

ASSESSMENT OF CHLORIDE ABSORPTION IN PRE-CONDITIONED IMPREGNATION FSC CUBES

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Abstract: The degradation of concrete in pavements and a bridge that may occur as a result of attack by chemical de-icers/anti-icers is the result of an increased concentration of dissociated calcium and magnesium ions in the concrete pore water. De-icing is defined as any effort to remove ice from road and bridge surfaces after ice deposition has occurred. This is in contrast to anti-icing, which is defined as a surface treatment applied prior to ice formation that eliminates ice accumulation or facilitates ice removal by lessening the bond between the ice and the riding surface. In general, de-icing and anti-icing are accomplished through the use of various chemicals including aqueous solutions of chlorides (e.g. magnesium chloride, sodium chloride, and calcium chloride) or other chemicals such as calcium magnesium acetate and urea. Although the efficacy of these chemicals for de-icing and anti-icing has been clearly demonstrated, possible detrimental effects to concrete in transportation structures have not been fully examined and documented. In this sense, the true cost effectiveness has not been determined as chemical attack on concrete is a possibility and in turn, the resulting deterioration of the structures from chemical attack may lead to costly rehabilitation or replacement. Based upon published research, the most problematic chemicals appear to be the chlorides of magnesium, calcium, and sodium and other chemicals containing calcium and magnesium (e.g. calcium magnesium acetate). The chemicals used in the snow and ice control operations (de-icers) may cause corrosion damage to the transportation infrastructure such as reinforced/pre-stressed concrete structures and steel bridges. There are many ways to manage the corrosive effects of de-icers, such as selection of high-quality concrete, adequate concrete cover and alternative reinforcement, control of the ingress and accumulation of deleterious species, injection of beneficial species into concrete, and use of non-corrosive de-icer alternatives and optimal application rates. In fact, snow and ice on streets and highways are a major threat to human life and limb. Traffic accidents and fatalities climb as snow and ice reduce traction on roadways. Lengthened emergency response times create additional risks for persons in urgent need of medical care, particularly in cases of heart attacks, burns, childbirth and poisoning. Thus the de-icing salts are necessary to provide safe winter driving conditions and save lives by preventing the freezing of a layer of ice on concrete infrastructure. However, the safety and sense of comfort provided by these salts is not without a price, as these salts can greatly contribute to the degradation and decay of reinforced concrete transportation systems. The importance of chloride concentration as a durability-based material property has received greater attention only after the revelation that chloride-induced corrosion is the major problem for concrete durability. There is a need to quantify the chloride absorption in concrete which is of paramount importance.

The present research work was made an attempt to interpret the concrete chloride absorption in order to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as fully saturated condition and salt ponded with chloride solution for about 28 days. Thus the objectives of this present research are such as: First, this research will examine the influence of conditioning such as fully saturated condition on the results of chloride absorption in concrete cubes with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Seventy-two concrete cubes (100 mm³) with grades of concrete ranges from 25-40 N/mm² were prepared and evaluate the chloride absorption under exposure condition. It's concluded from the results that, in saturated conditioned concrete cubes, the chloride absorption value was increased in all designed mixtures type. Similarly, the average chloride absorption was decreased in solvent based and water based impregnation FSC cubes as when compared to control FSC 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 FSC cubes for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride absorption was going on decreases with increased compressive strength and constant slump value. The variation of chloride absorption in control FSC cubes was higher as when compared to impregnation concrete cubes either in solvent based (SB) and water based (WB) impregnation material. It's possible to established relationship between rate of chloride absorption and square root of time by power type of equation in designed concrete mixtures type. Chloride absorption in FSC 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 FSC control/impregnation (SB/WB) concrete cubes with constant slump value and varied concrete compressive strength. The chloride absorption in FSC control/impregnation (SB/WB) concrete cubes was slightly decreased with lesser concrete compressive strength and constant slump value as when compared to pre-condition 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.

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

The steel reinforcement embedded within concrete, the main electrochemical reactions take place in the limited volume of aqueous solution present in the pores of the concrete surrounding the metal, as a result of this process, the steel loses mass, and its cross section decreases. However this is not one of the obvious risks associated with steel corrosion in concrete, instead it is about solid products of corrosion. These products are deposited in the gap between the concrete and steel, due to being in a very small place, this process generates efforts that can break the concrete coat causing a progressive deterioration of it [Aperador *et al.* 2009]. One of the most common reasons that cause corrosion in reinforcements is the chlorides penetration through the net of pores when these are located in marine environments. Chloride ions are capable of causing localized corrosion therefore lead to a premature and unexpected failure of the structure [Morón *et al.* 2003]. Reinforced concrete uses steel to provide the tensile properties that are needed in structural concrete. It prevents the failure of concrete structures which are subjected to tensile and flexural stresses due to traffic, winds, dead loads, and thermal cycling. However, when reinforcement corrodes, the formation of rust leads to a loss of bond between the steel and the concrete and subsequently delamination and spalling. If left unchecked, the integrity of the structure can be affected severely under various exposure conditions. The corrosion rate is controlled by many factors such as total chloride ion content of the pore solution, pH level, and availability of oxygen, water content, and temperature. In corrosion decay of steel in concrete several processes may be combined, making it difficult to identify a single mechanism. One of the mechanisms for surface penetration is intrusion of chloride-bearing water into capillary pores of unsaturated concrete by capillary action. Alternate wetting and drying can lead to build up of chloride ions through absorption. If a structure is not dried to a high degree for prolonged period of time, chloride penetration into concrete by absorption and capillary suction is basically restricted to a small depth below the surface. If there is a differential head of chloride bearing water, permeability will also influence the ingress of chlorides for which higher permeability coefficient will permit higher rate of flow. The other dominant mechanism of the chloride ion transport is the diffusion which takes place under a concentration gradient. If outside concentration is higher than the inside of concrete, the migration of chloride ions through pore water in concrete will take place by diffusion. The relative importance of the two major mechanisms of chloride transport, namely diffusion and absorption, depend on the moisture content of concrete. Absorption may be dominant if a dry concrete with significant loss of pore water is wetted with chloride-bearing water, whereas for a reasonably moist concrete (sufficient level of pore water exists) diffusion process will prevail. However, researchers tend to agree that in most cases diffusion can be assumed to be the basic transport mechanism of chloride ions for reasonably moist structures. As part of the chloride in concrete is chemically bound due to reaction of chloride ions with constituents of cement, the free chloride concentration is of importance for corrosion initiation. Research presents a study on the strength, chloride penetration and resistance to corrosion of SCC made with ternary blend of Portland cement containing ground bagasse ash (BA) and ground rice husk-bark ash (RB). Test results reveal that the use of BA and RB produced excellent resistance to chloride penetration. The compressive strength is a significant factor as it directly affects the chloride penetration of the self-compacting concrete [Sumrereng Rukzon and Prinya Chindaprasirt, 2018]. The research shows the development and implementation of a software that calculate the chloride penetration profile in concrete obtained using traditional Portland cements and cementitious mixtures from the addition of pozzolanic materials such as silica fume, metakaolin, and fly ash. The software calculates the penetration profile taking into account parameters such as the w/c ratio, initial chlorides concentration, and the pozzolan content in the mixture [Roa-Rodriguez *et al.* 2013]. To ensure the durability of concrete structures it is necessary to understand its behaviour in the presence of aggressive agents. Carbonation and chloride ingress are the two main causes of degradation in reinforced concrete. The combination of these factors can create a very harsh environment for concrete structures. Given the importance of chloride migration coefficient for areas such as service life prediction, this work intends to study the influence of carbonation on the chloride migration coefficient of ordinary Portland cement (OPC) concrete. Concrete specimens were cast with different w/c ratios: 0.4, 0.5 and 0.6. After 90 days of curing, half of samples were subjected to carbonation chamber (4% CO₂, 20 °C and 55% RH) for 6 months. The other half was protected with plastic sheet during the same period. Non-steady-state migration test was performed in specimens with and without exposure to carbon dioxide environment. The results show that, for these conditions, the carbonation has a direct influence on chloride diffusion coefficient. The carbonated samples studied showed a chloride migration coefficient up to 130% higher than noncarbonated

ones. This fact can be related to the reduce in chloride binding capacity caused by carbonation front [Malheiro Raphalee *et al.* 2018].

Mastering and optimizing the durability of concrete structures and also the rehabilitation of concrete structures is a major challenge for all actors of the concrete construction field. An experimental program is conducted to get a complete characterization of the mechanical, chemical and physical properties of four concretes and their performances towards the main aggressive environment for the reinforcement corrosion. The evaluated durability properties are chloride migration, porosity, water absorption and carbonation. Moreover, for each concrete, some reinforced specimens are manufactured to measure the electrochemical properties of the reinforcement such as potential. The project achievements are used to optimize and improve the durability model SDReaM-crete developed by Cerib and LMDC. This model can simulate the migration of chlorides, the combination of this migration with the mechanism of carbonation and the corrosion of reinforcing bars according to wetting-drying cycles. Finally, their present work aims to optimize the sizing of the cover thickness for new structures and to facilitate the lifespan prediction for existing structures. Some experimental results and some interpretations as well as simulations made with SDReaM-crete are also presented [Lucie Schmitt *et al.* 2018]. Chloride ions are penetrating rapidly under the combined action of capillary suction of seawater followed by diffusion of chloride ions by cyclic wetting /drying of concrete in the tidal zone. In order to study this behaviour, a test set-up was used immersing specimens in a chloride containing solution, followed by a drying period. After distinct test durations the penetration depth is determined. This test method was applied in the framework of a project studying the durability of self-compacting concrete. The influence of the combined action of capillary absorption and chloride diffusion on the penetration is investigated and a simplified model is proposed, leading to an accurate prediction [Audenaert and De Schutter, 2009]. The goal of current research is considering mechanism of transporting chloride ion in concrete and factors affecting it. In this direction 6 cases of methods of transporting chloride ion has been considered. Also parameters such as conditions of loading, conditions of confrontation, regards of designing and implementation and components and plan of mixing on penetration of concrete generally and penetration of chloride ion specifically are effective [Pooneh Shahmalekpour *et al.* 2015]. The prolonged periods of snowfall in countries with advanced infrastructure and transport systems have rendered the use of de-icing agents to a common occurrence on roads and highway structures. They are necessary in order to maintain a good level of service with respect to the transport systems, thus avoiding traffic jams and disruptions, but also to provide a high level of road safety. Today, chloride-based products, such as rock salt, are the most commonly encountered de-icers as they are easy to apply and store but mostly because they efficiently melt ice at an affordable price [TRB, 1991]. However, their widespread use over a long period has left the construction industry and the engineering community with a grave problem regarding the durability of highway reinforced concrete bridges and multi-storey parking structures [Pullar-Strecker, 2002], due mainly to the fact that they cause corrosion of the reinforcement and steel components [Pullar-Strecker, 2002]. In cold-climate regions, snow and ice control operations are crucial to maintaining highways that endure cold and snowy weather. The growing use of de-icers has raised concerns about their effects on motor vehicles, transportation infrastructure, and the environment. The deleterious effect of chloride-based de-icers on reinforcing steel bar in concrete structures is well known [Shi *et al.* 2009]. De-icers may also pose detrimental effects on concrete infrastructure through their reactions with cement paste and/or aggregates and thus reduce concrete integrity and strength, which in turn may foster the ingress of moisture, oxygen and other aggressive agents onto the rebar surface and promote rebar corrosion. Large amounts of solid and liquid chemicals (known as de-icers) as well as abrasives are applied onto winter highways to keep them clear of ice and snow. De-icers applied on to highways often contain chlorides because of their cost-effectiveness, including mainly sodium chloride (NaCl), magnesium chloride (MgCl₂), and calcium chloride (CaCl₂), 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.* 2013]. In The Netherlands 5% of motorway bridges, built predominantly between 1960 and 1980, shows cracking and spalling of the concrete cover due to chloride induced corrosion [Gaal, 2004]. This corresponds to 10% of the bridges showing corrosion initiation at an age of 40 years [Polder *et al.* 2012]. Older structures have been built according to older codes, which may not have provided sufficient protection. Moreover, for new infrastructure corrosion cannot be ruled out completely, even with today's emphasis on design for long service life (typically 100 years), either by composition requirements (Eurocodes) or based on service life modelling and performance testing [fib, 2006]. This may be due to various factors, such as unforeseen aggressive loads, e.g. leakage of joints; or to deviations from the intended concrete quality or cover thickness; or to modelling inadequacies (e.g. for carbonation induced corrosion see [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, and Zon, Q. van, 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 order to characterize the different concrete mixtures type for in case of 72 pre-conditioned concrete cubes (100 mm^3) such as fully saturated condition and salt ponded with chloride solution for about 28 days. This research will examine the influence of conditioning in fully/partially saturated condition on the results of chloride absorption in concrete cubes with different mixtures proportion in which slump (0-10, 10-30, 60-180) mm, and w/c ratio value was varied with constant compressive strength (40 N/mm^2) as in the first case and compressive strength ($25\text{-}40 \text{ N/mm}^2$), 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 order to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as fully saturated condition and salt ponded with chloride solution for about 28 days with 10% NaCl solution. Thus the objectives of this present research is to examine the influence of conditioning such as fully saturated condition on the results of chloride absorption in concrete cubes with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Seventy-two concrete cubes (100 mm^3) with grades of concrete ranges from $25\text{-}40 \text{ N/mm}^2$ were prepared and evaluate the chloride absorption under specified exposure condition.

3.0 Experimental program

In the present research work, six different mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm^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 used in this present research work. To avoid criticizing or promoting one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclosed and they will be referred to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

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

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

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

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

4.0 Interpretation of chloride absorption

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

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

Mix ID	1 day	3 day	6 day	9 day	12 day	15 day	18 day	21 day	24 day
M1CC	4.751	4.753	4.753	4.757	4.757	4.761	4.761	4.761	4.765
M1SB	2.162	2.162	2.162	2.163	2.164	2.164	2.165	2.165	2.165
M1WB	2.463	2.464	2.465	2.467	2.467	2.467	2.467	2.467	2.471
M2CC	4.016	4.016	4.018	4.018	4.018	4.019	4.019	4.023	4.065
M2SB	0.929	0.931	0.932	0.932	0.933	0.933	0.934	0.934	0.935
M2WB	2.299	2.299	2.300	2.300	2.300	2.300	2.304	2.304	2.304
M3CC	3.123	3.124	3.125	3.125	3.127	3.128	3.128	3.129	3.129
M3SB	2.799	2.800	2.800	2.800	2.800	2.800	2.800	2.800	2.801
M3WB	1.921	1.921	1.922	1.922	1.923	1.923	1.923	1.923	1.926
M4CC	2.845	2.850	2.854	2.859	2.861	2.861	2.861	2.862	2.864
M4SB	2.343	2.343	2.343	2.343	2.343	2.343	2.343	2.343	2.348
M4WB	3.305	3.306	3.306	3.306	3.307	3.307	3.309	3.310	3.310
M5CC	2.124	2.125	2.125	2.126	2.126	2.126	2.127	2.135	2.177

M5SB	2.172	2.172	2.173	2.173	2.173	2.173	2.174	2.174	2.176
M5WB	1.936	1.937	1.937	1.938	1.938	1.938	1.938	1.939	1.983
M6CC	2.199	2.199	2.199	2.199	2.199	2.199	2.204	2.204	2.208
M6SB	2.230	2.235	2.239	2.239	2.239	2.239	2.239	2.239	2.244
M6WB	2.171	2.172	2.172	2.172	2.172	2.172	2.174	2.174	2.174

5.0 Discussion about Results

The process of wetting/drying is a major problem for concrete infrastructures which was exposed to chlorides and its effects are most severe in many concrete infrastructures locations such as marine structures, particularly in the splash and tidal zones, parking garages exposed to de-icer salts, and highway structures, such as bridges and other elevated roadways for instance the Gardner expressway. When the concrete is dry/partially dry, which was then exposed to salt water, it will imbibe the salt water by capillary suction. The concrete will continue to suck in the salt water until saturation or until there is no more reservoir of salt water. A concentration gradient of chlorides will develop in the concrete, stopping at some point in the interior of the concrete. If the external environment becomes dry, then pure water will evaporate from the pores, and salts that were originally in solution may precipitate out in the pores close to the surface. The point of highest chloride concentration may exist within the concrete. On subsequent wetting, more salt solution will enter the pores, while re-dissolving and carrying existing chlorides deeper into the concrete. The rate to which the chlorides will penetrate the concrete depends on the duration of the wetting/drying periods. If the concrete remains wet, some salts may migrate in from the concrete surface by diffusion. However, if the wetting period is short, the entry of salt water by absorption will carry the salts into the interior the concrete and be further concentrated during drying. The process of wetting/drying increases the concentrations of ions such as chlorides, by evaporation of water. The drying of the concrete also helps to increase the availability of the oxygen required for steel corrosion, as oxygen has a substantially lower diffusion coefficient in saturated concrete. As the concrete dries and the pores become less saturated, oxygen will have a better chance to diffuse into the concrete and attain the level necessary to induce and sustain corrosion. There is an increased availability of oxygen that also contributes to the deterioration compared to the submerged part of the structure. The concrete is fully submerged, less chloride would enter the concrete as the dominant penetration mechanism is diffusion through the pore solution. There are several factors that can affect the degree that chlorides will enter concrete through wetting/drying. In fact the ingress of chlorides into concrete is strongly influenced by the sequence of wetting/drying, and on the time duration. Thus in the present research work, the effectiveness of 72 preconditioned concrete cubes of size (100) mm on chloride absorption under pre-conditions in fully saturated condition was evaluated for in case of six designed mixtures type (M1-M6). The variation of chloride absorption in control concrete cubes for in different mixtures type (M1CC-M6CC) is as shown in Figs.1a-1f respectively. Chloride absorption is correlated with square root of time by power type of equation for in all designed control mixtures type (M1CC-M6CC).

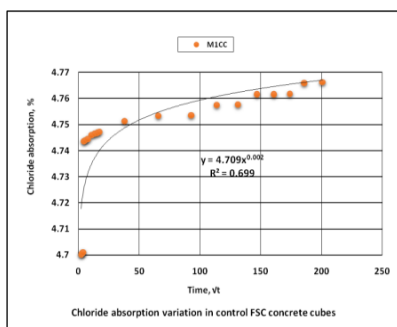


Fig.1a Cl⁻-time in control mix M1

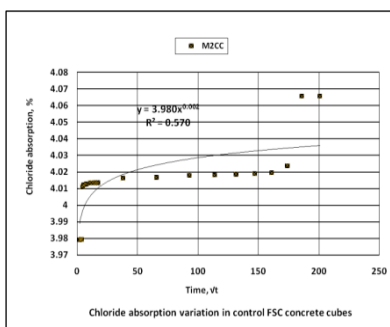


Fig.1b Cl⁻-time in control mix M2

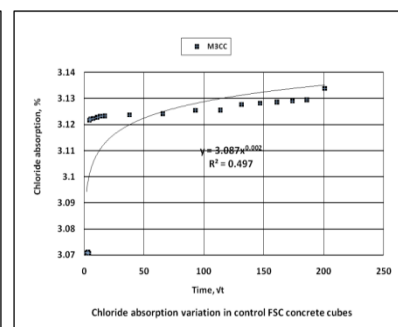


Fig.1c Cl⁻-time in control mix M3

The chloride absorption is gradually increased at initial time duration, afterwards deviates with square root of time duration and reaches equilibrium in turn indicates that, pore structure is attained fully saturated condition. The chloride absorption is increased at time interval (1 day) as when compared to time interval (28 day) for in case of all designed control mixtures type [(M1CC-M2CC:15.47-14.70, M1CC-M3CC:34.26-34.25, M1CC-M4CC:40.10-29.31, M1CC-M5CC:55.28-50.97, M1CC-M6CC:53.71-52.40, M2CC-M3CC:22.22-22.92, M2CC-M4CC:29.14-17.13, M2CC-M5CC:47.09-42.52, M2CC-M6CC:45.23-44.19, M3CC-M4CC:8.89-(-7.51), M3CC-M5CC:31.98-25.43, M3CC-M6CC:29.58-27.60, M4CC-M5CC:-25.34-30.64, M4CC-M6CC:22.71-32.66, and M5CC-M6CC:-3.51-2.91]%. Chloride absorption is initially increased at early stage due to concentration gradient.

Concentration gradient is more at an initial time duration, due to that the rate of absorption is also more, once the pore structure is fully saturated, the rate of chloride absorption goes on decreases with time duration. Thus the concentration gradient is more at an initial stage, goes on decreases as time passes and thus chloride absorption is reduced gradually as time in turn reaches equilibrium state.

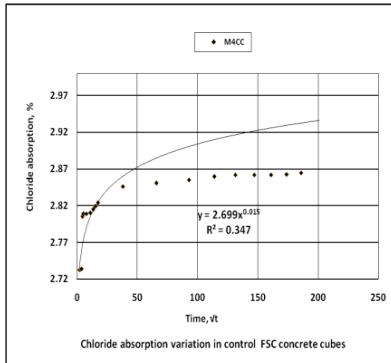


Fig.1d Cl-time in control mix M4

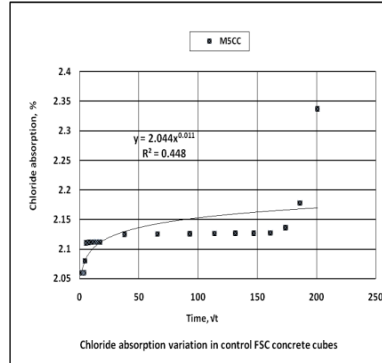


Fig.1e Cl-time in control mix M5

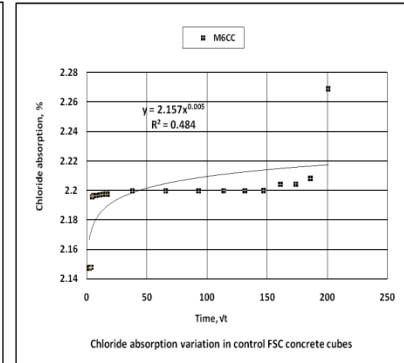


Fig.1f Cl-time in control mix M6

The chloride absorption is increased at initial time duration, deviates with square root of time duration and reaches equilibrium when the concrete structure is attained fully saturated condition. The chloride absorption is increased at time interval (1 day) as when compared to time interval (28 day) for in case of all designed control mixtures type as when compared to impregnation concrete cubes [(M1CC-M1SB:54.49-54.55, M1CC-M1WB:48.15-48.13, M2CC-M2SB:76.86-76.97, M2CC-M2WB:42.75-43.21, M3CC-M3SB:10.37-10.61, M3CC-M3WB:38.49-9.12, M4CC-M4SB:17.66-30.30, M4CC-M4WB:-16.15-1.72, M5CC-M5SB:-2.22-6.85, M5CC-M5WB:8.85-2.12, M6CC-M6SB:-1.42-1.10, M6CC-M6WB:1.27-0.36, and M1WB-M1SB:12.23-12.38, M2WB-M2SB:59.59-59.44, and M3WB-M3SB:-45.70-1.63, M4WB-M4SB:29.11-29.08, M5WB-M5SB:-12.15-4.84, M6WB-M6SB:-2.72-0.74]%. Chloride absorption is initially increased which may be due to concentration gradient. Variation of chloride absorption in impregnation concrete cubes for in case of different mixture type (M1SB-M6SB) is as shown in Figs.2a-2f respectively. Chloride absorption is directly correlated to the square root of time by power type of equation in all designed impregnation mixtures type (M1SB-M6SB). The chloride absorption is also increased in solvent based impregnation concrete cubes (M1SB-M6SB) at time interval (1 day) as when compared to time interval (28 day) for in case of all designed impregnation mixtures type as when compared to different designed impregnation mixture type [(M1SB-M2SB:57.03-56.77, M1SB-M3SB:-29.47-(-29.33), M1SB-M4SB:-8.36-(-8.41), M1SB-M5SB:-0.45-(-0.50), M1SB-M6SB:-3.16-(-3.60), M2SB-M3SB:-201.29-(-199.17), M2SB-M4SB:-152.17-(-150.78), M2SB-M5SB:-133.76-(-132.48), M2SB-M6SB:-140.07-(-139.65), M3SB-M4SB:16.30-16.18, M3SB-M5SB:22.41-22.29, M3SB-M6SB:20.32-19.90, and M4SB-M6SB:7.30-7.30, M4SB-M6SB:4.80-4.44, and M5SB-M6SB:-2.70-(-3.09)]%.

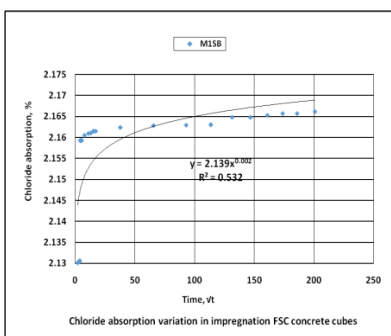


Fig.2a Cl-time in impregnation mix M1

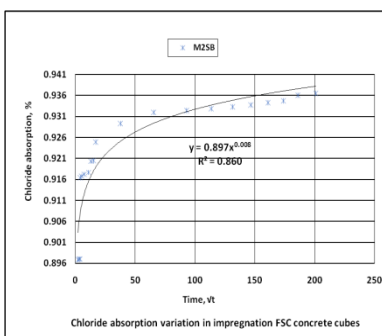


Fig.2b Cl-time in impregnation mix M2
M3

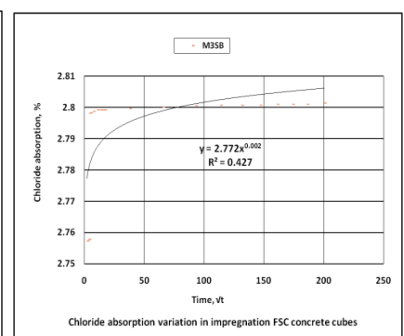


Fig.2c Cl-time in impregnation mix M3

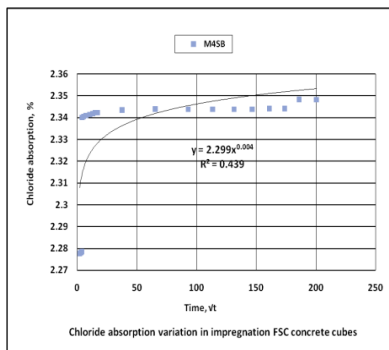


Fig.2d Cl-time in impregnation mix M4

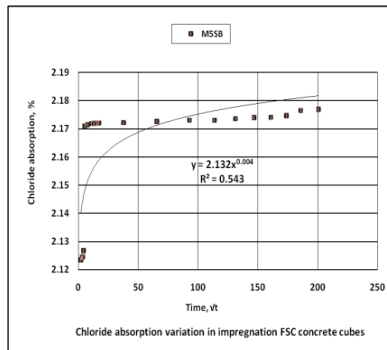


Fig.2e Cl-time in impregnation mix M5

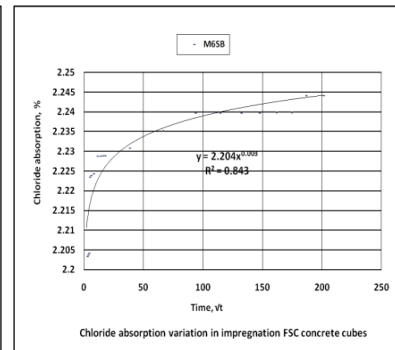


Fig.2f Cl-time in impregnation mix M6

The chloride absorption is initially increased which may be due to concentration gradient. Variation of chloride absorption in impregnation concrete cubes for in case of different mixture type (M1WB-M6WB) is as shown in Figs.3a-3f respectively. Chloride absorption is directly correlated to the square root of time by power type of equation in all designed impregnation mixtures type (M1WB-M6WB). The chloride absorption is increased at time interval (1 day) as when compared to time interval (28 day) for in case of all designed impregnation mixtures type as when compared to different designed impregnation mixture type [(M1WB-M2WB:6.67-6.61, M1WB-M3WB:22.00-(-15.20), M1WB-M4WB:-34.18-(-33.94), M1WB-M5WB:21.38-7.47, M1WB-M6WB:11.85-8.55, M2WB-M3WB:16.43-(-23.35), M2WB-M4WB:-43.77-(-43.42), M2WB-M5WB:15.77-0.92, M2WB-M6WB:5.55-2.09, M3WB-M4WB:-72.03-(-16.27), M3WB-M5WB:-0.79-19.68, M3WB-M6WB:-13.02-20.62, and M4WB-M6WB:41.41-30.92, M4WB-M6WB:34.30-31.73, and M5WB-M6WB:-12.13-1.17)]. The average chloride absorption was predominantly 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 FSC cubes as when compared to control FSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value at longer time duration.

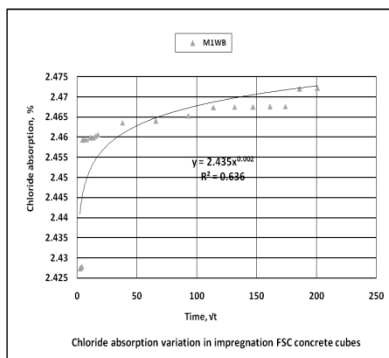


Fig.3a Cl-time in impregnation mix M1

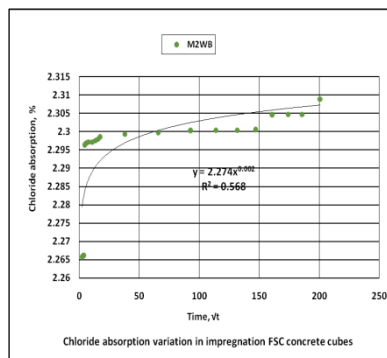


Fig.3b Cl-time in impregnation mix M2

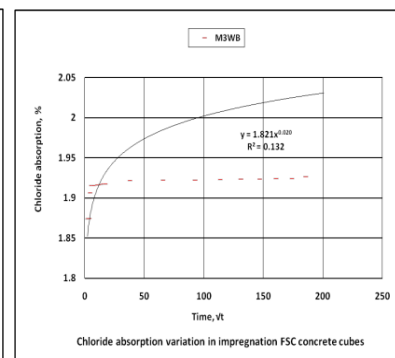


Fig.3c Cl-time in impregnation mix M3

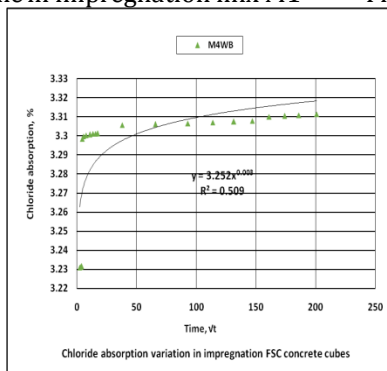


Fig.3d Cl-time in impregnation mix M4

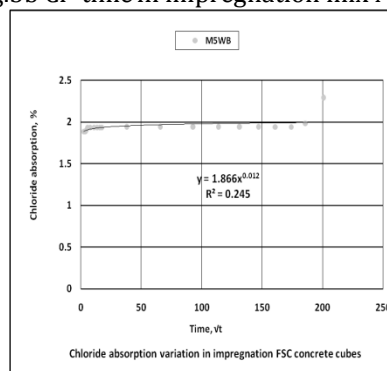


Fig.3e Cl-time in impregnation mix M5

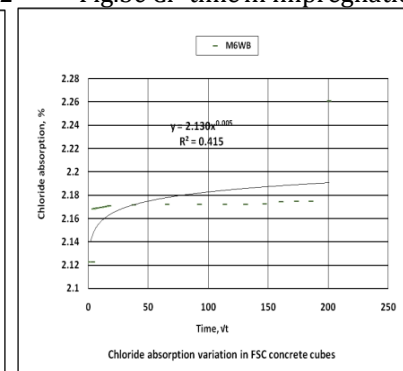


Fig.3f Cl-time in impregnation mix M6

The variation of chloride absorption in control/solvent/water based impregnation PSC cubes at longer time duration was represented in Fig.4a-4f for different designed mixtures type (M1-M6). The variation of average chloride absorption in control/solvent/water based impregnation FSC cubes at longer time duration (28 day) was represented in Fig.4a for different designed mixtures type (M1-M6). 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.

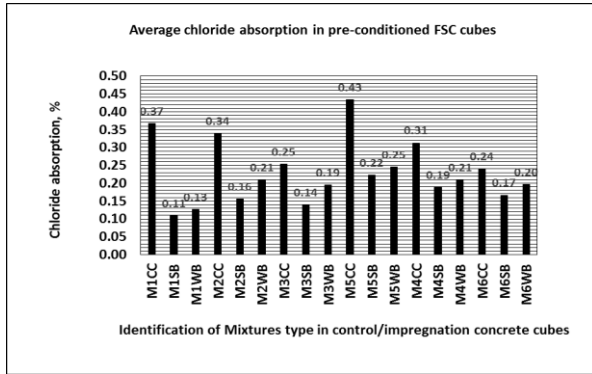


Fig.4a Cl⁻ absorption in control/IC FSC cubes

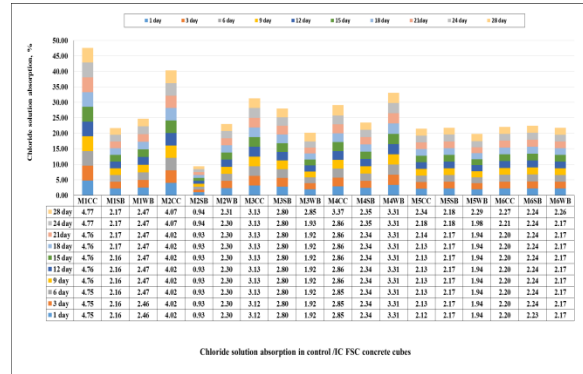


Fig.4b Cl⁻ absorption in control/IC FSC cubes

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 [15]. In case of absolute dry condition, the penetration rate of chloride ion will be much larger because of advection process than that in diffusion process in mortar with water saturated condition. Moreover, at the surface part of mortar, additional chloride content due to diffusion process can be also confirmed on distribution of chloride content due to advection process during absorption test. Therefore, in order to assess the penetration of chloride ion, effects of both advection and diffusion processes depending on moisture condition of mortar should be considered. The concrete are in a state of flux between saturated and partially saturated conditions as they undergo continuous cycles of wetting and drying. In saturated concrete, dissolved ions enter through diffusion, whereas in partially saturated concrete, ion-containing fluids are absorbed by capillary suction and concentrated by evaporation of water. It was found from the researchers [16] 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 FSC 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.

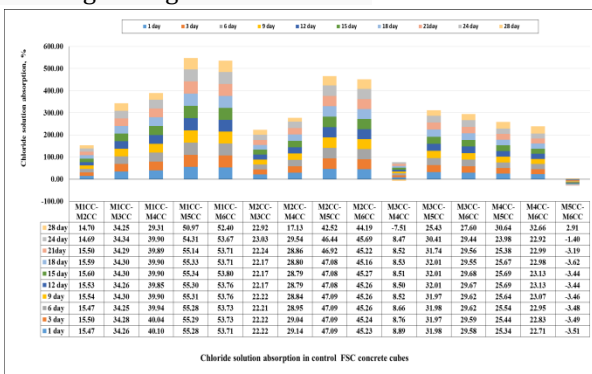


Fig.4c Cl⁻ absorption in control FSC cubes

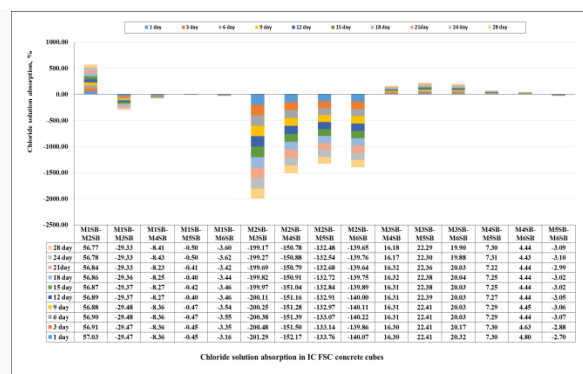


Fig.4d Cl⁻ absorption in impregnation FSC cubes

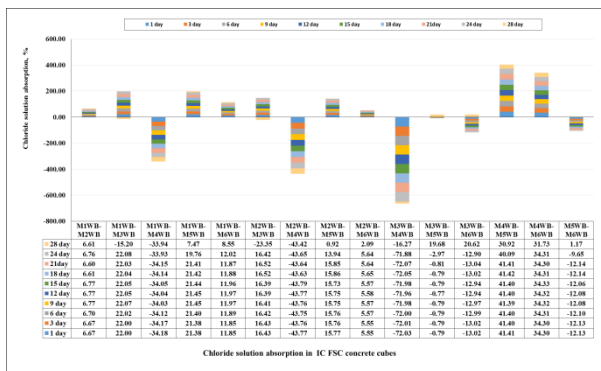


Fig.4e Cl⁻ absorption in impregnation FSC cubes

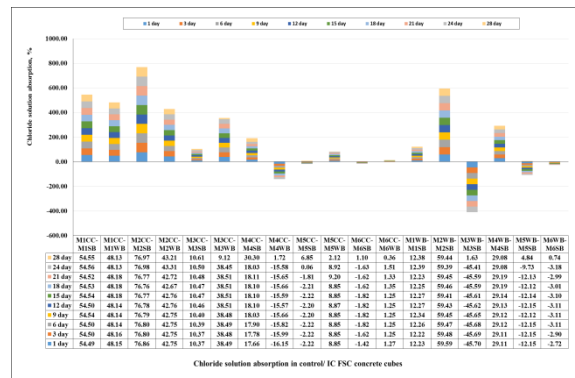


Fig.4f Cl⁻ absorption in control/IC FSC cubes

6.0 Conclusions

- The variation of chloride absorption in control FSC cubes was higher as when compared to impregnation concrete cubes either in solvent based (SB) and water based (WB) impregnation material. It's possible to established relationship between rate of chloride absorption and square root of time by power type of equation in designed concrete mixtures type.
- The chloride absorption in FSC 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 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 decreased with lesser concrete compressive strength and constant slump value as when compared to pre-condition 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.

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