

CHLORIDE PENETRATION AT DIFFERENT DRILL DEPTHS IN FSC CONCRETE CUBES

M.N. Balakrishna^{1*}, Robert Evans², Fouad Mohamad², and M.M. Rahman²

¹School of Architecture, Design and the Built Environment, Research scholar,
Nottingham Trent University, Nottingham, NG1 4FQ, UK

²School 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 concrete bridge decks are prone to ice accumulation. The use of road salts and chemicals for de-icing is cost effective but causes damage to concrete and corrosion of reinforcing steel in concrete bridge decks. This problem is a major concern to transportation officials and public works due to rapid degradation of existing concrete pavements and bridge decks. The use of insulation materials for ice control and electric or thermal heating for de-icing have been attempted and met limited success. Thus the de-icing salts are necessary to provide safe winter driving conditions and save lives by preventing the freezing of a layer of ice on concrete infrastructure. However, the safety and sense of comfort provided by these salts is not without a price, as these salts can greatly contribute to the degradation and decay of reinforced concrete transportation systems. The importance of chloride concentration as a durability-based material property has received greater attention only after the revelation that chloride-induced corrosion is the major problem for concrete durability. There is a need to quantify the chloride concentration in concrete which is of paramount importance.*

The present research work was made an attempt to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as fully saturated condition and salt ponded with chloride solution for about 160 days. Thus the objectives of this present research are such as: First, this research will examine the influence of conditioning such as fully saturated condition on the results of chloride concentration in concrete cubes at different drill depths (30-40-50 mm) with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Twenty four concrete cubes (100 mm³) with grades of concrete ranges from 25-40 N/mm² were prepared and evaluate the chloride absorption under specified exposure condition. Similarly, the average chloride concentration 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 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 penetration, de-icer, snow and ice control, reinforcing steel, corrosion, drill depth*

1.0 Introduction

Negative chemical and physical events that have negative effects on the durability of concrete are decomposition of calcium hydroxide in concrete and development of efflorescence on concrete surface, sulfate attack, sea water attack, acid attack, carbonation, alkali-aggregate reaction, and corrosion of reinforcing steel in concrete, freezing-thawing effect and peeling of concrete surface [Erdoğan, 2003]. Deterioration of concrete is a manifestation of inadequate durability of concrete structures. This deterioration can be due either to external factors or internal factors and those factors can be physical, chemical, or mechanical. The mechanical ways of deterioration include impact, abrasion, erosion or cavitation. The chemical mechanisms include the alkali-silica and alkalicarbonate reactions. External chemical attacks are generally caused by the action of aggressive ions (chlorides, sulfates) and carbon dioxide. Moreover a lot of natural and industrial liquids and gases lead to chemical attacks. The physical causes of deterioration of concrete structures include expansion of aggregate and of the hardened cement paste due to fluctuations in temperature. An important cause of the damage is alternating freezing and thawing of concrete and the associated action of de-icing salts. The transport of fluids should be examined and analysed in order to clarify the durability concerns of concrete structures [Neville, 2000]. There are three fluids which are related with

durability. These are water, pure or carrying aggressive ions, carbon dioxide and oxygen. The movement of these fluids can differ but their transportation in concrete depends mainly on the structure of the hydrated cement paste. The durability of concrete mostly depends on the ease with which fluids, both liquids and gases, can enter into, and move through the concrete. This mechanism is defined as the permeability of concrete. In other words, the permeability can be stated as flow through a porous medium. Movement of some fluids through concrete can also take place by diffusion and sorption. However, "permeability" is used as a general term to define the movement of fluids into and through concrete [Neville, 2000]. Transport properties of hardened concrete have an important role on the ingress of potentially deleterious and harmful materials. The resistance of hardened cement paste to chemical and physical impacts is related with the composition and microstructural properties of the paste and also environmental conditions around the concrete structures during both the fresh and hardened concrete phases. That is, the transport properties of concrete (diffusivity, permeability, and sorptivity) are important factors [Arjunan, 2000]. Corrosion of reinforcing steel because of chloride ingress is considered as an important deterioration mechanism in reinforced concrete. Transport of chloride ions is related with a few mechanisms including diffusion, migration in an electric field, water permeation because of a pressure gradient and absorption because of capillary action. Chloride ion transport through concrete is affected by the pore structure within concrete and the interaction between the ions and the pore walls. Moreover, water/cement ratio, presence of supplementary cementing materials and concrete age are parameters influencing the pore structure [Neithalath and Jain, 2010]. Research by [Li, 2009] into the influence of chloride concentration by the effect of salt concentration, air-entrainment agents and the addition of silica fume in the concrete showed that there is a pessimum concentration of chloride related to the amount of scaling damage of the concrete surface. In addition, the use of air entrainment and silica fume improved the performance of the concrete with regards to chloride penetration (measuring migration coefficients), but does not explain the moisture uptake, chloride transport and binding in the concrete. It also showed that freeze-thaw action accelerated the chloride penetration in concrete because of the significant liquid uptake (pumping effect). [Bouteille *et al.* 2010] also studied chloride penetration into concrete during laboratory testing for salt scaling. Based on the probability distribution curves of the chloride concentration fronts and that of the scaled surface they concluded that the phenomena are distinct and not interrelated. While the assumption that they are distinct is correct, they are interrelated as the consequences of frost scaling change the properties of the concrete surface which in turn influences the penetration of chlorides. Reinforced concrete structures during their exploitation may be exposed to the common action of carbonation and chlorides causing corrosion of steel reinforcement. Therefore, the related data seem to be interesting and important when the evaluation of the service life of the structures is the object of interest. This fact was a motivation for the present experimental study on the sequence of action of chloride solutions and carbonation of the embedding concrete. The results obtained show that carbonation of concrete foregoing the action of chloride solutions may intensify the process of corrosion of steel reinforcement in comparison to the converse sequence of the action of mentioned media. At the same time the sodium chloride solution has been shown as a more aggressive medium opposite to the calcium and magnesium chloride solutions [Vladimir Z Vivica, 2003].

The main and frequent cause of corrosion of reinforcement in reinforced concrete structures is chloride attack and carbonation. Chlorides come from several sources. They can be cast in concrete but often they can diffuse into concrete as a result of sea salt spray and direct seawater wetting. Further, they can diffuse into concrete due to the application of chloride de-icing salts and at the storage of chloride substances in concrete tanks and likewise. The source of carbonation of concrete is atmosphere preferably in the areas of industrial and transport activities. Mechanisms involved in the carbonation, chloride attack and corrosion of reinforcement have been studied by many researchers [Jones *et al.* 1996]. As is well known, the corrosive effect of carbonation is based on the decreasing trend of alkalinity of pore liquid in concrete and the resulting de-passivation of steel, making it able to corrode. The significant factors like cement type, w/c ratio, mineral additives, conditions of concrete preparation and site have been reported in many studies. Also the significant influence of ambient temperature and relative humidity, and permeability of concrete has been shown. The relative humidity has been shown as a deciding factor of carbonation rate, which is at a maximum within range between 50 and 70% of relative humidity. Corrosive effect of chlorides is based on their ability to destroy the electrochemical condition of the passive state of reinforcement even under the existing alkalinity in the concrete. Chlorides are reported to cause corrosion of reinforcement in three ways: (i) chlorides are held to pass through the protective oxide film, which exists on the steel surface in a high pH environment, hence, de-passivation the steel. A possible colloidal dispersion of the surface by chlorides, (ii) adsorption of chlorides on the steel surface and thus promoting the hydration of metal ions and facilitating de-passivation and (iii) it is supposed that chlorides are able to compete with hydroxyl ions for the ferrous ions produced by corrosion process. Formatted complex of ferric chloride diffuse away from the steel surface developing the passive layer breakdown. Due to the often common occurrence of carbonation and chloride effects on the reinforced concrete structures in practice, the related principles and information of the resulting corrosion process of reinforcement are interesting. Unfortunately, the data are very limited. It is reported that a reduction in pH in concrete due to its carbonation will increase the severity of the attack in the presence of chlorides [Broomfield, 1992]. According to [Roper and Baweja, 1991] the interactive effects of carbonation and chloride lead to much more rapid corrosion of reinforcement than where both the phenomena act separately. The effect was more pronounced when the w/c ratio was

increased. Chloride ions constitute one of the main factors causing corrosion of reinforcement, chloride ion penetration in concrete is of great concern [Zhao and Li, 2002; Valipour *et al.* 2013], with regard to durability of reinforced concrete structures subjected to chloride ion attack in coastal areas [Ma *et al.* 1999; Wu, Z.; Lian] or due to use of de-icing salt [Neville, 1993]. A common approach to counter chloride ion attack is to decrease the permeability of concrete, characterized by dense microstructure [Otsuki *et al.*, 2000], usually at a low water/binder (W/B) ratio and incorporating mineral admixtures. For this purpose, mineral admixtures mainly play the effect of densification of pore-structures in concrete [Feng, and Xing, 2001], as well as binding chloride ions in concrete [Wang, and Chen, 1997]. The mechanical properties of concrete pavement were studied under the various frost-salt conditions using Capillary Suction of De-icing Chemicals and Freeze-thaw Test Method (CDF method). The test results show that: with the increasing of freeze-thaw cycles, concrete surface damage has a tendency to accelerate. The concrete which is in a 5% concentration chloride snow-thawing agent solution has the greatest impact damage after 150 frost-salt cycles compared with soaking in other different densities (3%, 20%). Mixing appropriate amount of silica fume and high-performance air entraining agent in concrete can effectively improve the resistance of frost-salt scaling. With the frost-salt cycles increase, the concrete strength and the relative dynamic elastic modulus continues to decrease [Li Jun *et al.* 2015].

Recent research on the problems caused by de-icing salt penetration into concrete bridges is reviewed. The author discusses comparative studies of bridges of different ages, the detection of defects, crack repair, concrete repair materials, bridge deck waterproofing, protective coatings and cathodic protection [Gallagher, 1989]. The present study concerns the influence of C_3A in cement on chloride transport in reinforced concrete. Three modified cement was manufactured in the variation of the C_3A content, ranging from 6.0 and 10.5 up to 16.9%. The setting time of fresh concrete was measured immediately after mixing, together with the temperature at the time of initial set. For properties of hardened concrete in the variation in the C_3A , a development of the compressive strength and chloride permeation were measured using mortar specimens. Simultaneously, chloride binding capacity was measured by the water extraction method. To ensure the influence of pore structure on chloride transport, the pore structure was examined by the mercury intrusion porosimetry. As a result, it was found that an increase in the C_3A content resulted in an increase in chloride binding capacity. However, it seemed that increased binding of chlorides is related to the higher ingress of chlorides, despite denser pore structure. It may be attributed to the higher surface chloride, which could increase the gradient of chloride concentration from the surface, thereby leading to the higher level of chloride profiles. Substantially, the benefit of high C_3A in resisting corrosion, arising from removal of free chlorides in the pore solution, would be offset by increased chloride ingress at a given duration, when it comes to the corrosion-free service life [Min Jae Kim *et al.* 2016]. Durability of reinforced concrete structures is impacted by the chloride penetration and susceptibility of the reinforcement to chloride-induced corrosion, when exposed to marine environment or deicing salts. Once the chloride content at the reinforcement reaches a threshold value and enough oxygen and moisture are present, the reinforcement corrosion will be initiated. Quality concrete is able to prevent the embedded reinforcing steel from potential corrosion in many ways, including hydration products of cement which form high alkalinity where the passivated film covering the steel surface remains chemically stable enough to protect the reinforcing steel from corroding [Page and Treadaway, 1982]. However, chloride penetration may result in the accumulation of chloride content at the reinforcement to such a level that the high alkaline environment is destroyed and then the passivated film on the steel surface is disrupted [Townsend *et al.* 1981; Verbeck, 1975]. The corrosion of steel in concrete induced by chloride ion contamination is a major problem [Bamforth *et al.* 1997]. The importance of chloride ions in reinforcement corrosion has led to the concept of a chloride threshold level, namely the chloride content at the depth of steel necessary to initiate corrosion-induced deterioration [Schiessl, and Raupach, 1974]. It is widely perceived that the chloride threshold for corrosion-induced deterioration in steel reinforced concrete is best expressed as the chloride to hydroxyl concentration ratio present in the electrolyte in the concrete pores [Suryavanshi *et al.* 1998; Kayyali and Haque, 1995]. This implies that bound chloride presents a negligible corrosion risk and dissolved hydroxyl ions are the principal inhibitors in concrete [Alonso *et al.* 2000; Neville *et al.* 1995]. Most cases of deterioration in reinforced concrete structures under service conditions are related to corrosion of the reinforcement occurring as a consequence of chloride transport in concrete. The prolonged periods of snowfall in countries with advanced infrastructure and transport systems have rendered the use of de-icing agents to a common occurrence on roads and highway structures. They are necessary in order to maintain a good level of service with respect to the transport systems, thus avoiding traffic jams and disruptions, but also to provide a high level of road safety. Today, chloride-based products, such as rock salt, are the most commonly encountered de-icers as they are easy to apply and store but mostly because they efficiently melt ice at an affordable price [TRB, 1991]. However, their widespread use over a long period has left the construction industry and the engineering community with a grave problem regarding the durability of highway reinforced concrete bridges and multi-storey parking structures [Pullar-Strecker, 2002], due mainly to the fact that they cause corrosion of the reinforcement and steel components [Pullar-Strecker, 2002].

In cold-climate regions, snow and ice control operations are crucial to maintaining highways that endure cold and snowy weather. The growing use of de-icers has raised concerns about their effects on motor vehicles, transportation infrastructure,

and the environment. The deleterious effect of chloride-based de-icers on reinforcing steel bar in concrete structures is well known [Shi *et al.* 2009]. De-icers may also pose detrimental effects on concrete infrastructure through their reactions with cement paste and/or aggregates and thus reduce concrete integrity and strength, which in turn may foster the ingress of moisture, oxygen and other aggressive agents onto the rebar surface and promote rebar corrosion. Large amounts of solid and liquid chemicals (known as de-icers) as well as abrasives are applied onto winter highways to keep them clear of ice and snow. De-icers applied on to highways often contain chlorides because of their cost-effectiveness, including mainly sodium chloride, magnesium chloride, and calcium chloride, sometimes blended with proprietary corrosion inhibitors. The rock salt/sodium chloride is the most commonly used de-icing agent. It was first used to control snow and ice on roadways to improve transportation safety in the 1930s, and became widespread by the 1960s. The salt works by dissolving into precipitation on roadways and lowering the freezing point, thereby melting ice and snow. Eliminating the ice has enormous safety benefits, but depending on the amount of chemicals used, the dissolved salt can have negative effects on the surrounding environment. The melting snow and ice carries de-icing chemicals onto vegetation and into soils along the roadside where they eventually enter local waterways. Elevated salt levels in soils can inhibit the ability of vegetation to absorb both water and nutrients, which can slow plant growth and ultimately affect animal habitats. This degradation also affects the ability of these areas to act as buffers to slow the runoff of other contaminants into the watershed. Once the salt enters freshwater it can build up to concentration levels that further affect aquatic plants and other organisms. Salt deposits along roadways also attract birds, deer, and other animals which increases the chance of animal-vehicle accidents. While the major effect on public drinking water supplies for humans is merely an alteration of taste, high concentrations of sodium in drinking water can lead to increased dietary intake and possibly hypertension. Since salt is corrosive to automobiles, bridge decks, and other roadway infrastructure, de-icing chemicals are often combined with other substances to block corrosion. While eliminating ice is of great benefit to commerce and human safety, these drawbacks must be taken into consideration by communities as they plan for regular maintenance of the concrete infrastructure, as well as the health of the local ecosystem. The costs of maintaining reinforced concrete infrastructure (bridges, tunnels, harbours, parking structures) are increasing due to aging of structures, which are being exposed to aggressive environment. Corrosion of reinforcement due to chloride ingress is the main problem for existing structures in marine and de-icing salt environments [Bertolini *et al.* 2013]. In The Netherlands 5% of motorway bridges, built predominantly between 1960 and 1980, shows cracking and spalling of the concrete cover due to chloride induced corrosion [Gaal, 2004]. This corresponds to 10% of the bridges showing corrosion initiation at an age of 40 years [Polder *et al.* 2012]. Older structures have been built according to older codes, which may not have provided sufficient protection. Moreover, for new infrastructure corrosion cannot be ruled out completely, even with today's emphasis on design for long service life (typically 100 years), either by composition requirements (Eurocodes) or based on service life modelling and performance testing [fib, 2006]. This may be due to various factors, such as unforeseen aggressive loads, e.g. leakage of joints; or to deviations from the intended concrete quality or cover thickness; or to modelling inadequacies [Bertolini *et al.* 2011]. Repair of corrosion damage is possible, but costly, potentially disruptive and not necessarily long lived. A European study has shown that 50% of repairs fail within 10 years [Tilly, 2011]. These results were confirmed by a study in The Netherlands [Visser *et al.* 2012]. In the worst case, this means that after about 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 24 pre-conditioned concrete cubes (100 mm³) such as fully saturated condition and salt ponded with chloride solution for about 160 days. This research will examine the influence of conditioning such as fully saturated condition on the results of chloride absorption at different drill depths (30-40-50 mm) 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/mm²) as in the first case and compressive strength (25-40 N/mm²), 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 160 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 at different drill depths (30-40-50 mm) in concrete cubes with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Twenty four concrete cubes (100 mm³) with grades of concrete ranges from 25-40 N/mm² were prepared and evaluate the chloride absorption under different exposure condition at various drill depths respectively.

3.0 Experimental program

In the present research work, six different mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm³). Three of the mixtures were concrete cubes (100 mm³) with a compressive strength 40 N/mm², 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/mm², 30 N/mm², and 40 N/mm²), 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 mm³) 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/mm² and fine aggregate used was 4.75 mm sieve size down 600 microns for this research work. As concern to impregnation materials, Water based (WB) and Solvent based (SB) impregnate materials were used in this present research work. To avoid criticizing or promoting one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclosed and they will be referred to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

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

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

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

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

4.0 Chloride ingress in concrete cubes

The primary aim of this research was to interpret the effectiveness of wetting and drying pre-conditioned concrete cubes on chloride absorption, which was exposed to different pre-determined conditions such as fully saturated condition was evaluated in control/impregnation concrete cubes for about 160 days salt ponding test in all designed six mixtures type (M1-M6). The pre-conditioned fully saturated condition was achieved in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 31 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 [Zhan *et al.* 2005]. 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 transport mechanism of chloride absorption in concrete cubes during wetting/drying pre-conditioned concrete cubes is evaluated in this research work. The dry-wet pre-condition accelerate the transport process of chloride absorption within a certain distance from the surface, beyond this distance, chloride absorption in the complete immersion specimens migrate more rapidly than those under dry-wet pre-condition [Xu Gang *et al.* 2015]. Especially, in case of absolute dry condition, the penetration rate of chloride ion will be much larger because of advection process than that in diffusion process in mortar with water saturated condition. Moreover, at the surface part of mortar, additional chloride content due to diffusion process can be also confirmed on distribution of chloride content due to advection process during absorption test. Therefore, in order to assess the penetration of chloride ion, effects of both advection and diffusion processes depending on moisture condition of mortar should be considered. The concrete are in a state of flux between saturated and partially saturated conditions as they undergo continuous cycles of wetting and drying. In saturated concrete, dissolved ions enter through diffusion, whereas in partially saturated concrete, ion-containing fluids are absorbed by capillary suction and concentrated by evaporation of water. It was found from the researchers [Hong, and Hooton, 1999] that, the longer drying times increase the rate of chloride ingress. A good relationship exists between the depth of chloride penetration and the square root of the number of cycles. In fact several authors have shown that an effective chloride barrier can be established in pre-conditioned concrete by surface impregnation with a liquid water repellent. However, the question arises frequently as to whether chloride contaminated concrete structures with high moisture content can still be protected from further chloride penetration into the porous structure by surface impregnation. There is a need to determine the efficiency of surface impregnation of chloride-contaminated concrete before any protective treatment applied on the concrete. In the present research work, tests were run to investigate the influence of pre-condition such as 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. The variation of average chloride absorption was compared in pre-conditioned control/impregnation concrete cubes at different time duration such as 31th, 61th, 91th, 121th, and 160th days to determine the effectiveness of impregnation materials (solvent/water) based impregnation material for long time duration. The variation of average chloride absorption in pre-conditioned control/impregnation concrete cubes was recorded at different time duration as represented in Table.3.

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

Mix ID	31 day	61 day	91 day	121 day	160 day	Mix ID	31 day	61 day	91 day	121 day	160 day
M1CC	0.13	0.14	0.30	0.54	1.16	M4CC	0.25	0.26	0.39	0.45	1.31
M1SB	0.07	0.08	0.10	0.13	0.22	M4SB	0.14	0.16	0.21	0.25	0.44
M1WB	0.09	0.09	0.12	0.14	0.28	M4WB	0.15	0.16	0.23	0.29	0.53
M2CC	0.17	0.18	0.27	0.41	1.10	M5CC	0.14	0.16	0.30	0.35	1.03
M2SB	0.07	0.09	0.11	0.24	0.31	M5SB	0.10	0.11	0.19	0.22	0.45
M2WB	0.08	0.10	0.23	0.28	0.59	M5WB	0.10	0.11	0.19	0.23	0.64
M3CC	0.11	0.13	0.23	0.28	0.78	M6CC	0.12	0.14	0.22	0.29	0.74
M3SB	0.08	0.09	0.12	0.14	0.36	M6SB	0.08	0.10	0.18	0.22	0.40
M3WB	0.10	0.12	0.20	0.24	0.43	M6WB	0.10	0.11	0.18	0.23	0.53

The variation of average chloride absorption was compared in pre-conditioned control/impregnation concrete cubes at different time duration such as 31th, 61th, 91th, 121th, and 160th days to determine the effectiveness of impregnation materials

(solvent/water) based impregnation material for long time duration. The average chloride absorption in 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. The variation of chloride concentration in pre-conditioned control/impregnation concrete cubes was interpreted at different drill depths (30-40-50 mm) as represented in Table.4-6.

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

Mix ID	30 mm	40 mm	50 mm	Mix ID	30 mm	40 mm	50 mm
M1CC	0.059	0.056	0.054	M4CC	0.060	0.054	0.052
M1SB	0.054	0.052	0.049	M4SB	0.054	0.052	0.049
M1WB	0.056	0.055	0.053	M4WB	0.056	0.052	0.051
M2CC	0.059	0.056	0.054	M5CC	0.063	0.062	0.061
M2SB	0.054	0.052	0.049	M5SB	0.054	0.051	0.052
M2WB	0.056	0.054	0.052	M5WB	0.056	0.054	0.054
M3CC	0.068	0.066	0.063	M6CC	0.061	0.059	0.056
M3SB	0.061	0.056	0.054	M6SB	0.056	0.052	0.049
M3WB	0.063	0.061	0.059	M6WB	0.059	0.056	0.054

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

Mix ID	(30-40) mm, Incr (%)	(30-50) mm, Incr (%)	(40-50) mm, Incr (%)	Mix ID	(30-40) mm, Incr (%)	(30-50) mm, Incr (%)	(40-50) mm, Incr (%)
M1CC	4.38	8.89	4.71	M4CC	10.47	12.71	2.50
M1SB	4.29	8.67	4.58	M4SB	4.08	8.79	4.91
M1WB	1.88	6.14	4.34	M4WB	8.30	10.19	2.06
M2CC	4.25	8.07	3.99	M5CC	1.80	4.05	2.30
M2SB	4.18	8.64	4.65	M5SB	4.79	4.45	0.04
M2WB	4.59	8.75	4.36	M5WB	4.28	4.32	0.04
M3CC	3.86	7.16	3.43	M6CC	3.84	7.75	4.06
M3SB	7.60	11.54	4.26	M6SB	8.38	12.54	4.54

M3WB	3.73	6.65	3.04	M6WB	3.86	8.04	4.35
------	------	------	------	------	------	------	------

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

Mix ID	30 mm, decr(%)	40 mm, decr(%)	50 mm, decr(%)	Mix ID	30 mm, decr(%)	40 mm, decr(%)	50 mm, decr(%)
M1SB-	91.51	91.59	91.72	M5WB-	88.73	86.48	88.48
M1WB-	95.67	98.17	98.55	M6SB-	92.25	87.90	87.46
M2SB-	91.73	91.80	91.16	M6WB-	96.16	96.14	95.86
M2WB-	96.17	95.84	95.46	M1SB-	95.65	93.30	93.07
M3SB-	89.31	85.83	85.09	M2SB-	95.38	95.79	95.50
M3WB-	92.81	92.94	93.32	M3SB-	96.22	92.35	91.18
M4SB-	90.13	96.56	94.18	M5SB-	95.82	100.23	97.31
M4WB-	94.06	96.34	96.78	M4SB-	95.77	95.27	95.64
M5SB-	84.98	82.39	84.62	M6SB-	95.94	91.43	91.24

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

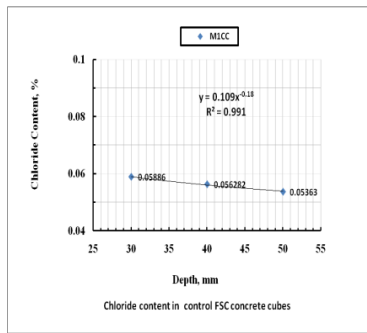


Fig.1a Cl⁻ concentration in mix M1

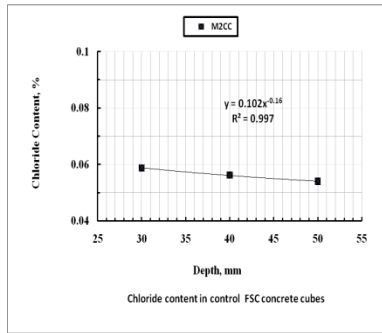


Fig.1b Cl⁻ concentration in mix M2

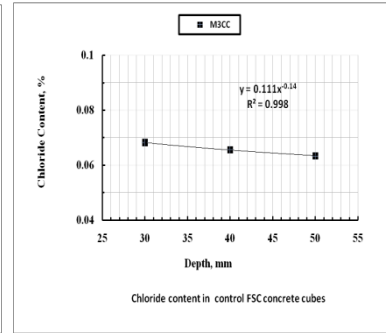


Fig.1c Cl⁻ concentration in mix M3

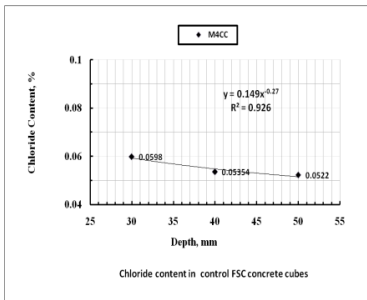


Fig.1d Cl⁻ concentration in mix M4

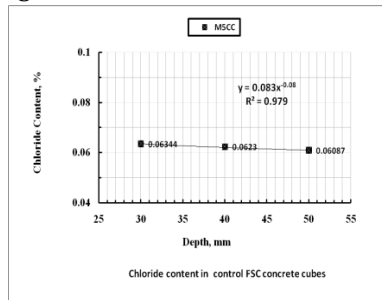


Fig.1e Cl⁻ concentration in mix M5

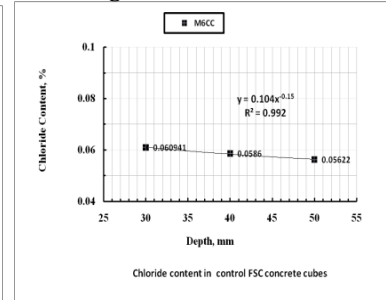


Fig.1f Cl⁻ concentration in mix M6

The average chloride 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. 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. The variation of chloride concentration-drill depth were indicated by power type of equation in the solvent based impregnation PSC cubes at different drill depths (30-40-50 mm) was represented in Fig.2a-2f for different designed mixtures type (M1SB-M6SB).

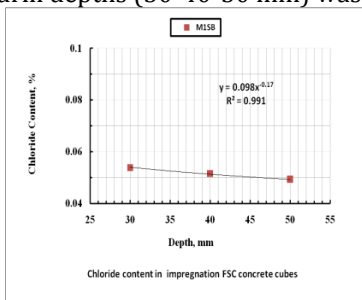


Fig.2a Cl⁻ concentration in mix M1

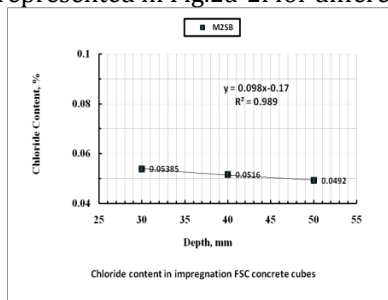


Fig.2b Cl⁻ concentration in mix M2

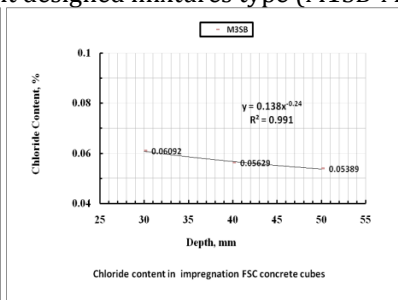


Fig.2c Cl⁻ concentration in mix M3

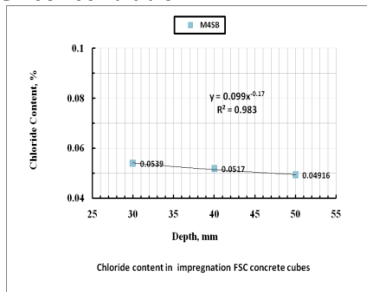


Fig.2d Cl⁻ concentration in mix M4

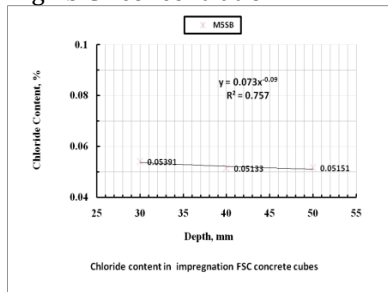


Fig.2e Cl⁻ concentration in mix M5

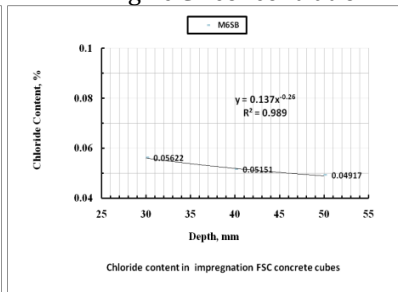


Fig.2f Cl⁻ concentration in mix M6

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

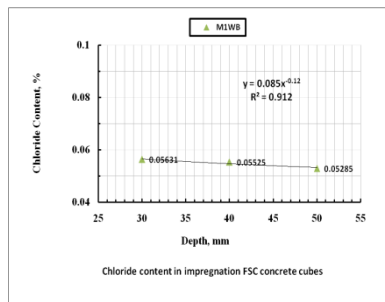


Fig.3a Cl- concentration in mix M1

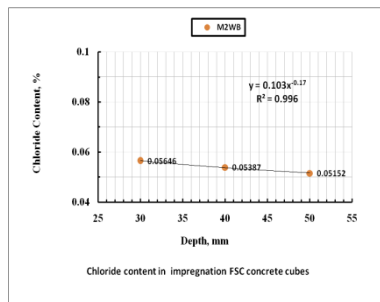


Fig.3b Cl- concentration in mix M2

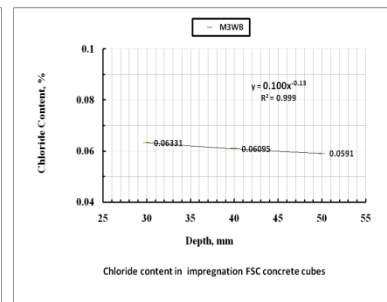


Fig.3c Cl- concentration in mix M3

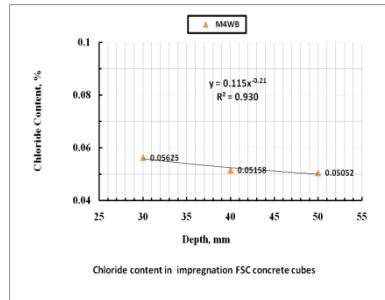


Fig.3d Cl- concentration in mix M4

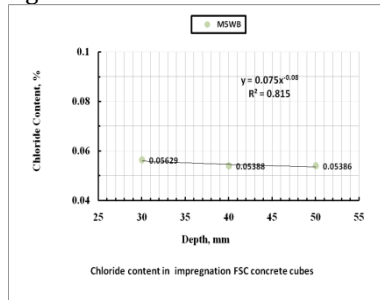


Fig.3e Cl- concentration in mix M5

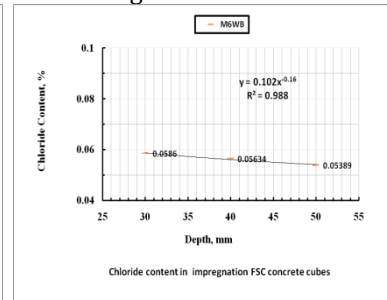


Fig.3f Cl- concentration in mix M6

6.0 Conclusions

- The chloride concentration was found to be decreased in impregnation FSC concrete cubes as when compared to control FSC concrete cubes at different drill depth. It's possible to correlate the chloride concentration- drill depths by power type of equation in designed concrete mixtures type.
- The average chloride absorption in 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

- Arjunan P., (2000), Ph.D. Thesis, *Detailed Characterization of Current North American Portland Cements and Clinkers and The Implications For The Durability of Modern Concrete*, The Graduate School Intercollege Graduate Program In Materials, The Pennsylvania State University, U.S.
- Alonso. C, Andrade. C, Castellote. M, and Castro.P. (2000). *Chloride threshold values to depassivate reinforcing bars embedded in a standardized OPC mortar*, Cem. Concr. Res., 30(7):1047-1055.
- Bouteille, S., Fen-Chong, T., Dierkens, M., Dangla, P., Moral, N., Boulanger, S. (2010). *Penetration of chlorides in hardened concrete during frost salt cycles*. EPJ Web of Conferences, 6, 22017, 8pp.
- Broomfield. J. P. (1992). *Corrosion of steel in concrete* (London: E FN Spon), 28pp.
- Bamforth. P, Price. W.F, and Emerson. M.(1997). *International review of chloride ingress into structural concrete*, Transport Res. Lab., Edinburgh, Scotland, TRL Contractor Rep. 359.
- Bertolini, L., Elsener, B., Pedferri, P., Redaelli, E., Polder, R.B. (2013). *Corrosion of steel in concrete: Prevention, Diagnosis, Repair*, 2nd Edition, Wiley-VCH Verlag GmbH & Co.KGaa, Weinheim, ISBN 3-527-33146-8, 414 pp.
- Bertolini, L., Lollini, F., Redaelli, E. (2011). *Durability design of reinforced concrete Structures*, Institution of Civil Engineers Construction Materials, (CM6), 64:273-282, Erdoğan, T.Y., 2003. *Concrete*. Ankara: METU Press.
- Gallagher. K. A. (1989). *Concrete bridge deterioration: Research into the problem by the TRRL*, construction and Building Materials, Issue 4, 3:184-190.
- Fib. (2006). *Model code for service life design*, fib Bulletin 34, Model Code, 116 pages, ISBN 978-2-88394-074-1.
- Gaal, G.C.M. (2004). *Prediction of deterioration of concrete bridges*, Ph.D. thesis, Delft University Press, Delft, NL.

- [11]. Hong, K, and Hooton, R. D. (1999). *Effects of cyclic chloride exposure on penetration of concrete cover*, Cement and Concrete Research, 29:1379-1386.
- [12]. Jones, M. R, Thomas, M. D. A, Dhir, R. K and Ng, S. L. D. (1996). *Durability of building materials and components*, (London: E FN Spon), 107pp.
- [13]. Kayyali, O. A, and Haque, M. N. (1995). *The Cl-OH ratio in chloride contaminated concrete -a most important criterion*, Mag. Conc. Res., 47:235-242.
- [14]. Li Jun, Gao Pei-Wei, and Liu Hong-Wei. (2015). *Study on the deterioration mechanism of concrete pavement for the de-icing*, The Open Civil Engineering Journal, 9:120-124.
- [15]. Li, B., *Chloride transport in concrete under frost action -An experimental study*. (2009). Master Thesis. TCH. Göteborg, 156p.
- [16]. Min Jae Kim, Ki Beom Kim, and Ki Yong Ann. (2016). *The influence of C₃A content in cement on the chloride transport*, Advances in Materials Science and Engineering, Volume 2016, Article ID 5962821, 8 pages.
- [17]. Neville, A.M., *Properties of Concrete*. (2000). Harlow, England; New York: Prentice Hall/Pearson Education, pp.8, 10, 482-485.
- [18]. Neithalath, N. and Jain, J. 2010. *Relating rapid chloride transport parameters of concretes to microstructural features extracted from electrical impedance*. Cement and Concrete Research, 40:1041-1051.
- [19]. Neville, A. (1995). *Chloride attack of reinforced concrete-an overview*, Mater. Struct, 28:63-73.
- [20]. Page, C. L and Treadaway, K. W. J. (1982). *Aspects of electrochemistry of steel in concrete*, Nature, 297:109-115.
- [21]. Pullar-Strecker, P., *Concrete reinforcement corrosion, from assessment to repair decisions*, 1st edition, Thomas Telford Ltd, London, 2002.
- [22]. Polder, R.B., Peelen, W.H.A., Courage, W.M.G. (2012). *Non-traditional assessment and Maintenance methods for aging concrete structures -Technical and non-technical issues*, Materials and Corrosion, 63(12):1147-1153.
- [23]. Roper H and Baweja D. (1991). *Durability of concrete second international conference* (ed.) V M Malhotra (Detroit, Michigan: American Concrete Institute), p. 295.
- [24]. Schiessl, P, and Raupach, M. (1974). *Influence of concrete composition and microclimate on the critical chloride content in concrete*, in *Corrosion of Reinforcement in Concrete*. C. L. Page, K. W. J. Treadway, and P. B. Bamforth, Eds. London: Elsevier Applied Science, 83-92pp.
- [25]. Suryavanshi, A. K, Scantlebury, J. D, and Lyon, S. B. (1998). *Corrosion of reinforcement steel embedded in high water-cement ratio concrete contaminated with chloride*, Cem. Conc. Comp., 3:263-269.
- [26]. 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.
- [27]. Townsend, H. E, Cleary, H. J, and Allegra, L. (1981). *Breakdown of oxide films in steel exposure to chloride solutions*, NACE Corrosion, 37:384-391.
- [28]. TRB. (1991). *Highway De-icing, Comparing salt and calcium magnesium acetate*, TRB, National Research Council, Washington D.C., Special Report, 235.
- [29]. Tilly, G. P. (2011). *Durability of concrete repairs*. Concrete repairs, M. Grantham, ed., Taylor and Francis, Oxford, U.K.
- [30]. Teychenné, D. C, R E Franklin, H. C, Erntroy. (1988). *Design of normal concrete mixes*, Second edition, BRE.
- [31]. Verbeck, G. J, *Mechanism of corrosion in concrete*, in *Corrosion of Metals in Concrete*, ACI SP-49, 1975.
- [32]. Vladimir Z. V. Ivica. (2003). *Corrosion of reinforcement induced by environment containing chloride and carbon dioxide*, Bull. Mater. Sci., 26(6):605-608. © Indian Academy of Sciences.
- [33]. Visser, J.H.M, 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, Alexander et al. (eds.), Taylor & Francis, London, ISBN 978-0-415-89952-9.
- [34]. 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, 16:289-296.
- [35]. Zhan, H, Wittmann, F. H, and Zhao, T. (2005). *Relation between the silicones profiles in water repellent treated concrete and their effectiveness as a chloride barrier*, Restoration of Buildings and Monuments, 11:35-45.