EVALUATION OF CHLORIDE ABSORPTION IN PRE-CONDITIONED IMPREGNATION 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*

**Corresponding Author: N0413461@my.ntu.ac.uk*

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. Therefore, there is a need to quantify the chloride concentration in concrete which is of paramount importance.*

The present research work was made an attempt to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as dry condition and salt pond with chloride solution for about 28 days. Thus the objectives of this present research are such as: First, this research will examine the influence of conditioning such as dry condition on the results of chloride concentration performed on concrete cubes with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Seventy-two concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride absorption under different exposure condition. It's concluded from the results that, in dry conditioned concrete cubes, the chloride absorption value was increased with time in all designed mixtures type and correlated by power type of equation. Similarly, the average chloride concentration 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. Whereas the average chloride absorption was increased in solvent based and water based impregnation DCC 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.

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

1.0 Introduction

There are many deleterious substances and deterioration mechanisms that impair the service-ability of concrete. Some of these mechanisms concern the chemical attack on concrete, while some others are related to physical interactions and mechanical damage. The chemical deterioration of concrete can be caused by sulphate attack, decalcification of the cement hydration products, alkali-silica reaction or corrosion of steel re-bars in concrete resulting from the de-passivation of steel. The physical deterioration of concrete is most often related to the freeze-thaw induced damage, differences between the thermal expansion of aggregates and cement paste and to the exposure of concrete to elevated temperatures. The mechanical damage can be caused by abrasion or impact. Nevertheless, in practice, the most often occurring mechanisms of deterioration of concrete are closely related to the ease of penetration of deleterious substances into the concrete and subsequent corrosion of steel [Neville, 2011]. The reason why fluids can penetrate into concrete is due to the porous microstructure of the hardened cement paste (predominantly the capillary pores, which are the pores in the size of micrometers forming a connected network).The transport processes of deleterious gases and water into concrete is based on a number of mechanisms. The durability of concrete, in most cases, is closely related to the ease with which aggressive substances can enter the concrete and cause its deterioration. One of the most commonly occurring durability issues in concrete is chloride attack on steel reinforcement. The service life of concrete exposed to chlorides (seawater/de-icing salts), and information on the chloride ingress rate into concrete is needed in order to properly design concrete structures. Service life prediction has emerged, over the last few years, as a major task in the design of concrete structures. The main long-term concrete deterioration mechanism involves moisture movement and the transport of dissolved harmful chemical species within concrete. In particular, the ingress of chlorides is a major cause of early deterioration of reinforced concrete structures. Although chloride ions in concrete do not directly cause severe damage to the concrete, they initiate and contribute to the corrosion of rebar in the structures when the chloride concentration at the surface of the rebar reaches a threshold level. The formation of rust is associated with large volume expansions which may result in cracking, spalling, and de-lamination of the concrete cover. In addition, severe corrosion reduces the load-carrying capacity of structures by reducing the cross sectional area of reinforcement. In cold countries, the use of de-icing salt on roads and bridges in winter causes a premature deterioration of structures. Typically, bridge decks are exposed to cyclic wetting and drying conditions, and are subject to direct impact and repeated loading by traffic. These conditions, combined with salt applications, create a severe environment for the concrete.

In general, the pore space of concrete is not fully saturated [Hall, 1994]. When the moisture content inside concrete is less than the saturation moisture content, water may be absorbed by the concrete through large capillary forces arising from the contact of the very small pores of the concrete with the liquid phase. This is an important mechanism of fluid invasion in concrete in most practical situations. Under unsaturated conditions, the water flux and subsequently the transport of dissolved chloride ions in response to a specified potential gradient is strongly dependent on the saturation of the material. The complexity of the microstructure of concrete makes the theoretical and experimental investigation of its transport properties a great challenge. Depending on the mix design, preparation and environmental exposure, the material properties can be highly variable. The movement of moisture and the transport of chloride ions depend on a large number of factors such as porosity, pore size distribution, connectivity, and tortuosity. Currently, there are no standards test methods to measure key transport properties of concrete such as permeability and capillary- driven moisture transfer. However, some test methods developed and used by some other disciplines like soil sciences, rock sciences and petroleum sciences can also be used for concrete. Moisture movement coupled with transport of chlorides in concrete is one of the main causes of deterioration of concrete structures. This chapter presents a review of current knowledge, mathematical models and test methods pertinent to the main transport properties of unsaturated concrete. The main properties and transport mechanisms affecting moisture movement and chloride ions transport include permeability, capillary absorption, and diffusion. Concrete is a porous material and when the pores inside concrete are filled with water it is referred to as a saturated concrete. When the pores are occupied by both water and gas it is called unsaturated concrete. The movement of moisture and associated transport of dissolved chlorides depend on the saturation level of concrete. The driving potential for moisture movement in both saturated and unsaturated concrete is a pressure gradient. Water is essential for cement and concrete as part of the main chemical reaction and it is present in all phases with different ratios. Free water can move between the capillary pores and plays an important role in most degradation processes of concrete. Freeze/thaw is directly related to water content. Freezing in the pores increases the pressure causing micro-cracks. Then when the water melts, it penetrates the concrete even further through the freeze-induced cracks. Carbonation and chloride ingress is responsible for the corrosion of reinforcement and the chloride is usually transported in water. Carbonation is due to the CO2 in the air reacting with the calcium hydroxide forming calcium carbonate. The problem with carbonation is that the pH of cement paste (pore solution) drops and no longer protects the steel reinforcement from corrosion. Chloride ingress plays an important role on the initiation of steel reinforcement corrosion. [Rama chandran, 2001]. Therefore, water transport measurements are key indicators for potential degradation and service life.

The long term performance of concrete structures is significantly controlled by its strength and durability. In recent years, durability performance of concrete has attracted the interest of many researchers and has influenced many standard design codes. Increasing concrete durability minimizes the need for large maintenance, rehabilitation and reconstruction costs. Sustainability will be achieved by improving concrete durability and providing long service life structures. Permeability is the most significant factor controlling concrete durability. Penetration of fluids and detrimental agents from the surrounding environment through concrete is associated with chemical and physical reactions which changes the concrete microstructure and results in premature deterioration. Carbonation, reinforcement corrosion and freezing and thawing action are the primary causes of concrete deterioration due to the lack of permeation quality. Therefore, the ease with which water and aggressive ions can ingress through concrete; indicates its resistance against extreme environmental conditions which has a great impact on concrete durability. Thus, reducing the permeability of concrete is an effective way to preserve its desired integrity and serviceability. Permeability reflects the concrete internal microstructure which in turn depends on the pore size distribution and connectivity of the pore network. Mixture constituents and water to cement ratio, degree of consolidation, degree of hydration and curing period are fundamental factors affecting the pore system properties of concrete. On the other hand, micro-crack development as a result of physical and chemical interactions between concrete and environment plays an important role on changing the concrete microstructure [Yang, *et al,* 2006]. Over consolidation will also occur when the freshly mixed concrete is subjected to the excessive vibration time which results in segregation and sedimentation of the aggregates and induces the water rise towards the top surface of the concrete. Accumulation of the bleed water weakens the concrete surface and increases the risk of plastic shrinkage cracking. The strength non-uniformity associated with the non-uniform distribution of the solid skeleton of concrete is another consequence of over vibration [Josserand, *et al,* 2006]. On the other hand, concrete mixtures properly consolidated and cured remain more watertight and more durable under severe environmental conditions. Sufficient degree of consolidation is required to assure the quality of finished concrete. Therefore, more attention must be paid to provide satisfactory construction practices that fulfil the durability requirements [Mehta 2000]. 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 [Transportation research board, 1991]. However, their widespread use over a long period has left the construction industry and the engineering community with a grave problem regarding the durability of highway reinforced concrete bridges and multi-storey parking structures [Pullar-Strecker, 2002], due mainly to the fact that they cause corrosion of the reinforcement and steel components [Pullar-Strecker, 2002].In cold-climate regions, snow and ice control operations are crucial to maintaining highways that endure cold and snowy weather. The growing use of de-icers has raised concerns about their effects on motor vehicles, transportation infrastructure, and the environment. The deleterious effect of chloride-based de-icers on reinforcing steel bar in concrete structures is well known [Shi, *et al*, 2009]. De-icers may also pose detrimental effects on concrete infrastructure through their reactions with cement paste and/or aggregates and thus reduce concrete integrity and strength, which in turn may foster the ingress of moisture, oxygen and other aggressive agents onto the rebar surface and promote rebar corrosion. Large amounts of solid and liquid chemicals (known as de-icers) as well as abrasives are applied onto winter highways to keep them clear of ice and snow. De-icers applied on to highways often contain chlorides because of their cost-effectiveness, including mainly sodium chloride (NaCl), magnesium chloride ($MgCl_2$), and calcium chloride ($CaCl_2$), sometimes blended with proprietary corrosion inhibitors. The rock salt/sodium chloride (NaCl), is the most commonly used de-icing agent. It was first used to control snow and ice on roadways to improve transportation safety in the 1930s, and became widespread by the 1960s. The salt works by dissolving into precipitation on roadways and lowering the freezing point, thereby melting ice and snow. Eliminating the ice has enormous safety benefits, but depending on the amount of chemicals used, the dissolved salt can have negative effects on the surrounding environment. The melting snow and ice carries de-icing chemicals onto vegetation and into soils along the roadside where they eventually enter local waterways. Elevated salt levels in soils can inhibit the ability of vegetation to absorb both water and nutrients, which can slow plant growth and ultimately affect animal habitats. This degradation also affects the ability of these areas to act as buffers to slow the runoff of other contaminants into the watershed. Once the salt enters freshwater it can build up to concentration levels that further affect aquatic plants and other organisms. Salt deposits along roadways also attract birds, deer, and other animals which increases the chance of animal-vehicle accidents. While the major effect on public drinking water supplies for humans is merely an alteration of taste, high concentrations of sodium in drinking water can lead to increased dietary intake and possibly hypertension. Since salt is corrosive to automobiles, bridge decks, and other roadway infrastructure, de-icing chemicals are often combined with other substances to block corrosion. While eliminating ice is of great benefit to commerce and human safety, these drawbacks must be taken into consideration by communities as they plan for regular maintenance of the concrete infrastructure, as well as the health of the local ecosystem.

The costs of maintaining reinforced concrete 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*, 2014].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 such as leakage of joints or to deviations from the intended concrete quality or cover thickness; or to modelling inadequacies (carbonation induced corrosion as noted in [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. 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 72 pre-conditioned concrete cubes (100 mm^3) such as dry/fully/partially saturated condition and salt ponded with chloride solution for about 160 days. This research will examine the influence of conditioning such as dry/fully/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 dry condition and salt ponded with chloride solution for about 28 days with 10% Nacl solution. Thus the objectives of this present research is to examine the influence of conditioning such as dry condition on the results of chloride absorption performed on concrete cubes with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Seventy-two concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride absorption under different exposure condition.

3.0 Experimental program

In the present research work, six different mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm^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 each mixture and overall seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crushed stone with maximum nominal size of 10 mm with grade of cement 42.5 N/mm^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 use in this present research work. To avoid criticizing or promoting one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclose and they will be refer to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material, which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

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 Interpretation of chloride absorption

The primary aim of this research was to interpret the effectiveness of wetting and drying pre-conditioned concrete cubes on chloride absorption, which was exposed to different pre-determined conditions such as dry condition was evaluated in control/impregnation concrete cubes for about 28 days salt ponding test in all designed six mixtures type (M1-M6).The pre-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. 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 [12-14]. In this way service life of reinforced concrete structures situated in an aggressive environment such as marine climate/de-icing performance can be significantly improved in different concrete infrastructures. Thus in the present research work that, the effectiveness of impregnation materials such as solvent/water based impregnation materials was evaluated in pre-conditioned concrete cubes in ordered to reduce chloride absorption for in case of designed mixtures type. The variation of average (1-28) days concrete chloride absorption, standard deviation, minimum, as well as maximum values under various pre-conditioned control/impregnation concrete cubes such as DCC (SB/WB) was represented in Tables.3.

Table.3 Interpretation of chloride absorption in DCC/IC cubes

Mix ID	Average	STD	Min,value	Max,value	Mix ID	Average	STD	Min,value	Max,value
M1CC	0.425	0.453	3.09	4.16	M4CC	0.968	1.01	2.52	4.89
M1SB	0.355	0.389	2.08	3.05	M4SB	0.771	0.81	2.36	4.19
M1WB	0.395	0.433	2.34	3.38	M4WB	0.812	0.84	3.18	5.06
M2CC	0.709	0.755	2.67	4.41	M5CC	0.560	0.60	2.71	4.21
M2SB	0.404	0.442	1.87	2.96	M5SB	0.271	0.32	3.07	4.22
M2WB	0.433	0.477	1.93	3.10	M5WB	0.452	0.49	1.93	3.39
M3CC	0.600	0.641	3.21	4.73	M6CC	0.551	0.59	3.14	4.55
M3SB	0.470	0.499	2.50	3.67	M6SB	0.311	0.36	1.02	1.96
M3WB	0.489	0.518	2.51	3.72	M6WB	0.444	0.48	1.86	3.06

The variation of average chloride absorption was compared in pre-conditioned control/impregnation concrete cubes at time duration (28th) day to interpret the effectiveness of impregnation materials (solvent/water) based impregnation material for in case designed control/impregnation concrete mixtures type (M1CC-M6CC, M1SB-M6SB, and M1WB-M6WB). The average chloride absorption in DCC control/impregnation concrete cubes was pre-dominantly decreased 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 increased with lesser concrete compressive strength and constant slump value and it goes on decreases with increased concrete compressive strength. 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 average chloride absorption in FSC control/impregnation concrete cubes was slightly decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned FSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in FSC control/impregnation concrete cubes was slightly increased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned FSC 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 [Balakrishna, *et al,* 2018].

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 location 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 rnechanisms 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.

In the present research work, the effectiveness of 72 preconditioned concrete cubes of size (100) mm on chloride absorption under pre-conditions such as dry condition was evaluated for in case of six designed mixtures type (M1-M6). The variation of average water weight loss in control DCC cubes was more/less more with constant higher compressive strength and varied slump value as when compared to variation of average water weight loss in control DCC cubes with varied compressive strength and constant slump value. But, the variation of average water weight loss in DCC cubes was pre-dominantly increased with lesser compressive strength and constant slump value and goes on decreased somewhat with increased compressive strength. The variation of average water weight gain in control PSC cubes was lesser with constant higher compressive strength and varied slump value/varied compressive strength and constant slump value as when compared to variation of average water weight gain in control FSC cubes with constant compressive strength and varied slump value/varied compressive strength and constant slump value. In fact, the variation of average water weight gain in control PSC/FSC cubes was pre-dominantly depends on saturation time duration and mixture proportioning method, pore structure, packing density of concrete, cement content, concrete matrix and cement paste interface zone, as well as aggregate volume fraction ratio in the concrete matrix. In fact, the average chloride absorption value in control and impregnation DCC/SB/WB cubes was found to be higher with higher constant concrete compressive strength, and varied slump values, as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control and impregnation PSC and FSC/SB/WB cubes at longer time duration. 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. 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.

In fact, the average chloride absorption value in control and impregnation PSC/SB/WB cubes was found to be higher with higher constant concrete compressive strength, and varied slump values, as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control and impregnation FSC/SB/WB cubes at longer time duration. The average chloride absorption was pre-dominantly increased in control and impregnation PSC/SB/WB cubes for lesser compressive strength and constant slump value and the chloride absorption value was decreases with increased compressive strength and constant slump value for in case of designed mixtures type at longer time duration. Similarly, the average chloride absorption was decreased in solvent and water based impregnation PSC cubes as when compared to control PSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value at longer time duration. The average chloride absorption value in control/impregnation FSC/SB/WB cubes was found to be pre-dominantly decreased with constant higher concrete compressive strength and varied slump values as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control/impregnation DCC/SB/WB cubes. The average chloride absorption was more increased in control/impregnation FSC/SB/WB cubes for lesser compressive strength and constant slump value. Whereas the average chloride absorption in control/impregnation FSC/SB/WB cubes was goes on decreases with increased compressive strength and constant slump value [Balakrishna, *et al*, 2018]. In the present research work, the variation of chloride absorption-square root of time (up to 28 days) was plotted for in case of designed control (M1CC-M6CC)/impregnation (M1SB-M6SB) concrete cubes as shown (1a-1f, 2a-2f, 3a-3f) respectively. The chloride absorption was lesser in control (M1CC:3.99-4.17%, M2CC:3.33-4.42%, M3CC:3.64-4.74%, M4CC:4.07-4.90%, M5CC:3.40-4.04%, and M6CC:3.61-4.56%)/impregnation (M1SB:2.29-3.05%, M2SB:2.28-2.96%, M3SB:2.82-3.68%, M4SB:3.57-4.20%, M5SB:3.64-3.07%, and M6SB:1.36-1.97%, M1WB:2.59-3.39%, M2WB:2.43-3.10%, M3WB:2.84-3.72%, M4WB:4.57-4.81%, M5WB:2.38-3.39%, M6WB:2.25-3.07%) concrete cubes at initial time duration (1 day) as when compared to longer time duration (28 day) as represented in the Fig.4a.

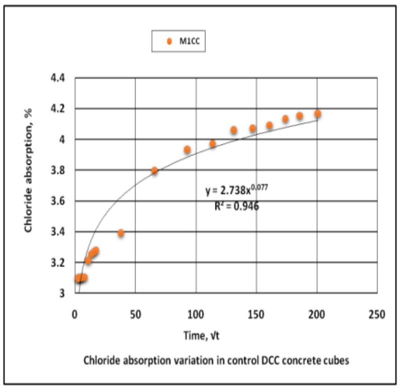

Fig.1a Cl^- absorption in control DCC cubes

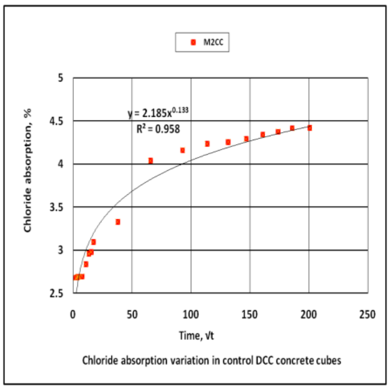

Fig.1b Cl^- absorption in control DCC cubes

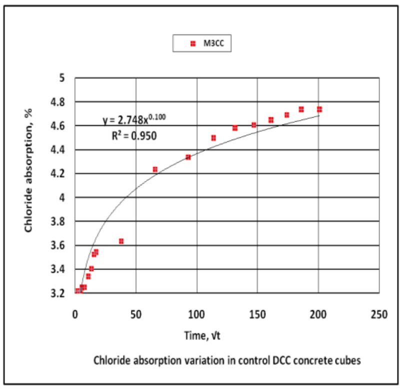

Fig.1c Cl^- absorption in control DCC cubes

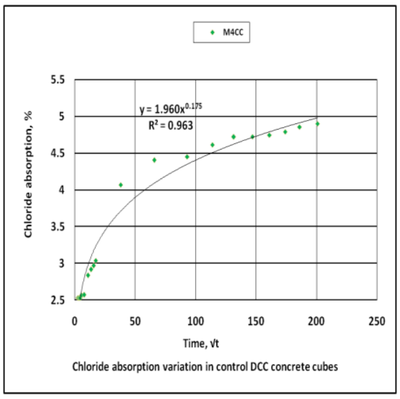

Fig.1d Cl^-absorption in control DCC cubes

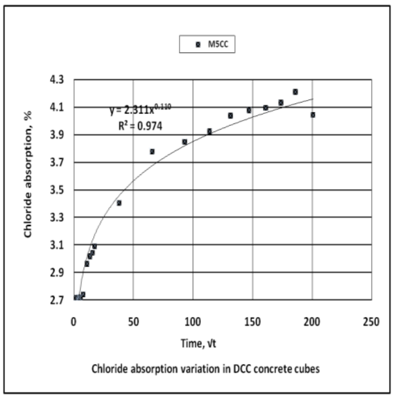

Fig.1e Cl^- absorption in control DCC cubes

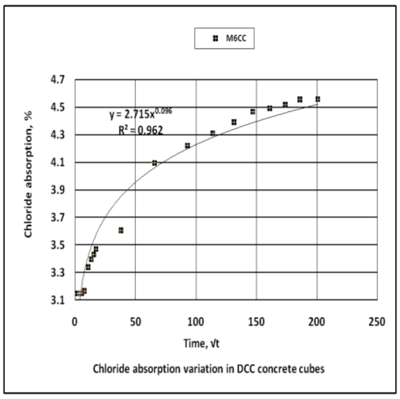

Fig.1f Cl^- absorption in control DCC cubes

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.

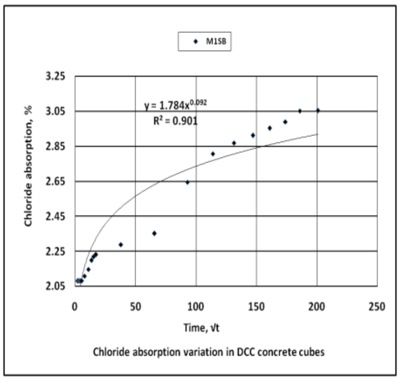

Fig.2a Cl^- absorption in DCC/IC cubes

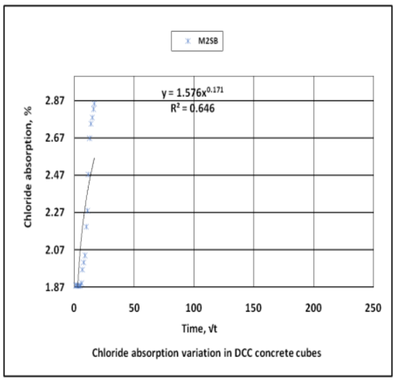

Fig.2b Cl^- absorption inDCC/IC cubes

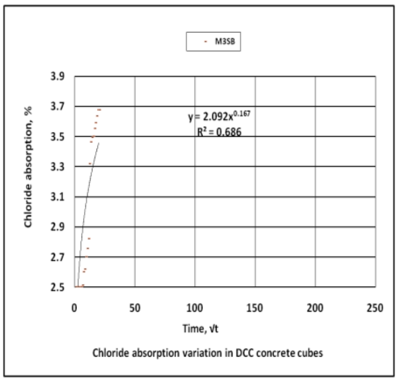

Fig.2c Cl^- absorption in DCC/IC cubes

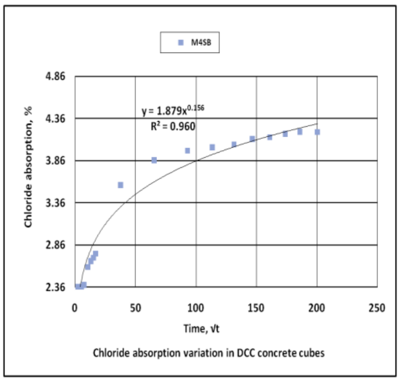

Fig.2d Cl^- absorption in DCC/IC cubes

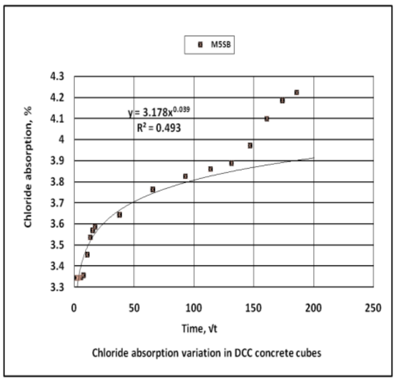

Fig.2e Cl^- absorption in DCC/IC cubes

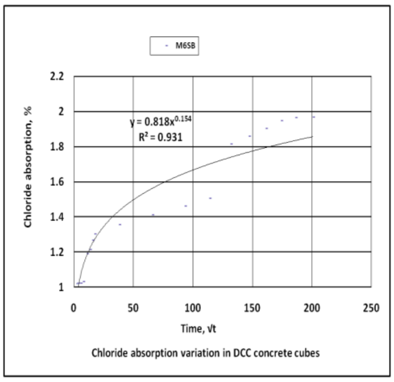

Fig.2f Cl^- absorption in DCC/IC cubes

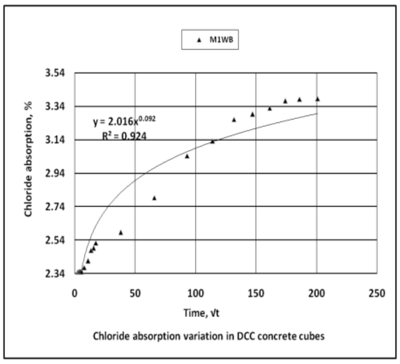

Fig.3a Cl^- absorption in DCC/IC cubes

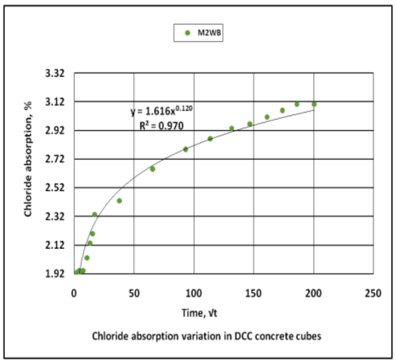

Fig.3b Cl^- absorption in DCC/IC cubes

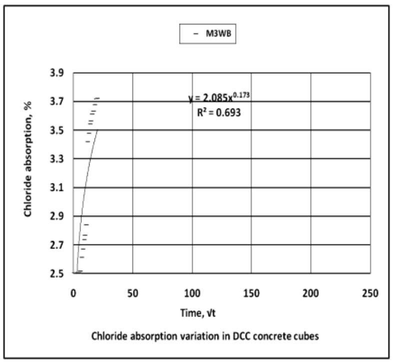

Fig.3c Cl^-absorption in DCC/IC cubes

The variation of chloride absorption-square root of time was increased in control/impregnation concrete cubes at time interval (1-3, 1-6, 1-9, 1-12, 1-15, 1-18, 1-21, 1-24, and 1-28 days) for in case of designed concrete mixtures type (M1CC-M6CC, M1SB-M6SB, and M1WB-M6WB). The chloride absorption was increase in control (M1CC:10.64-18.58%, M2CC:17.66-24.73%, M3CC:14.18-23.24%, M4CC:7.58-16.96%, M5CC:9.88-15.88%, and M6CC:11.94-20.87%)/impregnation (M1SB:2.65-25%, M2SB:7.85-22.96%, M3SB:14.97-23.26%, M4SB:7.65-15.08%, M5SB:3.21-18.57%, and M6SB:4.08-31.15%, M1WB:7.44-23.62%, M2WB:8.29-21.74%, M3WB:16.99-23.73%, M4WB:5.46-5%, M5WB:12.45-29.86%, M6WB:10.32-26.52%) concrete cubes at initial time duration (1-3 day, % increase) as well as at final time duration (1-28 day, % increase) as indicated in the Fig.4d.

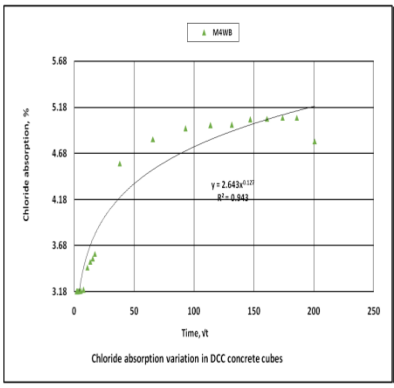

Fig.3d Cl- absorption in DCC/IC cubes

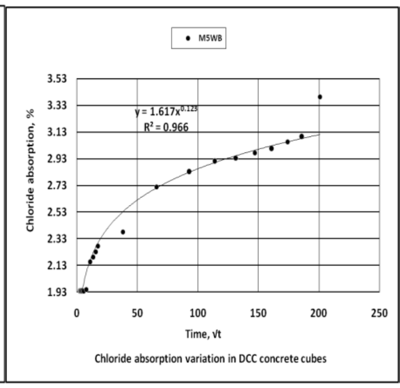

Fig.3e Cl- absorption in DCC/IC cubes

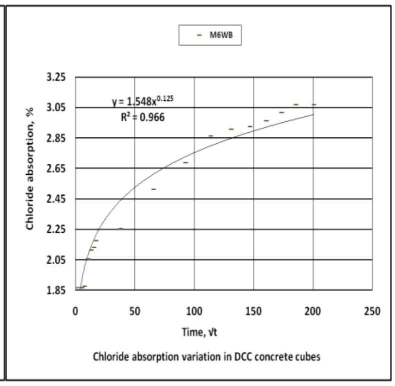

Fig.3f Cl- absorption in DCC/IC cubes

The variation of chloride absorption-square root of time was decreased in impregnation concrete cubes at time interval (1, 3, 6, 9, 12, 15, 18, 21, 24 and 28 days) for in case of designed concrete mixtures type (M1SB-M6SB, and M1WB-M6WB) as when compared to control concrete cubes (M1CC-M6CC). The chloride absorption was decrease in impregnation concrete cubes at time interval (1 day) as when compared to (28 day) control concrete cubes (M1SB-M1CC:67.44-73.21%, M2WB-M1CC:76.19-81.22%, M2SB-M2CC:68.56-66.98%, M2WB-M2CC:73.02-70.23%, M3SB-M3CC:77.65-77.67%, and M3WB-M3CC:78.10-78.61%, M4SB-M4CC:87.64-85.71%, M4WB-M4CC:112.31-98.17%, M5SB-M5CC:106.99-75.98%, M5WB-M5CC:69.93-83.95%, M6SB-M6CC:37.59-43.20%, and M6WB-M6CC:62.52-67.33%). It's also possible to compare the decrease in the chloride absorption for in case of impregnation concrete cubes (M1SB-M6SB) as when compared to impregnation concrete cubes (M1WB-M6WB) at time duration (1day and 28 day). Chloride solution absorption was decreased in impregnation concrete cubes in the following range as (M1SB-M1WB:88.51-90.14%, M2SB-M2WB:93.89-95.38%, M3SB-M3WB:99.42-98.81%, M4SB-M4WB:78.04-87.31%, M5SB-M5WB:153.01-90.51%, M6SB-M6WB:60.12-64.16%) concrete cubes at initial time duration (1 day, % decrease) as when compared to final time duration (28 day, % decrease) as shown in the Fig.4b.

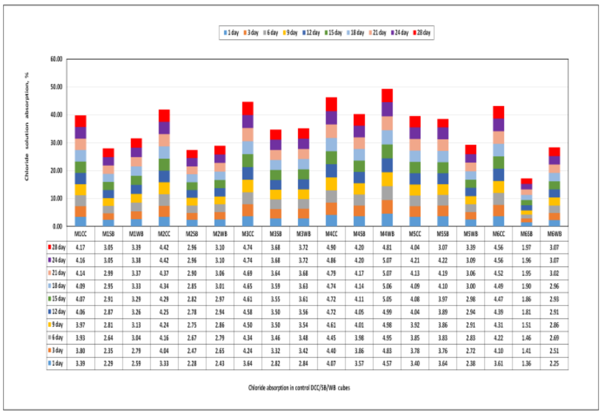

Fig.4a Cl- absorption in control DCC/SB cubes

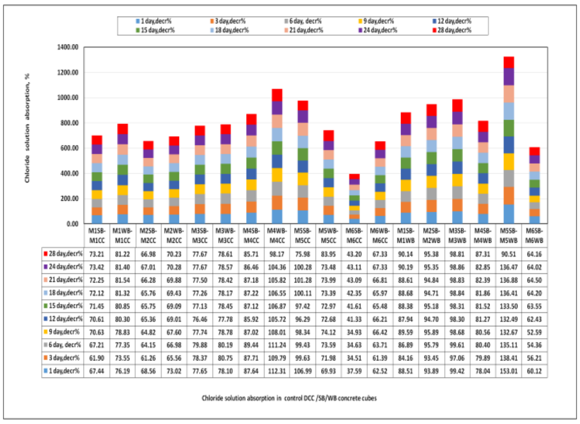

Fig.4b Cl- absorption in control DCC/WB cubes

The variation of chloride absorption-square root of time was increased in control concrete cubes at time interval (1, 3, 6, 9, 12, 15, 18, 21, 24 and 28 days) for in case of designed concrete mixtures type (M1CC-M6CC) as when compared to impregnation concrete cubes (M1SB-M6SB and M1WB-M6WB). The chloride absorption was increase in control concrete cubes at time interval (1 day) as when compared to (28 day) impregnation concrete cubes (M1CC-M1SB:32.56-26.79%, M1CC-M1WB:23.81-18.78%, M2CC-M2SB:31.44-33.02%, M2CC-M2WB:26.98-29.77%, M3CC-M3SB:22.35-22.33%, and M3CC-M3WB:21.90-21.39%, M4CC-M4SB:12.36-14.29%, M4CC-M4WB:-12.31-1.83%, M5CC-M5SB:-6.99-24.02%, M5CC-M5WB:30.07-16.05%, M6CC-M6SB:62.41-56.80%, and M6CC-M6WB:37.48-32.67%). It's also possible to compare the increase in the chloride absorption for in case of impregnation concrete cubes (M1WB-M6WB) as when compared to impregnation concrete cubes (M1SB-M6SB) at time duration (1day and 28 day). Chloride solution absorption was increased in impregnation concrete cubes in the following range as (M1WB-M1SB:11.49-9.86%, M2WB-M2SB:6.11-4.62%, M3WB-M3SB:0.58-1.19%, M4WB-M4SB:21.96-12.69%, M5WB-M5SB:-53.01-9.49%, M6WB-M6SB:39.88-35.84%) concrete cubes at initial time duration (1 day, % decrease) as when compared to final time duration (28 day, % decrease) as shown in the Fig.4c.

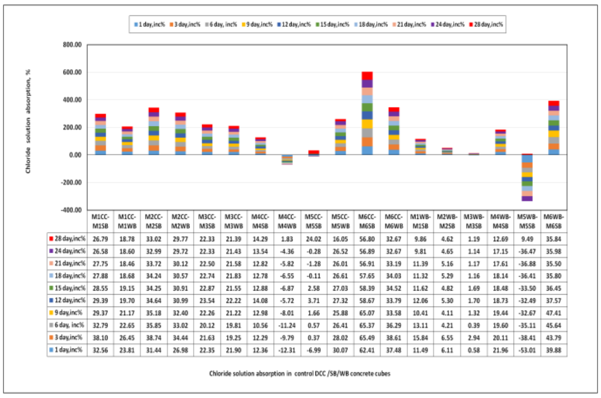

Fig.4c Cl- absorption in DCC/SB/WB cubes

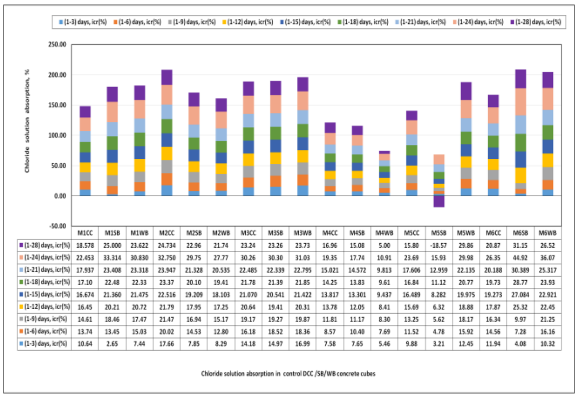

Fig.4d Cl- absorption in DCC/SB/WB cubes

6.0 Conclusions

- In the present research work, it's possible to establish relationship between chloride absorption-time by power type of equation.

- For different designed mixtures type of concrete, varying time durations are required in ordered to achieve a desired pre-conditions such as DCC/PSC/FSC 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 rate of absorption (sorptivity) is controlled by the pore structure of the concrete and its degree of saturation for in case of PSC and FSC cubes.

- The variation of average water weight loss in control DCC cubes was more/less more with constant higher compressive strength and varied slump value as when compared to variation of average water weight loss in control DCC cubes with varied compressive strength and constant slump value. But, the variation of average water weight loss in DCC cubes was pre-dominantly increased with lesser compressive strength and constant slump value and goes on decreased somewhat with increased compressive strength.

- The variation of average water weight gain in control PSC cubes was lesser with constant higher compressive strength and varied slump value/varied compressive strength and constant slump value as when compared to variation of average water weight gain in control FSC cubes with constant compressive strength and varied slump value/varied compressive strength and constant slump value. In fact, the variation of average water weight gain in control PSC/FSC cubes was pre-dominantly depends on saturation time duration and mixture proportioning method, pore structure, packing density of concrete, cement content, concrete matrix and cement paste interface zone, as well as aggregate volume fraction ratio in the concrete matrix.

- 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.

- 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.

- The average chloride absorption in FSC control/impregnation (SB/WB) concrete cubes were slightly decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned FSC control/impregnation (SB/WB) concrete cubes with constant slump value and varied concrete compressive strength.

- The average chloride absorption in FSC control/impregnation (SB/WB) concrete cubes was slightly increased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned FSC 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

[1].Bertolini, L., Elsener, B., Pedeferri, P., Redaelli, E., Polder, R.B.(2013). *Corrosion of steel in concrete: Prevention, diagnosis, repair,* 2nd Edition, Wiley-VCH Verlag GmbH and Co.KGaA, Weinheim, ISBN 3-527-33146-8, 414 pp.
[2].Bertolini, L., Lollini, F., and Redaelli, E. (2011). *Durability design of reinforced concrete Structures*, Institution of Civil engineers construction materials, (CM6), V.64, pp.273-282.
[3].Fib, 2006, Model code for service life design, fib Bulletin 34, Model Code, 116 pp, ISBN 978-2-88394-074-1.
[4].Gaal, G.C.M. (2004). *Prediction of deterioration of concrete bridges*, Ph.D. thesis, Delft University Press, Delft, NL.
[5].Hall, C. (1994). *Barrier performance of concrete*: A review of fluid transport theory, Materials and Structures, V.27, pp. 291-306.
[6].Hong. K, and Hooton. R. D. (1999). *Effects of cyclic chloride exposure on penetration of concrete cover*, Cement and concrete research, V.29, pp.1379–1386.
[7].Josserand, L., Coussy, O., and de Larrard, F. (2006). Bleeding of concrete as an ageing consolidation process. Cement and concrete research, V.36, No.9, pp.603-1608.
[8].Mehta, P. K., and Burrows, R. W. (2000). Building durable structures in the 21st century. Concrete international, 23(3), 57-63.
[9].Neville. A.M. (2011). *Properties of Concrete*, 5th ed.
[10].Pullar-Strecker, P. (2002).*Concrete reinforcement corrosion from assessment to repair decisions*, 1st edition, Thomas Telford Ltd, London.
[11].Polder, R.B., Peelen, W.H.A., and Courage, W.M.G.(2012). *Non-traditional assessment and Maintenance methods for aging concrete structures* - Technical and non-technical Issues, Materials and corrosion, V.63, No.12, pp.1147-1153.
[12].Ramachandran. V.S. *1 - concrete science*, in Handbook of Analytical techniques in concrete science and technology, V. S. Ramachandran and J. J. Beaudoin, Eds. 2001, .
[13].Shi.X ., Fay. L, Yang. Z, Nguyen. T.A, and Liu. Y. (2009). *Corrosion of de-icers to metals in transportation infrastructure*: introduction and recent developments 0/00", Corrosion. Reviews, in press.
[14].TRB. (1991). *Highway De-icing*, *Comparing salt and calcium magnesium acetate*, National research council, Washington D.C., Special Report 235.
[15].Tilly, G. P. (2011). *Durability of concrete repairs*. Concrete repairs, M. Grantham, ed., Taylor and Francis, Oxford, U.K.
[16].Teychenné, D. C, R E Franklin., H. C, and Erntroy. (1988). *Design of normal concrete mixes*, Second edition, BRE.
[17].Visser, J. H. M, and Zon, Q. Van. (2012). *Performance and service life of repairs of concrete structures in the Netherlands*, International conference on concrete repair, rehabilitation and retrofitting III,
[18].Alexander et al. (eds.), Taylor & Francis, London, ISBN 978-0-415-89952-9.
[19]. Xu Gang, Li Yun-pan, Su Yi-biao, and Xu Ke. (2015). *Chloride ion transport mechanism in concrete due to wetting and drying cycles,* Structural concrete, Issue 2, V.16, pp.289–296.
[20].Yang, Z., Weiss, W. J., and Olek, J. (2006). *Water transport in concrete damaged by tensile loading and freeze–thaw cycling,* Journal of materials in Civil Engineering, V.18, No.3, pp. 424-434.
[21].Zhao. T. J, Zhang. P, and Wittmann. F.H. (2006). *Influence of freeze-thawcycles on carbonation and chloride penetration,* Proc. Int. Workshop on life cycle management of coastal concrete structures, NagaokaUniversity, Japan, H. Yokota and T. Shimomura, editors, 37-42pp.
[22].Zhan. H, Wittmann. F.H, and Zhao. T.(2003). *Chloride barrier for concretein saline environment established by water repellent treatment*, Restoration of buildings and monuments, V.9, pp.535-550.
[23].Zhan. H, Wittmann. F.H, and Zhao. T. (2005). *Relation between the siliconresins profiles in water repellent treated concrete and theeffectiveness as a chloride barrier*, Restoration of buildings and monuments, V.11, pp.35-45 .