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EFFECTIVENESS OF MOISTURE ON CHLORIDE DIFFUSION COEFFICIENT IN DCC CUBES

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Abstract: *In recent years a growing interest in the effect of chloride diffusion into concrete structure has resulted in a number of extensive studies, both in the laboratory and field. Important and often expensive decisions regarding design or maintenance of concrete structures are made based on such studies. Thus a thorough consideration of the methodologies used to obtain and interpret the data is important. In practice, the diffusion of chlorides into concrete structure will be important in one aspect only, when it causes initiation and growth of critical corrosion in such a way that the lifetime of the concrete structure is severely impaired There is a need to quantify the effectiveness of moisture content on chloride diffusion coefficient in concrete cubes which is of most important factor. The 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 concrete cubes. Thus the objectives of this present research are such as, First, this research will examine the influence of concrete ingredients on the results of chloride diffusion coefficient in concrete cubes with different mixtures proportion in which slump, and w/c ratio value is 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. 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 in dry conditioned concrete cubes. It's possible to establish power type of relationship between chloride diffusion coefficient and moisture content for in case of control/impregnation concrete cubes. The chloride diffusion coefficient is higher at an initial stage when the moisture content is lesser at an initial stage for in case of all mixtures type. The moisture content is slightly lesser for in case of higher compressive strength and varied slump value. But in the case of lower compressive strength and constant slump, the moisture content is slightly higher for in lower compressive strength and constant slump value and goes on reduces with increased higher compressive strength and constant slump value for in case of control/impregnation concrete cubes.*

Keywords: *Concrete, mixture proportion, grade of concrete, w/c ratio, chloride diffusion, moisture content, slump*

1.0 Introduction

The reinforced concrete structures are exposed to harsh environments yet is often expected to last with little or no repair or maintenance for long periods of time. To do this, a durable structure needs to be produced. For reinforced concrete bridges, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. This may lead to early repair or premature replacement of the structure. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of the reinforcing steel bar by using relatively impenetrable concrete. The ability of chloride ions to penetrate the concrete must then be known for design as well as quality control purposes. The penetration of the concrete by chloride ions, however, is a slow process. It cannot be determined directly in a time frame that would be useful as a quality control measure. Therefore, in order to assess chloride penetration, a test method that accelerates the process is needed, to allow the determination of diffusion values in a reasonable time. Capillary absorption, hydrostatic pressure, and diffusion are the means by which chloride ions can penetrate concrete. The most familiar method is diffusion, the movement of chloride ions under a concentration gradient. For this to occur the concrete must have a continuous liquid phase and there must be a chloride ion concentration gradient. A second mechanism for chloride ingress is permeation, driven by pressure gradients. If there is an applied hydraulic head on one face of the concrete and chlorides are present, they may permeate into the concrete. A situation where a hydraulic head is maintained on a highway structure is rare, however a more common transport method is absorption. As a concrete surface is exposed to the environment, it will undergo wetting and drying cycles. When water (possibly containing chlorides) encounters a dry surface, it will be drawn into the pore structure though capillary suction. Absorption is driven by moisture gradients. Typically, the depth of drying is small, however, and this transport mechanism will not, by itself, bring chlorides to the level of the reinforcing steel unless the concrete is of extremely poor quality and the reinforcing steel is shallow. It does serve to quickly bring chlorides to some depth in the concrete and reduce the distance that they must diffuse to reach the rebar [Thomas *et al*. 1995]. The rate of ingress of chlorides into concrete depends on the pore structure of the concrete, which is affected by factors including materials, construction practices, and age. The penetrability of concrete is obviously related to the pore structure of the cement paste matrix. This will be influenced by the water-cement ratio of the concrete, the inclusion of supplementary cementing materials which serve to subdivide the pore structure [McGrath, 1996], and the degree of hydration of the concrete. The older the concrete, the greater amount of hydration that has occurred and thus the more highly developed will be the pore structure. This is especially true for concrete containing slower reacting supplementary cementing materials such as fly ash that require a longer time to hydrate [Bamforth, 1995]. Another influence on the pore structure is the temperature that is experienced at the time of casting. High-temperature curing accelerates the curing process so that at young concrete ages, a high temperature cured concrete will be more mature and thus have a better resistance to chloride ion penetration than a normally-cured, otherwise identical, and concrete at the same at age. However, at later ages when the normally-cured concrete has a chance to hydrate more fully, it will have a lower chloride ion diffusion coefficient than the high-temperature-cured concrete [Cao and Detwiler, 1996].

This finding has been attributed to the coarse initial structure that is developed in the high-temperature-cured concrete due to its initial rapid rate of hydration as well as the possible development of initial internal micro cracking. The rate of chloride penetration into concrete is affected by the chloride binding capacity of the concrete. Concrete is not inert relative to the chlorides in the pore solution. A portion of the chloride ions reacts with the concrete matrix becoming either chemically or physically bound, and this binding reduces the rate of diffusion. However, if the diffusion coefficient is measured after steady-state conditions have been reached, then all the binding can be presumed to have taken place and this effect will not then be observed. If a steady state condition has not been reached, then not all the binding will have occurred and this will affect the results. The chloride binding capacity is controlled by the cementing materials used in the concrete. The inclusion of supplementary cementing materials affects binding, though the exact influence is unclear [Thomas *et al.* 1995]. Also, the C3A content of the cement influences its binding capacity, with increased C3A content leading to increased binding [Midgely and Illston, 1984]. Chloride penetration into the reinforced concrete cover is at the origin of early damage due to corrosion of the steel reinforcement. The penetration rate of chloride, however, depends strongly of water content. Diffusion coefficients as measured on saturated concrete are used for the prediction of service life by means of Fick's second law, chloride penetration may be overestimated. Chloride mobility in concrete, which is in equilibrium with 50 % RH, is very low. This has to be taken into consideration in realistic service life prediction [Zhang *et al*. 2014]. Exposure conditions (harsh marine) provide an aggressive condition for reinforced concrete structures, mainly due to its hot, humid and saline environment. In this study, variations in diffusion coefficient value over time is investigated and compared in five different exposure conditions for silica fume concrete with different water to binder ratios under long-term exposure in a marine environment. Regression analysis of the surface chloride content data is carried out by applying two empirical models that were in the literature and compared to each other to suggest the best fitted model in order to make a logical trend about surface chloride content for long term exposure conditions [Siamak Riyazi *et al*. 2013]. Research proposes a combined application of composite theory and Powers' model for microstructural development for the estimation of the diffusion coefficient as a function of the moisture content of a defect-free cementitious material. Measurements of chloride diffusion in mortar samples stored at 65% and 85% RH, as well as in vacuum-saturated mortar samples illustrate the applicability of the method [Erik *et al*. 2003].

The concrete durability is dependent on mechanism of moisture transport within the concrete matrix. The moisture transport is occurred in marine environment, where drying and wetting cycles occur, which leads chloride to penetrate into reinforced concrete structures. In fact that, when chloride reaches the rebars, corrosion can appear and that decreases the service life time of the concrete structures. Actually so many descriptions about moisture transport in concrete can be found in the literature such as the authors [Arfvidsson.1999] describe moisture transport in concrete structures by using a single diffusion coefficient. The moisture diffusion factor is very the long term duration performance of cementitious materials which is described by so many diffusion equations as well as solved by numerous numerical methods if provided the coefficients are well known. However, there is a need to investigate about diffusion coefficient and transport behavior of the materials which is still remain an unsolved problem even though many different models have been proposed [Bazant, and Najjar, 1972]. There is a major difficulty in establishing reliable diffusion parameters, because diffusion of moisture inside cementitious materials is basically controlled by the micro-structure of the material, and pore-size distribution. In fact that, the microstructure is changing with age as well as with relative humidity in the pores. Therefore, all of the parameters, such as the water/cement ratio, type of cement, and curing time, which affect the formation of the microstructure of cementitious materials, thus have significant effects on diffusion parameters. The water movement is very slow in the concrete in turn it takes too much time to attain the equilibrium state as when compared to other porous materials and the study of water movement is firstly done by [Sakata, 1983]. He is the one who is used Boltzmann-Matano method other methods, in fact that, Boltzmann-Matano method has a benefit regarding cement based material research. Also an extensive research is carried out by Akita and Fujiwara on the water movement [Akita *et al.* 1990]. They used different approaches to obtain the relationship between water content and water diffusion coefficient, and obtained consistent results to those by [Sakata, 1983]. In addition to these results that, they found the temperature dependency of water diffusion coefficient, water diffusion coefficient in very low water content region, and water diffusion coefficient of desorption and adsorption processes. An improved formula for the dependence of diffusivity on pore humidity is proposed by [Yunping Xi, *et al* 1994]. The improved model for moisture diffusion is found to give satisfactory diffusion profiles and long-term drying predictions. The model is suited for incorporation into finite element programs for shrinkage and creep effects in concrete structures. An extensive research is carried out by researchers [Rafik Belarbi *et al*. 2006] that, gravimetric method is adopted for the determination of moisture diffusion coefficient and moisture distribution inside porous building materials. It's confirmed from the results that, the moisture diffusion coefficient during absorption is higher than desorption process due to the absorption hysteresis, an increase of water-cement ratio in cement paste. It's also clear from results that, the high-strength concrete has a lower moisture diffusion coefficient than that of normal strength concrete under the same curing period. An experimental work is carried out by [Su-Tae Kang et al. 2012] on moisture diffusion in order to investigate the variation of the moisture diffusion coefficient with age and temperature under different temperature conditions. Based on these experimental results, it's possible to develop a new model of the moisture diffusion coefficient considering the aging and temperature which is implemented by a numerical inverse analysis. As this model is considers factors such as porosity, humidity, and temperature, beyond the existing model for hardened concrete, and the suggested diffusion coefficient model is applicable to early age concrete. The investigation about the moisture transport mechanisms in concrete is important in order to determine the service life of a concrete structure. In fact so many authors were managed to describe the global moisture transport mechanisms in concrete structures during wetting/drying cycles by using Fick's laws of diffusion. An extensive comparison is made between the results of a model with two diffusion coefficients and a model with a single diffusion coefficient, where the diffusion coefficient is the average of the wetting and drying diffusion coefficient by investigators [Taher *et al*. 2013].The result is computed for one cycle of wetting and drying and simulations show that, there are differences in the results of the models. In order to validate the model and to investigate which of the models describes the moisture transport most accurately, in fact that, there is an extensive experimental work is needed. The research work is carried out by investigators [Xiao Zhang and Hongduo Zhao, 2015] that, in order to investigate the characterization of moisture diffusion inside early-age concrete slabs subjected to curing and in which time-dependent relative humidity distributions of three mixture proportions subjected to three different curing methods and sealed condition were measured for about 28 days. Experimental results show that the RH reducing rate inside concrete under air curing is greater than the rates under membrane-forming compound curing and water curing. In addition to that, the comparison between model simulation and experimental results indicates that, the improved model is able to reflect the effect of curing on moisture diffusion in early-age concrete slabs.

2.0 Research Objectives

There is a need to study chloride transport mechanisms with different designed mixtures type in order to assess the rate of chloride diffusion coefficient in concrete structures. The 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 concrete cubes. Thus the objectives of this present research is to examine the influence of concrete ingredients on the results of concrete chloride diffusion coefficient in concrete cubes with different mixtures proportion in which slump, and w/c ratio value is 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. Seventy-two concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the concrete chloride diffusion coefficient in concrete cubes.

3.0 Experimental program

In the present research work, six different mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm^3). Three of the mixtures type were concrete cubes (100 mm^3) with a compressive strength 40 N/mm^2, slump (0-10, 10-30, and 60-180 mm), and different w/c (0.45, 0.44, and 0.43). These mixtures were designated 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 designated as M4, M5, and M6. The overall details of the mixture proportions were to be represented in Table.1-2. Twelve concrete cubes of size (100 mm^3) were cast for each mixture and overall Seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used is crushed 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 will not be disclosed and they will be referred to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

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

Mix No	Comp/mean target strength(N/mm²)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA(Kg) 10 mm	Mixture Proportions
M1	40/47.84	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M2	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M3	40/47.84	60-180	0.43	5.43	2.34	6.42	14.30	1:1.18:2.63

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

Mix No	Comp/mean target strength(N/mm²)	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 is determined from the solution of one-dimensional Fick's theory for unsteady diffusion process. The percentage of moisture gain at any time t, (M_t) can obtain from the solution of the one-dimensional Fick's model with constant boundary conditions as:

$$Mt = M_{\infty}\{1 - \frac{8}{\pi^2}\sum_{n=0}^{\infty}(2n+1)^{-2}\exp[\frac{-D(2n+1)^2\pi^2 t}{L^2}]]$$

Where $M\infty$ is the moisture gain at saturation equilibrium (%), n is a known integer which is varied from material to material, L is the thickness of the material, and D is the diffusivity of the material. At initial stages of diffusion, the solution for Fick's law at lesser time reduces to as:

$$\frac{Mt}{M\infty} = 4\sqrt{\left(\frac{D}{\pi L^2}\right)t}$$

The variation of diffusion coefficient and moisture content in concrete cubes for in case of different mixtures type is represented as in Table.3-4.

Table: 3Chloride diffusion coefficient in concrete cubes

Mix ID	1 day	3 day	6 day	9 day	12 day	15 day	18 day	21 day	24 day
M1CC	0.971	0.782	0.689	0.609	0.573	0.542	0.520	0.503	0.487
M1SB	0.932	0.718	0.690	0.598	0.562	0.536	0.516	0.499	0.488
M1WB	0.940	0.744	0.689	0.599	0.569	0.541	0.520	0.504	0.488
M2CC	0.932	0.783	0.686	0.610	0.569	0.541	0.520	0.502	0.488
M2SB	0.945	0.749	0.689	0.600	0.562	0.536	0.515	0.499	0.488
M2WB	0.952	0.757	0.689	0.598	0.564	0.536	0.517	0.501	0.488
M3CC	0.941	0.774	0.689	0.607	0.570	0.541	0.519	0.502	0.488
M3SB	0.942	0.778	0.690	0.608	0.566	0.539	0.518	0.502	0.488
M3WB	0.939	0.786	0.565	0.608	0.567	0.541	0.518	0.502	0.488
M4CC	0.980	0.776	0.634	0.604	0.569	0.538	0.516	0.499	0.486
M4SB	0.992	0.786	0.690	0.609	0.570	0.543	0.521	0.503	0.488

M4WB	1.052	0.823	0.690	0.636	0.592	0.563	0.538	0.519	0.502
M5CC	0.988	0.792	0.658	0.614	0.580	0.551	0.528	0.510	0.499
M5SB	1.180	0.912	0.690	0.702	0.656	0.627	0.609	0.593	0.576
M5WB	0.900	0.732	0.634	0.576	0.539	0.513	0.493	0.478	0.465
M6CC	0.956	0.776	0.679	0.606	0.569	0.543	0.521	0.502	0.488
M6SB	0.894	0.694	0.690	0.544	0.557	0.533	0.516	0.502	0.488
M6WB	0.922	0.741	0.676	0.602	0.565	0.536	0.515	0.501	0.488

Table: 4 Moisture content in concrete cubes

Mix ID	1 day	3 day	6 day	9 day	12 day	15 day	18 day	21 day	24 day
M1CC	3.513	3.948	4.096	4.139	4.234	4.246	4.269	4.314	4.336
M1SB	2.342	2.408	2.716	2.888	2.953	2.998	3.042	3.080	3.147
M1WB	2.655	2.874	3.139	3.235	3.372	3.405	3.444	3.490	3.502
M2CC	3.441	4.210	4.340	4.423	4.442	4.486	4.538	4.574	4.620
M2SB	2.334	2.538	2.742	2.823	2.859	2.905	2.939	2.986	3.049
M2WB	2.490	2.721	2.866	2.948	3.024	3.057	3.108	3.153	3.203
M3CC	3.773	4.424	4.534	4.710	4.801	4.829	4.875	4.921	4.971
M3SB	2.905	3.434	3.589	3.624	3.630	3.684	3.725	3.772	3.819
M3WB	2.923	3.542	3.604	3.674	3.695	3.749	3.771	3.819	3.865
M4CC	4.242	4.606	4.658	4.837	4.953	4.955	4.981	5.029	5.104
M4SB	3.698	4.017	4.145	4.183	4.226	4.290	4.317	4.356	4.383
M4WB	4.789	5.079	5.208	5.245	5.251	5.314	5.325	5.337	5.339
M5CC	3.525	3.926	4.002	4.085	4.209	4.250	4.269	4.311	4.397
M5SB	3.781	3.911	3.978	4.015	4.046	4.136	4.274	4.368	4.410
M5WB	2.439	2.795	2.914	2.997	3.024	3.066	3.098	3.154	3.193
M6CC	3.741	4.270	4.407	4.505	4.592	4.676	4.704	4.732	4.774
M6SB	1.374	1.433	1.484	1.529	1.848	1.894	1.940	1.986	2.004
M6WB	2.307	2.579	2.763	2.947	2.994	3.013	3.054	3.113	3.165

4.0 Discussion about Results

The chloride diffusion coefficient is gradually increased at initial time duration, afterwards deviates with square root of time duration and reaches equilibrium in turn indicates that, pore structure is attained fully saturated condition. The chloride diffusion coefficient is increased at time interval (1 day) as when compared to time interval (28 day) for in case of all designed control mixtures type [M1CC-M2CC:4.01-0.14, M1CC-M3CC:3.07-0.10, M1CC-M4CC:-0.96-0.80, M1CC-M5CC:-1.76-(-1.55), M1CC-M6CC:1.51-0.04, M2CC-M3CC:-0.98-(-0.03), M2CC-M4CC:-5.18-0.67, M2CC-M5CC:-6.02-(-1.69), M2CC-M6CC:-2.61-(-0.10), M3CC-M4CC:-4.15-0.70, M3CC-M5CC:-4.99-(-1.66), M3CC-M6CC:-1.61-(-0.06), M4CC-M5CC:-0.80-(-2.37), M4CC-M6CC:2.44-(-0.77), and M5CC-M6CC:3.22-1.57]%. The diffusion coefficient is initially increased, in turn due to concentration gradient. Concentration gradient is more at an initial time duration, due to that the rate of absorption is also more, once the pore structure is fully saturated, the rate of diffusion coefficient goes on decreases with time duration. Thus the concentration gradient is more at an initial stage, goes on decreases as time passes and thus diffusion coefficient is reduced gradually as time in turn reaches equilibrium state. The variation of chloride diffusion coefficient in control concrete cubes with moisture content for in different mixtures type (M1CC-M6CC) is as shown in Figs.1a-1f respectively. Chloride diffusion coefficient is correlated with square root of time by power type of equation for in all designed control mixtures type (M1CC-M6CC).

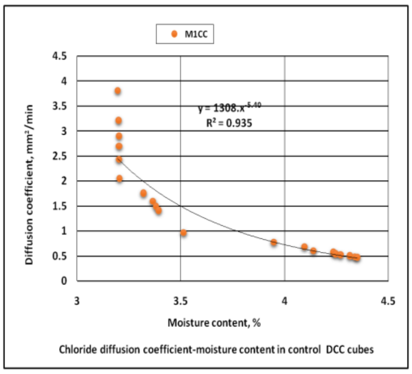


Fig.1a Cl$^-$ diffusion coefficient in mix M1

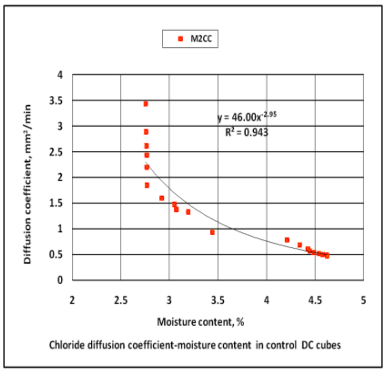


Fig.1b Cl$^-$ diffusion coefficient in mix M2

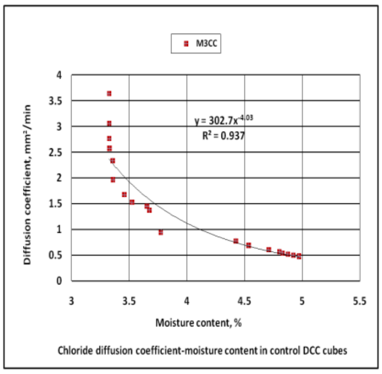


Fig.1c Cl$^-$ diffusion coefficient in mix M3

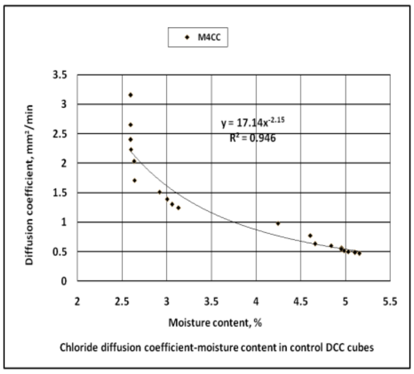


Fig.1d Cl$^-$ diffusion coefficient in mix M4

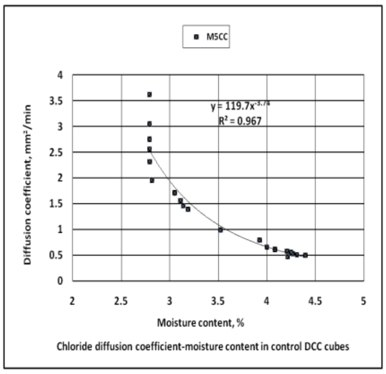


Fig.1e Cl$^-$ diffusion coefficient in mix M5

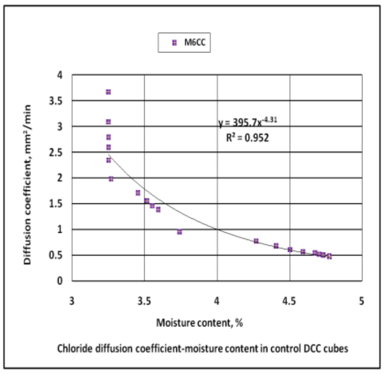


Fig.1f Cl$^-$ diffusion coefficient in mix M6

The chloride diffusion coefficient is increased at initial time duration, deviates with square root of time duration and reaches equilibrium when the concrete structure is attained fully saturated condition. The chloride diffusion coefficient is increased at time interval (1 day) as when compared to time interval (21 day) for in case of all designed control mixtures type as when compared to impregnation concrete cubes [M1CC-M1SB:4.01-0.67, M1CC-M1WB:3.16-(-0.20), M2CC-M2SB:-1.39-0.53, M2CC-M2WB:-2.19-0.25, M3CC-M3SB:-0.12-0.11, M3CC-M3WB:0.20-0.12, M4CC-M4SB:-1.23-(-0.90) M4CC-M4WB:-7.29-(-4.03), M5CC-M5SB:-19.41-(-16.07), M5CC-M5WB:8.90-6.32, M6CC-M6SB:6.55-0.11, M6CC-M6WB:-3.56-0.39, and M1WB-M1SB:0.89-0.87, M2WB-M2SB:0.78-0.29, and M3WB-M3SB:-0.32-(-0.01), M4WB-M4SB: 5.65-3.00, M5WB-M5SB:-31.09-(-23.90), M6WB-M6SB:3.10-(-0.28)]%. The diffusion coefficient is initially increased which may be due to concentration gradient. Variation of chloride diffusion coefficient in impregnation concrete cubes for in case of different mixture type (M1SB-M6SB) is as shown in Figs.2a-2f respectively. Chloride diffusion coefficient is directly correlated to the square root of time by power type of equation in all designed impregnation mixtures type (M1SB-M6SB). The chloride diffusion coefficient is increased at time interval (1 day) as when compared to time interval (21 day) for in case of all designed impregnation mixtures type as when compared to different designed impregnation mixture type [M1SB-M2SB:-1.39-0.00, M1SB-M3SB:-1.10-(-0.46), M1SB-M4SB:-6.47-(-0.77), M1SB-M5SB:-26.60-(-18.67), M1SB-M6SB:4.11-(-0.52), M2SB-M3SB:0.29-(-0.46), M2SB-M4SB:-5.01-(-0.77), M2SB-M5SB:-24.86-(-18.67), M2SB-M6SB:5.43-(-0.52), M3SB-M4SB:-5.31-(-0.31), M3SB-M5SB:-25.22-(18.12), M3SB-M6SB:5.15-(-0.06), and M4SB-M6SB:-18.91-(-17.76), M4SB-M6SB:9.94-0.25, and M5SB-M6SB:24.26-15.29]%.

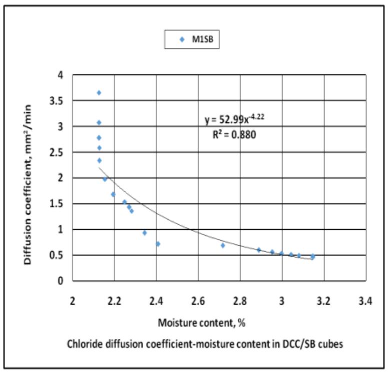


Fig.2a Cl^- diffusion coefficient in mix M1

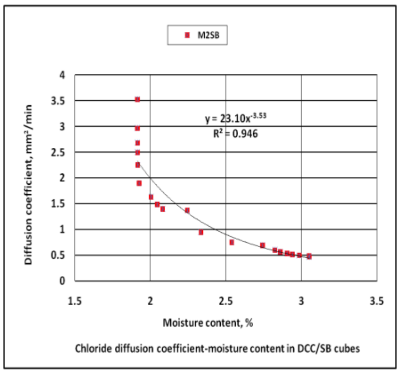


Fig.2b Cl^- diffusion coefficient in mix M2

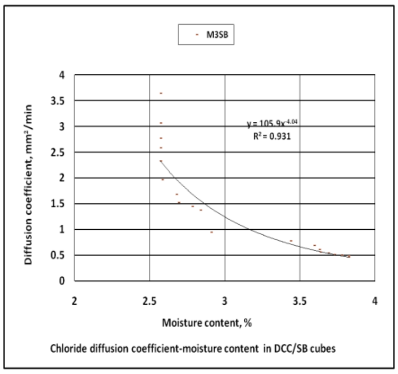


Fig.2c Cl^- diffusion coefficient in mix M3

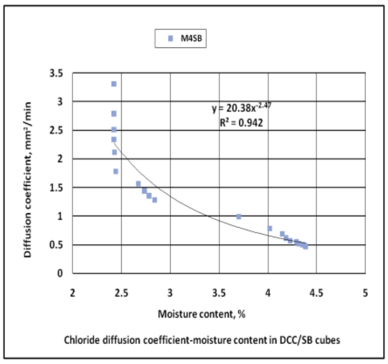


Fig.2d Cl^- diffusion coefficient in mix M4

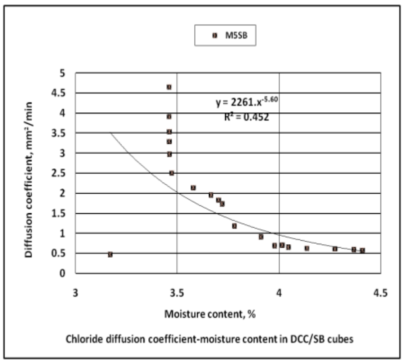


Fig.2e Cl^- diffusion coefficient in mix M5

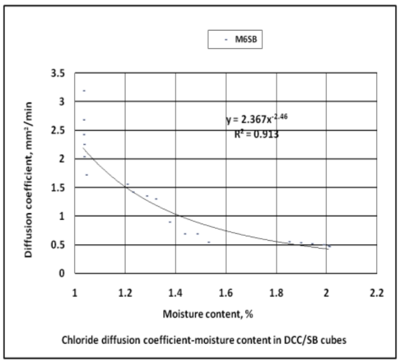
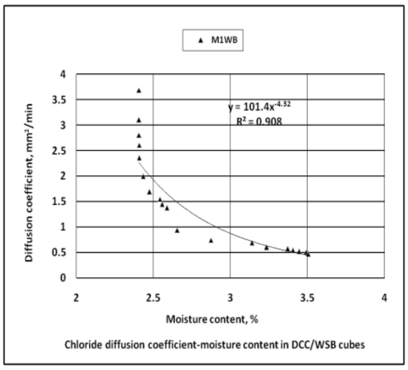


Fig.2f Cl^- diffusion coefficient in mix M6

The chloride diffusion coefficient is increased at time interval (1 day) as when compared to time interval (21 day) for in case of all designed impregnation mixtures type as when compared to different designed impregnation mixture type [M1WB-M2WB:-1.29-0.58, M1WB-M3WB:0.11-0.43, M1WB-M4WB:-11.85-(-2.98), M1WB-M5WB:4.28-5.06, M1WB-M6WB:1.92-0.63, M2WB-M3WB:1.38-(-0.16), M2WB-M4WB:-10.42-(-3.59), M2WB-M5WB:5.45-4.50, M2WB-M6WB:3.17-0.05, M3WB-M4WB:-11.97-(-3.42), M3WB-M5WB:4.17-4.66, M3WB-M6WB:1.81-0.21, and M4WB-M6WB:14.42-7.81, M4WB-M6WB:12.31-3.51, and M5WB-M6WB:-2.46-(-4.67)]%. The diffusion coefficient is initially increased which may be due to concentration gradient. Variation of chloride diffusion coefficient in impregnation concrete cubes for in case of different mixture type (M1WB-M6WB) is as shown in Figs.3a-3f respectively. Chloride diffusion coefficient is directly correlated to the square root of time by power type of equation in all designed impregnation mixtures type (M1WB-M6WB).



ig.3a Cl^- diffusion coefficient in mix M1

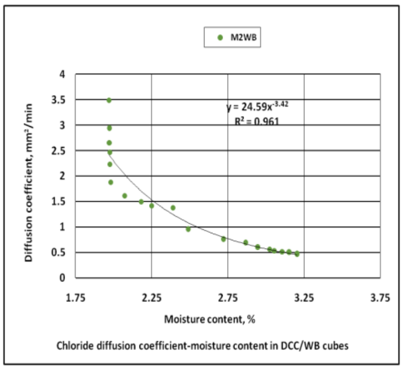


Fig.3b Cl^- diffusion coefficient in mix M2

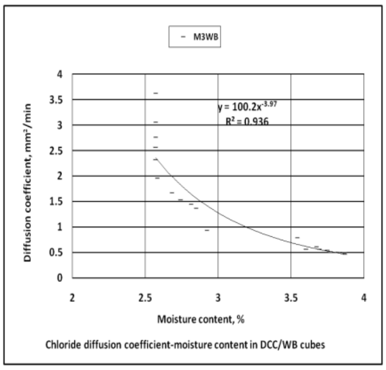


Fig.3c Cl^- diffusion coefficient in mix M3

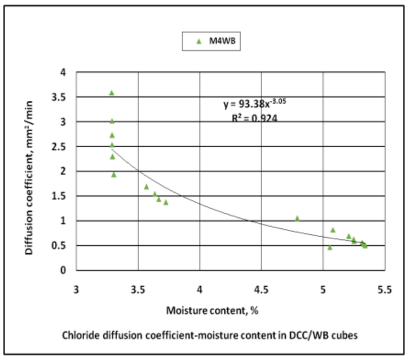


Fig.3d Cl^- diffusion coefficient in mix M4

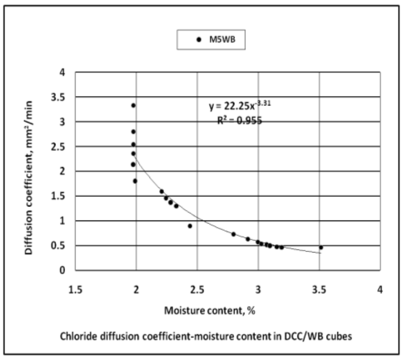


Fig.3e Cl^- diffusion coefficient in mix M5

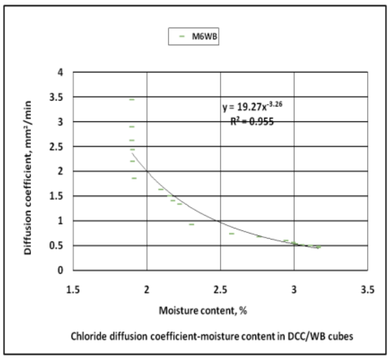
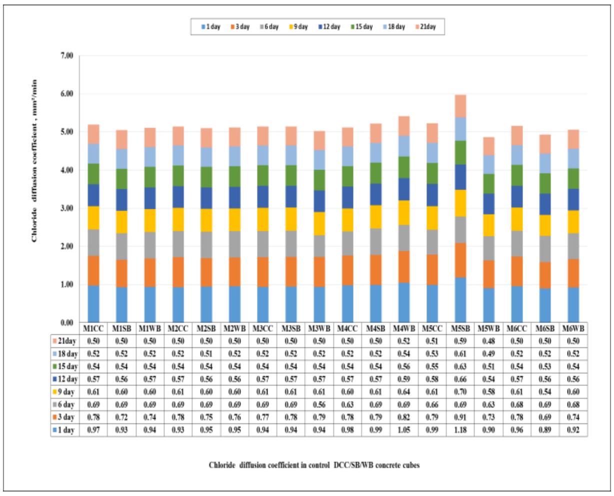


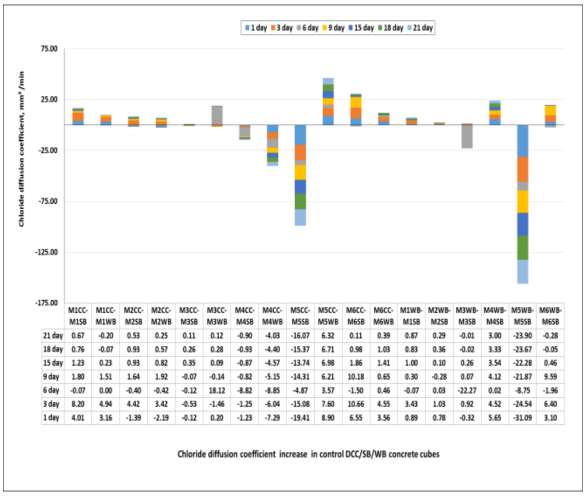
Fig.3f Cl^- diffusion coefficient in mix M6

The chloride diffusion coefficient is initially increased/decreased in control concrete cubes (M1CC-M6CC) as when compared to impregnation concrete cubes (M1SB-M6SB, and M1WB-M6WB) and variation of chloride diffusion coefficient in control/impregnation concrete cubes for in case of different mixture type is as shown in Figs.4a-4f respectively.



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
21day	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.52	0.51	0.59	0.48	0.50	0.50	0.50
18 day	0.52	0.52	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.52	0.52	0.54	0.53	0.61	0.49	0.52	0.52	0.52
15 day	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.56	0.55	0.63	0.51	0.54	0.53	0.54
12 day	0.57	0.56	0.57	0.57	0.56	0.56	0.57	0.57	0.57	0.57	0.57	0.59	0.58	0.66	0.54	0.57	0.56	0.56
9 day	0.61	0.60	0.60	0.61	0.60	0.60	0.61	0.61	0.61	0.60	0.61	0.64	0.61	0.70	0.58	0.61	0.54	0.60
6 day	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.56	0.63	0.69	0.69	0.66	0.69	0.63	0.68	0.69	0.68
3 day	0.78	0.72	0.74	0.78	0.75	0.76	0.77	0.78	0.79	0.78	0.79	0.82	0.79	0.91	0.73	0.78	0.69	0.74
1 day	0.97	0.93	0.94	0.93	0.95	0.95	0.94	0.94	0.94	0.98	0.99	1.05	0.99	1.18	0.90	0.96	0.89	0.92

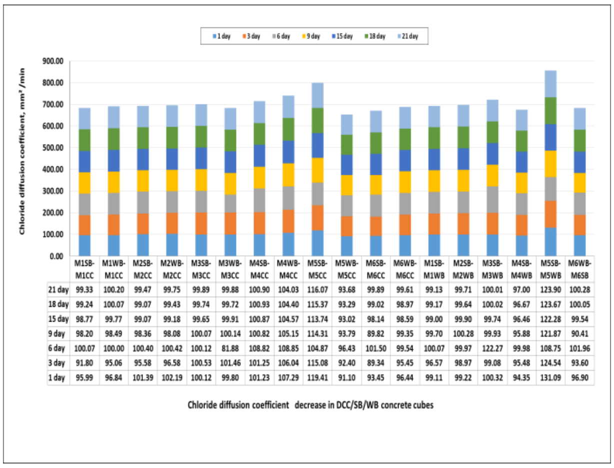
Chloride diffusion coefficient in control DCC/SB/WB concrete cubes



	M1CC-M1SB	M1CC-M1WB	M2CC-M2SB	M2CC-M2WB	M3CC-M3SB	M3CC-M3WB	M4CC-M4SB	M4CC-M4WB	M5CC-M5SB	M5CC-M5WB	M6CC-M6SB	M6CC-M6WB	M1WB-M1SB	M2WB-M2SB	M3WB-M3SB	M4WB-M4SB	M5WB-M5SB	M6WB-M6SB
21 day	0.67	-0.20	0.53	0.25	0.11	0.12	-0.90	-4.03	-16.07	6.32	0.11	0.39	0.87	0.29	-0.01	3.00	-23.90	-0.28
18 day	0.76	-0.07	0.93	0.57	0.26	0.28	-0.93	-4.40	-15.37	6.71	0.98	1.03	0.83	0.36	-0.02	3.33	-23.67	-0.05
15 day	1.23	0.23	0.93	0.82	0.35	0.09	-0.87	-4.57	-13.74	6.98	1.86	1.41	1.00	0.10	0.26	3.54	-22.28	0.46
9 day	1.80	1.51	1.64	1.92	-0.07	-0.14	-0.82	-5.15	-14.31	6.21	10.18	0.65	0.30	-0.28	0.07	4.12	-21.87	9.59
6 day	-0.07	0.00	-0.40	-0.42	-0.12	18.12	-8.82	-8.85	-4.87	3.57	-1.50	0.46	-0.07	0.03	-22.27	0.02	-8.75	-1.96
3 day	8.20	4.94	4.42	3.42	-0.53	-1.46	-1.25	-6.04	-15.08	7.60	10.66	4.55	3.43	1.03	0.92	4.52	-24.54	6.40
1 day	4.01	3.16	-1.39	-2.19	-0.12	0.20	-1.23	-7.29	-19.41	8.90	6.55	3.56	0.89	0.78	-0.32	5.65	-31.09	3.10

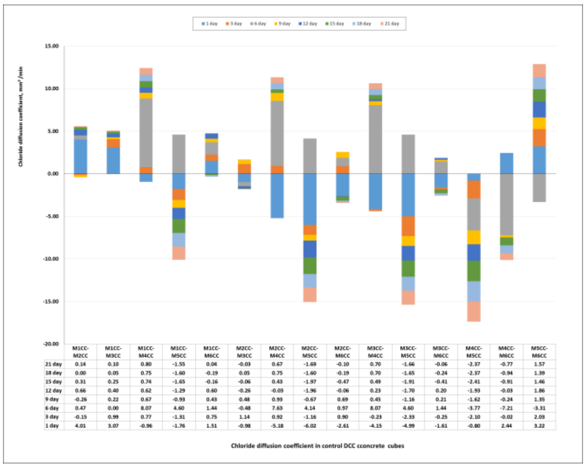
Chloride diffusion coefficient increase in control DCC/SB/WB concrete cubes

Fig.4a Cl^- diffusion coefficient in control DCC/IC concrete cubes Fig.4b Cl^- diffusion coefficient in control DCC/IC concrete cubes



	M1SB-M1CC	M1WB-M1CC	M2SB-M2CC	M2WB-M2CC	M3SB-M3CC	M3WB-M3CC	M4SB-M4CC	M4WB-M4CC	M5SB-M5CC	M5WB-M5CC	M6SB-M6CC	M6WB-M6CC	M1SB-M1WB	M2SB-M2WB	M3SB-M3WB	M4SB-M4WB	M5SB-M5WB	M6WB-M6SB
21 day	99.33	100.20	99.47	99.75	99.89	99.88	100.90	104.03	116.07	93.68	99.89	99.61	99.13	99.71	100.01	97.00	123.90	100.28
18 day	99.24	100.07	99.07	99.43	99.74	99.72	100.93	104.40	115.37	93.29	99.02	98.97	99.17	99.64	100.02	96.67	123.67	100.05
15 day	98.77	99.77	99.07	99.18	99.65	99.91	100.87	104.57	113.74	93.02	98.14	98.59	99.00	99.90	99.74	96.46	122.28	99.54
9 day	98.20	98.49	98.36	98.08	100.07	100.14	100.82	105.15	114.31	93.79	89.82	99.35	99.70	100.28	99.93	95.88	121.87	90.41
6 day	100.07	100.00	100.40	100.42	100.12	81.88	108.82	108.85	104.87	96.43	101.50	99.54	100.07	99.97	122.27	99.98	108.75	101.96
3 day	91.80	95.06	95.58	96.58	100.53	101.46	101.25	106.04	115.08	92.40	89.34	95.45	96.57	98.97	99.08	95.48	124.54	93.60
1 day	95.99	96.84	101.39	102.19	100.12	99.80	101.23	107.29	119.41	91.10	93.45	96.44	99.11	99.22	100.32	94.35	131.09	96.90

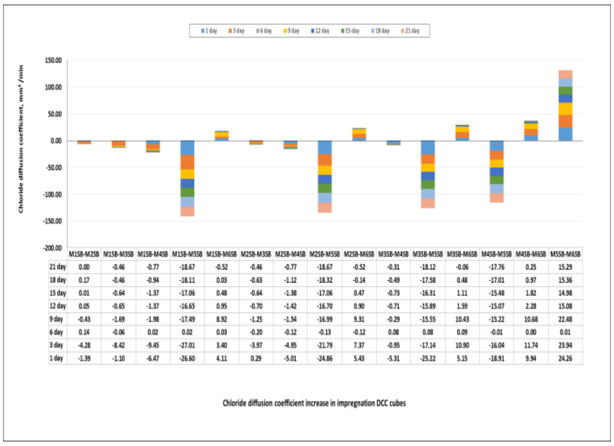
Chloride diffusion coefficient decrease in DCC/SB/WB concrete cubes



	M1CC-M2CC	M1CC-M3CC	M1CC-M4CC	M1CC-M5CC	M1CC-M6CC	M2CC-M3CC	M2CC-M4CC	M2CC-M5CC	M2CC-M6CC	M3CC-M4CC	M3CC-M5CC	M3CC-M6CC	M4CC-M5CC	M4CC-M6CC	M5CC-M6CC
21 day	0.14	0.10	0.80	-1.55	0.04	-0.03	0.67	-1.69	-0.10	0.70	-1.66	-0.06	-2.37	-0.77	1.57
18 day	0.00	0.05	0.75	-1.60	-0.19	0.05	0.75	-1.60	-0.19	0.70	-1.65	-0.24	-2.37	-0.94	1.39
15 day	0.31	0.25	0.74	-1.65	-0.16	-0.06	0.43	-1.97	-0.47	0.49	-1.91	-0.41	-2.41	-0.91	1.46
12 day	0.66	0.40	0.62	-1.29	0.60	-0.26	-0.03	-1.96	-0.06	0.23	-1.70	0.20	-1.93	-0.03	1.86
9 day	-0.26	0.22	0.67	-0.93	0.43	0.48	0.93	-0.67	0.69	0.45	-1.16	0.21	-1.62	-0.24	1.35
6 day	0.47	0.00	8.07	4.60	1.44	-0.48	7.63	4.14	0.97	8.07	4.60	1.44	-3.77	-7.21	-3.31
3 day	-0.15	0.99	0.77	-1.31	0.75	1.14	0.92	-1.16	0.90	-0.23	-2.33	-0.25	-2.10	-0.02	2.03
1 day	4.01	3.07	-0.96	-1.76	1.51	-0.98	-5.18	-6.02	-2.61	-4.15	-4.99	-1.61	-0.80	2.44	3.22

Chloride diffusion coefficient in control DCC cconcrete cubes

Fig.4c Cl^- diffusion coefficient in control DCC/IC concrete cubes Fig.4d Cl^- diffusion coefficient in control DCC concrete cubes



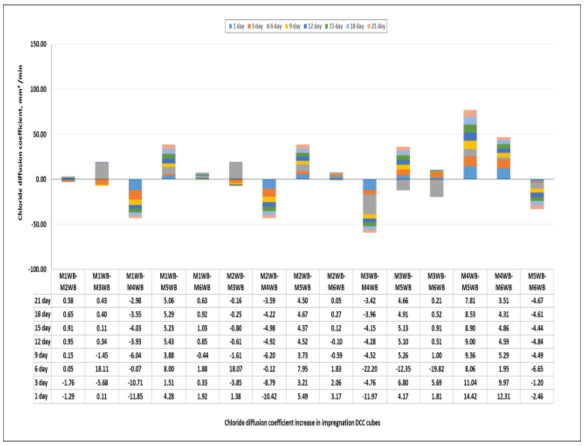
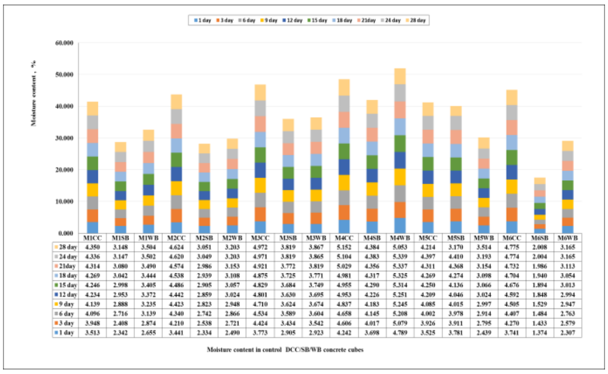


Fig.4e Cl⁻ diffusion coefficient in DCC/IC concrete cubes Fig.4f Cl⁻ diffusion coefficient in DCC/IC concrete cubes

The moisture content is initially increased in control concrete cubes (M1CC-M6CC) as when compared to impregnation concrete cubes (M1SB-M6SB, and M1WB-M6WB) and variation of moisture content in control/impregnation concrete cubes for in case of different mixture type is as shown in Figs.5a-5e respectively.



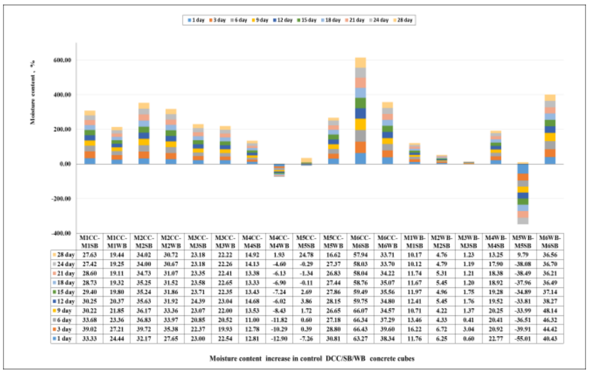


Fig.5a Moisture content in control DCC/IC concrete cubes Fig.5b Moisture content in control DCC/IC concrete cubes

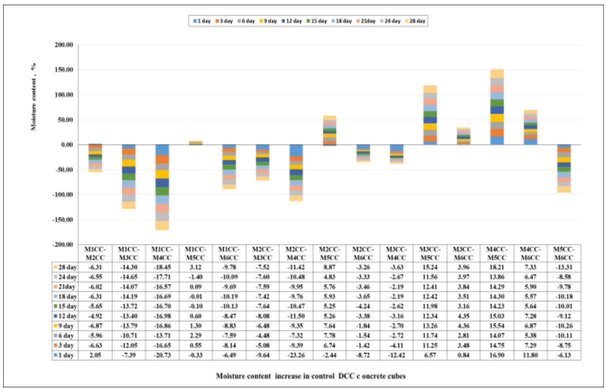
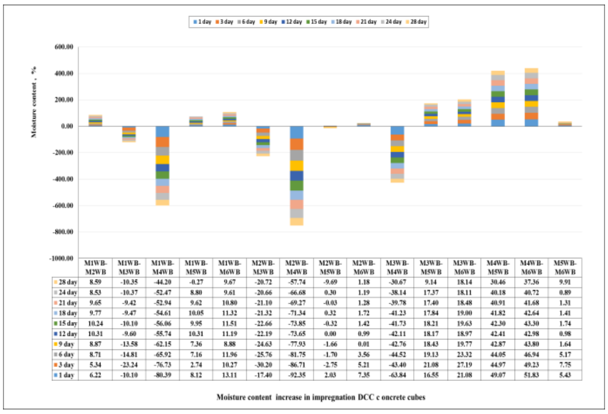


Fig.5c Moisture content increase in control DCC concrete cubes Fig.5d Moisture content increase in DCC/IC concrete cubes



	M1WB-M2WB	M1WB-M3WB	M1WB-M4WB	M1WB-M5WB	M1WB-M6WB	M2WB-M3WB	M2WB-M4WB	M2WB-M5WB	M2WB-M6WB	M3WB-M4WB	M3WB-M5WB	M3WB-M6WB	M4WB-M5WB	M4WB-M6WB	M5WB-M6WB
28 day	8.59	-10.35	-44.20	-0.27	9.67	-20.72	-57.74	-9.69	1.18	-30.67	9.14	18.14	30.46	37.36	9.91
24 day	8.53	-10.37	-52.47	8.80	9.61	-20.66	-66.68	0.30	1.19	-38.14	17.37	18.11	40.18	40.72	0.89
21 day	9.65	-9.42	-52.94	9.62	10.80	-21.10	-69.27	-0.03	1.28	-39.78	17.40	18.48	40.91	41.68	1.31
18 day	9.77	-9.47	-54.61	10.05	11.32	-21.32	-71.34	0.32	1.72	-41.23	17.84	19.00	41.82	42.64	1.41
15 day	10.24	-10.10	-56.06	9.95	11.51	-22.66	-73.85	-0.32	1.42	-41.73	18.21	19.63	42.30	43.30	1.74
12 day	10.31	-9.60	-55.74	10.31	11.19	-22.19	-73.65	0.00	0.99	-42.11	18.17	18.97	42.41	42.98	0.98
9 day	8.87	-13.58	-62.15	7.36	8.88	-24.63	-77.93	-1.66	0.01	-42.76	18.43	19.77	42.87	43.80	1.64
6 day	8.71	-14.81	-65.92	7.16	11.96	-25.76	-81.75	-1.70	3.56	-44.52	19.13	23.32	44.05	46.94	5.17
3 day	5.34	-23.24	-76.73	2.74	10.27	-30.20	-86.71	-2.75	5.21	-43.40	21.08	27.19	44.97	49.23	7.75
1 day	6.22	-10.10	-80.39	8.12	13.11	-17.40	-92.35	2.03	7.35	-63.84	16.55	21.08	49.07	51.83	5.43

Fig.5e Moisture content increase in DCC/IC concrete cubes

5.0 Conclusions

- From this research work that, it's possible to establish power type of relationship between chloride diffusion coefficient and moisture content for in case of control/impregnation concrete cubes. The chloride diffusion coefficient is higher at an initial stage when the moisture content is lesser at an initial stage for in case of all mixtures type.

- The moisture content is slightly lesser for in case of higher compressive strength and varied slump value. But in the case of lower compressive strength and constant slump, the moisture content is slightly higher for in lower compressive strength and constant slump value and goes on reduces with increased higher compressive strength and constant slump value for in case of control/impregnation concrete cubes.

6.0 References

Arfvidsson. J. (1999). *A new algorithm to calculate the isothermal moisture penetration for periodically varying relative humidity at the boundary*. Nordic journal of building physics; 2.
Akita, H., Fujiwara, T, and Ozaka, Y. (1990). *Water movement within mortar due to drying and wetting*, Proceedings of JSCE, 420: 61-69 (In Japanese).
Bazant, Z.P., and Najjar, L.J.(1972). *Nonlinear water diffusion in non-saturated concrete,* Matriaux et constructions, 5: 3-20.
Bamforth, P.B. (1995). *Improving the durability of concrete using mineral admixtures*, Concrete durability in the Arabian Gulf, pp. 1-26.
Cao, Y., and Detwiler, R.J. (1995). *Backscatter Electron imaging of cement pastes cured at elevated temperatures*, Cement and Concrete Research, 25(3):627-638.
Erik P. Nielsena , Mette R. Geike. (2003). *Chloride diffusion in partially saturated cementitious material*, Cement and Concrete Research 33:133-138.
McGrath. P.(1996). *Development of test methods for predicting chloride penetration into high performance concrete*, Ph.D. Thesis, Department of Civil Engineering, University of Toronto.
Midgley, H.G., and Illston, J.M. (1984). *The Penetration of chlorides into hardened cement pastes*, Cement and Concrete Research, 14(4):546-558.
Rafik Belarbi, Menghao Qin, and Abdelkarim Aït-Mokhtar. (2006). *Modeling of moisture transport in porous building materials by Gravimetric sorption-de-sportion tests*, Annex 41 Moist-Engineering, Working meeting, April 3-5, Kyoto, Japan.
Siamak Riyazi, Ali Dousti, and Mohammad Shekarchi. (2013).*Effect of water to binder ratio on chloride diffusion parameters into concrete in Persian Gulf*, International Conference on Civil Engineering, Architecture and Urban Sustainable Development, 27 & 28 , Tabriz , Iran.
Su-Tae Kang, Jeong-Su Kim, Yun Lee, Yon-Dong Park, and Jin-Keun Kim. (2012). *Moisture diffusivity of early age concrete considering temperature and porosity*, KSCE Journal of civil Engineering, Issue 1, 16:179–188.
Sakata, K. (1983). *A Study on moisture diffusion in Drying and drying shrinkage of concrete*, Cement and Concrete Research, 13:216-224.
Thomas, M.D.A., Pantazopoulou, S.J., and Martin-Perez, B. (1995). *Service life modelling of reinforced concrete structures exposed to chlorides-A Literature review*, prepared for the Ministry of Transportation, Ontario, at the University of Toronto.
Taher. A, Cao. X, Pop. I. S, van der Zanden. A. J. J, and Brouwers. H. J. H. (2013). *Moisture transport in concrete during wetting/drying cycles,* Chemistry and materials research, V.5, Special issue for International congress on Materials and Structural stability, Rabat, Morocco, 27-30.

Teychenné. D. C, Franklin. R. E., and Erntroy. H. C. (1988). *Design of normal concrete mixes,* Second edition, BRE.
Xiao Zhang and Hongduo Zhao, *Characterization of moisture diffusion in cured concrete slabs at early ages*, Advances in materials science and Engineering, Volume 2015 (2015), Article ID 154394, 10 pages.
Yunping Xi, Zdeng, K. P. Bazant, Larissa Molina, and Hamlin M. (1994). *Jennings, Moisture diffusion in cementitious materials moisture capacity and diffusivity*, Advance cement based materials, 1:258--266 KEY.
Zhang, M, Wang. P. G and Wittmann, F. H. (2014). *Influence of moisture content on chloride diffusion in concrete*, Restoration of Buildings and Monuments, 20 (2):127-130.