International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 04 | Apr 2020 www.irjet.net p-ISSN: 2395-0072

EFFECTIVENESS OF CONCRETE INGREDIENTS ON CHLORIDE DIFFUSION COEFFICIENT IN CONCRETE CUBES

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Abstract: *The chloride ions arise from marine exposure/de-icing salts were the most important threat factors to the durability of concrete structures. The corrosion of steel reinforcement in concrete is mainly due to the chemical reaction between the chloride ions and iron ions. The penetration of chloride ingress into the concrete structure is one of most important factors, which leads to the de-passivation of reinforcing bars and therefore, may shorten the service life of the concrete structure. The time needed by these chloride ions to reach the rebar depends first, on the mechanism of intrusion and secondly, on the external concentration of the chlorides and the microstructure of the concrete. In fact, when the concrete structure is completely saturate that, 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. The diffusion occurs because of concentration gradients. In other words, if the chloride ions are not evenly distribute in a liquid then the ions move from the place with the highest concentration to the place with a lower concentration.*

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 cubes 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 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. Seventy-two concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 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 cubes, the 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 cubes as when compare to control DCC/PSC/FSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride diffusion coefficient was increased in solvent/water based impregnation DCC/PSC/FSC cubes for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride diffusion coefficient was going on decreases with increased compressive strength and constant slump value.

Keywords: *Concrete, mixture proportion, grade of concrete, pre-conditioning, slump, w/c ratio, chloride diffusion*

1.0 Introduction

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 [Collepardi *et al.* 1972] 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 [Gjorv, and Vennesland, 1979] 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 attributing 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 was 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 [Page *et al.* 1986]. Increase in diffusion rate with increased w/c is noted. It has concluded that [Midgley, and Illston, 1984] sulphate-resisting cement performs poorly against corrosion and diffusion of chlorides. Researcher [Hansson et *al*. 1985] investigated the effect of chloride concentration by considering two solutions of NaCl with different concentrations. Test results showed that the depth of penetration at a given time increases with w/c ratio and the concentration of chloride ions. The study also concluded that the presence of chloride ions alters the pore-size distribution of the hardened cement paste and smaller pores are associated with higher chloride ions. It was also inferred that the total chloride ion content of the pore solution does not alone account for the corrosion rate, but the rate of corrosion is also controlled by other factors that include porosity, pH level and the availability of oxygen. The chloride is a very important factor, which influences the durability of concrete structures in their service life. It can induce the steel corrosion and concrete cover cracking. Ingress of chloride in the concrete was investigate since 1970' [Boddy *et al.*1999].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 [Rahman *et al.* 2012].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.

In fact, the parameters affecting the chloride diffusion are reviewed by briefly presenting the salient features of the past voluminous work in this area and following this, its importance is highlighted in estimating the corrosion initiation time under a given exposure condition by many researchers. The relative importance of the two major mechanisms of chloride transport, namely diffusion and absorption, depend on the moisture content of concrete. Absorption may be dominant if a dry concrete with significant loss of pore water is wetted with chloride-bearing water, whereas for a reasonably moist concrete (sufficient level of pore water exists) diffusion process will prevail under concentration gradient. However, researchers tend to agree that in most cases diffusion can be assume the basic transport mechanism of chloride ions for reasonably moist structures [Tuutti, 1985].An argument against the validity of pore diffusion of chloride ingress is that some part of the chloride is chemically bound in concrete due to reaction with cement and remains as immobilized [Bruenfield, 1986]. The chloride concentration profile therefore depends to some extent upon the type of cement used in concrete. Its [Raharinaivo, and Jean-Marie, 1986] arrived at a formulation to find the apparent diffusivity considering the trapping or the reaction of the chloride ions with the constituents of cement. The study concluded from others, chloride penetration could be model by Fick's diffusion law in most cases and if other factors such as pressure, evaporation and frost action are neglect. However, when cement has a high proportion of tri-calcium aluminate content/concrete is of small porosity, Fick's law cannot be applying with full validity. Investigator [Gau, and Cornet, 1985] have considered a reaction rate between chloride ions, cement paste and a chloride convection coefficient for the solution of Fick's law. However, as the convection effect over long term with large area is small, it can be ignore to obtain a reasonable solution of Fick's law [Funahasi, 1990]. Thus, greater emphasis now being place 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 exists 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 interprets the chloride diffusion coefficient with/without impregnation in ordered to characterize different designed mixtures type.

2.0 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. 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 cubes 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 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. Seventy-two concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride diffusion coefficient under different exposure condition.

3.0 Experimental program

In the present research work, six different mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm^3). Three of the mixtures were concrete cubes (100 mm^3) with a compressive strength 40 N/mm^2, slump (0-10, 10-30, and 60-180 mm), and different w/c (0.45, 0.44, and 0.43). These mixtures were designate as M1, M2, and M3. Another Three of the mixtures were concrete cubes with a compressive strength (25 N/mm^2, 30 N/mm^2, and 40 N/mm^2), slump (10-30 mm), and different w/c (0.5 0.45, and 0.44). These mixtures were designate as M4, M5, and M6. The overall details of the mixture proportions were to be representing 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 strength(N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA(Kg) 10 mm	Mixture Proportions
M1	40/47.84	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M2	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M3	40/47.84	60-180	0.43	5.43	2.34	6.42	14.30	1:1.18:2.63

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

Mix ID	Comp/mean target strength(N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA(Kg) 10 mm	Mixture Proportions
M4	25/32.84	10-30	0.50	3.84	1.92	5.98	17.04	1:1.55:4.44
M5	30/37.84	10-30	0.45	4.27	1.92	6.09	16.50	1:1.42:3.86
M6	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87

3.1 Chloride diffusion coefficient

The chloride diffusion coefficient in concrete is one of the important factors 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 developing 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 apply directly 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 [Aperador W, Mejía de Gutiérrez R and Bastidas, D.M. 2009]. One of the most common reasons that cause corrosion in reinforcements is the chlorides penetration through the net of pores when these are located in marine environments 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 [Morón *et al.* 2003].Normally, 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) was 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 [Princigallo, 2012]. Chloride ions that are harmful to the reinforcing steel are those, which are dissolve/free, but due to the balances that occur, it is possible that chloride ions, which are adsorb, be incorporate into the solution and become hazardous [Aperador *et al.* 2012]. Free chloride ions penetrate the pore system of the concrete structure, some of the ions are fixing to solid concrete structure. The transient chemical reaction affects the flow of free ions in the pore solution [Chalee *et al.* 2009].Diffusion through a porous medium such as concrete is a phenomenon of chloride ion transport, is the principal mechanism of chloride penetration into concrete. This study is aim to obtaining three main parameters: the concentration of chloride, the diffusion coefficient and the concentration of chlorides in the concrete surface. According to Fick's second law of diffusion, it is assuming a uni-dimensional transport process [Juárez, and Castro, 2011].

The primary aim of this research was to interpret the effects of wetting/drying pre-conditioned concrete cubes on chloride diffusion coefficient. Which was exposing to different pre-determined conditions such as dry/fully saturated/partially saturated condition was evaluate in control/impregnation concrete cubes for about 160 days salt ponding test in all designed six mixtures type (M1-M6).The pre-conditioning was induce in order achieve desired dry condition in specified 24 concrete cubes. In which all 24 concrete cubes were expose to natural room temperature for about 28 days. The pre-conditioned fully saturated condition was achieve in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 31 days. The pre-conditioned partially saturated condition was assess in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 21 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 cubes in all six mixtures type (M1-M6). The chloride profiles were analysed by drilling the concrete cubes. 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] 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 determined as a percentage of chloride ions 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 or partly filled with water. The penetration occurs either through the capillary pores/through cracks by permeation, capillary suction, and diffusion. In the exposure conditions, the concrete moisture content, and the pore structure will determine the relative importance of those penetration mechanisms. The chloride ingress into the concrete due to the various transport mechanisms obeys different laws. However, Fick's second law of diffusion is apply to quantify the chloride penetration in marine environment due to the multiple transport mechanism. This law is representing 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:

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

Whereas C_s is the surface chloride concentration and erf is 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 cubes such as DCC/PSC/ and FSC was represent in Tables.3-5.

Table.3 Interpretation of chloride diffusion coefficient in DCC concrete cubes

MIX ID	Co-relation Equation	R^2	MIX ID	Co-relation Equation	R^2
M1CC	$Dc = 0.0019x^{-0.413}$	0.9919	M4CC	$Dc = 0.00123x^{-0.440}$	0.8509
M1SB	$Dc = 0.0209x^{-0.705}$	0.9476	M4SB	$Dc = 0.00317x^{-0.753}$	0.9326
M1WB	$Dc = 0.02x^{-0.604}$	0.9998	M4WB	$Dc = 0.0397x^{-0.793}$	0.9932
M2CC	$Dc = 0.0093x^{-0.379}$	0.9914	M5CC	$Dc = 0.0148x^{-0.552}$	0.8554
M2SB	$Dc = 0.0123x^{-0.524}$	0.9733	M5SB	$Dc = 0.0114x^{-0.520}$	0.9732
M2WB	$Dc = 0.0144x^{-0.557}$	0.9694	M5WB	$Dc = 0.0099x^{-0.462}$	0.9557
M3CC	$Dc = 0.0378x^{-0.793}$	0.9933	M6CC	$Dc = 0.0171x^{-0.610}$	0.9466
M3SB	$Dc = 0.0187x^{-0.650}$	0.9586	M6SB	$Dc = 0.0114x^{-0.526}$	0.8913
M3WB	$Dc = 0.0075x^{-0.416}$	0.8793	M6WB	$Dc = 0.0078x^{-0.403}$	0.8207

Table.4 Interpretation of chloride diffusion coefficient in PSC concrete cubes

MIX ID	Co-relation Equation	R^2	MIX ID	Co-relation Equation	R^2
M1CC	$Dc = 0.0054x^{-0.275}$	0.974	M4CC	$Dc = 0.007x^{-0.351}$	0.9781
M1SB	$Dc = 0.0026x^{-0.140}$	0.867	M4SB	$Dc = 0.0035x^{-0.187}$	0.9534
M1WB	$Dc = 0.0022x^{-0.079}$	0.8773	M4WB	$Dc = 0.0028x^{-0.124}$	0.9786
M2CC	$Dc = 0.0022x^{-0.676}$	0.9216	M5CC	$Dc = 0.0049x^{-0.235}$	0.8267
M2SB	$Dc = 0.0024x^{-0.130}$	0.9876	M5SB	$Dc = 0.0055x^{-0.308}$	0.952
M2WB	$Dc = 0.0016x^{-0.002}$	0.0053	M5WB	$Dc = 0.0051x^{-0.274}$	1.000
M3CC	$Dc = 0.0114x^{-0.497}$	0.8405	M6CC	$Dc = 0.0064x^{-0.322}$	0.9842
M3SB	$Dc = 0.004x^{-0.247}$	0.902	M6SB	$Dc = 0.0031x^{-0.180}$	0.8447
M3WB	$Dc = 0.0017x^{-0.011}$	0.1501	M6WB	$Dc = 0.0059x^{-0.331}$	0.9219

Table.5 Interpretation of chloride diffusion coefficient in FSC concrete cubes

MIX ID	Co-relation Equation	R^2	MIX ID	Co-relation Equation	R^2
M1CC	$Dc = 0.0023x^{-0.126}$	0.9984	M4CC	$Dc = 0.0025x^{-0.157}$	0.9999
M1SB	$Dc = 0.0021x^{-0.115}$	0.9474	M4SB	$Dc = 0.0024x^{-0.156}$	0.9962

M1WB	$Dc = 0.002x^{-0.102}$	0.9989	M4WB	$Dc = 0.0022x^{-0.126}$	0.9435
M2CC	$Dc = 0.0025x^{-0.139}$	0.9939	M5CC	$Dc = 0.0024x^{-0.137}$	0.8779
M2SB	$Dc = 0.0019x^{-0.079}$	0.9934	M5SB	$Dc = 0.0019x^{-0.080}$	0.9103
M2WB	$Dc = 0.0024x^{-0.143}$	0.9005	M5WB	$Dc = 0.0018x^{-0.071}$	0.9356
M3CC	$Dc = 0.002x^{-0.080}$	0.9928	M6CC	$Dc = 0.0021x^{-0.097}$	0.9969
M3SB	$Dc = 0.0017x^{-0.053}$	0.5496	M6SB	$Dc = 0.0019x^{-0.085}$	0.8762
M3WB	$Dc = 0.0018x^{-0.056}$	0.9846	M6WB	$Dc = 0.0017x^{-0.056}$	0.9633

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 different drill depths 50 mm under various pre-conditioned concrete cubes such as DCC/PSC/FSC condition was represented in Table.6.

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

CDC in DCC cubes				CDC in PSC cubes				CDC in FSC cubes			
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	12.60	18.92	7.23	M1CC	9.36	12.98	3.99	M1CC	3.77	6.23	2.55
M1SB	23.90	29.82	7.77	M1SB	6.16	6.73	0.6	M1SB	4.37	5.62	1.31
M1WB	16.24	26.53	12.38	M1WB	1.02	4.08	3.09	M1WB	2.84	5.07	2.29
M2CC	11.67	17.51	6.61	M2CC	24.27	28.67	5.82	M2CC	4.38	6.84	2.57
M2SB	17.10	23.23	7.40	M2SB	4.26	6.38	2.20	M2SB	2.50	3.91	1.45
M2WB	18.30	24.48	7.57	M2WB	1.16	0.06	1.11	M2WB	5.96	6.90	1.00
M3CC	22.57	33.16	13.68	M3CC	20.92	21.79	1.10	M3CC	2.57	4.00	1.47
M3SB	21.67	27.90	7.95	M3SB	10.02	11.59	1.74	M3SB	3.51	2.51	1.04
M3WB	16.87	18.66	2.15	M3WB	1.35	0.44	0.92	M3WB	1.90	2.82	0.93
M4CC	18.51	19.59	1.32	M4CC	7.57	16.57	9.74	M4CC	4.36	7.74	3.53
M4SB	26.10	31.42	7.20	M4SB	3.57	9.26	5.90	M4SB	4.78	7.63	2.99
M4WB	22.58	33.14	13.65	M4WB	4.26	6.08	1.91	M4WB	4.80	6.11	1.38
M5CC	22.49	23.91	1.84	M5CC	10.68	10.94	0.28	M5CC	5.92	6.58	0.70
M5SB	16.98	23.07	7.34	M5SB	11.11	14.32	3.61	M5SB	1.22	4.07	2.89
M5WB	16.07	20.74	5.56	M5WB	7.61	13.08	5.92	M5WB	2.80	3.51	0.73
M6CC	20.82	26.05	6.61	M6CC	10.41	15.04	5.17	M6CC	2.99	4.83	1.90
M6SB	20.48	23.04	3.22	M6SB	8.09	8.51	0.46	M6SB	3.73	4.14	0.42
M6WB	17.79	18.05	0.31	M6WB	5.30	15.87	11.16	M6WB	2.05	2.77	0.74

4.0 Discussion about Results

Thus in the present research work, the effectiveness of 72 preconditioned concrete cubes of size (100) 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 which first three mixtures type (M1-M3) was designed as constant compressive strength (40 N/mm^2) with varied slump value (0-10, 10-30, and 60-180) mm and whereas second three mixtures type (M4-M6) was designed as constant slump value (10-30) mm with different compressive strength (25-30-40)N/mm^2. Average chloride diffusion coefficient value in DCC cubes 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 cubes at different drill depths. Average chloride diffusion coefficient was increase in control DCC cubes for constant higher compressive strength and varied slump value. Average chloride diffusion coefficient was more increase in control DCC cubes for lesser compressive strength and constant slump value and the chloride diffusion coefficient was decreases with increased compressive strength and constant slump value. Similarly, average chloride diffusion coefficient was decrease in solvent based and water based impregnation DCC cubes as when compare 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 diffusion coefficient was increased in solvent/water, based impregnation DCC cubes 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. Average variation of chloride diffusion coefficient in control/solvent based/water based impregnation DCC cubes was represent in Fig.1 for different designed mixtures type (M1-M6).

Average chloride diffusion coefficient in PSC cubes was increase from different drill depths (30-40-50) mm as when compared to average chloride diffusion coefficient in FSC concrete cubes at different drill depths. Average chloride diffusion coefficient was decrease in control PSC cubes for constant higher compressive strength and varied slump value. Whereas it has more increase in control, PSC cubes for lesser compressive strength and constant slump value and the chloride diffusion coefficient was decreases with increased compressive strength and constant slump value. Similarly, it has decrease in solvent based and water based impregnation PSC cubes as when compare 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 diffusion coefficient was increased in solvent/water, based impregnation DCC cubes 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. Average chloride diffusion coefficient in control/solvent based/water based impregnation PSC cubes was represent in Fig.2 for different designed mixtures type (M1-M6). Average chloride diffusion coefficient in FSC cubes was decrease from different drill depths (30-40-50) mm as when compare to average chloride diffusion coefficient in DCC and PSC concrete cubes at different drill depths. Average chloride diffusion coefficient was slightly increase in control FSC cubes for constant higher compressive strength and varied slump value. Whereas it has decrease in controlled FSC cubes for lesser compressive strength and constant slump value and the chloride diffusion coefficient value was increases with increased compressive strength and constant slump value. Similarly, it has decreased in solvent based and water based impregnation FSC cubes as when compare to control FSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride diffusion coefficient was decreased in solvent/water, based impregnation FSC cubes for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride diffusion coefficient was going on decreases with increased compressive strength and constant slump value. Average chloride diffusion coefficient in control/solvent based/water based impregnation FSC cubes was represent in Fig.3 for different designed mixtures type (M1-M6).

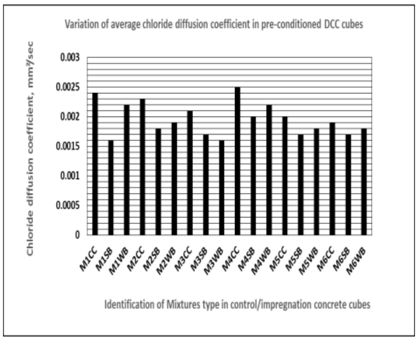


Fig.1 Cl$^-$ diffusion coefft in DCC cubes

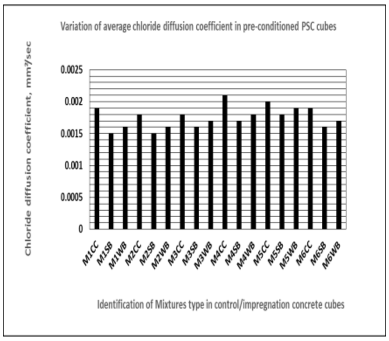


Fig.2 Cl$^-$ diffusion coefft in PSC cubes

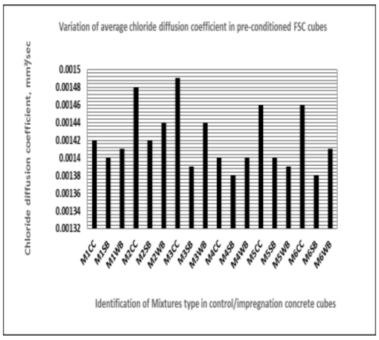


Fig.3 Cl$^-$ diffusion coefft in FSC cubes

Average chloride diffusion coefficient was varied with w/c ratio in control/solvent based/water based impregnation DCC/PSC/FSC cubes was represent in Figs.4-12 for different designed mixtures type (M1-M6). Chloride diffusion coefficient could be increase at lower drill depth ($D^{30\ mm}$) as when compare higher drill depths ($D^{40\ mm}$ and $D^{50\ mm}$) respectively for lower w/c ratio and control/impregnation FSC concrete cubes as shown in the Figs.4-6. Chloride diffusion coefficient could be increase at lower drill depth ($D^{30\ mm}$) and higher drill depths ($D^{40\ mm}$ and $D^{50\ mm}$) respectively for lower/higher w/c ratio in control/impregnation DCC concrete cubes as shown in the Figs.7-9.

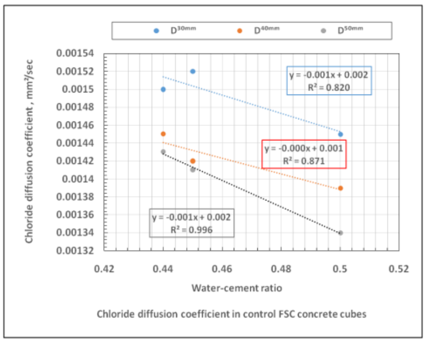


Fig.4 Cl^- diffusion coefft in FSC cube

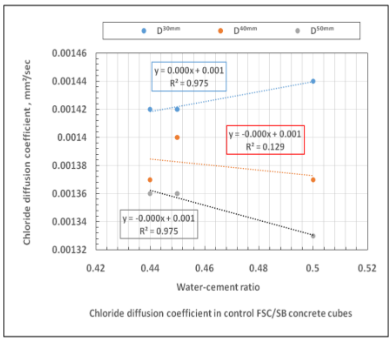


Fig.5 Cl^- diffusion coefft in FSC cubes

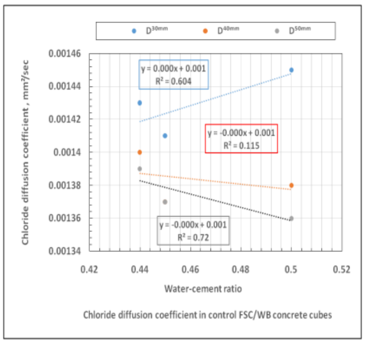


Fig.6 Cl^- diffusion coefft in FSC cubes

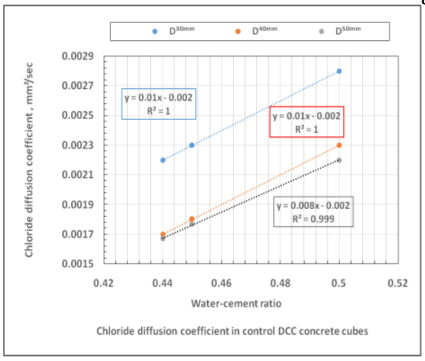


Fig.7 Cl^-diffusion coefft in DCC cube

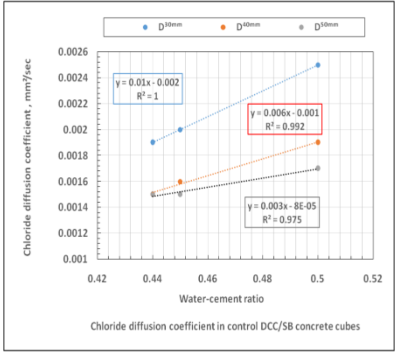


Fig.8 Cl^-diffusion coefft in DCC cubes

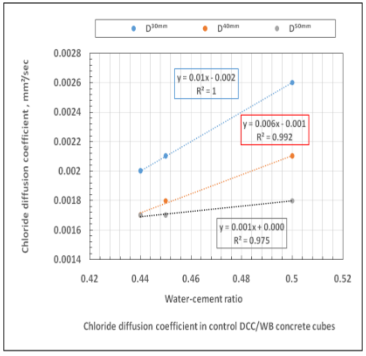


Fig.9 Cl^-diffusion coefft in DCC cubes

Chloride diffusion coefficient could be increase at lower drill depth ($D^{30\ mm}$) and w/c ratio as when compare higher drill depths ($D^{40\ mm}$ and $D^{50\ mm}$) respectively for lower w/c ratio in control/impregnation FSC concrete cubes as shown in the Figs.10-12.

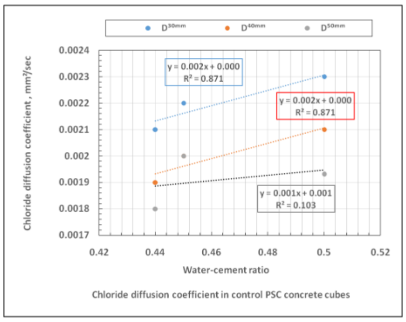


Fig.10 Cl^- diffusion coefft in PSC cube

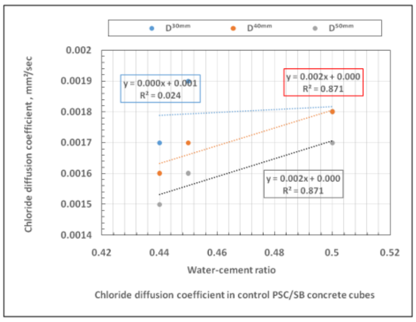


Fig.11 Cl^- diffusion coefft in PSC cube

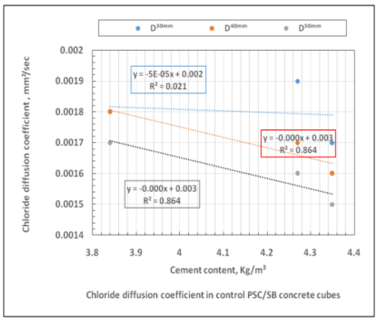
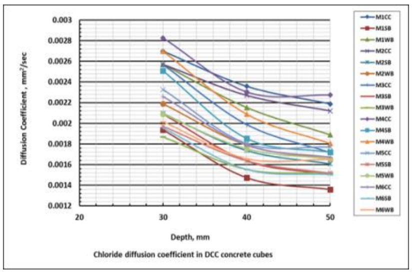
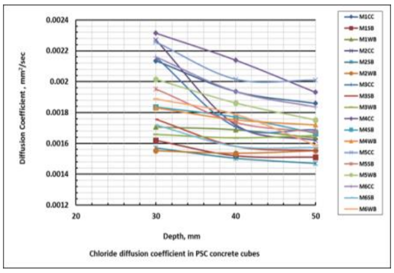


Fig.12 Cl^- diffusion coefft in PSC
cube

The chloride diffusion coefficient (CDC) was increase at drill depth 30 mm as when compare to chloride diffusion coefficient at drill depth 40 mm and 50 mm. It has also increased at drill depth 40 mm against different drill depths 50 mm under various pre-conditioned concrete cubes such as DCC/PSC/FSC condition was represent in Figs.13-15. In fact, the chloride diffusion coefficient was predominately increase in DCC cubes 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 cubes. Similarly, the chloride diffusion coefficient was decrease in PSC/FSC cubes 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 cubes. 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 DCC/PSC/FSC cubes were represent as in Table.6.





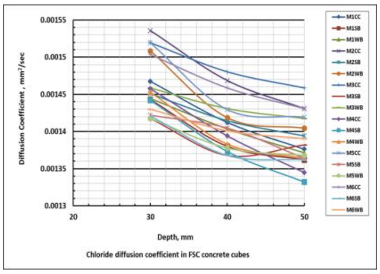
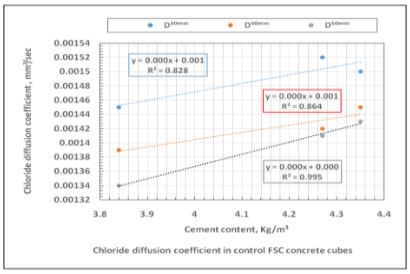
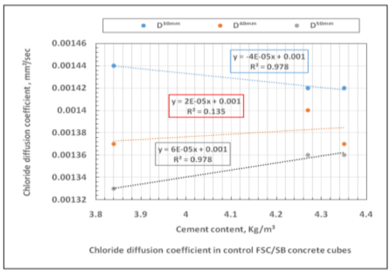


Fig.13 Cl^{-}diffusion coefft in DCC cubes Fig.14 Cl^{-}diffusion coefft in PSC cubes Fig.15 Cl^{-}diffusion coefft in FSC cubes

The chloride diffusion coefficient (CDC) was increase at drill depth 30 mm as when compare to chloride diffusion coefficient at drill depth 40 mm and 50 mm at lower cement content. It has also increased at drill depth 40 mm against different drill depths 50 mm under various pre-conditioned concrete cubes such as FSC/DCC/PSC condition at lower cement content was represent in Figs.16-24 for in case of control/impregnation concrete cubes.





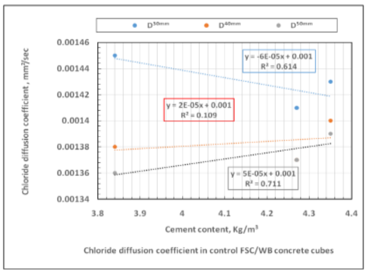
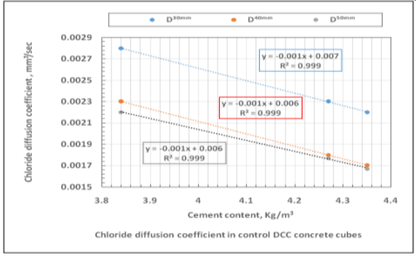
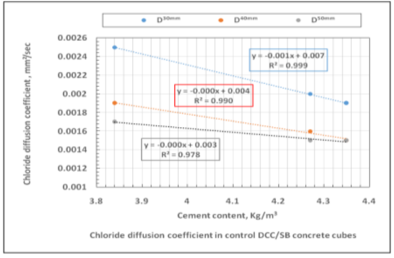


Fig.16 Cl^{-}diffusion coefft in FSC cubes Fig.17 Cl^{-}diffusion coefft in FSC cubes Fig.18 Cl^{-}diffusion coefft in FSC cubes





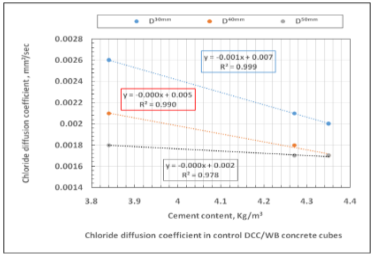
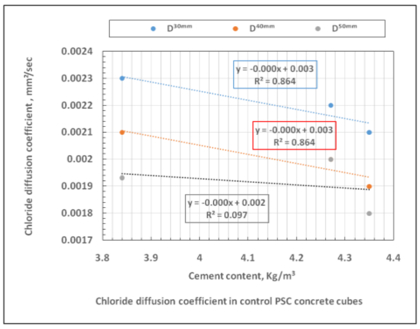
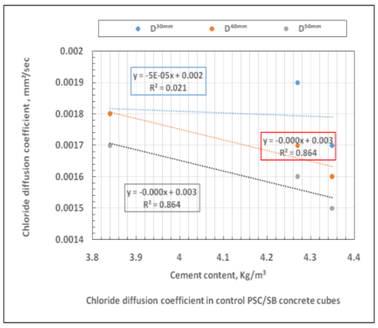


Fig.19 Cl^{-} diffusion coefft in DCC cubes Fig.20 Cl^{-} diffusion coefft in DCC cubes Fig.21 Cl^{-} diffusion coefft in DCC cubes





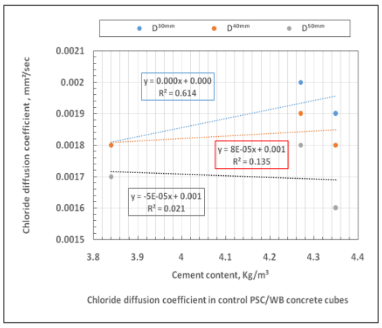


Fig.22 Cl^{-} diffusion coefft in PSC cubes Fig.23 Cl^{-} diffusion coefft in PSC cubes Fig.24 Cl^{-} diffusion coefft in PSC cubes

The chloride diffusion coefficient (CDC) was increase at drill depth 30 mm as when compare to chloride diffusion coefficient at drill depth 40 mm and 50 mm at lower aggregate volume fraction. It has also increased at drill depth 40 mm against different drill depths 50 mm under various pre-conditioned concrete cubes such as FSC/DCC/PSC condition at lower aggregate volume fraction was represent in Figs.25-33 for in case of control/impregnation concrete cubes.

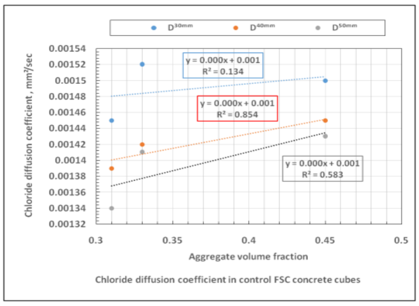


Fig.25 Cl^- diffusion coefft in FSC cubes

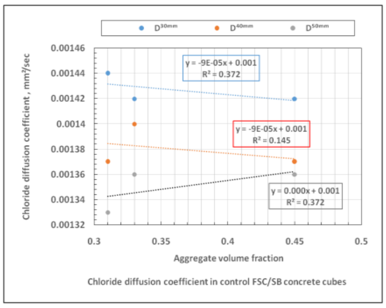


Fig.26 Cl^- diffusion coefft in FSC cubes

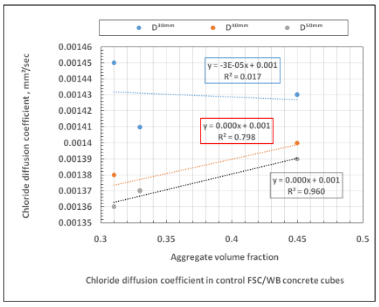


Fig.27 Cl^- diffusion coefft in FSC cubes

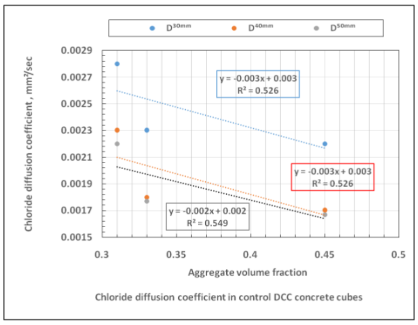


Fig.28 Cl^- diffusion coefft in DCC cubes

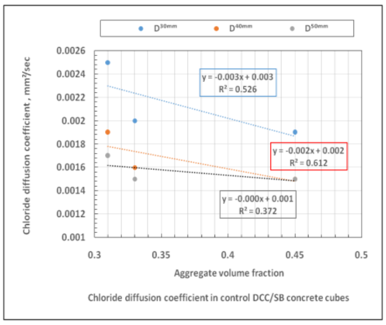


Fig.29 Cl^- diffusion coefft in DCC cubes

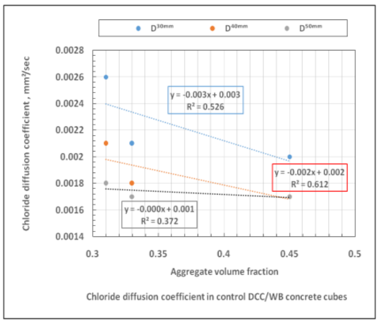


Fig.30 Cl^- diffusion coefft in DCC cubes

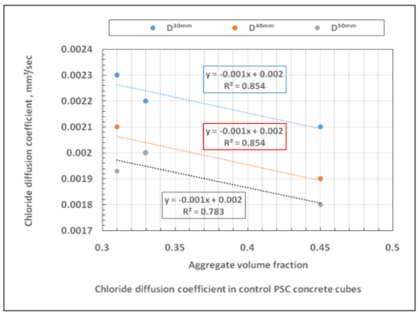


Fig.31 Cl^- diffusion coefft in PSC cubes

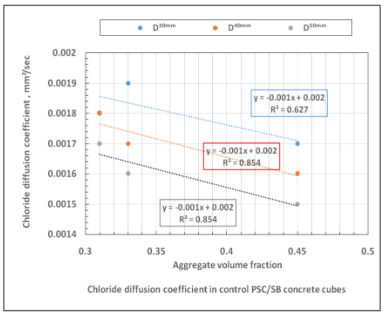


Fig.32 Cl^- diffusion coefft in PSC cubes

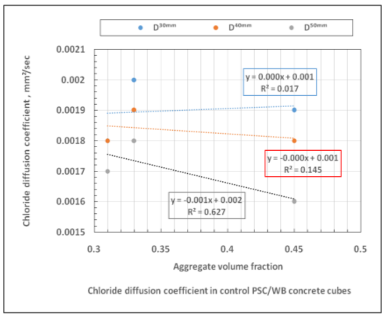


Fig.33 Cl^- diffusion coefft in PSC cubes

5. Conclusions

- The chloride diffusion coefficient (average) in DCC cubes 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 cubes at different drill depths. Average chloride diffusion coefficient was increase in control DCC cubes for constant higher compressive strength and varied slump value. Whereas it has more increase in controlled DCC cubes for lesser compressive strength and constant slump value and the chloride diffusion coefficient was decrease with increased compressive strength and constant slump value.

- Chloride diffusion coefficient (average) was decrease in solvent based and water based impregnation DCC/PSC cubes as when compare to control DCC/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 diffusion coefficient was increased in solvent/water based impregnation DCC/PSC cubes 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.

- Average chloride diffusion coefficient value in PSC cubes was increase from different drill depths (30-40-50) mm as when compared to average chloride diffusion coefficient in FSC concrete cubes at different drill depths. Average chloride diffusion coefficient was decrease in control PSC cubes for constant higher compressive strength and varied slump value. Whereas it has more increase in control, PSC cubes for lesser compressive strength and constant slump value and the chloride diffusion coefficient was decreases with increased compressive strength and constant slump value.

- Average chloride diffusion coefficient value in FSC cubes was decrease from different drill depths (30-40-50) mm as when compare to average chloride diffusion coefficient in DCC and PSC concrete cubes at different drill depths. Average chloride diffusion coefficient was slightly increase in control FSC cubes for constant higher compressive strength and varied slump value. It has decreased in controlled FSC cubes for lesser compressive strength and constant slump value. Chloride diffusion coefficient was increases with increased compressive strength and constant slump value.

- Average chloride diffusion coefficient was decrease in solvent based and water based impregnation FSC cubes as when compare to control FSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride diffusion coefficient was decreased in solvent/water, based impregnation FSC cubes for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride diffusion coefficient was going on decreases with increased compressive strength and constant slump value.

- The chloride diffusion coefficient (CDC) was increase at drill depth 30 mm as when compare to chloride diffusion coefficient at 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 cubes such as DCC, PSC, and FSC condition was represented in Figs.4-6. In fact, it has predominately increased in DCC cubes 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 cubes. Similarly, the chloride diffusion coefficient was decrease in PSC/FSC cubes 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 cubes.

- In addition to that, from this research work it is possible to establish a relationship between concrete chloride diffusion coefficient and drill depth for different designed mixtures type.

6.0 References

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