CHLORIDE SOLUTION ABSORPTION-MOISTURE CONTENT IN PRE-CONDITIONED DCC CUBES

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Abstract: *Deterioration of reinforced concrete is often associated with ingress of aggressive agents from the exterior such that the near-surface concrete quality largely controls durability. The bulk of durability problems concern the corrosion of reinforcing steel rather than deterioration of the concrete fabric itself. The problem is then cast in terms of the adequacy of the protection to steel offered by the concrete cover layer, which is subjected to the action of aggressive agents such as chloride ions or carbon dioxide from the surrounding environment. For concrete structures, durability is generally defined as the capability of maintaining the serviceability over a specified period of time without significant deterioration. In general, design concepts for durability can be divided into prescriptive concepts and performance concepts. Prescriptive concepts are based on material specification from given parameters such as exposure classes and life span of the structure. However, durability is a material performance concept for a structure in a given environment and as such it cannot easily be assessed through intrinsic material properties. Performance concepts, on the other hand, are based on quantitative predictions for durability from exposure conditions and measured material parameters. Therefore, there is a need to quantify the chloride absorption in concrete cubes, which is of most important factor. The present research work was made an attempt to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as dry condition which is salt ponded with chloride solution for about 160 days at 10% Nacl solution. Thus, the objectives of this present research are such as; first, this research will examine the influence of conditioning such as dry condition on the results of chloride absorption performed on concrete cubes with different mixtures proportion. In which slump, and w/c ratio value was vary with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Twenty four concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride absorption under specified exposure condition. It has concluded from the results that, in dry conditioned concrete cubes, the chloride absorption value was increase in all designed mixtures type at longer time duration. Similarly, the average chloride absorption was decrease in solvent/water based impregnation DCC cubes as when compared to control DCC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride absorption was increase in solvent/water based impregnation DCC cubes for lesser compressive strength and constant slump value as when compare to constant higher compressive strength and varied slump value and the chloride absorption was goes on decreases with increased compressive strength and constant slump value. Furthermore it's possible to correlate chloride solution absorption-time duration by linear type of equation for in case of control/impregnation concrete cubes under specified exposure condition.*

Keywords: *Concrete, mixture proportion, grade of concrete, water-cement ratio, slump, chloride absorption, impregnation, solvent/water based impregnate, moisture content*

1.0 Introduction

The reinforced concrete structures are exposed to harsh environments yet is often expected to last with little or no repair or maintenance for long periods of time. To do this, a durable structure needs to be produced. For reinforced concrete bridges, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. This may lead to early repair or premature replacement of the structure. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of the reinforcing steel bar by using relatively impenetrable concrete. The ability of chloride ions to penetrate the concrete must then be known for design as well as quality control purposes. The penetration of the concrete by chloride ions, however, is a slow process. It cannot be determined directly in a time frame that would be useful as a quality control measure. Capillary absorption, hydrostatic pressure, and diffusion are the means by which chloride ions can penetrate concrete. The most familiar method is diffusion, the movement of chloride ions under a concentration gradient. For this to occur the concrete must have a continuous liquid phase and there must be a chloride ion concentration gradient. A second mechanism for chloride ingress is permeation, driven by pressure gradients. If there is an applied hydraulic head on one face of the concrete and chlorides are present, they may permeate into the concrete. A situation where a hydraulic head is maintained on a highway structure is rare, however. A more common transport method is absorption. As a concrete surface is exposed to the environment, it will undergo wetting and drying cycles. When water (possibly containing chlorides) encounters a dry surface, it will be drawn into the pore structure though capillary suction. Absorption is driven by moisture gradients. Typically, the depth of drying is small, however, and this transport mechanism will not, by itself, bring chlorides to the level of the reinforcing steel unless the concrete is of extremely poor quality and the reinforcing steel is shallow. It does serve to quickly bring chlorides to some depth in the concrete and reduce the distance that they must diffuse to reach the rebar [Thomas, *et al*., 1995]. The rate of ingress of chlorides into concrete depends on the pore structure of the concrete, which is affected by factors including materials, construction practices, and age. The penetrability of concrete is obviously related to the pore structure of the cement paste matrix. This will be influenced by the water-cement ratio of the concrete, the inclusion of supplementary cementing materials which serve to subdivide the pore structure [McGrath, 1996], and the degree of hydration of the concrete. The older the concrete, the greater amount of hydration that has occurred and thus the more highly developed will be the pore structure. This is especially true for concrete containing slower reacting supplementary cementing materials such as fly ash that require a longer time to hydrate [Bamforth, 1995]. Another influence on the pore structure is the temperature that is experienced at the time of casting. High-temperature curing accelerates the curing process so that at young concrete ages, a high temperature cured concrete will be more mature and thus have a better resistance to chloride ion penetration than a normally-cured, otherwise identical, concrete at the same at age. However, at later ages when the normally-cured concrete has a chance to hydrate more fully, it will have a lower chloride ion diffusion coefficient than the high-temperature-cured concrete [Cao and Detwiler, 1996]. This finding has been attributed to the coarse initial structure that is developed in the high-temperature-cured concrete due to its initial rapid rate of hydration as well as the possible development of initial internal micro-cracking. The chloride-induced corrosion of the embedded steel has become the most common cause of loss of integrity and failure in concrete structures and infrastructures placed in the marine environment [Pritzl et al. 2014]. Hence, the chloride permeability has been recognized to be a critical intrinsic property of the concrete [Guneyisi et al. 2009], and a lot of research has been conducted to enhance concrete resistance to chloride permeability [Shekarchi et al. 2009].From durability point of view, concrete cover quality plays significant role in blocking of aggressive substance ingress such as chloride ions into the reinforced concrete [Bonavetti, *et al.* 2000]. There are several methods to improve the quality of the concrete cover such as use of supplementary cementitious materials, reduction in water-to-cementitious materials ratio (w/cm), and appropriate initial curing regimes [Ghassemzadeh, *et al*. 2010]. Although it is a very simple and inexpensive procedure, proper initial curing, prior to exposure to marine environment, has an important influence on improving concrete cover quality so that the concrete acting as a fine barrier to the access of aggressive species and accordingly extend the service life of reinforced concrete structures exposed to chloride [Radlinski and Olek 2015]. The objective of curing is considered by the duration of providing concrete with sufficient humidity and appropriate temperature conditions to reduce the loss of moisture to ensure the progress of hydration reactions causing the filling and segmentation of capillary voids by hydrated compounds [Guneyisi *et al*. 2005]. On the contrary, drying of concrete particularly at the concrete surface, caused by a poor curing regime, leads to a restricted hydration and thus higher porosity and permeability in the surface layers which form covers for the reinforcement protections [Khanzadeh-Moradllo, *et al*. 2009]. A proper initial curing is a very simple and inexpensive alternative to improve concrete cover quality and accordingly extend the service life of reinforced concrete structures exposed to aggressive species. A current study investigates the effect of wet curing duration on chloride penetration in plain and blended cement concretes which subjected to tidal exposure condition in south of Iran for 5 years. The results show that wet curing extension preserves concrete against high rate of chloride penetration at early ages and decreases the difference between initial and long-term diffusion coefficients due to improvement of concrete cover quality. But, as the length of exposure period to marine environment increased the effects of initial wet curing became less pronounced. Furthermore, a relationship is developed between wet curing time and diffusion coefficient at early ages and the effect of curing length on time-to-corrosion initiation of concrete is addressed [Mehdi Khanzadeh, *et al*. 2015].

The concrete infrastructures such as bridge decks, parking garages, pre-stressed concrete structures, steel structures, and marine structures may deteriorate when they are exposing to de-icing agents. The de-icing agents can be absorbed into the pores of concrete and can modify the cementitious matrix structure. The interaction between the de-icing agents and the cementitious matrix may result in the deterioration of concrete structures [Jones, 2013]. Physical damage can occur due to a number of processes such as exposure of concrete with a high degree of saturation to freeze-thaw cycles [Li, *et al*. 2012], scaling of concrete surfaces [Jacobsen, *et al*. 1997], crystallization of salt in concrete pores that results in production of an internal stress [Scherer, 1999], and expansive forces as a result of corrosion of reinforcement when a chloride-based de-icing salt is used [Wang, *et al,* 2014]. While the physical attack of de-icing salts has been widely investigated, the chemical reaction between the matrix and the de-icing salts has been investigated often less frequently. The use of de-icing salts can cause damage in cementitious materials even if a concrete does not experience freezing and melting [Marchand, *et al*, 1994]. This may be cause by the formation of Friedel’s salt, Kuzel’s salts [Collepardi, *et al,* 1994], and/or calcium oxychloride, changes in the pore solution properties [Farnam, *et al*, 2014], or changes in the microstructure of hydration products [Pigeon. and Regourd, 1986]. De-icing salt solution, like many external solutions, dissolve calcium hydroxide, causing leaching that leads to an increase in permeability and a reduction of concrete alkalinity [Muethel, 1997]. De-icing salts have different chemical and physical interactions with cementitious materials. The usage of NaCl de-icing salt increases freeze-thaw damage in concrete. This increase in freeze-thaw damage has been explained by the formation of an unexpected phases and the creation of osmotic pressures [Farnam, *et al,* 2014]. Concrete exposed to $CaCl_2$ and $MgCl_2$ de-icing salts exhibited changes in the concrete microstructure. These changes have been accompanied by a severe cracking and deterioration, even if the concrete did not experience any freeze-thaw cycles [Collepardi, *et al.* 1994]. The concrete infrastructures were deteriorating in different regions of the world without satisfying the stipulated service life. Therefore, there is a need to predict service life, which is a major task in the design of concrete infrastructures. In fact, the chloride concentration is a major cause of any early deterioration of reinforced concrete infrastructures. Because of this concrete deterioration, it may lead to cracking, spalling, and delamination of concrete cover, reduce load carrying capacity, and cross sectional area of reinforcement. Whereas, in the cold countries region it may lead to pre-mature deterioration of concrete infrastructures due to the application of de-icing salts on roads and concrete infrastructures. In fact, the bridge-decks were simultaneously expose to wetting-drying condition and, it has subjected to direct impact as well as repeated loading by continuous flow of traffic. Almost all the concrete structures were working under dry conditions. Even though most of the researchers have dedicated their efforts to study transport of chloride in concrete under wet conditions with limited publication data on dry concrete. In fact major diffusion models are applicable to the concrete structures that remains fully wet condition at all the times. They underestimate the amount of chloride penetrating a concrete structure, which is subject to wetting/drying for in case of splash/tidal zones of structures exposed to marine environment/highway structures exposed to de-icing salts. An experimental study is performing on the influence of water absorption in ordered to evaluate the effectiveness of durability of concrete by researchers [Zhang, and Zong, 2014]. It is confirm from results that the most significant effect of sorptivity on long-term chloride ingress to concrete is its effect on surface chloride content. It has decided to consider an effective amount of absorption when modelling chloride ingress under cyclic wetting and drying conditions. It is also possible from research work to produce higher surface chloride contents (0·29–0·62%) that would lower the time to corrosion using the cover depths recommended in the code. Its confirmed long time ago that [Zhao, *et al,* 2008], young and uncontaminated concrete can be surface impregnated by liquid silanes in order to provide a protective barrier against ingress of chloride ions and moderate chloride content allows to apply surface impregnation of silanes successfully as a protective measure as well as to avoid further chloride ingress. It is also confirm that, higher chloride concentration and low water-cement ratio make surface impregnation more difficult. It has confirmed that deep impregnation of the concrete surfaces with water repellent agent's forms an efficient and long lasting barrier with respect to chloride ingress [Wittmann, *et al,* 2006]. In this way, service life of reinforced concrete structures erected in an aggressive environment such as marine climate can be significantly extend for long time duration. It is cite by investigators [Brandt, 2009] that, the corrosion of steel reinforcement induces expansion in volume due to corrosion products, cracking, and spalling of concrete from the reinforcement. Furthermore, chloride concentration together with frost attack can cause another form of concrete deterioration such as concrete scaling. As confirmed that [Hall, 1994], the pore space of concrete is not fully saturated. If the moisture content inside concrete is less than the saturation moisture content, it may be absorb by the concrete through large capillary forces arising from the contact of the very small pores of the concrete with the liquid phase. Therefore, determination of the moisture retention function is necessary for the modelling of moisture flow and transport of chlorides in concrete. In fact, there has been very little effort to establish relationships for the capillary pressure as a function of degree of saturation for concrete. The chloride diffusion can only occur for a continuous water phase is present in the capillary pores of concrete in order to provide a path for diffusion. Therefore, in the case of dry concrete, the diffusion process is lessen since the number of water filled pores decreases and that decreases the continuity of pore solution [Saetta, *et al*, 1993]. Under dry conditions, the effective diffusion coefficient is no longer a constant but a function of saturation [Garboczi, 1990] and therefore cannot be describe by simple diffusion theory. This is noted by researchers that [Vriesl, *et al,* 1998], hydrophobic treatment makes a concrete surface absorb lesser water and chloride. It is confirm that, the corrosion, which had already started before application of the hydrophobic agent was not influence by hydrophobic treatment. No effect of hydrophobic treatment is measure on carbonation. It has also shown that, long term absorption tests with drinking and salt water showed significantly less absorption by hydrophobic concrete. Furthermore, its highlighted by researchers [Jacob, *et al,* 1998] that, hydrophobic agents could be effective for at least 10 years when applied to a 6-month-old concrete façade provide that, the concrete of the substrate needs to have a minimum age of 28 days or more. In addition to that, some conditions must be avoid when applying hydrophobic agents such as high or low temperatures, high air humidity and high construction element humidity. Therefore there is a need to investigate about the rapid deterioration of concrete structures due to reinforcement corrosion has now become a day-day growing problem in recent years at all over the world in so many cold countries region. Considerable resources were use to repair and rehabilitate deteriorated structures around the world. In addition to that, consequently, an extensive research [McCarter, 1996] has been conduct to evaluate the effectiveness of sealers and other concrete surface treatment materials. Among the various procedures used to protect concrete surfaces, hydrophobic impregnations are the least harmful to essential concrete appearance, mainly inhibiting capillary water absorption of the concrete.

2.0 Research Objectives

The most significant corrosive constituents in coastal salt are sodium chloride, calcium chloride, and magnesium chloride, which are the same salts (chlorides) used for de-icing. Salts influence corrosion rates in several ways. First, salt is hygroscopic, meaning it absorbs water from the air. The importance of chloride absorption 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 is made an attempt to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures design for in case of pre-conditioned dry concrete cubes which is salt ponded with chloride solution for about 160 days. Thus the objectives of this present research is to examine the influence of conditioning such as dry condition on the results of chloride absorption performed on concrete cubes with different mixtures proportion. In which slump, and w/c ratio value varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with constant slump as in the second case. Twenty four concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride absorption under specified exposure condition.

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 type 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 designate as M1, M2, and M3. Another Three of the mixtures type 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 designate as M4, M5, and M6. The overall details of the mixture proportions were represent in Table.1-2. Twelve concrete cubes of size (100 mm^3) were casted for each mixture and overall Seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crush 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 could not be disclose and they could be refer to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material, which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

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

Mix ID	Comp/mean target	Slump	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10	Mix 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 ID	Comp/mean target stg, N/mm^2	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10mm	Mix 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

3.1 Salt ponding test

The chloride absorption tests were conduct out on concrete cubes of size (100 mm^3), and tested in accordance to [BS: 1881-122]. They were water cured before subjected to the salt ponding test for about160 days. Before testing, the concrete specimens were oven dried to constant mass at 105±5^{0}C for 72±2 hours and then stored in airtight containers before subjected to testing. The chloride absorption test with 10% Nacl solution is carried out on pre-conditioned dry concrete cubes of size (100 mm^3) which is fully submerged and noted their weights at each time interval for about 160 days. For chloride absorption test, totally 72 concrete cubes were casted, out of which 36 control concrete cubes, and 18 solvent based concrete cubes as well as 18 water based concrete cubes. The chloride penetration and moisture diffusion are two important transport processes for studying the long-term durability of concrete. The chloride penetration and moisture transfer in concrete are consider as two coupled transport processes. The interaction between moisture diffusion and chloride penetration in concrete affects the durability of reinforced concrete structures. The corrosion of the reinforcement in concrete takes place when the chloride content of concrete near steel bar has reached a threshold value and the moisture content in concrete is sufficiently high. Therefore, moisture and chloride ions are two necessary conditions for the onset of corrosion of rebar in concrete. The diffusion of chloride and moisture in concrete were study for two different situations such as fully and partially saturated condition. In fist instance, the concrete is fully saturated and dominant mechanisms for both chloride diffusion and moisture diffusion is the concentration gradient of chloride. In turn, the chloride concentration gradient drives not only the chloride penetration but also the moisture movement in the concrete. In another instance, the concrete is partially saturated, and the moisture concentration gradient (in addition to the chloride concentration gradient) results in the moisture penetration as well as the chloride diffusion. In this case, both concentration gradients are driving forces. Thus in the present research work chloride absorption test was carried out on pre-conditioned concrete cubes (100 mm^3) such as dry condition concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent/water based impregnation material respectively. In turn it's possible to interpret the effectiveness of impregnation (SB/WB) concrete cubes with control DCC concrete cubes for designed six mixtures type [Balakrishna, *et al*, 2018].

4.0 Discussion about Results

Corrosion of steel reinforcement in concrete is the most common problem affecting the durability of reinforced concrete structures. Chloride-induced corrosion is one of the main mechanisms of deterioration affecting the long-term performance of such structures [Cement and Concrete Association of Australia, 1989]. Concrete provides physical and chemical protection to the reinforcing steel from penetrating chlorides which may cause steel de-passivation leading to increased risk of steel corrosion. The chloride resistance depends on the permeability of the concrete and the thickness of cover to the reinforcement. The integrity of the concrete cover under service load, in terms of cracking and crack width, also influences the resistance to penetrating chlorides. Corrosion of steel reinforcement is an electrochemical process. Hence electrochemical properties of concrete, such as resistivity, are important inherent properties affecting the corrosion rate of reinforcing steel. [Metha, 1988] reconfirmed from a review of case studies that it is the permeability of concrete, rather than its chemistry, which is the key to overall durability. The causes of high permeability are not limited to poor concrete proportion but poor concreting practice, such as incomplete mixing, inadequate consolidation and curing after placement, insufficient cover to reinforcing steel, and badly constructed joints. In service, concrete may exhibit various forms of cracking for reasons such as settlement, premature loading, overloads, and repeated impact. To obtain long-term durability of concrete marine structures, the control of concrete cracking in service through proper mix proportioning and concreting practice is of as much importance as the control of concrete permeability. Chloride induced reinforcement corrosion is the main durability problem for concrete structures in a marine environment. If the chlorides reach the reinforcement steel, it will de-passivate and start to corrode in presence of air and water. Since the corrosion products have a larger volume than the initial components, concrete stresses are induced, leading to spalling and degradation of the concrete structures. The most common transport mechanisms determining the chloride penetration velocity are diffusion (chloride gradients in standing water), capillary suction (chlorides transported with moving water) and permeation (chlorides transported with water under pressure). All three transport mechanisms may occur simultaneously. The chloride penetration in concrete is largest for the part of a structure in the tidal zone. This is experimentally noted and is explained as the combined action of capillary suction and diffusion. The chloride containing sea water is penetrating the concrete by capillary suction in the wetting period. Because capillary suction is a fast transport mechanism, the chloride ions are penetrating to a relatively high penetration depth. In the drying period, the water is evaporating from the concrete, leaving the chloride ions in the concrete. From there, the ions will diffuse into the concrete. In the following wetting period, new chlorides will be penetrating into the concrete together with the sea water by capillary suction. The continuously increasing amount of chloride ions at the penetration depth by capillary suction is creating a high concentration gradient over the remaining concrete. From this a high diffusion velocity is created. In this way, the penetration velocity of the chloride ions in the concrete is higher for the tidal zone than for example for the permanently immersed zone. Thus in the present research work chloride absorption test was carried out on pre-conditioned concrete cubes ($100\ mm^3$) such as dry conditioned concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent/water based impregnation material respectively. It's observed from results that (DCC concrete cubes) for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). In addition, it is observe from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M4-M6). The average chloride absorption for in case of DCC concrete cubes is increased at 61th, 91th, 121th, and 160th days as when compared to 31th day in control concrete cubes, solvent based impregnation concrete cubes (SB), and water based impregnation concrete cubes (WB) in mixtures type (M1-M6) respectively. In the same way, the chloride absorption was decrease in solvent-based impregnation concrete cubes as when compared to water based impregnation concrete cubes. It's possible to correlate mass gain (chloride absorption)-time relationship by linear expression for in case of control/impregnation such as solvent based (SB) and water based (WB) DCC concrete cubes at different time intervals (31, 61, 91, 121, and 160) days respectively as representing in the (Figs.1a-1f, 2a-2f, and 3a-3f).

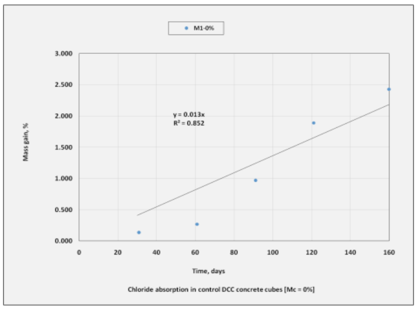


Fig.1a Mass gain-time in Mix type 1

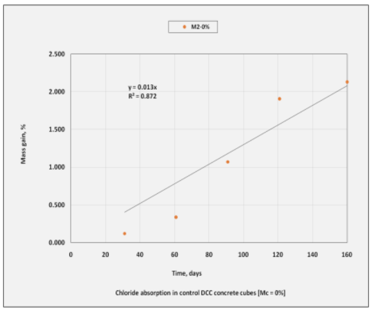


Fig.1b Mass gain-time in Mix type 2

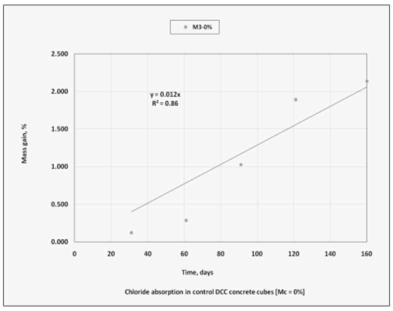


Fig.1c Mass gain-time in Mix type 3

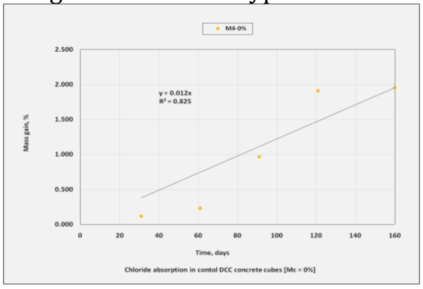


Fig.1d Mass gain-time in Mix type 4

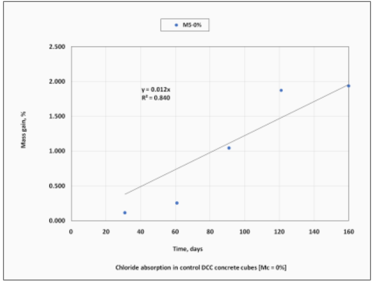


Fig.1e Mass gain-time in Mix type 5

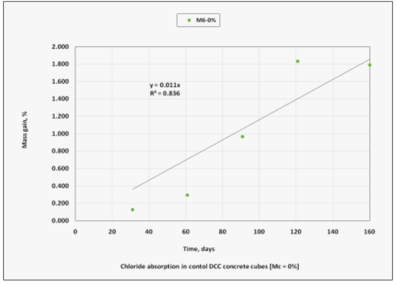


Fig.1f Mass gain-time in Mix type 6

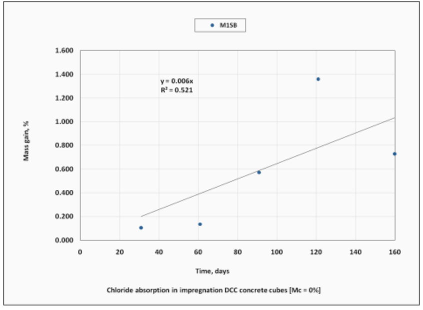


Fig.2a Mass gain-time in Mix type 1

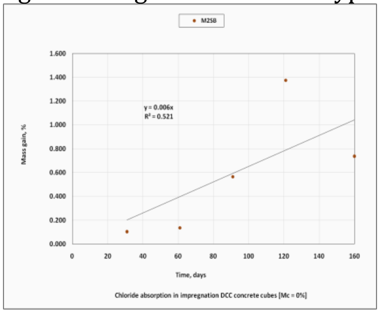


Fig.2b Mass gain-time in Mix type 2

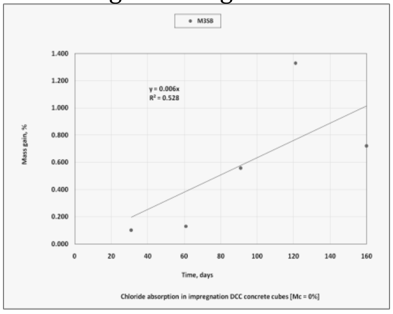


Fig.2c Mass gain-time in Mix type 3

From this relationship between chloride absorption and time, it's possible to determine chloride absorption at any specified time duration in the concrete mixes design for in the case of control/impregnation concrete cubes.

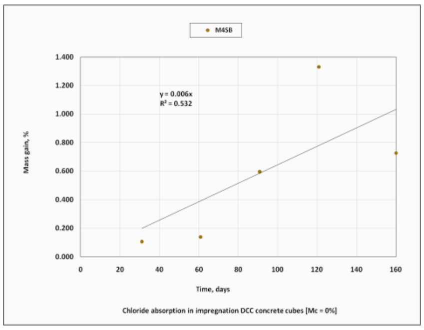


Fig.2d Mass gain-time in Mix type 4

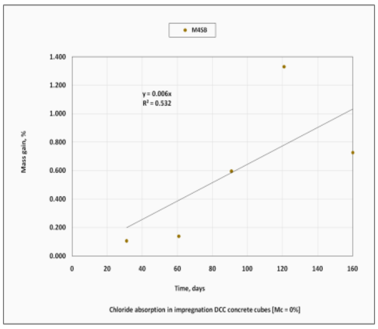


Fig.2e Mass gain-time in Mix type 5

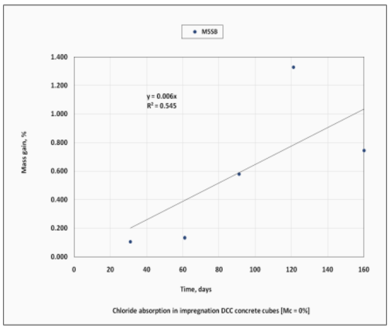


Fig.2f Mass gain-time in Mix type 6

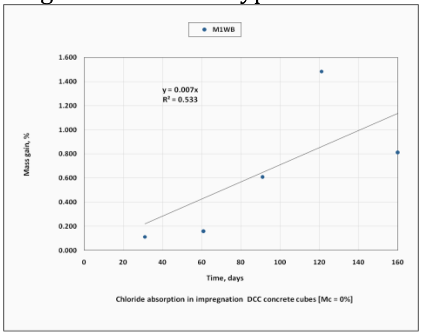


Fig.3aMass gain-time in Mix type1

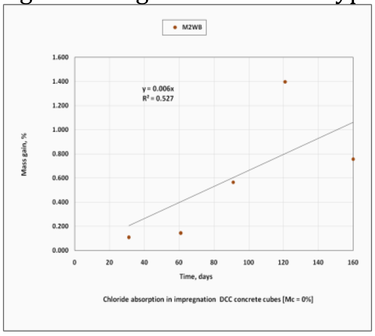


Fig.3bMass gain-time in Mix type2

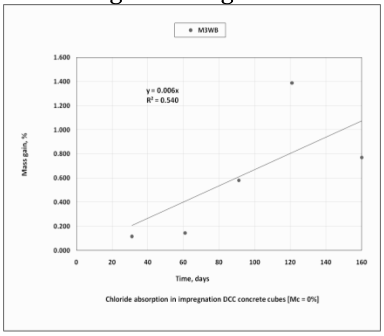


Fig.3cMass gain-time in Mix type3

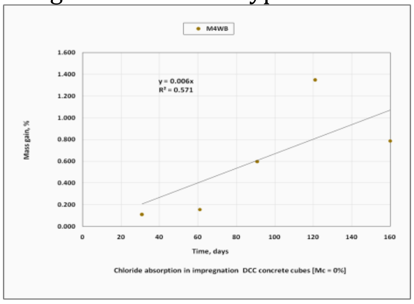


Fig.3d Mass gain-time in Mix type 4

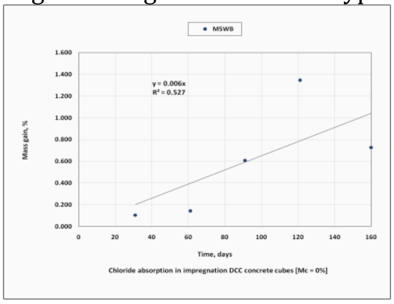


Fig.3e Mass gain-time in Mix type 5

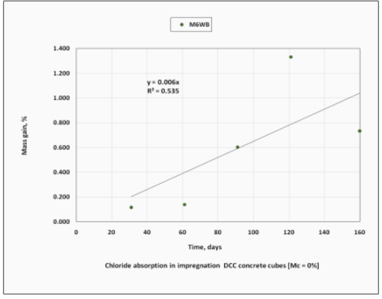
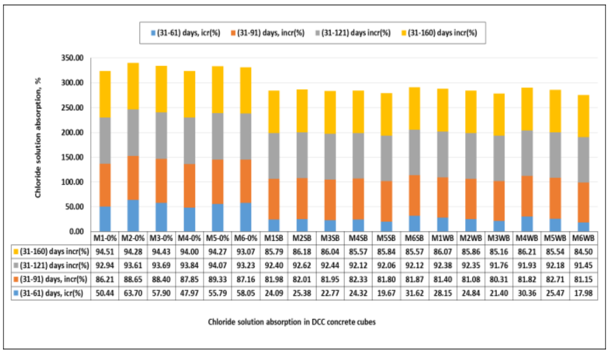
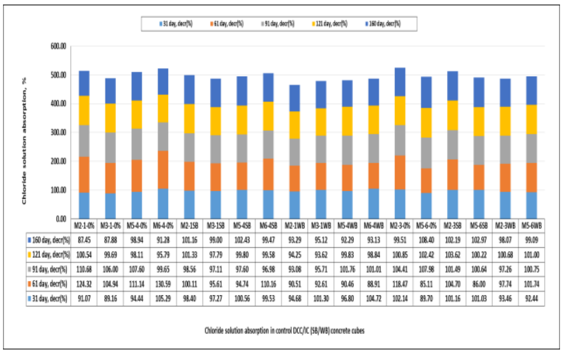


Fig.3f Mass gain-time in Mix type 6

It's possible to interpret the variation (increase) in chloride absorption-time for in case of control (M1-0%-M6-0%)/impregnation (M1SB-M6SB and M1WB-M6WB) DCC cubes at time interval (31 day) as when compared to longer time intervals (61, 91, 121, and 160) days respectively as representing in the (Figs.4a). The chloride solution absorption was observed to decrease for in case of control concrete cube as when compared to different designed concrete mixtures type at different time duration (31, 61, 91, 121, and 160 days) as indicated in the Fig.4b.



	M1-0%	M2-0%	M3-0%	M4-0%	M5-0%	M6-0%	M1SB	M2SB	M3SB	M4SB	M5SB	M6SB	M1WB	M2WB	M3WB	M4WB	M5WB	M6WB
(31-160) days incr(%)	94.51	94.28	94.43	94.00	94.27	93.07	85.79	86.18	86.04	85.57	85.84	85.57	86.07	85.86	85.16	86.21	85.54	84.50
(31-121) days incr(%)	92.94	93.61	93.69	93.84	94.07	93.23	92.40	92.62	92.44	92.12	92.06	92.12	92.38	92.35	91.76	91.93	92.18	91.45
(31-91) days, incr(%)	86.21	88.65	88.40	87.85	89.33	87.16	81.98	82.01	81.95	82.33	81.80	81.87	81.40	81.08	80.31	81.82	82.71	81.15
(31-61) days, icr(%)	50.44	63.70	57.90	47.97	55.79	58.05	24.09	25.38	22.77	24.32	19.67	31.62	28.15	24.84	21.40	30.36	25.47	17.98

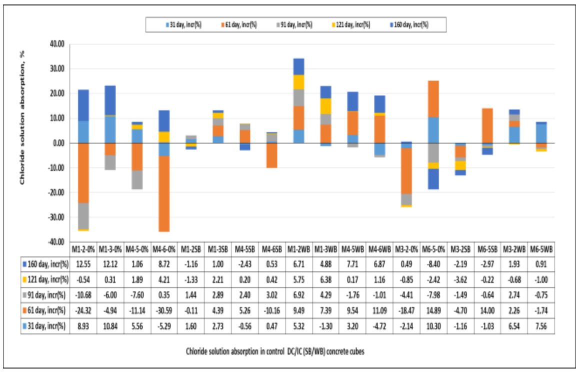


	M2-1-0%	M3-1-0%	M5-4-0%	M6-4-0%	M2-1SB	M3-1SB	M5-4SB	M6-4SB	M2-1WB	M3-1WB	M5-4WB	M6-4WB	M2-3-0%	M5-6-0%	M2-3SB	M5-6SB	M2-3WB	M5-6WB
160 day, decr(%)	87.45	87.88	98.94	91.28	101.16	99.00	102.43	99.47	93.29	95.12	92.29	93.13	99.51	108.40	102.19	102.97	98.07	99.09
121 day, decr(%)	100.54	99.69	98.11	95.79	101.33	97.79	99.80	99.58	94.25	93.62	99.83	98.84	100.85	102.42	103.62	100.22	100.68	101.00
91 day, decr(%)	110.68	106.00	107.60	99.65	98.56	97.11	97.60	96.98	93.08	95.71	101.76	101.01	104.41	107.98	101.49	100.64	97.26	100.75
61 day, decr(%)	124.32	104.94	111.14	130.59	100.11	95.61	94.74	110.16	90.51	92.61	90.46	88.91	118.47	85.11	104.70	86.00	97.74	101.74
31 day, decr(%)	91.07	89.16	94.44	105.29	98.40	97.27	100.56	99.53	94.68	101.30	96.80	104.72	102.14	89.70	101.16	101.03	93.46	92.44

Fig.4a Cl$^-$ absorption in control/IC cubes

Fig.4b Cl$^-$ absorption in IC cubes (SB/WB)

It's also confirmed from the results that, the chloride solution absorption was predominantly increased in control concrete cubes (M1-0%-M6-0%) as when compared to different designed control concrete cubes and impregnation concrete cubes (M1SB-M6SB and M1WB-M6WB) respectively. Chloride solution absorption (increase) was interpreted at time duration (31, 61, 91,121, and 160) days as representing in the Fig.4c.



	M1-2-0%	M1-3-0%	M4-5-0%	M4-6-0%	M1-2SB	M1-3SB	M4-5SB	M4-6SB	M1-2WB	M1-3WB	M4-5WB	M4-6WB	M3-2-0%	M6-5-0%	M3-2SB	M6-5SB	M3-2WB	M6-5WB
160 day, incr(%)	12.55	12.12	1.06	8.72	-1.16	1.00	-2.43	0.53	6.71	4.88	7.71	6.87	0.49	-8.40	-2.19	-2.97	1.93	0.91
121 day, incr(%)	-0.54	0.31	1.89	4.21	-1.33	2.21	0.20	0.42	5.75	6.38	0.17	1.16	-0.85	-2.42	-3.62	-0.22	-0.68	-1.00
91 day, incr(%)	-10.68	-6.00	-7.60	0.35	1.44	2.89	2.40	3.02	6.92	4.29	-1.76	-1.01	-4.41	-7.98	-1.49	-0.64	2.74	-0.75
61 day, incr(%)	-24.32	-4.94	-11.14	-30.59	-0.11	4.39	5.26	-10.16	9.49	7.39	9.54	11.09	-18.47	14.89	-4.70	14.00	2.26	-1.74
31 day, incr(%)	8.93	10.84	5.56	-5.29	1.60	2.73	-0.56	0.47	5.32	-1.30	3.20	-4.72	-2.14	10.30	-1.16	-1.03	6.54	7.56

Fig.4c Cl$^-$ absorption in control/IC cubes

5.0 Conclusions

Thus in the present research work chloride absorption test was carried out on pre-conditioned concrete cubes such as dry conditioned concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent based and water based impregnation material respectively. In turn to interpret the effectiveness of impregnation concrete cubes with control cubes for six mixtures type under pre-conditioned concrete cubes with constant compressive strength (40 N/mm^2), and varied slump (0-10, 10-30, 60-180) mm in one case as well as varied compressive strength (25-30-40 N/mm^2) with constant slump (10-30) mm in second case.

- It's possible to correlate chloride absorption-time relationship by linear type of equation for in case of control/impregnation DCC cubes at different time intervals (31, 61, 91, 121, and 160) days.
- It is observed from results that, the chloride absorption in DCC control concrete cubes was increased as when compared to the chloride absorption in DCC (SB) and DCC (WB) impregnation concrete cubes.
- From this chloride absorption-time relationship, it's possible to interpret the chloride absorption at any specified time duration in order to characterize the designed concrete mixtures type.

6.0 References

[1].Bamforth, P.B. (1995). *Improving the Durability of Concrete Using Mineral Admixtures*, Concrete Durability in the Arabian Gulf, pp. 1-26.
[2].Bonavetti, V., Donza, H., Rahhal, V., and Irassar, E. (2000). *Influence of initial curing on the properties of concrete containing limestone blended cement*. Journal of Cement and Concrete Research, V.30, pp.703-708.
[3].Brandt, A. M. (2009). *Cement based composites: materials, mechanical properties and performance*,
Taylor and Francis.
[4].Balakrishna. M. N, Fouad Mohammad, Robert Evans, and Rahman. M. M. (2018). *Evaluation of chloride absorption in pre-conditioned concrete cubes*, MJCE, V.30, No.2, No.173-192.
[5].Cao, Y., and Detwiler, R.J. (1996). *Backscatter Electron Imaging of Cement Pastes Cured at Elevated Temperatures*, Cement and Concrete Research, V.25, No.3, pp.627-638.
[6].*Durable Concrete Structures*. (1989). Cement & Concrete Association of Australia
[7].Collepardi. M, Coppola. L, and Pistolesi. C. (1994). *Durability of concrete structures exposed to $CaCl_2$ based de-icing salts*, in: V.M. Malhotra (Ed.), Durab. Concr. ACI SP-145, 3rd CANMET/ACI Int. Conf, 107-120pp.
[8].Farnam. Y, Bentz. D, Sakulich. A , Flynn. D, and Weiss. J. (2014). *Measuring freeze and thaw damage in mortars containing De-icing salt using a low-temperature longitudinal guarded comparative calorimeter and acoustic emission*, Adv. Civ. Eng. Mater. V.3, pp.316–337.
[9].Guneyisi, E., Gesoglu, M., Ozturan, T., and Ozbay, E. (2009). *Estimation of chloride permeability of concretes by empirical modeling*: Considering effects of cement type, curing condition and age. Journal of Construction and Building Materials, V.23, pp.469-481.
[10].Ghassemzadeh, F., Shekarchi, M., Sajedi, S., Mohebbi, M. J. and Khanzadeh-Moradllo, M. (2011). *Performance of repair concretes in marine environments*. In Proceedings of the annual conference canadian society for civil Engineering pp.1654-1664, Ottawa, Canada.

[11].Guneyisi, E., Ozturan, T., and Gesoglu, M. (2005). *A study on reinforcement corrosion and related properties of plain and blended cement concretes under different curing conditions*. Journal of Cement and Concrete Composites, V.27, pp.449-461.
[12].Garboczi, E.J. (1990). *Permeability, diffusivity, and micro structural parameters*: A Critical review, Cement and Concrete Research, V.20, pp.591-601.
[13].Hall, C. (1994). *Barrier performance of concrete*: A review of fluid transport theory, Materials and Structures, V.27, pp.291-306.
[14].Jones. W, Farnam. Y, Imbrock. P, Sprio. J, Villani. C, and Olek. J. (2013). *An overview of joint deterioration in concrete pavement*: Mechanisms, solution properties, and sealers.
[15].Jacobsen. S, Sœther. D, and Sellevold. E. (1997). *Frost testing of high strength concrete: Frost/salt scaling at different cooling rates*, Mater. Struct, V.30, pp. 33–42.
[16].Jacob. T, and Hermann. K .(1998). *Protection of concrete surfaces*: hydrophobic impregnations. Construction Technology's. (March) 18–23 (only available in Spanish).
[17].Li. W, Pour-Ghaz. M, Castro. J, and Weiss. J. (2012). *Water absorption and critical degree of saturation relating to freeze-thaw damage in concrete pavement joints*, J. Mater. Civ. Eng, V.24, pp.299–307.
[18].McGrath. P. (1996). *Development of Test Methods for Predicting Chloride Penetration into High Performance Concrete*, Ph.D. Thesis, Department of Civil Engineering, University of Toronto.
[19].Mehdi Khanzadeh-Moradllo, Mohammad H. Meshkini, Ehsan Eslamdoost, Seyedhamed Sadati, Mohammad Shekarchi. (2015) *Effect of Wet Curing Duration on Long-Term Performance of Concrete in Tidal Zone of Marine Environment*, International Journal of Concrete Structures and Materials, Issue 4, V.9, pp.487–498. |
[20].Mehta P K *Durability of Concrete Exposed to Marine Environment*-A Fresh Look. (1988). Proc, Second Int. Conf. on Concrete in Marine Environment, SP-109, St. Andrews by-the-Sea, Canada.
[21].Marchand. J, Sellevold. E. J, and Pigeon. M. (1994). *TheDe-icer Salt Scaling Deterioration of Concrete* - An Overview, in: Malhotra, V.M (Ed.), Third Int. Conf. Durab. Concr., Nice, France, pp.1-46.
[22].Muethel. R. W. (1997). *Investigation of calcium hydroxide depletion as a cause of concrete pavement deterioration*.
[23].McCarter. W. J. (1996). *Assessing the protective qualities of treated, and untreated concrete surfaces under cyclic wetting and drying*. Building Environ, V.31, No.6, pp.551–556.
[24].Pigeon. M, and Regourd.M. (1986). *The effects of freeze-thaw cycles on the microstructure of hydration products*, Durab. Build. Mater, V.4, pp.1–19.
[25].Pritzl, M. D., Tabatabai, H., and Ghorbanpoor, A. (2014). *Laboratory evaluation of select methods of corrosion prevention in reinforced concrete bridges*. International Journal of Concrete Structures and Materials, V.8, No.3, pp.201-212.
[26].Radlinski, M., and Olek, J. (2015). *Effects of curing conditions on the properties of ternary (ordinary portland cement/fly ash/silica fume) concrete*. ACI Materials Journal, V.112, No.1, pp.49–58.
[27].Shekarchi, M., Rafiee, A., and Layssi, H. (2009). *Long-term chloride diffusion in silica fumes concrete in harsh marine climates*. Journal of Cement and Concrete Composites, V.31, No.10, pp.769-775.
[28].Scherer. G. (1999). *Crystallization in pores*, Cem. Concr. Res, V.29, pp.1347-1358.
[29].Saetta, A.V., Scotta, R.V. and Vitaliani, R.V. (1993). *Analysis of chloride diffusion into partially saturated concrete*, ACI Materials journal, 90-M47.
[30].Thomas, M.D.A., Pantazopoulou, S.J., and Martin-Perez, B. (1995). *Service Life Modelling of Reinforced Concrete Structures Exposed to Chlorides*-A Literature Review, prepared for the Ministry of Transportation, Ontario, at the University of Toronto.
[31].Teychenné, D. C, Franklin. R. E, Erntroy. H. C. (1988). *Design of normal concrete mixes*, Second edition, BRE.
[32].Vriesl. J. de, Polde. R. B, and Borsje. H. (1998). Durability of hydrophobic treatment of concrete, Water repellent treatment of building materials, Proceedings of Hydrophobe ll, ZLirich, Aedificatio Publishers, pp.77-90.
[33].Wang. Z, Zeng. Q, Wang. L, Yao. Y, and Li. K. (2014). *Corrosion of rebar in concrete under cyclic freeze–thaw and Chloride salt action*, Constr. Build. Mater. V.53, pp.40–47.
[34].Wittmann. F. H, Zhao. T. J, Zhan. H, and Xian. Y.(2006). *Establishment of an effective chloride barrier in reinforced concrete structures by means of water repellent agents*, Proc. Int. Workshop on life cycle management of coastal concrete Structures, Nagaoka University, Japan, H. Yokota and T. Shimomura, editors, pp.201-208.
[35].Zhang. S. P, and Zong. L. (2014). *Evaluation of Relationship between Water Absorption and Durability of concrete Materials*, Advances in materials science and Engineering, Article ID 650373.
[36].Zhao. T, Zhu. G , F. H. Wittmann. F. H, and Li. W. (2008). *On surface impregnation of chloride contaminated cement based materials*, Hydrophobe V, 5th International conference on water repellent treatment of building materials Aedificatio Publishers, pp.311-324.