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Determination of chloride diffusion coefficient in pre-conditioned concrete slabs

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ABSTRACT

The damaging effect of de-icing chemicals and various exposure conditions such as dry/partially/fully saturated condition on concrete slabs was investigate. Chemicals used in the snow and ice control operations (also known as de-icers) may cause corrosion damage to the transportation infrastructure such as reinforced or pre-stressed concrete structures and steel bridges. The time needed by the chloride ions to reach the rebar depends on the mechanism of intrusion, an external concentration of the chlorides, and the microstructure of the concrete. In fact, when the concrete structure was fully saturated, in which the chloride penetrated in to the concrete structure by diffusion mechanism. However, in partially saturated concrete structure, the chloride may have penetrated into the concrete structure by absorption. The chloride diffusion coefficient is an indication of the capacity of any type of concrete to resist chloride penetration and is use to predict the service life of reinforced concrete structures. In fact, the Diffusion occurs because of concentration gradients. The importance of chloride diffusion coefficient as a durability-based material property has received greater attention only after the revelation that chloride-induced corrosion is the major problem for concrete durability. Therefore, there is a need to quantify the chloride diffusion coefficient in concrete, which is of paramount importance. The present research work made an attempt to interpret the concrete chloride diffusion coefficient in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete slabs such as dry/fully/partially 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 dry/fully/partially saturated condition on the results of chloride diffusion coefficient performed on concrete slabs 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. Eighteen concrete slabs (450x450x100) mm with Grades of concrete ranges from 25 to 40 N/mm^2 were prepared and evaluate the chloride diffusion coefficient under different exposure condition. It is conclude from the results that, in dry/saturated conditioned concrete slabs, chloride diffusion coefficient was increase in all designed mixtures type at lesser drill depth as when compare to higher drill depth. Similarly, average chloride diffusion coefficient was decrease in solvent based and water based impregnation DCC/PSC/FSC concrete slabs as when compare to control DCC/PSC/FSC concrete slabs for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride diffusion coefficient was increased in solvent/water based impregnation DCC/PSC/FSC concrete slabs for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride diffusion coefficient was going on decreases with increased compressive strength and constant slump value.

Keywords: Concrete, Mixture proportion, Grade of concrete, pre-conditioning, Slump, Water-cement ratio, chloride diffusion, chloride diffusion coefficient

1. INTRODUCTION

The chloride-induced corrosion of the steel reinforcement is identifying as the main cause of deterioration of different types of concrete structures such as bridges, parking garages, and offshore structure. The sources of chlorides are the seawater and de-icing salts used during winter. The corrosion of the steel reinforcement leads to concrete fracture through cracking, delamination and spalling of the concrete cover, reduction of concrete and reinforcement cross sections, loss of bond between the reinforcement and concrete, and reduction in strength and ductility. As a result, the safety and serviceability of concrete structures are reducing. The de-icers can affect concrete both physically and chemically. Physical effects are typically manifests as cracking and salt scaling. Several mechanisms have been propose to explain the phenomenon of salt scaling, including thermal shock, precipitation and growth of salt crystals, osmotic pressure, and glue spalling. Chemical effects can result from reactions involving cement hydration products, aggregates, or reinforcing steel. Reactions caused by de-icer ions include the leaching of calcium hydroxide from the paste, the decalcification of calcium silicate hydrate (C-S-H), the conversion of C-S-H to magnesium silicate hydrate (M-S-H), and the formation of brucite, complex salts, and oxychlorides. The alkali-silica reaction and alkali-carbonate reaction can be initiate and accelerated by alkalis from de-icers. Accumulation of critical concentrations of chloride ions approximately the steel can initiate corrosion.

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 expose 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. Most diffusion models in the published literature are applicable to concrete structures that remain fully saturated at all times. They underestimate the amount of chloride penetrating a structure subjected to wetting and drying cycles, as is the case for the splash and tidal zones of structures exposed to marine environments or for highway structures exposed to de-icing salts. Chloride profiles in these structures depend strongly on moisture fluctuation in the concrete cover.

In general, the pore space of concrete is not fully saturated [1]. When the moisture content inside concrete is less than the saturation moisture content, water 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. This is an important mechanism of fluid invasion in concrete in most practical situations. Under unsaturated conditions, the water flux and subsequently the transport of dissolved chloride ions in response to a specified potential gradient is strongly dependent on the saturation of the material. The equilibrium state of water in an unsaturated porous material is characterize by its capillary pressure-degree of saturation function (also known as moisture retention function). Therefore, determination of the moisture retention function is necessary for the modelling of moisture flow and transport of chlorides in concrete. There has been very little effort to establish relationships for the capillary pressure as a function of degree of saturation for concrete. Chloride diffusion can only occur if a continuous water phase is present in the capillary pores of concrete to provide a path for diffusion. Therefore, in the case of unsaturated concrete the diffusion process is hinder since the number of water filled pores decreases and that decreases the continuity of pore solution [2]. Under unsaturated conditions, the effective diffusion coefficient is no longer a constant but a function of saturation [3] and therefore cannot be describe by simple diffusion theories that are typically use in the present literature. Dependence of the diffusion coefficient on the degree of saturation is essential for determining the moisture flow and transport of chlorides in unsaturated concrete, in addition to the basic physical properties of concrete (porosity, density, saturated hydraulic conductivity and moisture retention function). Up to now, relatively few authors have focused on the effect of water saturation upon the diffusion coefficient in unsaturated porous materials, despite the fact that this is an essential component needed to model the transport of ions under unsaturated conditions. There is no direct experimental method found in the concrete literature to determine the dependence of the diffusion coefficient on the degree of saturation of concrete. The complexity of the microstructure of concrete makes the theoretical and experimental investigation of its transport properties a great challenge. Depending on the mix design, preparation and environmental exposure, the material properties can be highly variable. The movement of moisture and the transport of chloride ions depend on a large number of factors such as porosity, pore size distribution, connectivity, and tortuosity.

The chloride-induced corrosion of reinforcement is a major problem for concrete durability in a salt-laden environment. For a concrete with negligible amount of initial chloride inherited at the construction stage, the gradual build-up of the required amount of chloride to initiate corrosion of reinforcement takes place predominantly through diffusion of chloride ions from external sources under a concentration gradient. Consequently, diffusion of chloride ions in concrete has received a great deal of interest. Most of the researchers have modelled the chloride ingress by Fick’s law of diffusion, advocating its general applicability to concrete. It appears that [4] was first calculated meaningfully the diffusion coefficient from laboratory tests for various cement paste mixes using Fick's second law of diffusion and concluded that chloride penetration proceeds by ionic diffusion. Researcher [5] studied the diffusion of chloride ions into concrete from seawater. The results showed that porosity and permeability, which increase with w/c ratio, affect the diffusion only in the exterior layers while in the interior, chloride binding and ion exchange affected diffusion. The lower diffusion in blended cements was attribute to the lesser amount of calcium hydroxide, which means a lesser capacity for ion exchange and therefore lesser penetration of chlorides. The tri-calcium aluminate (C_3A) was seen to have no significant effect on chloride diffusion if its percentage was less than 8.6%.The study of diffusion through hardened cement pastes of various compositions received considerable attention [6]. Increase in diffusion rate with increased w/c is noted. It has concluded that [7] sulphate-resisting cement performs poorly against corrosion and diffusion of chlorides.

The reinforced concrete structures form the basis for most construction in civil engineering. However, a considerable number of reinforced concrete structures cannot achieve its design service life because of premature durability problems. Many factors influence the durability of a structure, including chloride ingress, carbonation resulting from penetrating carbon dioxide, and moisture transport. Extensive research has shown that chloride ingress in concrete is one of the most significant processes that can seriously impair the long-term durability of RC structures [8].Many studies have focused on Fick’s second law of diffusion as the basis for the description of chloride transport in concrete, assuming that diffusion is the dominant transport mechanism. However, obtaining a sound analytical solution can be difficult in practical engineering of complicated structures. Therefore, development of more effective methods for predicting chloride concentration in concrete structures is necessary. The transport phenomenon associated with the movement of chloride ions in structures exposed to salt-laden environment is attribute mostly to diffusion of chloride ions into a porous concrete under a concentration gradient. Chloride diffusion coefficient of a concrete, which depends upon the pore structure of the concrete, characterizes this flow under a given concentration of chloride exposure and is consider as a characteristic property of a hardened concrete. Thus, greater emphasis now being placed on the durability of concrete and the need for on-site characterization of concrete for durability, there is an increasing dependence on the measurement of the permeation properties of concrete. An important factor that influences permeation measurements is the moisture state of the concrete prior to testing. Moisture gradients are known to exist in exposed concretes therefore; all laboratory tests are generally carry out after preconditioning. An extensive effort has been direct in the present research work towards improving concrete properties by pre-conditioning such as dry/fully/partially saturated condition and interpret the chloride diffusion coefficient with/without impregnation in ordered to characterize different designed mixtures type.

2. RESEARCH OBJECTIVES

The importance of chloride diffusion coefficient 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. This present research work is made an attempt to interpret the concrete chloride diffusion coefficient in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete slabs such as dry/fully/partially saturated condition and 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/fully/partially saturated condition on the results of chloride diffusion coefficient performed on concrete slabs 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. Eighteen concrete slabs (450x450x100) mm with Grades of concrete ranges from 25 to 40 N/mm^2 were prepared and evaluate the chloride diffusion coefficient under different exposure condition.

3. EXPERIMENTAL PROGRAM

In the present research work, six different mixtures type were prepared in total as per BRE, 1988 [9] code standards with a concrete slabs of size (450x450x100) mm. Thus totally 18 concrete slabs of size (450mm x 450mm x 100mm) were fabricated with different six mixtures type (M1-M6). Out of which three mixtures type with constant compressive strength (40 N/mm^2) and varied slump (0-10, 10-30, and 60-180 mm) were design as one group (M1-M3). In second group (M4-M6), rest of three mixtures type were designed as with different compressive strength (25 N/mm^2, 30 N/mm^2, and 40 N/mm^2), and constant slump (10-30 mm). Actually the mixture ingredients quantities were found to be more or less same/equivalent that is why, the mixture proportions were adopted in dry conditioned concrete slabs (DCC) as mixture type (M1=M2), (M3=M5), and (M4=M6) for in case of partially saturated (PSC) as well as fully saturated conditioned concrete (FSC) slabs. As concern to DCC concrete slabs, the control/impregnation concrete slabs were represent as (M1CS, M2CS) with solvent based/water based concrete slabs as (M1S1, M2S3) and (M1S2, M2S4). For in case of PSC concrete slabs, the control/impregnation concrete slabs were represent as (M3CS, M5CS) with solvent based/water based concrete slabs as (M3S5, M5S7) and (M3S6, M5S8). With reference to FSC concrete slabs, the control/impregnation concrete slabs were represent as (M4CS, M6CS) with solvent based/water based concrete slabs as (M4S9, M6S11) and (M4S10, M6S12). After 28 days of initial curing in water, the concrete slabs were subject to different exposure conditions such as drying, fully and partially saturated conditions for a specified time duration. Hence, it is possible to develop a better understanding of the long-term tests to assess the resistance of concrete to chloride penetration under different pre-conditions such as drying, partially saturated, and fully saturated conditions with/without impregnation. The results show that the most significant effect of sorptivity on long-term chloride ingress to concrete is its effect on surface chloride content. The value of this parameter is a way of taking account of absorption when modelling chloride ingress under cyclic wetting and drying conditions. In which totally 12 concrete slabs were treated with two different impregnation materials such as Solvent based (M1S1, M2S3, M3S5, M5S7, M4S9, M6S11) and Water based (M1S2, M2S4, M3S6, M5S8, M4S10, M6S12). The other six concrete slabs is untreated as control concrete slabs (M1CS, M2CS, M3CS, M4CS, M5CS, and M6CS).The overall details of the mixture proportions were to be represent in Table.1-2. Three concrete slabs of size (450x450x100) mm were casted for each mixture and overall eighteen concrete slabs 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.

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

Mix ID	Comp/mean target strength (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mix Proportions
M1	40/47.84	0-10	0.45	18.23	8.20	29.70	94.16	1:1.63:5.17

M2	40/47.84	10-30	0.44	22.05	9.72	28.49	85.47	1:1.29:3.88
M3	40/47.84	60-180	0.43	27.51	11.85	32.50	72.41	1:1.18:2.63

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

Mix ID	Comp/mean target strength (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mixture Proportions
M4	25/32.84	10-30	0.50	19.44	9.72	30.31	86.27	1:1.55:4.44
M5	30/37.84	10-30	0.45	21.63	9.72	30.86	83.55	1:1.42:3.86
M6	40/47.84	10-30	0.44	22.05	9.72	28.49	85.47	1:1.29:3.87

4. CHLORIDE DIFFUSION COEFFICIENT

The chloride diffusion coefficient in concrete is one of the important factor in determining the service life of concrete structures exposed to marine environments/de-icing salt. Traditional methods (such as bulk diffusion test and migration test) used to determine the chloride diffusion coefficients are usually time and labour consuming. The electrical resistivity method has been develop as a non-destructive technique to evaluate the chloride permeability of concrete specimens. As a quality control method, however, the disadvantage of the resistivity method is that its values cannot be, apply in the service life-prediction models to predict the chloride diffusion coefficients. The main electrochemical reactions take place in the limited volume of aqueous solution present in the pores of the concrete surrounding the metal within the concrete. Because of this process, the steel loses mass, and its cross section decreases. However, this is not one of the obvious risks associated with steel corrosion in concrete and solid products of corrosion. These products are deposit in the gap between the concrete and steel, due to being in a very small place, this process generates efforts that can break the concrete coat causing a progressive deterioration of it [10]. One of the most common reasons that cause corrosion in reinforcements is the chlorides penetration through the net of pores when these are located in marine environments or when in the mixture such ions are incorporated. Chloride ions are capable of causing localized corrosion therefore lead to a premature and unexpected failure of the structure [11].The concrete is an excellent protection for steel reinforcements inside the structure, but exposure to various environmental conditions during its service life may accelerate the destruction process. A well-known cause of steel corrosion is chloride penetration; many factors govern the phenomenon of chloride penetration into concrete, such as the type of cementitious material, the water-cement ratio, curing time, period of exposure to chlorides and other physical factors. Generally, the ingress of chlorides rate depends on the diffusion coefficient of chlorides, which varies with the exposure time. The evaluation of the transport properties into concrete (chloride's diffusion), results essential in order to project the lifetime of concrete structures. The interest is concentrated in the critical threshold of chlorides concentration that cannot be overpass in the reinforcement surface, to avoid the corrosion phenomena [12].

The primary aim of this research was to interpret the effects of wetting and drying pre-conditioned concrete slabs on chloride diffusion coefficient, which was exposed to different pre-determined conditions such as dry/fully saturated/partially saturated condition was evaluated in control/impregnation concrete slabs for about 160 days' salt ponding test in all designed six mixtures type (M1-M6). The pre-conditioning was induce in order to achieve desired dry condition in specified six concrete slabs. In which all six concrete slabs were expose to natural room temperature for about 28 days. The pre-conditioned fully saturated condition was achieved in specified 6 concrete slabs by partially submerged in water with one surface exposed for about 60 days. The pre-conditioned partially saturated condition was assess in specified six concrete slabs by partially submerged in water with one surface exposed for about 40 days. In turn chloride profiles of samples exposed to different pre-determined conditions such as dry/fully saturated/partially was evaluate in control/impregnation concrete slabs in all six mixtures type (M1-M6). The chloride profiles were analysed by drilling the concrete slabs. The drilling was done with a diameter of 20 mm (max aggregate size) and drill depths of (30, 40, and 50) mm. The dust sample collected weighted between 1-5 grams as specified by (BS EN 15629:2007) [13] for the determination of the chloride penetration. The chloride concentration for each of the dust samples, including from the control specimens was determined in accordance with BS EN 15629:2007 in hardened concrete. The chloride content was calculate as a percentage of chloride ion by mass of the sample of concrete. Volhards Method was use for the determination of the total chloride content in the concrete. The chloride ingress in to the concrete can only take place if the concrete pores are totally/partly fill 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 chloride ingress into the concrete due to the various transport mechanisms obeys different laws. However, Fick's second law of diffusion is commonly apply to quantify the chloride penetration in marine environment due to the multiple transport mechanism. This law is represent by the following expression:

$$\frac{\partial C}{\partial t} = D\frac{\delta^2 C}{\delta x^2}\text{---} (1)$$

Where C (x, t) is the chloride concentration at depth (x) at time (t) and D is the diffusion coefficient. For a semi-finite uni-directional diffusion, the solution of this equation is as follows:

$$C\,(x,t) = C_s\,[1 - erf(\tfrac{x}{2\sqrt{Dt}})]\text{-----------------} (2)$$

Whereas C_s is the surface chloride concentration and erfis the error function. Actually equations (1) and (2) assumes that, concrete is homogenous in structure and that D is independent of the humidity of concrete, chloride concentration, and temperature, in turn assume that the binding isotherm is linear. In fact, for a certain time interval, this law is a good approximation for the chloride variation with depth in structure either exposed to the atmosphere or submerged environmental condition. The solution is valid only if the boundary and material properties are constant and the initial conditions are such that: Cx = 0 when x > 0 and Cx = Cs for x = 0. In other words, it is assume that initially there are no chlorides in the concrete and the only chlorides in the system are the surface chlorides. This equation is an integral part of the determination of the service life of marine reinforced concrete structures prone to chloride ingress. The variation of concrete chloride diffusion coefficient against different drill depths (30-40-50) mm under various pre-conditioned concrete slabs such as DCC/PSC/FSC condition was represent in Tables.3-5.

Table 3 Chloride diffusion coefficient equation in DCC concrete slabs

MIX ID	Co-relation Equation	R^2
M1CC	$Dc = 0.0086x^{-0.356}$	0.9026
M1SB	$Dc = 0.0049x^{-0.223}$	0.9019
M1WB	$Dc = 0.0054x^{-0.241}$	0.8568
M2CC	$Dc = 0.0053x^{-0.250}$	0.9808
M2SB	$Dc = 0.0050x^{-0.253}$	0.9580
M2WB	$Dc = 0.0051x^{-0.248}$	0.8886

Table 4 Chloride diffusion coefficient equation in PSC concrete slabs

MIX ID	Co-relation Equation	R^2
M3CC	$Dc = 0.0055x^{-0.271}$	0.991
M3SB	$Dc = 0.0050x^{-0.259}$	0.9986
M3WB	$Dc = 0.0046x^{-0.230}$	0.9235
M5CC	$Dc = 0.0051x^{-0.264}$	0.9873
M5SB	$Dc = 0.0028x^{-0.113}$	0.6191
M5WB	$Dc = 0.0025x^{-0.075}$	0.3313

Table 5 Chloride diffusion coefficient equation in FSC concrete slabs

MIX ID	Co-relation Equation	R^2
M4CC	$Dc = 0.0044x^{-0.207}$	0.9385
M4SB	$Dc = 0.012x^{-0.518}$	0.9334
M4WB	$Dc = 0.0059x^{-0.317}$	0.9730
M6CC	$Dc = 0.0068x^{-0.340}$	0.9628
M6SB	$Dc = 0.0053x^{-0.302}$	0.9998
M6WB	$Dc = 0.0036x^{-0.192}$	0.9793

The chloride diffusion coefficient (CDC) was increased at drill depth 30 mm as when compared to drill depth 40 mm and 50 mm as well as chloride diffusion coefficient was also increased at drill depth 40 mm against drill depths 50 mm under various pre-conditioned concrete slabs such as DCC/PSC/ FSC condition was represented in Table.6.

Table 6 Variation of chloride diffusion coefficient in pre-conditioned concrete slabs

CDC in DCCslabs [M1 = M2]				CDC in PSC slabs [M3 = M5]				CDC in FSC slabs [M4 = M6]			
Drill depth	(30-40) mm	(30-50) mm	(40-50) mm	Drill depth	(30-40) mm	(30-50) mm	(40-50) mm	Drill depth	(30-40) mm	(30-50) mm	(40-50) mm
MIX ID	%, incr	%, incr	%, incr	MIX ID	%, incr	%, incr	%, incr	MIX ID	%, incr	%, incr	%, incr
M1CC	14.11	16.27	2.52	M1CC	8.52	12.86	4.75	M1CC	7.86	2.15	2.15
M1SB	9.09	10.52	1.57	M1SB	7.55	12.34	5.18	M1SB	18.76	5.05	5.05
M1WB	10.50	11.24	0.83	M1WB	8.97	10.85	2.05	M1WB	10.73	4.07	4.53
M2CC	8.30	11.86	3.88	M2CC	8.49	12.53	4.41	M2CC	11.86	6.84	4.41
M2SB	9.09	11.96	3.15	M2SB	6.79	5.31	1.58	M2SB	8.16	3.91	6.67
M2WB	10.28	11.61	1.47	M2WB	6.48	3.39	3.31	M2WB	6.49	6.90	2.95

5. DISCUSSION ABOUT RESULTS

Thus in the present research work, the effectiveness of 18 preconditioned concrete slabs of size (450x450x100) mm on chloride diffusion coefficient under various pre-conditions such as dry/fully/partially saturated condition was evaluated for in case of six designed mixtures type (M1-M6).In fact, average chloride diffusion coefficient in DCC slabs was slightly more/less high from different drill depths (30-40-50) mm as when compare to average chloride diffusion coefficient in PSC and FSC concrete slabs at different drill depths. Average chloride diffusion coefficient was increase in control DCC slabs for constant higher compressive strength and varied slump value. Average chloride diffusion coefficient was slightly decrease in solvent/water based impregnation DCC slabs for higher compressive strength and varied slump value as when compare to control DCC slabs with same higher compressive strength and varied slump value. Average chloride diffusion coefficient was decrease in control PSC slabs and solvent/water based impregnation PSC slabs as when compare to control DCC/impregnation (solvent/water) based slabs for constant higher compressive strength and varied slump value. Average chloride diffusion coefficient was more/less decreased in control FSC/impregnation (solvent/ water) based impregnation slabs with varied higher compressive strength and constant slump value as when compare to control PSC/impregnation (solvent/water) based slabs with constant higher compressive strength and varied slump value. The average variation of chloride diffusion coefficient from different drill depth (30-40-50) mm in control/solvent/water based impregnation DCC/PSC/FSC slabs was represent in Fig.1 for different designed mixtures type (M1-M6).

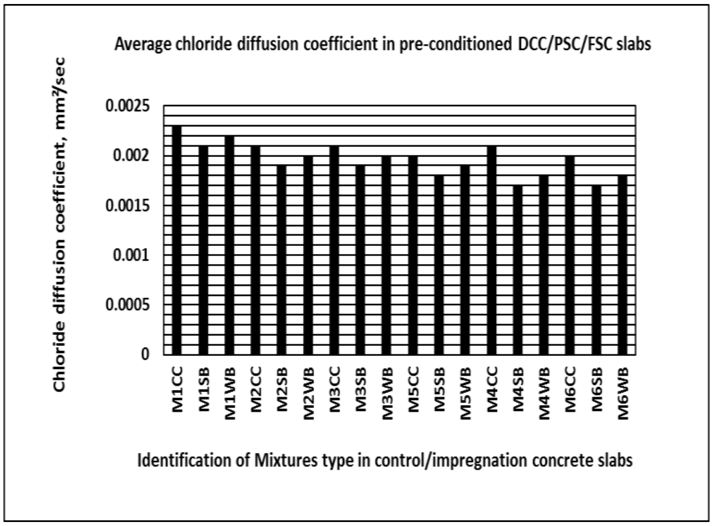

Figure 1 Chloride diffusion coefficient in DCC/PSC/FSC slabs

The chloride diffusion coefficient (CDC) was increase at drill depth 30 mm as when compared to drill depth 40 mm/50 mm. Chloride diffusion coefficient was also increased at drill depth 40 mm against different drill depths 50 mm under various pre-conditioned concrete slabs such as DCC/PSC/FSC/impregnation (solvent/water) concrete slabs condition was represented in Figs.2-4.

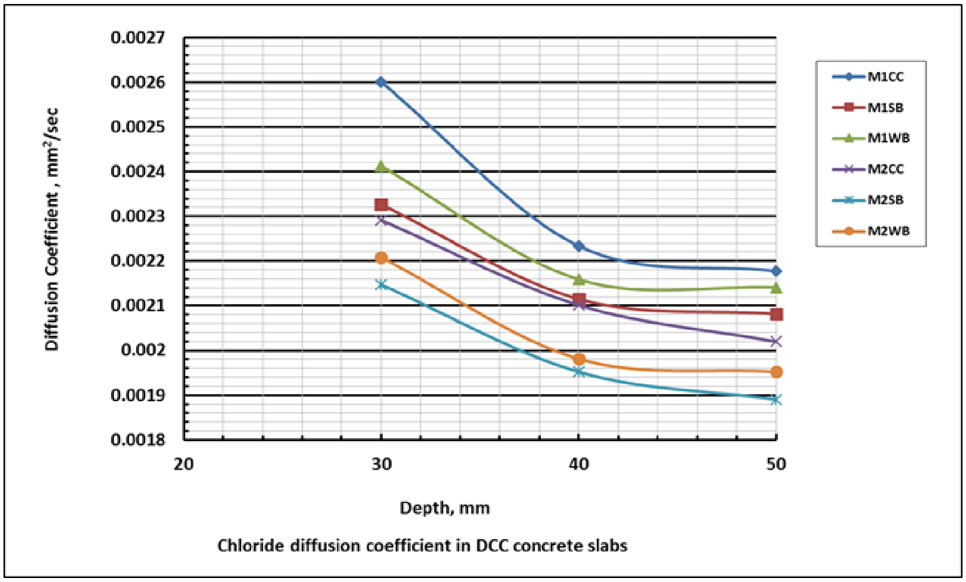

Figure 2 Chloride diffusion coefficient in DCC slabs

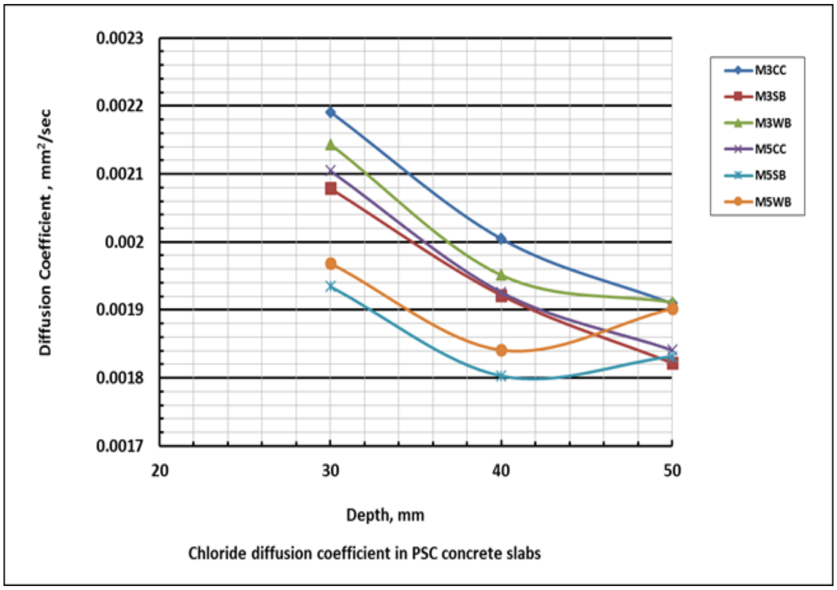

Figure 3 Chloride diffusion coefficient in PSC slabs

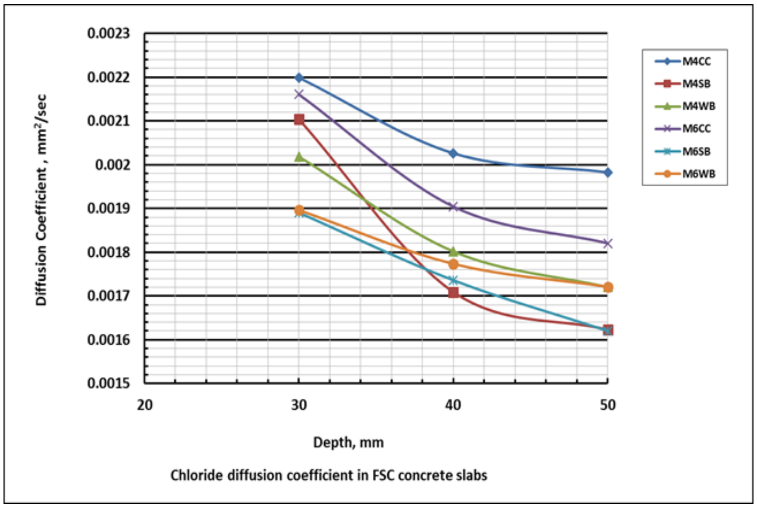

Figure 4 Chloride diffusion coefficient in FSC slabs

In fact, the chloride diffusion coefficient was predominately increased in DCC concrete slabs as observed from drill depth (30-40) mm, (30-50) mm, and (40-50) mm for in case of control/solvent/water based impregnation concrete slabs. Similarly, the chloride diffusion coefficient was decrease in PSC/FSC concrete slabs as noted from drill depth (30-40) mm, (30-50) mm, and (40-50) mm for in case of control/solvent based/water based impregnation concrete slabs. Thus, the variation of chloride diffusion coefficient at different drill depth (30-40) mm, (30-50) mm and (40-50) mm for in case of control DCC/PSC/FSC/impregnation (solvent/water) based concrete slabs was represent in Table 6.

6. CONCLUSION

1. The average chloride diffusion coefficient value in DCC slabs was found to be slightly more/less high from different drill depths (30-40-50) mm as when compared to average chloride diffusion coefficient in PSC and FSC concrete slabs at different drill depths.
2. Average chloride diffusion coefficient was increase in control DCC slabs for constant higher compressive strength and varied slump value. Chloride diffusion coefficient was slightly decrease in solvent/water based impregnation DCC slabs for higher compressive strength and varied slump value as when compare to control DCC slabs with same higher compressive strength and varied slump value.
3. The average chloride diffusion coefficient was decreased in control PSC/solvent/water based impregnation concrete slabs as when compared to control DCC/impregnation (solvent/water) based concrete slabs for constant higher compressive strength and varied slump value. An average chloride diffusion coefficient was more/less decreased in control FSC/impregnation (solvent/ water) based impregnation concrete slabs with varied higher compressive strength and constant slump value as when compared to control PSC/impregnation (solvent/water) based concrete slabs with constant higher compressive strength and varied slump value.
4. The chloride diffusion coefficient (CDC) was increased at drill depth 30 mm as when compared to chloride diffusion coefficient at drill depth 40 mm and 50 mm as well as chloride diffusion coefficient was also increased at drill depth 40 mm against different drill depths 50 mm under various pre-conditioned concrete slabs such as DCC/PSC/FSC condition. In fact, the chloride diffusion coefficient was predominately increase in DCC concrete slabs as observed from drill depth (30-40) mm, (30-50) mm, and (40-50) mm for in case of control/solvent based/water based impregnation concrete slabs. Similarly, the chloride diffusion coefficient was decrease in PSC/FSC concrete slabs as noted from drill depth (30-40) mm, (30-50) mm, and (40-50) mm for in case of control/solvent based/water based impregnation concrete slabs.
5. In addition to that, from this research work it's possible to establish a relationship between concrete chloride diffusion coefficient and drill depth in DCC/PSC/FSC/impregnation (solvent/water) based concrete slabs for designed different mixtures type.

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