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CHLORIDE PENETRATION AT DIFFERENT DEPTHS IN PSC CONCRETE 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 bridges. 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. 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 ordered 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 160 days. Thus the objectives of this present research are such as: First, this research will examine the influence of conditioning in partially saturated condition on the results of chloride concentration at different drill depths (30-40-50 mm) 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. Twenty four concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride absorption under specified exposure condition. It's concluded from the results that, in partially saturated conditioned concrete cubes, the chloride absorption value was increased in designed mixtures type. Similarly, the average chloride concentration was decreased in solvent based 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. Whereas the average chloride absorption was increased in solvent based and water based impregnation PSC cubes for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride concentration was going on decreases with increased compressive strength and constant slump value. It's possible to correlate the chloride concentration-drill depths by power type of equation in designed concrete mixtures type.

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

1.0 Introduction

Chloride-induced corrosion of steel bars in reinforced concrete is one of the major causes of deterioration of reinforced concrete structures in North America. Highway bridges and parking garages exposed to de-icing salts are among the structures most affected by corrosion induced damage. This damage is usually manifested in the form of cracking and spalling of the concrete cover due to the expansion of corrosion products accumulating around the reinforcement. Over time it can also cause structural distress due to either loss of bond along the steel/concrete interface resulting from splitting of the concrete cover/reduction of the cross-sectional area of the reinforcing bars. Chloride ion is a key factor affecting durability of reinforced concrete structures. In order to investigate chloride migration in cracked concrete, considering the mesoscopic heterogeneity of concrete, concrete modelled here is treated as a four-phase composite consisting aggregate, mortar, crack, and interfacial transition zone. Two dimensional finite element models of cracked concrete with different crack widths and crack quantity are established and the control parameters are determined based on the non-steady-state chloride migration test. In addition, based on the concrete finite element models, influences of crack width, crack quantity, and erosion time on chloride migration behaviours and characteristics are studied. Furthermore, a prediction model of chloride concentration on the simulated surface of a rebar in concrete influenced by different crack states is established. This model is used to derive the corrosion current density and corrosion depth prediction models of a rebar in this paper, which can be used by engineers to estimate the migration behaviours of chloride and rebar corrosion degree in RC structures in a short time and evaluate the duration of RC structures after knowing the status of cracks and chloride diffusion sources [Yongchun Cheng *et al*. 2018]. Comparative effect of temperature and relative humidity data at five places along Indian coasts on corrosion initiation time of steel reinforcement in concrete members subjected to chloride ingress is investigated. Corrosion initiation time at all the places is predicted by considering respective temperature and relative humidity data and assuming same values of all other parameters. A large variation is found in corrosion initiation time which showed necessity to consider the temperature and relative humidity data in a region. Corrosion initiation time is useful for owner, designer, or to an organization to take decision in time of priority of repairs, repair strategy, corrosion protection. Cover required for 50 years' time to initiate corrosion is also determined and presented. Similar approach can be applied to design a new structure for expected time to initiate corrosion [Satish. B. Allamallewari and Srividya, 2008]. Simulation tool, based on proven predictive models utilizing principles of chemical and material engineering, for the estimation of concrete service life is applied on an existing reinforced concrete bridge (Ø resund Link) located in a chloride environment. After a brief introduction to the structure of the models used, emphasis is given on the physicochemical processes in concrete leading to chloride induced corrosion of the embedded reinforcement. By taking under consideration the concrete, structural and environmental properties of the bridge investigated, an accurate prediction of its service life is taking place. It was observed that the proposed, and already used, relationship of service lifetime-cover is almost identical with a mean line between the lines derived from the minimum and maximum critical values considered for corrosion initiation. Thus, an excellent agreement with the project specifications is observed despite the different ways used to approach the problem. Furthermore, different scenarios of concrete cover failure, in the case when a coating is utilized, and extreme de-icing salts attack is also investigated [Vagelis G. Papadakis, 2013]. A method for predicting the chloride ingress into concrete structures, which is the first and main phase of chloride induced reinforcement corrosion, is developed. The heat transfer, moisture transport and chloride diffusion, that contribute to the rate and amount of transported chlorides into concrete are modeled. The proposed finite element model and its associated program are capable of handling pertinent material nonlinearities and variable boundary conditions that simulate real exposure situations. The numerical performance of the model was examined through few examples to investigate the effect of the different model parameters and mechanisms considered on the process of chloride penetration into concrete, and eventually, on the service life of concrete [H'mida Hamidane, and Ayman Ababneh. 2014]. Chloride induced reinforcement corrosion is one of the most important degradation processes in reinforced concrete structures exposed to marine environment and road environment where de-icing salt is used in the winter. The degradation of reinforced concrete structures, especially infrastructures, has very important economic and social consequences due to the need for diverting resources for repairing damaged structures and sometimes the need to close the facility for carrying out the repair work. Owing to its long coastline and intensive application of de-icing salt, the topic of chloride ingress in concrete has special significance in Sweden. In the beginning of 1990's, a Swedish national project called "BMB"– Durability of marine concrete structures was initiated [Sandberg, 1996]. The study investigates the effect of metakaolin as replacement of cement on durability of mix to chloride attack when subjected to freezing/thawing and wetting/drying exposure conditions. The investigations indicated that metakaolin as replacement of cement increased the chloride resistance of mortar. The various chloride salts have different penetration rates into the given mix, resulting in different degree of damages. Calcium chloride was found to be most destructive under the applied exposure conditions. Also, the compatibility of corrosion inhibitor was found to depend on the type of salt solution to which the specimens were exposed. Among the exposure conditions, freezing/thawing cycles were found to be more detrimental as compared to wetting/drying cycles [Shweta Goyal *et al*. 2008]. The main objective of the study was to develop the service life prediction model related to the penetration of chloride ions into concrete. To this purpose, some phenomena pertaining to the penetration of chloride ions have been modeled mathematically, which include heat transfer, moisture transport and diffusion and convection of chloride ions. The developed models are ready to account for the various environmental exposure conditions. Traditional model for chloride penetration is to use so-called error-function solution with respect to the Fick's second law of diffusion. In the present study, special attention was given to the coupling of moisture and chloride transport, which makes it possible to estimate the chloride penetration under drying-wetting condition and with de-icing salts. Two-dimensional finite element program was developed to deal with these environmental conditions. By comparing the calculated chloride content with some experimental data, it has been confirmed that the analysis program trace real chloride distribution well [Kim *et al*. 2008]. Experiments have been carried out to study the influence of moisture condition, including moisture content and its distribution, on the chloride diffusion in partially saturated ordinary Portland cement mortar. It is found that the relative chloride diffusion coefficient depends on the degree of water saturation. At a given degree of water saturation level, the chloride diffusion coefficient is larger for a higher w/c ratio. The role of the w/c ratio in the chloride diffusion coefficient-water saturation level relation, however, becomes less pronounced with increasing w/c ratio. There exists a critical saturation, below which the water-filled capillary pores are discontinuous and the chloride diffusion coefficient value tends towards infinitely small. An increase of the w/c ratio results in a decrease of the critical saturation level [Yong Zhang *et al*. 2018]. Concrete is seldom saturated due to its self-desiccation. Even the submerged concrete structures may remain unsaturated for quite a long time. It has been reported the saturation level of pore solution has significant effect on species penetration. However, very little work was proposed regarding the transport properties and serviceability of concrete structures made of blended cementitious materials. This paper initiated the study of chloride ion diffusion in various blended cement-based system under non-saturated condition by resistivity measurements. Experiments have been performed on mortars made of different cement-based materials (Portland cement, fly ash, blast furnace slag, limestone powder) with different water to binding ratio. The mortar specimens have been curing for 200 days conditioning with 98% RH and 20°C, followed by oven drying at 50°C until the specimens reach different saturation levels from 95% down to 18%. The resistivity measurements for different cement-based systems are performed. The results showed that saturation level has significant effect on the chloride diffusion coefficient. As to the relation between relative diffusivity and water saturation, the effect of w/b is less obvious in system with higher w/b. Compared with FA and LP system, the deepest decrease in relative diffusivity was found in BFS-blended system with the decrease of water saturation level [Yong Zhang, and Guang Ye, 2014].

Determination of the degree of saturation and chloride penetration in cracked hydraulic concrete structures. Methods: Depending on Electrical Conductivity principle, developed method called Electrical Conductivity Technique, was submitted for purposes of evaluating and calculating the accurate degree of saturation and amount of chloride penetration in mentioned structures. The experimental results were obtained by using this new test, agreed fairly with results which obtained from numerical solutions. So the developed ECT is the more suitable method for determining the degree of saturation and penetration of chloride ions in the laboratory. The research ensures a novel application for the use of the electrical conductivity principles to find the chloride concentrations in the concrete model with a very precise manner, which contributes to better understanding of the penetration processes in terms of salts or saturation within the concrete structures [Thair Jabar Mizhir Alfatlawi and Riyadh Abdulabbas Ali Alsultani, 2018]. Steel reinforced cement based materials are susceptible to degradation when exposed to chloride-laden environments [Khan *et al*. 2017]. Chlorides ingress in these materials mostly from chloride contaminated waters such as industrial effluents, mixing waters, and sea water [Nielsen and Geiker, 2003]. They are also deliberately introduced as admixtures to modify certain properties of cement [Pacewska and Wilińska, 2015]. Deicing salts such as sodium chloride usually added to clear the ice on roads also acts as a rich source of chlorides in cement based materials [Nielsen and Geiker, 2003]. When chlorides ingress into the mortar/concrete to the level of rebars, if their amounts are beyond the critical threshold concentration, they induce and propagate pitting corrosion. Chloride-induced corrosion causes premature deterioration of cement based structures hence reducing their service life [Woubishet Zewdu, and Esko, 2013]. Chlorides ingress in cement based materials mainly through capillary absorption, permeation, and diffusion. Capillary absorption occurs when the surface moisture and liquids are introduced to the cement based materials through capillary action as a result of wetting and drying cycles. Permeation occurs due to buildup of hydraulic pressure gradient that causes liquids/ions to penetrate the mortar/concrete networks. High pressure is essential for permeation process to occur and therefore the process is of concern in instances such as deep sea oil rigs, tunnel linings, and hydrothermal wells. Diffusion involves movement of molecules in form of gas or a liquid from a high concentration to a low concentration in order to achieve system equilibrium [Gardner. 2006]. Diffusion is the most predominant method through which chlorides ingress in cement based materials [Wang, *et al*. 2014]. Chloride ingress also occurs through a combination of two or more aforementioned processes. Chlorides penetration in cementitious materials is majorly dependent on cement type and binding capacity [Marinescu and Brouwers, 2009]. Cementitious materials have the potential to bind a proportion of chlorides to them. When chlorides penetrate cement based structures, some are either bound physically by the calcium silicate hydrate phase or chemically by the alumina-ferric oxide-monosulphate phase, while some remain as free chlorides in the pore solution. The free chlorides in pore solution cause depassivation of rebar [Florea and Brouwers, 2012]. They also lower the pH of the mortar/concrete surrounding the embedded steel reinforcement, leading to pitting corrosion. Binding of chlorides results in their immobilization and subsequently reducing their amount in mortar/concrete matrix. It is generally agreed that blended cements exhibit higher chloride binding ability due to higher amount of alumina and CSH phases that result from the incorporated pozzolana. Blended cement exhibits low porosity as a result of increased amount of secondary cementitious materials due to pozzolana reaction [Chindaprasirt and Rukzon, 2008]. Low porosity has been found to greatly reduce the penetration of chlorides in mortars. Other research work shows that chloride diffusion coefficient is dependent on pore structure since pore can be both room for holding chloride ion and route for ion diffusion [Gardner, 2006]. Pozzolana materials increase nucleation sites for precipitation of hydration products resulting in pore refinement. Low porosity can also be achieved by use of mortars with high compressive strength [Al-Amoudi *et al*. 2009]. Incorporation of pozzolanic materials in blended cements has been found to lower the permeability of aggressive ions such as chlorides. Reduced penetration of chloride ions in hydrated cements has been found to lower the susceptibility of rebars to pitting corrosion [Dong *et al*. 2011]. 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, magnesium chloride, and calcium chloride, sometimes blended with proprietary corrosion inhibitors. The rock salt/sodium chloride, 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 infrastructure (bridges, tunnels, harbours, parking structures) 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 and1980, 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 ten years the structure must again be repaired, involving more costs; and possibly this will go on until the structure is taken out of service. The transport mechanism of chloride absorption in concrete cubes during wetting/drying pre-conditioned concrete cubes is evaluated in this research work. 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].Especially, in case of 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. Therefore, 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. Thus in the present research work, an attempt was made to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures type for in case of 24 pre-conditioned concrete cubes (100 mm^3) in partially saturated condition and salt ponded with chloride solution for about 160 days. This research will examine the influence of conditioning such as partially saturated condition on the results of chloride absorption performed on 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^2) as in the first case and compressive strength (25-40 N/mm^2), 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 ordered 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 160 days with 10% Nacl solution. Thus the objectives of this present research is to examine the influence of conditioning in partially saturated condition on the results of chloride absorption and chloride concentration at drill depths (30-40-50 mm) 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. Twenty four concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride absorption under different exposure condition at different drill depths respectively.

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^3). Three of the mixtures were concrete cubes (100 mm^3) with a compressive strength 40 N/mm^2, 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^2, 30 N/mm^2, and 40 N/mm^2), 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^3) were cast 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^2 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^2)	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^2)	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 Chloride ingress in concrete cubes

The primary aim of this research was to interpret the effectiveness of wetting pre-conditioned concrete cubes on chloride absorption, which was exposed to different pre-determined conditions in partially saturated condition was evaluated in control/impregnation concrete cubes for about 160 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 extended 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 average chloride absorption was compared in pre-conditioned control/impregnation concrete cubes at different time duration such as 31th, 61th, 91th, 121th, and 160th days to determine the effectiveness of impregnation materials (solvent/water) based impregnation material for long time duration. The variation of average chloride absorption in pre-conditioned control/impregnation concrete cubes was recorded at different time duration as represented in Table.3.

Table.3 Variation of chloride absorption (%) in pre-conditioned 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

The average chloride absorption in PSC control/impregnation concrete cubes was slightly increased/decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned PSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in PSC control/impregnation concrete cubes was slightly decreased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned PSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength. The variation of chloride concentration in pre-conditioned control/impregnation concrete cubes was interpreted at different drill depths (30-40-50 mm) as represented in Table.4-6.

Table.4 Chloride concentration (%) in pre-conditioned PSC/IC concrete cubes

Mix ID	30 mm	40 mm	50 mm	Mix ID	30 mm	40 mm	50 mm
M1CC	0.066	0.064	0.061	M4CC	0.061	0.056	0.061
M1SB	0.059	0.059	0.056	M4SB	0.059	0.056	0.056
M1WB	0.061	0.061	0.059	M4WB	0.061	0.059	0.059
M2CC	0.064	0.061	0.061	M5CC	0.068	0.067	0.066
M2SB	0.059	0.059	0.056	M5SB	0.061	0.058	0.057
M2WB	0.061	0.061	0.059	M5WB	0.066	0.064	0.059
M3CC	0.073	0.071	0.071	M6CC	0.066	0.065	0.062
M3SB	0.068	0.066	0.064	M6SB	0.061	0.058	0.057
M3WB	0.071	0.068	0.066	M6WB	0.064	0.063	0.061

Table.5 Chloride concentration (%) increase in pre-conditioned PSC/IC concrete cubes

Mix ID	(30-40) mm, incr (%)	(30-50) mm, incr (%)	(40-50) mm, incr (%)	Mix ID	(30-40) mm, incr (%)	(30-50) mm, incr (%)	(40-50) mm, incr (%)
M1CC	3.61	7.27	3.80	M4CC	7.95	0.29	8.32
M1SB	0.15	3.87	3.73	M4SB	4.21	4.26	0.05
M1WB	0.15	4.33	4.19	M4WB	3.83	3.88	0.05
M2CC	3.81	4.14	0.34	M5CC	1.73	3.38	1.68
M2SB	0.34	4.10	3.77	M5SB	5.82	7.53	1.82
M2WB	0.52	4.26	3.76	M5WB	3.46	11.06	7.88
M3CC	2.89	3.34	0.46	M6CC	1.40	5.78	4.45
M3SB	3.51	6.94	3.55	M6SB	5.12	6.77	1.74
M3WB	3.71	6.91	3.33	M6WB	1.82	4.25	2.48

Table.6 Chloride concentration (%) increase in pre-conditioned PSC/IC concrete cubes

Mix ID	30 mm, decr(%)	40 mm, decr(%)	50 mm, decr(%)	Mix ID	30 mm, decr(%)	40 mm, decr(%)	50 mm, decr(%)
M1SB-M1CC	88.77	91.95	92.03	M4WB-	99.79	104.26	96.20
M1WB-	92.82	96.15	95.77	M5SB-	89.58	85.85	85.73
M2SB-M2CC	92.16	95.48	92.20	M5WB-	96.56	94.86	88.88
M2WB-	96.11	99.40	95.99	M6SB-	92.82	89.32	91.85
M3SB-M3CC	93.42	92.82	89.94	M6WB-	96.72	96.31	98.29
M3WB-	96.94	96.11	93.35	M1SB-	95.64	95.64	96.09

M4SB-M4CC	96.16	100.07	92.34	M2SB-	95.89	96.06	96.05
M3SB-	96.37	96.57	96.35	M4SB-	92.77	90.50	96.46
M5SB-	96.37	95.99	95.98	M6SB-	95.97	92.74	93.44

5.0 Discussion about Results

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 rnechanism 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 24 preconditioned concrete cubes of size (100) mm on chloride concentration in pre-conditions partially saturated condition was evaluated for in case of six designed mixtures type (M1-M6). The variation of chloride concentration-drill depths (30-40-50 mm) in control PSC concrete cubes was represented by power type of equation as shown in the Fig.1a-1f for different designed mixtures type (M1CC-M6CC).

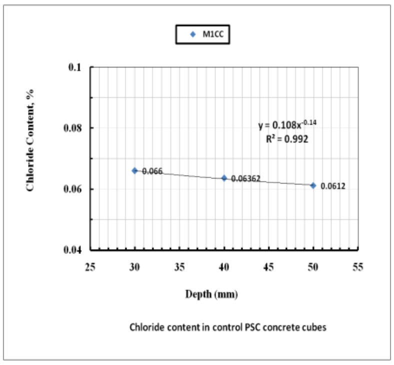

Fig.1a Cl^- concentration in mix M1

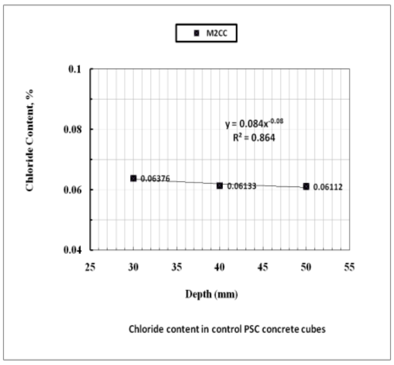

Fig.1b Cl^- concentration in mix M2

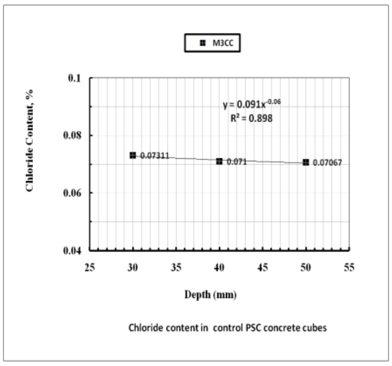

Fig.1c Cl^- concentration in mix M3

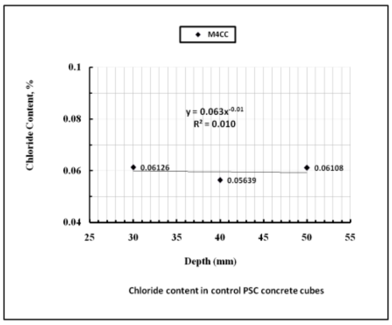

Fig.1d Cl^- concentration in mix M4

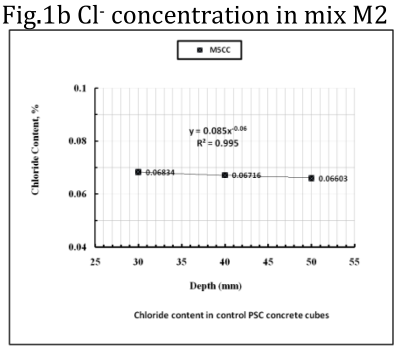

Fig.1e Cl^- concentration in mix M5

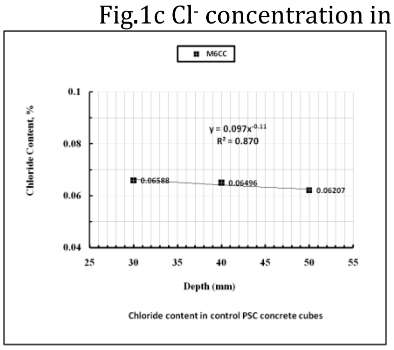

Fig.1f Cl^- concentration in mix M6

The average chloride concentration 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 was decreases with increased compressive strength and constant slump value for in case of designed mixtures type at drill depth. Similarly, the average chloride concentration 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 chloride concentration-drill depth were indicated by power type of equation in the solvent based impregnation PSC cubes at different drill depths (30-40-50 mm) was represented in Fig.2a-2f for different designed mixtures type (M1SB-M6SB).

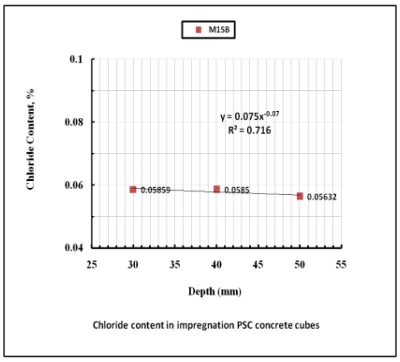

Fig.2a Cl^- concentration in mix M1

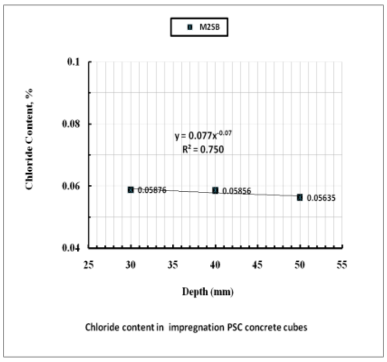

Fig.2b Cl^- concentration in mix M2

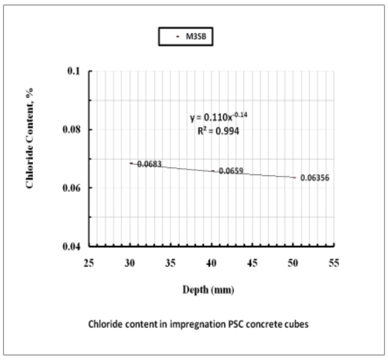

Fig.2c Cl^- concentration in mix M3

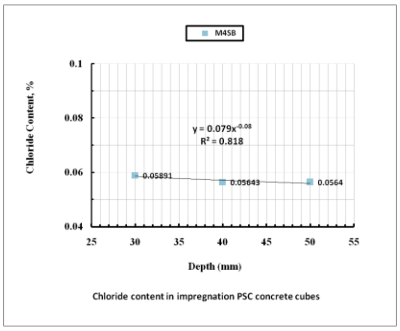

Fig.2d Cl^- concentration in mix M4

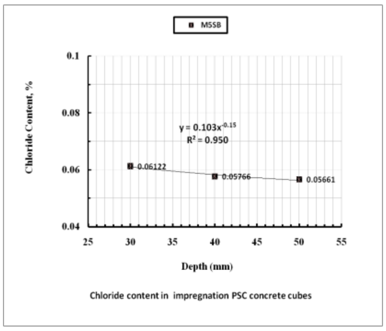

Fig.2e Cl^- concentration in mix M5

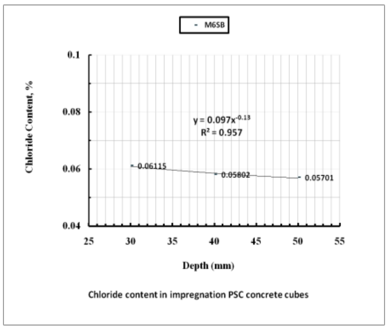

Fig.2f Cl^- concentration in mix M6

The variation of chloride concentration-drill depth were also designated by power type of equation in the water based impregnation PSC cubes at different drill depths (30-40-50 mm) was represented in Fig.3a-3f for different designed mixtures type (M1WB-M6WB).

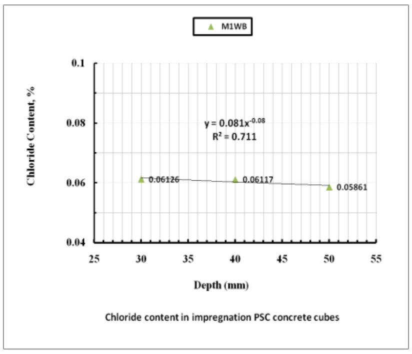

Fig.3a Cl^- concentration in mix M1

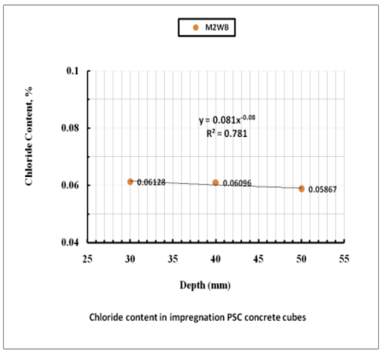

Fig.3b Cl^- concentration in mix M2

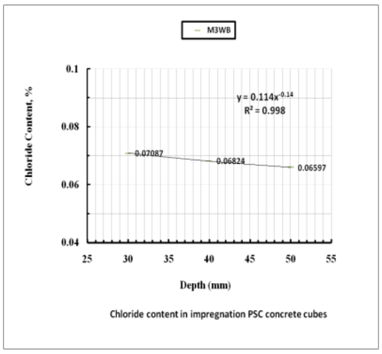

Fig.3c Cl^- concentration in mix M3

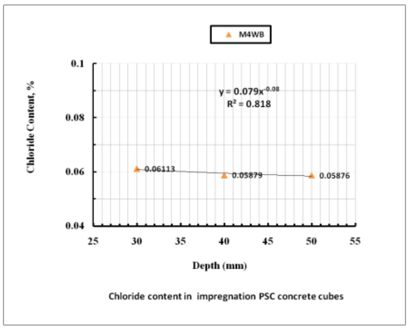

Fig.3d Cl^- concentration in mix M4

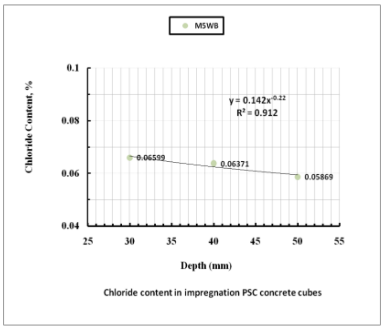

Fig.3e Cl^- concentration in mix M5

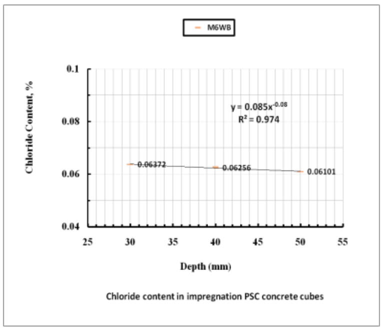

Fig.3f Cl^- concentration in mix M6

6.0 Conclusions

- The chloride concentration was found to be decreased in impregnation PSC concrete cubes as when compared to control PSC concrete cubes at different drill depth. It's possible to correlate the chloride concentration- drill depths 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.

7.0 References

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