Chloride penetration at different drill depths in DCC concrete cubes

M.N. Balakrishna[1], Robert Evans[2], Fouad Mohamad[2] and M.M. Rahman[2]

[1]*School of Architecture, Design and the Built Environment, Research scholar,
Nottingham Trent University, Nottingham, NG1 4FQ, UK*
[2]*School of Architecture, Design and the Built Environment, Faculty of Engineering,
Nottingham Trent University, Nottingham, NG1 4FQ, UK*

Abstract

De-icing chemicals, along with plowing and sanding, are important tools for highway snow and ice control. For many years, however, it has been widely acknowledged that the most popular de-icing chemical, sodium chloride or common road salt, has many unintended and often costly side effects. Sodium chloride, or common road salt, is by far the most popular chemical de-icer, because it is reliable, inexpensive, and easy to handle, store, and apply. Since 1970, highway agencies have applied an average of approximately 10 million tons of road salt each winter. Salt damages motor vehicles and infrastructure primarily because of its corrosive effects on metals. The chloride ions in salt disrupt natural protective films on metal surfaces and increase the conductivity of water, which induces and accelerates corrosion. By far the costliest damage is to motor vehicles, followed by bridges and parking structures. Less obvious side effects, which collectively may be significant, include damage to concrete pavements, underground utilities, and roadside objects. Other infrastructure components affected by road salt include non-bridge highway components, such as reinforced concrete pavements and roadside hardware (e.g., signposts and light stands); objects buried under or alongside highways, such as utility lines, pipelines, and steel storage tanks; and some non-highway objects near salt treated roads, such as bronze monuments. For many of these items, repair and maintenance requirements due to corrosion (from numerous sources) and other sources of damage are serious problems with large annual costs. Available data, however, are insufficient to isolate the incremental effect of road salt on this much broader set of infrastructure costs.

1.   Introduction

A review of the impacts of de-icers used in winter maintenance practices of Portland cement concrete and asphalt concrete roadways and airport pavements is presented. Traditional and

relatively new de-icers are incorporated in this review, including sodium chloride, magnesium chloride, calcium chloride, calcium magnesium acetate, potassium acetate, potassium formate, sodium acetate, and sodium formate. The detrimental effects of de-icers on Portland cement concrete exist through three main pathways: 1) physical deterioration such as "salt scaling"; 2) chemical reactions between de-icers and cement paste (a cation-oriented process, especially in the presence of magnesium chloride and calcium chloride); and 3) de-icers aggrevating aggregate-cement reactions (such as the anion-oriented process in the case of chlorides, acetates, and formates affecting alkali-silica reactivity and the cat ion-oriented process in the case of calcium chloride and magnesium chloride affecting alkali-carbonate reactivity). The de-icer impacts on asphalt concrete pavements had been relatively mild until acetate- and formate-based de-icers were introduced in recent years. The damaging mechanism seems to be a combination of chemical reactions, emulsifications and distillations, as well as the generation of additional stress in the asphalt concrete [Xianming Shi *et al*. 2009]. Sodium chloride (NaCl) remains the principal road de-icer in use despite its well-known corrosive effects on metals. It has a eutectic point of -23°C, good ice-melting rates at low temperatures and, above all, is relatively inexpensive. Generally, salt scaling appears to be limited to the concrete surface when NaCl is used. Unless reactive aggregates are included in thick concrete structures such as bridge decks, NaCl, when used as a deicer, does not cause serious deterioration in concrete except for the surface distress caused by the physical mechanism of scaling. Long-term use of NaCl does not result in strength loss in the cement paste matrix via chemical mechanisms except for the slow process of accelerating alkali-silica reaction. While NaCl itself may be innocent, de-icers originating from mines (rock salt, as opposed to solar salt) may contain significant traces of calcium sulfate. Research by [Pitt *et al*. 1987] showed that even low levels of CaSO4 can damage mortar, especially in combination with freezing and thawing cycles, due to pore filling by possibly Friedel's salt and ettringite. To minimize such damage, changes in mix design or treating joints and cracks with silane sealers can be effective, while establishing restrictions on CaSO4 limits in rock salt used for de-icing may be difficult. Deicers available on the market have various impacts, the level of which depends on many factors including the application rate of de-icers, the winter precipitation rate, the specific road environment of the application, the traffic volume. Based on the literature review, de-icers may pose detrimental effects to portland cement concrete (PCC) infrastructure and thus reduce concrete strength and integrity (as indicated by expansion, mass change and loss in the dynamic modulus of elasticity). The proper use of air entrainment, high-quality cementitious materials and aggregates, and mineral admixtures is promising in mitigating the de-icer impact on PCC. Second, de-icers may pose detrimental effects to asphalt pavement. While their impact on skid resistance is still inconclusive, de-icers are known to affect pavement structure and cause loss of the strength and elasticity of asphalt concrete (mixture of asphalt binder and aggregates). Formate/acetate-based deicers were found to significantly damage asphalt pavements, through the combination of chemical reactions, emulsifications and distillations, as well as generation of additional stress inside the asphalt concrete. In order to manage de-icer effects on asphalt concrete, it is recommended to: 1) follow best possible practices in asphalt mix design and paving (low void contents); 2) use binders with high viscosity or polymer-modified binders; 3) use alkaline aggregates or high-quality (sound) aggregates (avoid limestone filler or heavily-contaminated recycled asphalt pavement when acetates/formats are used as de-icers); and 4) test the compatibility of the materials in advance. Third, de-icers may cause corrosion damage to the transportation infrastructure such as reinforced or pre-stressed concrete structures and steel bridges. The relative corrosivity of de-icers is dependent on many details related to the metal/de-icer system; and it is important to note the test protocol employed, the metal coupons tested, the de-icer concentrations, the test environment, etc. 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

ions or molecules from de-icers, injection of beneficial ions or molecules into concrete, and use of non-corrosive de-icer alternatives and optimal application rates [Shi *et al*. 2008]. The formation of ice and snow on the road creates hazardous driving conditions, restricts public mobility and has adverse economic effects. Hazardous driving conditions are caused by a reduction in the coefficient of friction between the tyres and pavement surface, and the presence of ice is not always apparent to the road user. In order to ensure, as far as possible, that road users can travel safely and with minimum disruption in cold and severe climatic conditions, highway authorities have a responsibility to provide adequate levels of winter service. Winter service is `the collective term for all specialist winter operations` [Road Liaison Group 2005]. It is estimated by [Thornes, 2003a] that the cost of keeping UK local authority highways free of frost, ice and snow was in the region of £168 million for the year 2001-2002. Design for durability of road infrastructures is becoming increasingly important in view of its large impact on economics. Reinforcement corrosion is the most common cause of concrete deterioration of bridge structures in Latvia. The ingress of chlorides is often considered to be the major threat to durability of concrete structures. During the winter season de-icing salts are spread out on roads to avoid formation of ice and ensure the anti-sliding properties of the road surface. The melting water mixes with de-icing salt are splashed and sprayed on reinforced concrete pier structures by passing vehicles. Absorbed water with chloride ions initiates and accelerates the reinforcement corrosion process. This paper highlights the results of investing accumulation of chlorides in reinforced concrete bridge piers located near high traffic volume roads in Latvia. The chloride contents were determined on different surfaces of reinforced concrete piers. Environmental conditions were analysed and prediction of remaining service life for chloride induced reinforcement corrosion was performed [Ainars Paeglitis, and Kristaps Gode, 2014].

The use of various chemicals for snow and ice control is an integral part of the winter maintenance activities of most transportation agencies. Although the use of "road salt" and other de-icing materials can be traced back to some of the earliest days of paved roadways, the application of these materials became more widespread, and their need more acute, with the dawning of the Interstate era in the mid1950s. In the last few decades, implementation of new snow and ice control strategies has been implemented, as well as the introduction of new chemicals. For example, many agencies now employ both "anti-icing" and "de-icing" strategies, in which anti-icing is defined as any treatment applied prior to ice formation to eliminate ice accumulation or facilitate its removal, and de-icing is defined as any effort to remove ice from roads or bridges after deposition on the surface [Sutter 2008]. There are two general forms of deterioration that can occur when concrete is exposed to high concentrations of chloride-based de-icing chemicals. The first is a degradation of the concrete itself and the second is the corrosion of embedded steel leading to deterioration of the concrete. Degradation of concrete as a result of exposure to de-icing chemicals occurs as the result of physical and chemical mechanisms. Physical mechanisms associated with the repeated application of de-icing chemicals lead to scaling or crazing of the slab surface [Van Dam *et al.* 2002]. However, even adequately properly finished concrete can be susceptible to the development of salt scaling if it possesses inadequate entrained air and/or is of poor quality. Although steel embedded in concrete forms a thin passivity layer of oxide providing protection from reaction with oxygen and water, this passivity film can be easily broken down under the action of chloride ions [Neville 1996]. The soluble chloride ion level at which steel reinforcement corrosion begins in concrete is about 0.2-0.4 % by mass of cement [Kosmatka, Kerkhoff, and Panarese 2002]. In most transportation structures, the primary source of the chloride ions is from the application of de-icing salts, although it can also come from other sources such as seawater or the presence of a calcium chloride accelerator in the concrete mix [Van Dam et al. 2002]. De-icing chemicals have the potential to create significant damage and deterioration to concrete structures. However, there are a number of strategies that can be

employed to help minimize their deleterious effects. The first and foremost strategy for eliminating or reducing the adverse effects of de-icing chemicals is the development of a durable concrete mix. Durability is defined as the ability of concrete to resist weathering action, chemical attack, abrasion, or any other process of deterioration [ACI 2001]. Inherent in this definition is that different concretes may be exposed to different environmental forces, suggesting that different concrete mixes are required to maintain the same level of durability for different conditions. Durability in and of itself is not an intrinsic property of the concrete, but rather the sum total of all of the factors that are part of the concrete production process and the environment in which the structure serves. This includes constituent materials, mix proportioning, and construction as well as the climatic conditions and external exposure to potentially harmful materials. By adopting a more holistic approach in which the entire concrete structure is viewed as a system, more durable concrete will result [Van Dam *et al.* 2002]. The permeability of the concrete is a key property contributing to concrete durability, and plays an important role in determining the effects of de-icing chemicals on the degradation of the concrete and the corrosion of embedded steel. A denser concrete material, or in other words less permeable, has greater capability to resist the ingress of chemicals and their accompanying deleterious effects. Permeability is defined as the ease with which fluids can penetrate concrete, and should not be confused with porosity, which is a measure of the number of voids in concrete [Taylor *et al.* 2006]. Permeability can be reduced by minimizing voids and cracks, ensuring a good bond between the aggregate and cementitious paste, minimizing the porosity of the paste, and minimizing the paste fraction in the concrete [Leek, Harper, and Ecob 1995]. Mehta 1997 states that it is desirable from the perspective of durability to maximize the aggregate content and minimize the paste content to promote the water-tightness of the concrete. At the same time, other critical aspects of a durable concrete mix cannot be ignored such as the use of durable aggregates, maintaining necessary strength or workability, or the development of an effective air-void system. Detailed information on the production of durable concrete is provided in a number of documents [Taylor *et al.* 2006]. Some general guidelines are provided in the following sections. A thorough mix design analysis and the preparation of trial mixes using project-specific materials is strongly recommended to ensure that the resultant mixture exhibits the required durability, strength, and workability characteristics for the application. Mix proportioning procedures are available from both the PCA and the ACI [ACI 1991].

In order to minimize the scaling of concrete exposed to severe freeze-thaw, de-icer, and sulfate exposures, some sources recommend a minimum cement content of 335 kg/m3 [Kosmatka, Kerkhoff, and Panarese 2002]. These sources indicate that lean concrete with cement contents of [240 kg/m3] are particularly vulnerable to de-icer scaling. Other references state that a minimum cement content is not necessary as long as the concrete can be easily placed and has sufficient strength, low permeability, and an adequate air-void system to protect it against paste freeze-thaw damage [Taylor *et al.* 2006]. Supplementary cementitious materials, which include materials such as fly ash, ground granulated blast furnace slag, and silica fume, are often used in concrete mixtures to enhance durability. As the name implies, some SCMs have cementitious properties on their own that contribute to strength development in concrete by undergoing hydration and forming hydration products similar to those formed through the hydration of portland cement. Other SCMs are almost entirely pozzolanic, which means that they react with calcium hydroxide produced through cement hydration to form calcium-silicate-hydrate, a very desirable hydration product. This latter property can provide an effective way of minimizing the effects of chemical attacks involving calcium hydroxide [alkali-silica reaction or ASR, deicer attack], as it reduces the amount of soluble calcium hydroxide in the hardened cement paste [Sutter 2008], which in turn reduces the hydroxide ion available to react. Because of their very fine particle size, these materials also act as "micro-aggregate," packing into and filling spaces that would otherwise

be left empty [Van Dam *et al*. 2002]. This not only improves workability and reduces the water demand of the fresh concrete, but it also produces a denser, significantly less permeable microstructure. Acceptance criteria for mixing water used in the production of concrete are given in AASHTO T26. In general, the water should be relatively free of chlorides, sulfates, alkalis, and other potential contaminants or impurities. According to ACI, a maximum water-to-cementitious material ratio (w/cm) of 0.40 to 0.45 should be used in the mix proportioning, depending on exposure conditions [ACI 201]. In general, a lower w/cm results in a less permeable concrete. Therefore, it is widely accepted that a lower w/cm results in better protection from de-icer attack. However, the recent study by [Sutter, 2008] indicates that lower w/cm mixtures do not perform better than mixtures with a higher w/cm with regards to chemical attack by de-icers. In fact, there was strong evidence that the lower w/cm perform worse. Therefore, it is not recommended that a reduced permeability be achieved by means of lowering the w/cm alone. The use of SCMs is recommended as a first choice for effecting concrete permeability. Additional research is needed to confirm the observations reported by [Sutter, 2008]. 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 10years [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 is 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 DCC 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 concentration in ordered to characterize the different concrete mixtures type for in case of 24 pre-conditioned concrete cubes (100 mm^3) such as dry condition and salt ponded with chloride solution for about 160 days. This research will examine the influence of conditioning such as dry condition on the results of chloride concentration 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.   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 concentration in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as dry condition and salt ponded with chloride solution for about 160 days with 10% NaCl solution. Thus, the objectives of this present research are to examine the influence of conditioning such as dry condition on the results of chloride concentration 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 -two concrete cubes (100 mm3) with grades of concrete ranges from 25-40 N/mm2 were prepared and evaluate the chloride concentration under different exposure condition.

3.   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. Twenty-four concrete cubes of size (100 mm^3) 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^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 environmentally 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. Chloride ingress in concrete cubes

The primary aim of this research was to interpret the effectiveness of drying pre-conditioned concrete cubes on chloride absorption, which was exposed to pre-determined conditions such as dry 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-conditioning was induced in order to achieve desired dry condition in specified 24 concrete cubes. In which all 24 concrete cubes were exposed to natural room temperature for about 28 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. Thus, in the present research work that, the effectiveness of impregnation materials such as solvent/water-based impregnation materials were 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. 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 average chloride absorption in DCC control/impregnation concrete cubes was pre-dominantly increased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned DCC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in DCC control/impregnation concrete cubes was pre-dominantly increased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned DCC 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.

Table 3
Variation of chloride absorption (%) in pre-conditioned DCC/IC concrete cubes

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

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 were evaluated in pre-conditioned concrete cubes in ordered to reduce chloride absorption for in case of designed mixtures type. 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 DCC/IC concrete cubes

Mix ID.	30 mm	40 mm	50 mm	Mix ID.	30 mm	40 mm	50 mm
M1CC	0.070	0.066	0.064	M4CC	0.075	0.067	0.064
M1SB	0.060	0.053	0.053	M4SB	0.061	0.059	0.057
M1WB	0.064	0.064	0.061	M4WB	0.061	0.061	0.059
M2CC	0.066	0.064	0.063	M5CC	0.071	0.068	0.067
M2SB	0.061	0.058	0.056	M5SB	0.064	0.061	0.059
M2WB	0.063	0.061	0.059	M5WB	0.068	0.066	0.066
M3CC	0.074	0.072	0.072	M6CC	0.068	0.066	0.064
M3SB	0.071	0.068	0.066	M6SB	0.064	0.061	0.061
M3WB	0.072	0.071	0.068	M6WB	0.066	0.064	0.062

Table 5
Chloride concentration (%) increase in pre-conditioned DCC/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	5.74	8.99	3.45	M4CC	10.99	15.27	4.81
M1SB	11.48	11.85	0.41	M4SB	3.17	7.14	4.10
M1WB	1.18	5.35	4.21	M4WB	0.10	3.84	3.75
M2CC	3.16	3.56	0.41	M5CC	3.41	4.93	1.58
M2SB	5.76	7.66	2.01	M5SB	3.71	7.43	3.87
M2WB	3.42	6.80	3.50	M5WB	3.31	3.76	0.47
M3CC	1.98	2.37	0.40	M6CC	3.20	6.89	3.82
M3SB	3.83	6.99	3.28	M6SB	3.32	3.68	0.37
M3WB	1.98	5.59	3.68	M6WB	3.52	5.28	1.83

Table 6
Chloride concentration (%) increase in pre-conditioned DCC/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	85.77	80.54	83.07	M5WB-M5CC	96.55	96.65	97.74
M1WB-M1CC	92.13	96.58	95.82	M6SB-M6CC	93.13	93.00	96.33
M2SB-M2CC	92.91	90.42	88.96	M6WB-M6CC	96.53	96.20	98.19
M2WB-M2CC	96.15	95.90	92.92	M1SB-M1WB	93.10	83.39	86.70
M3SB-M3CC	97.82	94.09	91.37	M2SB-M2WB	96.63	94.28	95.74
M3WB-M3CC	97.82	97.81	94.60	M3SB-M3WB	98.05	96.20	96.59
M4SB-M4CC	81.27	88.41	89.07	M5SB-M5WB	99.58	96.52	96.16
M4WB-M4CC	81.62	91.61	92.63	M4SB-M4WB	93.19	92.81	89.64
M5SB-M5CC	89.98	89.70	87.62	M6SB-M6WB	96.48	96.68	98.11

5.   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 infrastructure 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.
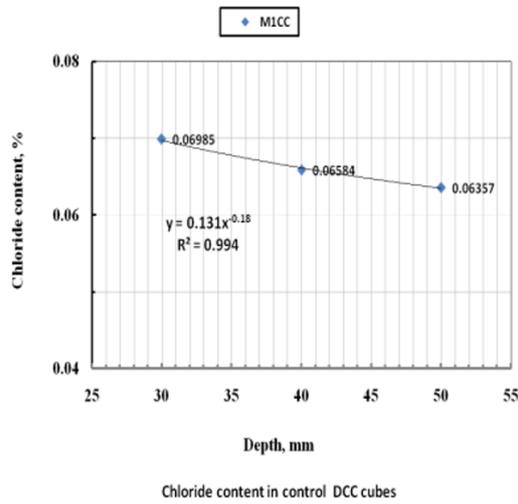

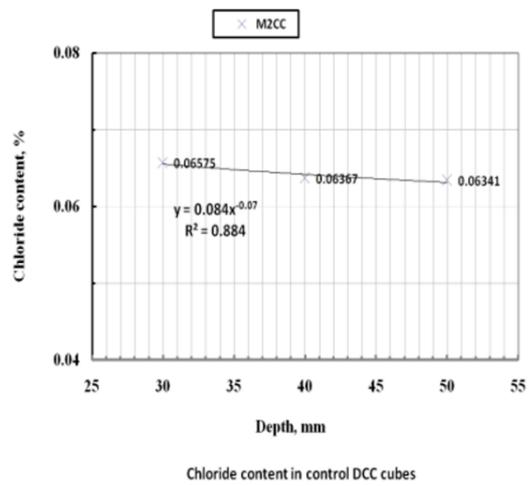Fig. 1a. Cl⁻ concentration in mix M1
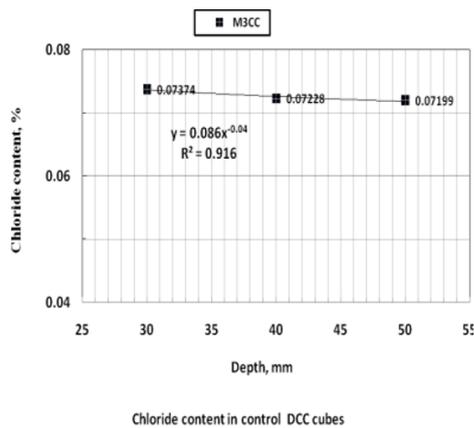
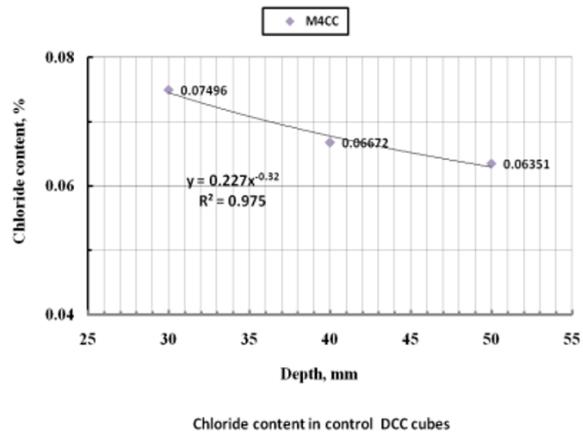Fig.1b Cl⁻ concentration in mix M2

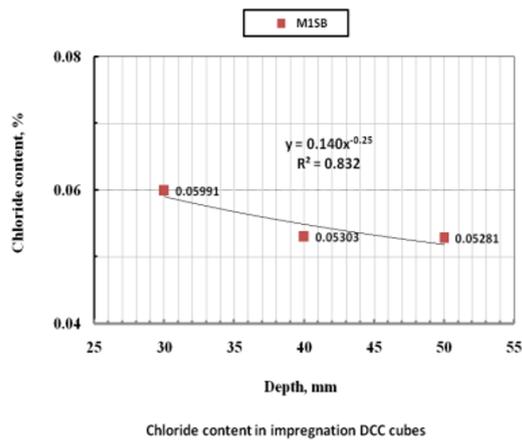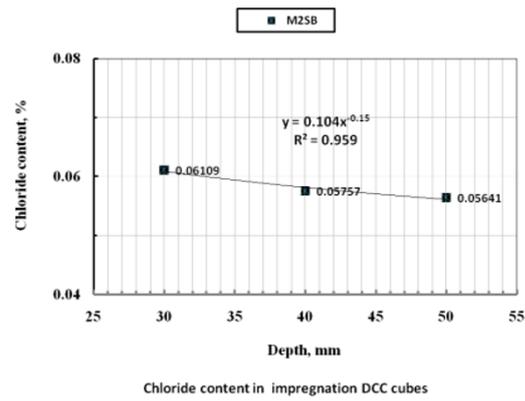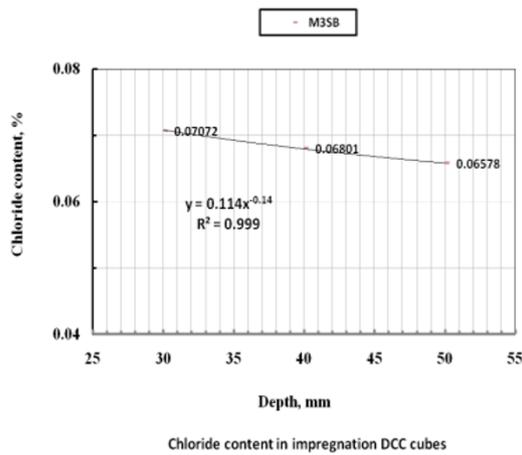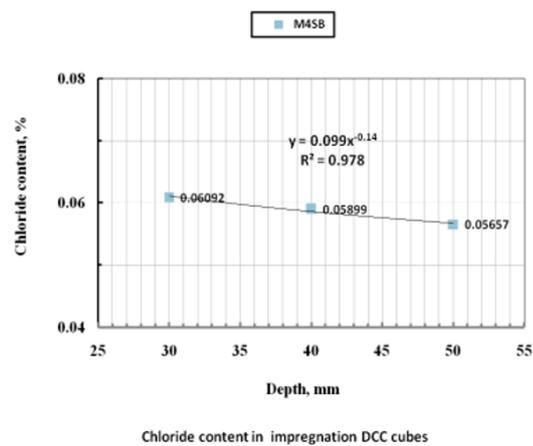Fig. 1c. Cl⁻ concentration in mix M3

Fig. 1d. Cl⁻ concentration in mix M4
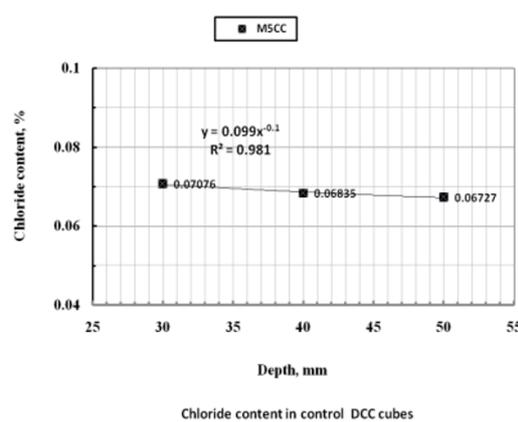
Fig. 1e. Cl⁻ concentration in mix M5
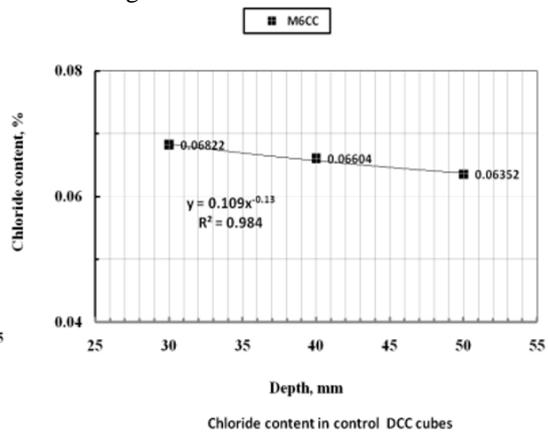
Fig. 1f. Cl⁻ concentration in mix M6

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.

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
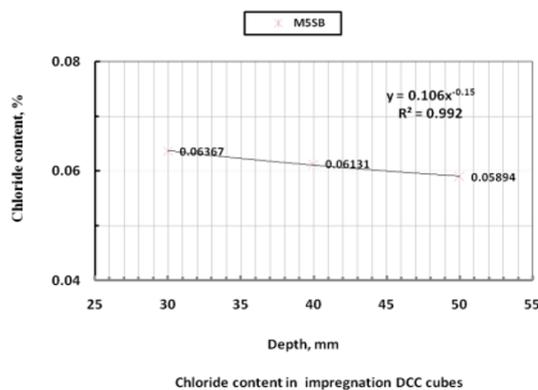
Fig. 2e. Cl- concentration in mix M5
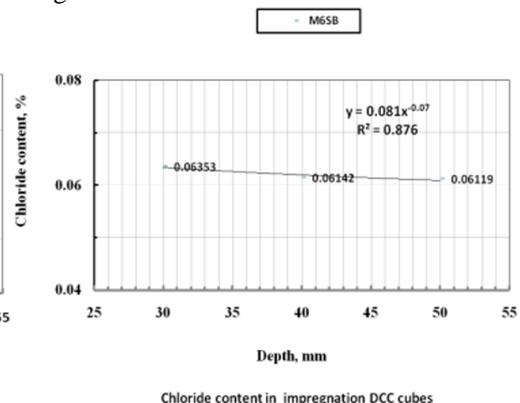
Fig. 2f. Cl- concentration in mix M6

Thus, in the present research work, the effectiveness of 24 preconditioned concrete cubes of size (100) mm on chloride absorption under pre-dry 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 DCC concrete cubes was represented by power type of equation as shown in the Figure 1a-1f for different designed mixtures type (M1CC-M6CC).
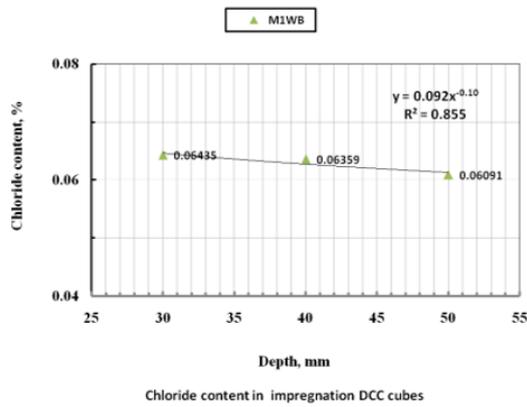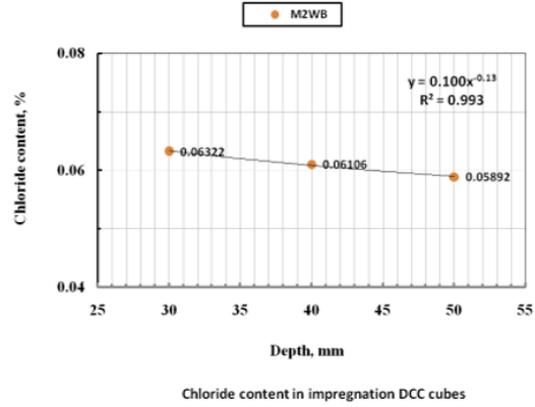

Fig. 3a. Cl- concentration in mix M1
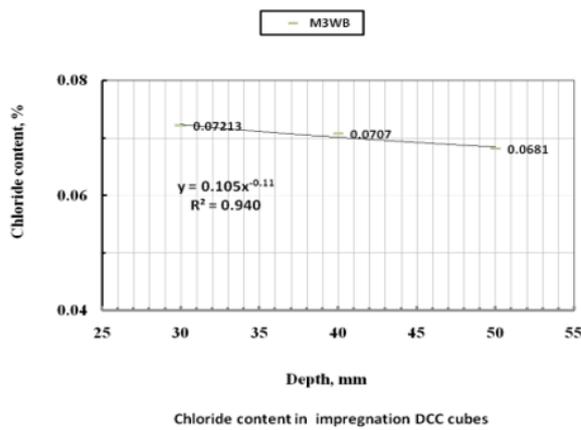

Fig. 3b. Cl- concentration in mix M2

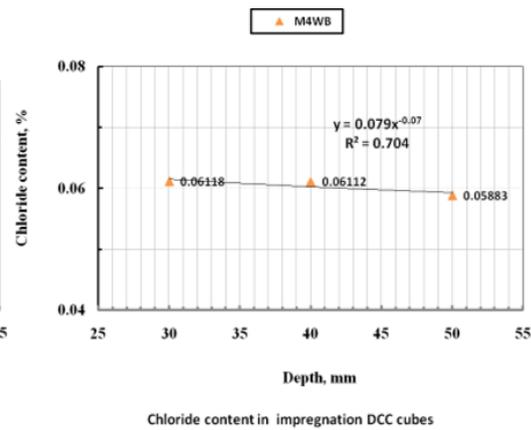Fig. 3c. Cl- concentration in mix M3

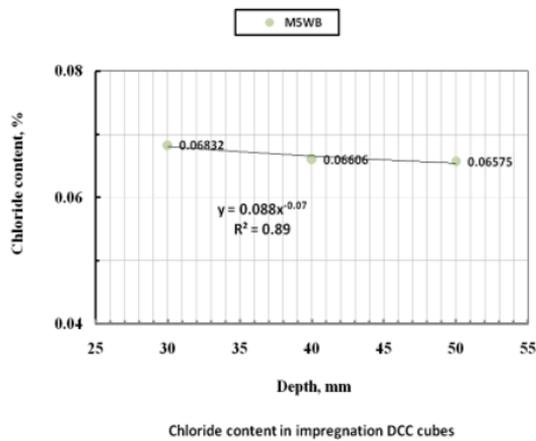Fig. 3d. Cl- concentration in mix M4

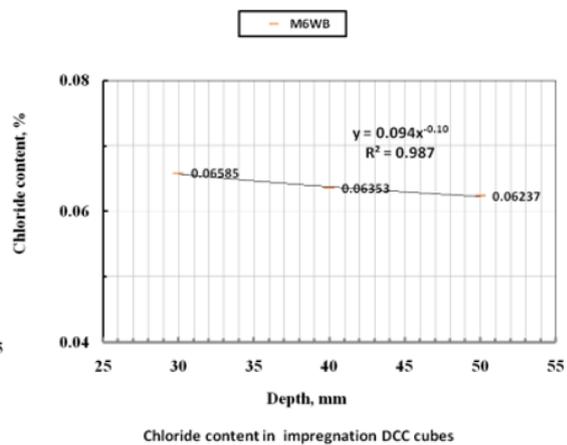Fig. 3e. Cl- concentration in mix M5

Fig. 3f. Cl- concentration in mix M6

The average chloride absorption was pre-dominantly increased in control and impregnation DCC/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 longer time duration (160 day).

Similarly, the average chloride absorption was decreased in solvent based and water-based impregnation DCC cubes as when compared to control DCC 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 was indicated by power type of equation in the solvent based impregnation PSC cubes at different drill depths (30-40-50 mm) was represented in Figure 2a-2f for different designed mixtures type (M1SB-M6SB). The variation of chloride concentration-drill depth was also designated by power type of equation in the water-based impregnation DCC cubes at different drill depths (30-40-50 mm) was represented in Figure 3a-3f for different designed mixtures type (M1WB-M6WB).

6.   Conclusions

− For different designed mixtures type of concrete, varying time durations are required in ordered to achieve a desired pre-condition such as DCC conditioned cubes. Actually, 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 chloride diffusion in saturated pores at greater depths continues to occur during the drying phase. In which an extending the drying period appears to increase the chloride ingress by capillary sorption in subsequent wetting process, rather than by continued diffusion during the drying phase. Furthermore, the rate of drying is dependent on the pore structure of the concrete and as a result higher quality concretes dry at a slower rate.

− The average chloride absorption in DCC control/impregnation (SB/WB) concrete cubes were pre-dominantly increased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned DCC control/impregnation (SB/WB) concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in DCC control/impregnation (SB/WB) concrete cubes was pre-dominantly increased with lesser concrete compressive strength and constant slump value as when compared to pre-condition DCC 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.

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