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Influence of moisture content on chloride absorption in concrete cubes

Balakrishna MN[1✉], **Fouad Mohamad**[2], **Robert Evans**[2], **Rahman MM**[2]

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

✉**Correspondence author**
School of Architecture, Design and the Built Environment, Research scholar, Nottingham Trent University,
Nottingham, NG1 4FQ, UK
Email: N0413461@my.ntu.ac.uk

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ABSTRACT

Concrete structures deteriorate in their operating environment under the combined action of harsh environmental conditions and external loading. Although the applied load can lead to a certain degradation of the structure, the main long-term deterioration mechanism involves moisture movement and the transport of chlorides within concrete. In order to build durable and reliable structures, it is necessary to be able to accurately predict the movement of moisture and chlorides within concrete. The exposure of concrete infrastructures to chloride ions is the primary cause of premature corrosion of steel reinforcement. The intrusion of chloride ions, present in de-icing salts into reinforced concrete can cause steel corrosion if oxygen and moisture are also available to sustain the reaction. In fact that, the chlorides dissolved in water can also permeate through sound, concrete/reach the steel reinforcement through cracks. 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 partially saturated condition (Mc = 2%) 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 partially 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 partially saturated 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 PSC cubes as when compared to control PSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride absorption was increase in solvent/water based impregnation PSC 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.

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

1. INTRODUCTION

Concrete structures constitute a large and important part of the built environment, but they can severely deteriorate and lose functionality if exposed to aggressive substances such as chloride ions. Deterioration will induce loss in bearing capacity and can ultimately lead to structural collapse. Thus, controlling the ingress rate of chloride ions is an important aspect of the maintenance of concrete structures since the ingress of chloride ions impose high safety risks to the end users (motorists driving on a concrete bridge).Chloride ions will initiate corrosion of embedded reinforcement bars if the ion concentration is sufficiently high. For a concrete structure subjected to constant loading, corrosion will yield higher tensile stresses in the reinforcement bars since the corrosion process reduces the cross sectional area of reinforcement bars. Additionally, the corrosion product will create tensile stresses in the concrete which may lead to spalling of the concrete cover, thereby making the reinforcement bars exposed to the ambient environment. Typical sources of chloride ions are de-icing salts put on roads in winter times and salt dissolved in sea water. The dissolved ions will through different transport mechanisms migrate inwards from the surface of the concrete structure to the embedded reinforcement bars. Hence, it becomes important to predict chloride ion ingress and to understand the parameters that govern the ingress mechanisms because such predictions and understanding allow for a time estimate of possible corrosion initiation. In addition, chloride ingress interacts with moisture transport; therefore, the moisture conditions need to be considered as well for improved time prediction. Transport mechanisms related to moisture and chloride transport in concrete. Comprehensive literature on this subject can be found in the work by [Cerný and Rovnaníková, 2002] concrete specific and in the classical work by [Bird *et al*. 2007] (generic mass transport). First, a brief introduction to the composition of concrete is provided for completeness. Comprehensive literature on this topic can be found in the work by [Mehta and Monteiro, 2006]. For saturated 1conditions, pressure gradients are the main driving forces for moisture transport. For unsaturated conditions, moisture exists simultaneously in two phases 2 as liquid and as vapour. The driving forces for the liquid phase are pressure gradients in addition to capillary forces. For the vapour phase, diffusion and convection are the two main transport mechanisms. It may be difficult to distinguish between the above listed transports mechanisms in an experimental environment; depending on the degrees of moisture saturation, these mechanisms often act in combination with each other. Moisture diffusivity of unsaturated concrete was early on expressed by [Bažant and Najjar, 1972] as a non-linear function of pore humidity and their proposed analytical model was in the same work calibrated with experimental data. [Xi *et al*., 1994] later extended this model to include moisture capacity as a function of water-cement ratio, curing time, temperature and type of cement as the derivative of the adsorption isotherm. [Vanderheijden *et al*., 2007] did experimental work on the effect of temperature on moisture transport and [Poyet, 2009] did the corresponding numerical modelling. Chlorides are solved only in the liquid phase of moisture, not in the vapour phase. This phenomenon makes the transport of chloride ions intrinsically coupled to the transport of moisture. The three main transport processes are diffusion, convection and migration. As the ions are electrically charged, they will move with electric currents, a phenomenon commonly referred to as migration. As with moisture, the various transport processes can be difficult to differentiate between, and it is common to apply a constitutive model assumed to capture all different transport types combined as done in this work. [Tang and Nilsson, 1993] proposed a method for evaluating the chloride binding capacity of concrete and suggested that the relationship between free and bound chlorides could be described by the Freundlich isotherm. In [Tang and Nilsson, 1992], the same authors established a relationship between the diffusivity and pore size distribution of hardened cement paste. [Xi and Bažant, 1999] modelled chloride ingress in saturated concrete whereas [Delagrave *et al*., 1997] and [Halamickova *et al*., 1995] studied the influence of ITZ on chloride diffusivity. [Johannesson, 2003] developed theoretical transport models of chloride ions and moisture in concrete which were numerically evaluated using FEM. [Wang *et al*., 2005] modelled chloride ingress from a saline environment, Koniorczyk and Wojciechowski, 2009] modelled the influence of salt on the moisture isotherm and concluded that salt has great influence on moisture capacity. [Li *et al*., 2011] computed effective chloride diffusivities using two- and three dimensional heterogeneous models of concrete and concluded that the aggregate shape has small influence on the diffusivity. The coupled action of chloride ion and moisture transports has been studied and modelled by several authors including [Halamickova *et al.,* 1995]; [Ababneh et al., 2003]; [Cerný, 2004]; [Puatatsananon and Saouma, 2005]; [Suwito *et al*., 2006] and [Baroghel-Bouny et al., 2011]. Concrete structures typically have steel reinforcement embedded to take over tensile stresses. In order to activate the steel under tension, the concrete surface layer cracks. When intact, the concrete cover delays the onset of steel corrosion by creating an alkaline environment [Poursaee, and Hansson, 2007] and preventing ingress of deleterious materials [Ahmad, 2003]. Ingress is typically limited by surface densification [Song *et al*., 2008]. Surface density is enhanced by curing [Bouwmeester, and Schlangen, 2008]. Carbon dioxide is a typical agent that can affect the steel through de-alkalinisation of the surrounding concrete matrix, called carbonation [Parrott, 1992]. Carbonation can make the surface less susceptible to the ingress of water, particularly when using ordinary Portland cement [Chi *et al*., 2002]. However, upon using high slag containing cement (CEM III/B), the surface becomes more open of structure [De Ceukelaire, and Van Nieuwenburg, 1993] due to limited alkaline buffer in the slag-based matrix and carbonation of calcium silicate hydrate (CSH). A direct relation was found between carbonation depth and capillary absorption [Carvajal *et al.,* 2009]. Further related to the reduction of water absorption is the limitation of deterioration mechanisms [Basheer *et al*., 2001]. The main material formed in the cementitious matrix upon carbonation is carbonates, and further enhancement of the sealing function should occur through promotion of additional carbonate depositions [De Rooij *et al.,* 2013]. Enhanced carbonate formation potential can be built in by application of a bacteria-based agent to mortar or concrete [Jonkers, 2007]. Carbonates can be formed from the microbial metabolic conversion of an organic carbon source [Jonkers, 2010]. Limitation of freeze–thaw salt scaling damage was found for surface application of a bacteria-based agent in liquid form to concrete surfaces [Wiktor and Jonkers, 2015]. Regain of water-tightness of cracked mortar was found from incorporation of a solid bacteria-based additive or healing agent at the mixing stage [Mors and Jonkers, 2016]. Where negligible influence was found for mortar strength development and high sealing capacity of cracks upon immersion in water, the effect on the water transport properties of intact mortar or concrete was not determined.

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 citing 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.

Research Objectives

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 partially saturated conditioned 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 partially saturated condition on the results of chloride absorption performed in 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.

2. 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. Twenty two concrete cubes of size (100 mm^3) 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.The variation of chloride absorption in the control (M1-2%-M6-2%)/solvent based impregnation (M1SB-M6SB) and water based impregnation (M1WB-M6WB) concrete cubes were represent as shown in the Table 3-4.

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

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

Table 3 Cl$^-$ absorption in control/solvent based impregnation concrete cubes (Mc = 2%)

Mix ID	31 day	61 day	91 day	121 day	160 day	Mix ID	31 day	61 day	91 day	121 day	160 day
M1-2%	0.015	0.123	0.374	0.506	1.002	M1SB	0.011	0.123	0.199	0.209	0.556
M2-2%	0.011	0.096	0.195	0.205	0.387	M2SB	0.010	0.093	0.142	0.147	0.227
M3-2%	0.012	0.115	0.298	0.301	0.690	M3SB	0.011	0.110	0.185	0.192	0.485
M4-2%	0.010	0.094	0.187	0.204	0.283	M4SB	0.010	0.081	0.141	0.143	0.215
M5-2%	0.013	0.125	0.202	0.212	0.664	M5SB	0.011	0.108	0.182	0.187	0.430
M6-2%	0.011	0.093	0.159	0.170	0.258	M6SB	0.010	0.036	0.129	0.136	0.210

Table 4 Cl$^-$ absorption in control/water based impregnation concrete cubes (Mc = 2%)

Mix ID	31 day	61 day	91 day	121 day	160 day	Mix ID	31 day	61 day	91 day	121 day	160 day
M1-2%	0.0086	0.0092	0.0148	0.3317	1.1095	M1WB	0.0087	0.0090	0.0097	0.1530	0.5723
M2-2%	0.0076	0.0085	0.0101	0.0904	0.4304	M2WB	0.0076	0.0084	0.0092	0.0912	0.2527
M3-2%	0.0080	0.0087	0.0137	0.2089	0.7407	M3WB	0.0080	0.0087	0.0095	0.1108	0.5206
M4-2%	0.0076	0.0082	0.0091	0.0685	0.3127	M4WB	0.0073	0.0083	0.0088	0.0529	0.2415
M5-2%	0.0078	0.0081	0.0102	0.1778	0.6818	M5WB	0.0076	0.0082	0.0093	0.0793	0.4655
M6-2%	0.0076	0.0080	0.0086	0.0633	0.2707	M6WB	0.0071	0.0075	0.0080	0.0384	0.2324

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 partially saturated conditioned 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 24 concrete cubes were casted, out of which 12 control concrete cubes, and 6 solvent based concrete cubes as well as 6 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 partially saturated condition concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent/water based impregnation material respectively.

3. DISCUSSION ABOUT RESULTS

The service life prediction has emerged, over the last few years, as a major task in the design of concrete structures. The main long-term concrete deterioration mechanism involves moisture movement and the transport of dissolved harmful chemical species within concrete. In particular, the ingress of chlorides is a major cause of early deterioration of reinforced concrete structures. Although chloride ions in concrete do not directly cause severe damage to the concrete, they initiate and contribute to the corrosion of rebar in the structures when the chloride concentration at the surface of the rebar reaches a threshold level. The formation of rust is associated with large volume expansions which may result in cracking, spalling and delamination of the concrete cover. In addition, severe corrosion reduces the load-carrying capacity of structures by reducing the cross sectional area of reinforcement. In cold countries, the use of de-icing salt on roads and bridges in winter causes a premature deterioration of structures. Typically, bridge decks are exposed to cyclic wetting and drying conditions, and are subject to direct impact and repeated loading by traffic. These conditions, combined with salt applications, create a severe environment for the concrete. One of the worst types of environmental exposure conditions leading to the premature degradation of structures is the case of concrete that is subject to repeated drying and wetting cycles. Although a very large number of concrete structures do operate under unsaturated conditions, most researchers in the concrete community have devoted their efforts to study transport of chloride in concrete under saturated conditions with little published data on the case of unsaturated concrete. Moisture movement coupled with transport of chlorides in concrete is one of the main causes of deterioration of concrete structures. The main properties and transport mechanisms affecting moisture movement and chloride ions transport include permeability, capillary absorption, and diffusion. Concrete is a porous material and when the pores inside concrete are filled with water it is referred to as a saturated concrete. When the pores are occupied by both water and gas it is called unsaturated concrete. The movement of moisture and associated transport of dissolved chlorides depend on the saturation level of concrete. The driving potential for moisture movement in both saturated and unsaturated concrete is a pressure gradient. Thus in the present research work chloride absorption test was carried out on pre-conditioned concrete cubes (100 mm^3) such as partially saturated 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 (PSC concrete cubes) for higher compressive strength and varied slump value, the chloride absorption (M1-2%-M6-2%) was found to be slightly higher in magnitude as when compared to solvent based impregnation concrete cubes for in case of mixtures type (M1SB-M6SB). In addition, it is observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly lower as when compared to higher compressive strength for in case of mixtures type (M4-2%-M6-2%). The average chloride absorption for in case of PSC 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 the designed mixtures type 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 interpret mass gain (chloride absorption)-time for in case of control/impregnation PSC cubes at different time intervals (31, 61, 91, 121, and 160) days respectively as representing in the (Figs.1a-f). 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. The chloride solution absorption was observed to lesser in magnitude at short time duration (31days) as when compared to longer time duration (160 days).

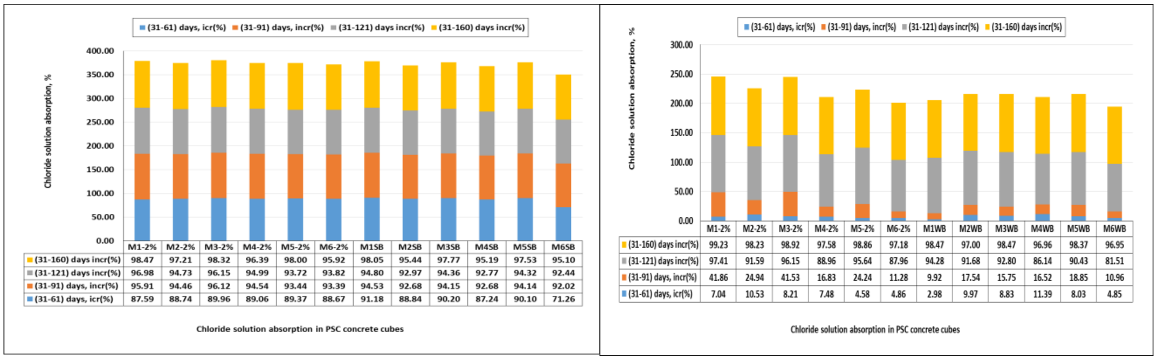
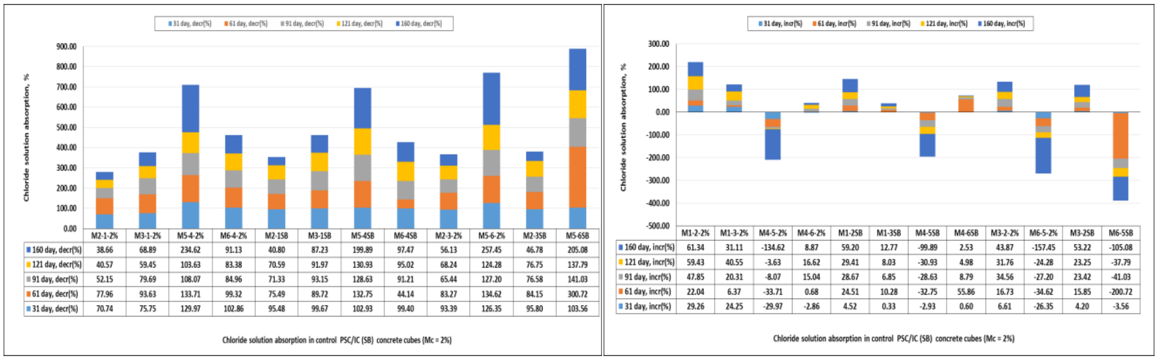


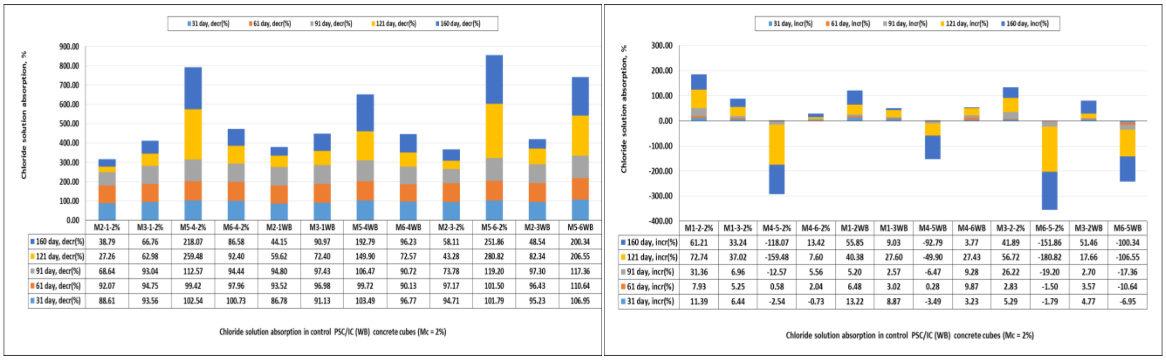
Figure 1 a) Cl$^-$ absorption in (Mc = 2%) control/IC cubes (SB) b) Cl$^-$ absorption in (Mc = 2%) control/ IC cubes (WB)

The chloride solution absorption (decrease) was interpreted at time duration 31, 61, 91, 121, and 160 days for in case of control (M2-1-2%, M3-1-2%, M5-4-2%, M6-4-2%, M2-3-2%, and M5-6-2%)/impregnation (M2-1SB, M3-1SB, M5-4SB, M6-4SB, M2-3SB, and M5-6SB) concrete cubes as representing in the Fig.1c. It's also possible to compared the chloride solution absorption (increase) in impregnation concrete cubes ((M1-2SB, M1-3SB, M4-M5SB, M4-6SB, M3-2SB, and M6-5SB) as against control concrete cubes (M1-2-2%, M1-3-2%, M4-5-2%, M4-6-2%, M3-2-2%, and M6-5-2%) as shown in the Fig.1d.



c) Cl$^-$ absorption in (Mc = 2%) control/IC cubes (SB) d) Cl$^-$ absorption in (Mc = 2%) control/IC cubes (SB)

The chloride solution absorption (decrease) was interpreted at time duration 31, 61, 91, 121, and 160 days for in case of control (M2-1-2%, M3-1-2%, M5-4-2%, M6-4-2%, M2-3-2%, and M5-6-2%)/impregnation (M2-1WB, M3-1WB, M5-4WB, M6-4WB, M2-3WB, and M5-6WB) concrete cubes as representing in the Fig.1e. It's also possible to compared the chloride solution absorption (increase) in impregnation concrete cubes ((M1-2WB, M1-3WB, M4-M5WB, M4-6WB, M3-2WB, and M6-5WB) as against control concrete cubes (M1-2-2%, M1-3-2%, M4-5-2%, M4-6-2%, M3-2-2%, and M6-5-2%) as shown in the Fig.1f.



	M2-1-2%	M3-1-2%	M5-4-2%	M6-4-2%	M2-1WB	M3-1WB	M5-4WB	M6-4WB	M2-3-2%	M5-6-2%	M2-3WB	M5-6WB
160 day, decr(%)	38.79	66.76	218.07	86.58	44.15	90.97	192.79	96.23	58.11	251.86	48.54	200.34
121 day, decr(%)	27.26	62.98	259.48	92.40	59.62	72.40	149.90	72.57	43.28	280.82	82.34	206.55
91 day, decr(%)	68.64	93.04	112.57	94.44	94.80	97.43	106.47	90.72	73.78	119.20	97.30	117.36
61 day, decr(%)	92.07	94.75	99.42	97.96	93.52	96.98	99.72	90.13	97.17	101.50	96.43	110.64
31 day, decr(%)	88.61	93.56	102.54	100.73	86.78	91.13	103.49	96.77	94.71	101.79	95.23	106.95

	M1-2-2%	M1-3-2%	M4-5-2%	M4-6-2%	M1-2WB	M1-3WB	M4-5WB	M4-6WB	M3-2-2%	M6-5-2%	M3-2WB	M6-5WB
160 day, incr(%)	61.21	33.24	-118.07	13.42	55.85	9.03	-92.79	3.77	41.89	-151.86	51.46	-100.34
121 day, incr(%)	72.74	37.02	-159.48	7.60	40.38	27.60	-49.90	27.43	56.72	-180.82	17.66	-106.55
91 day, incr(%)	31.36	6.96	-12.57	5.56	5.20	2.57	-6.47	9.28	26.22	-19.20	2.70	-17.36
61 day, incr(%)	7.93	5.25	0.58	2.04	6.48	3.02	0.28	9.87	2.83	-1.50	3.57	-10.64
31 day, incr(%)	11.39	6.44	-2.54	-0.73	13.22	8.87	-3.49	3.23	5.29	-1.79	4.77	-6.95

e) Cl^- absorption in (Mc = 2%) control/IC cubes (WB)

f) Cl^- absorption in (Mc = 2%) control IC cubes (WB)

4. CONCLUSIONS

Thus in the present research work chloride absorption test was carried out on 24 pre-conditioned concrete cubes such as partially saturated 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 in case of designed pre-conditioned concrete cubes.

It's possible to interpret variations of chloride absorption-time for in case of control/impregnation PSC cubes at different time intervals (31, 61, 91, 121, and 160) days.

Chloride absorption in PSC control concrete cubes was increased as when compared to the chloride absorption in PSC (SB) and PSC (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.

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