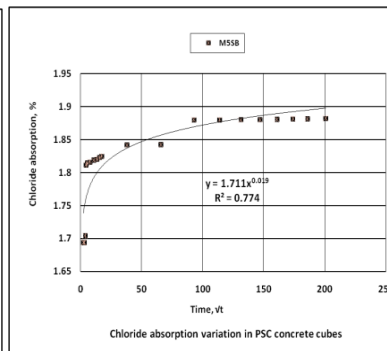


Fig.2e Cl-time in impregnation mix M5

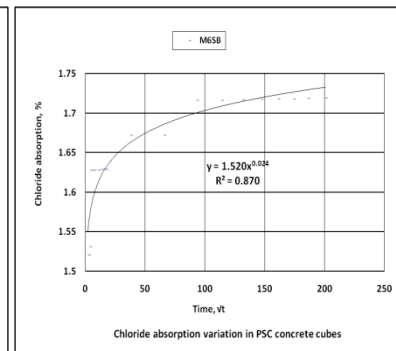


Fig.2f Cl-time in impregnation mix M6

The chloride absorption is initially increased which may be due to concentration gradient. Variation of chloride absorption in impregnation concrete cubes for in case of different mixture type (M1WB-M6WB) is as shown in Figs.3a-3f respectively. Chloride absorption is directly correlated to the square root of time by power type of equation in all designed impregnation mixtures type (M1WB-M6WB).

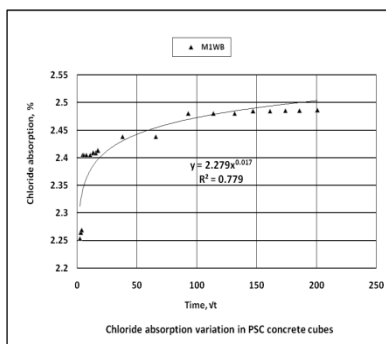


Fig.3a Cl-time in impregnation mix M1

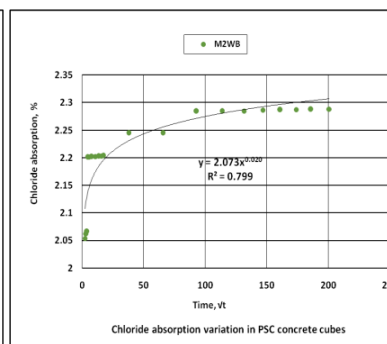


Fig.3b Cl-time in impregnation mix M2

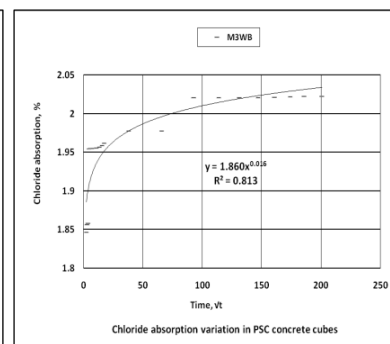


Fig.3c Cl-time in impregnation mix M3

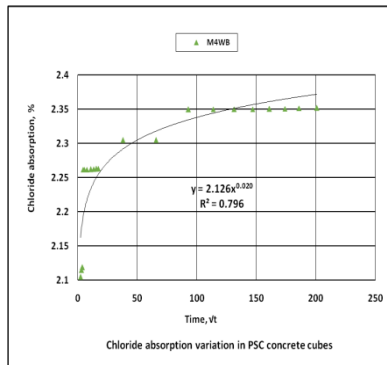


Fig.3d Cl-time in impregnation mix M4

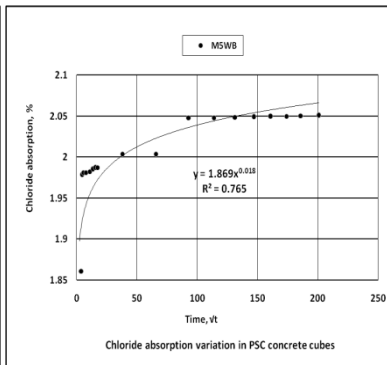


Fig.3e Cl-time in impregnation mix M5

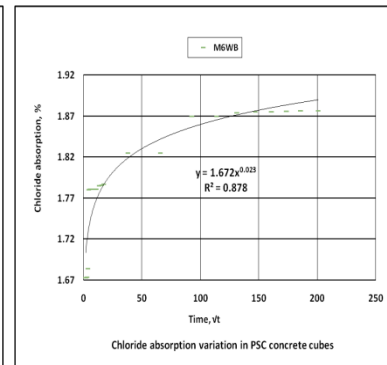


Fig.3f Cl-time in impregnation mix M6

The chloride absorption is increased at time interval (1 day) as when compared to time interval (28 day) for in case of all designed impregnation mixtures type as when compared to different designed impregnation mixture type [(M1WB-M2WB:7.94-7.98, M1WB-M3WB:18.91-18.66, M1WB-M4WB:5.48-5.41, M1WB-M5WB:17.83-17.52, M1WB-M6WB:25.18-24.52, M2WB-M3WB:11.91-11.61, M2WB-M4WB:-2.67-(-2.79), M2WB-M5WB:10.74-10.37, M2WB-M6WB:18.72-17.98, M3WB-M4WB:-16.56-(-16.29), M3WB-M5WB:-1.33-(-1.39), M3WB-M6WB:7.73-7.21, and M4WB-M6WB:13.07-12.81, M4WB-M6WB:20.84-20.20, and M5WB-M6WB:8.94-8.48]%. The average chloride absorption was pre-dominantly increased in control and impregnation PSC/SB/WB cubes for lesser compressive strength and constant slump value and the chloride absorption value decreases with increased compressive strength and constant slump value for in case of designed mixtures type at longer time duration. Similarly, the average chloride absorption was decreased in solvent and water based impregnation PSC cubes as when compared to control PSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value at longer time duration. The variation of average chloride absorption in control/solvent/water based impregnation PSC cubes at longer time duration was represented in Fig.4a-4f for different designed mixtures type (M1-M6).

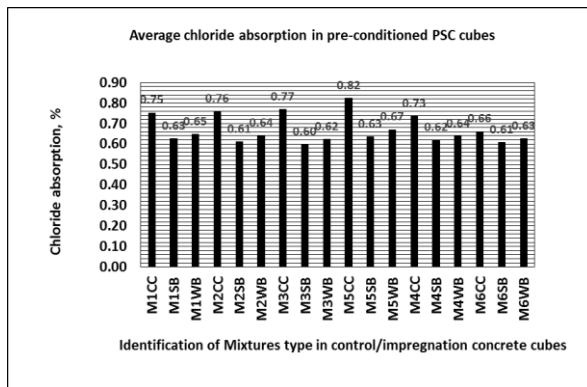


Fig.4a Cl absorption in control/IC PSC cubes

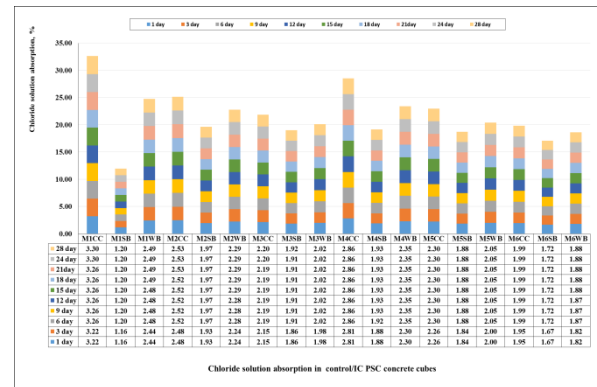


Fig.4b Cl absorption in control/IC PSC cubes

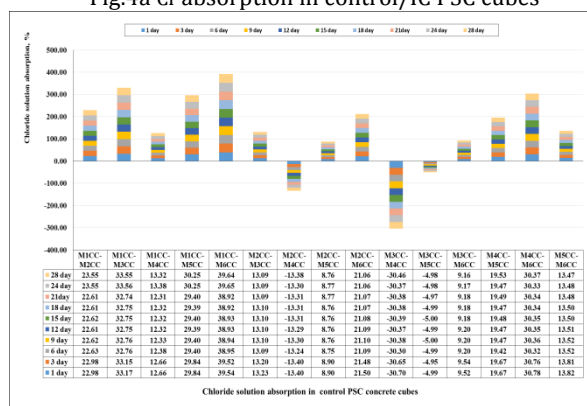


Fig.4c Cl absorption in control PSC cubes

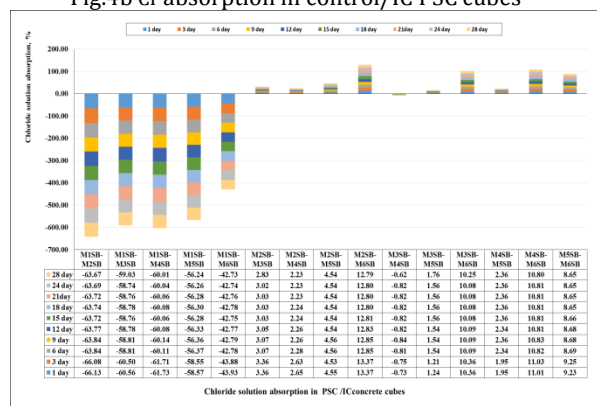


Fig.4d Cl absorption in impregnation PSC cubes

The chloride absorption is also increased in solvent based impregnation concrete cubes (M1SB-M6SB) at time interval (1 day) as when compared to time interval (28 day) for in case of all designed impregnation mixtures type as when compared to different designed impregnation mixture type [(M1SB-M2SB:-66.13-(-63.67), M1SB-M3SB:-60.56-(-59.03), M1SB-M4SB:-61.73-(-60.01), M1SB-M5SB:-58.57-(-56.24), M1SB-M6SB:-43.93-(-42.73), M2SB-M3SB:3.36-2.83, M2SB-M4SB:2.65-2.23, M2SB-M5SB:4.55-4.54, M2SB-M6SB:13.37-12.79, M3SB-





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