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Chloride diffusion coefficient in dry conditioned concrete cubes

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ABSTRACT
The concrete is strong in compression but weak in tension, versatile, and brittle material which is serving from so many decades for construction industries all over the world. The successful key for making durable concrete is to limit its ability to transport fluids like water. In order to devise realistic testing methods, that determine the ability of concrete to with stand chloride penetration requires an understanding of water mobility. In order to build durable oriented and practicable concrete structures, it is needed to be able to accurately predict the chloride diffusion coefficient the within concrete structures. Therefore, there is a need to quantify the 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 performed on 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 under dried conditioned concrete cubes. Chloride diffusion coefficient is co-related with square root of time by power type of equation in control/impregnation concrete cubes. Chloride diffusion coefficient is initially increased, which may be 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. 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. It's also possible to correlate the variation of chloride solution absorption content ratio with square root of time by linear type of equation. From this relationship it's possible to predict chloride diffusion coefficient at any time duration based on chloride solution absorption in control/impregnation concrete cubes.

Keywords:
Concrete, mixture proportion, grade of concrete, w/c ratio, chloride diffusion coefficient, chloride solution absorption content ratio

1. INTRODUCTION

The reinforced concrete is the most extensively used construction material, primarily due to its exceptional resistance to water, the ease with which the structural elements can be cast into different shapes and sizes, and its availability in most parts of the world [Mehta and Monteiro, 2006]. Concrete provides physical and chemical protection to the reinforcing steel against attack by aggressive chemical species such as chloride ions and carbon dioxide, thus making RC a durable construction material. Concrete structures are intended to last for decades or even centuries. However, the problem of premature deterioration of RC structures, more specifically those exposed to harsh conditions such as marine environments, continues to be a serious issue in the concrete construction industry. Several researchers have acknowledged the gravity of the problem through developing and promoting the implementation of performance-based specifications approach over the prescriptive method, in order to facilitate quality control of concrete as well as enable service life prediction of RC structures [Alexander and Thomas, 2015]. It is clear that deteriorating RC structures require durable repairs in order to realise their remaining service life. The durability of concrete and mortars is largely controlled by transport processes such as diffusion, permeation, capillary absorption and wick action, which occur within their pore system [Nilsson, 2003]. The transport of fluids and aggressive chemical species play a significant role in reducing the service life of RC structures. The ease with which water, chloride ions and carbon dioxide penetrates the concrete determines the rate of deterioration of RC structures [Mehta and Monteiro, 2006]. The key aspects of durability, which comprise resistance to chloride ingress and resistance to carbonation, therefore are vital in the design of durable repair mortars [Oh and Jang, 2007].

It has been reported that chloride ingress and carbonation are the main mechanisms that initiate reinforcement corrosion. Literature further suggests that reinforcement corrosion is the main cause of deterioration in RC structures [Roziere *et al*, 2009]. The damage to concrete members due to corrosion of steel is manifested in the forms of cracking, spalling and delamination, which emanate from the accumulation of corrosion products that occupy a volume greater than that of the original steel [Ballim *et al*, 2009]. In marine environments and structures exposed to de-icing salts (bridges), chloride transport is a decisive factor for service life design. Chloride attack is not a concern in unreinforced concrete, since it does not affect the concrete, but initiates corrosion of steel, which consequently affects concrete. The main processes that transport chloride ions in uncracked concrete include, inter alia, capillary absorption, diffusion, permeation, wick action and migration [Savija, 2014]. Studies have shown that the transport of chloride ions in concrete is a complex process involving an interaction of several transport processes, accompanied by physical or chemical binding of these ions [Gjorv, 2009]. Diffusion is the principal mechanism that drives the transport of chloride ions in concrete exposed to a marine environment [Gjorv, 2009]. It is defined as the process through which fluids and ionic species move through materials, due to concentration gradient [Pack *et al.*, 2010]. Dissolved chloride ions require continuous liquid pathways in order to diffuse through materials [Nilsson, 2003]. The key factors that influence the rate of diffusion are moisture content, temperature, characteristics of the diffusing substance and the diffusivity of the material [Ballim *et al*, 2009]. The diffusion coefficient provides an indication of the ease with which the diffusion process occurs in a material. It provides a measure of a material's resistance to chloride penetration. Factors that influence the diffusion coefficient include the size, connectivity and tortuosity of the pores [Wegen *et al*, 2012]. Several test methods attempt to estimate the diffusion coefficient of cement-based materials. A typical method is the bulk diffusion test discussed and the diffusion coefficient is determined from the chloride profiles of concrete specimens [Stanish and Thomas, 2003]. The diffusion coefficient of concrete decreases with time due to continued cementing reactions, chloride binding and evaporation [Wegen *et al,* 2012]. For this reason, the diffusion coefficient at early age may not accurately represent the actual chloride resistance for concretes in service [ASTM C1556-04, 2004]. As mentioned by [Hamilton *et al,* 2007], extended exposure of test specimens may yield diffusion coefficients that provide a better representation of concrete in service.

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; Fujiwara, et al, 1988; Fujiwara, *et al*, 1992]. 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, *et al*, 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. RESEARCH OBJECTIVES

The water transport in a porous network like concrete is a complex criterion. This is due to the fact that, many different kinds of transport mechanisms in combination with various types of pores that typically appears in the same porous system. Therefore there is a need to study water 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 performed on 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. 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 use 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 disclose and they will 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 No	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 No	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 is determined from the solution of one-dimensional Fick's theory for unsteady diffusion process. The percent of chloride solution absorption 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_∞ is the chloride solution absorption 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:

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

It's also possible within this present research work that, to interpret the chloride diffusion coefficient in pre-conditioned control DCC (M1CC-M6CC) and impregnation concrete cubes (M1SB-M6SB/M1WB-M6WB) on the basis of chloride solution absorption at different specified time intervals (1, 3, 6, 9, 12, 15, 18, 21, and 24 days) with their varied chloride diffusion coefficients in DCC cubes as represented in the Table.3.

Table 3 Chloride diffusion coefficients in DCC/SB/WB concrete cubes

Mix ID	1 day	3 day	6 day	9 day	12	15	18	21	24
M1CC	0.97	0.78	0.68	0.60	0.57	0.54	0.52	0.50	0.48
M1SB	0.93	0.71	0.68	0.59	0.56	0.53	0.51	0.49	0.48
M1WB	0.94	0.74	0.68	0.60	0.57	0.54	0.52	0.50	0.49
M2CC	0.93	0.78	0.69	0.61	0.57	0.54	0.51	0.50	0.48
M2SB	0.94	0.74	0.68	0.60	0.56	0.53	0.52	0.49	0.48
M2WB	0.95	0.75	0.69	0.59	0.56	0.53	0.51	0.50	0.49
M3CC	0.94	0.77	0.68	0.60	0.57	0.54	0.51	0.50	0.48
M3SB	0.94	0.77	0.69	0.61	0.56	0.54	0.52	0.50	0.49
M3WB	0.93	0.78	0.56	0.60	0.56	0.54	0.51	0.50	0.48
M4CC	0.98	0.77	0.63	0.60	0.57	0.54	0.52	0.49	0.49
M4SB	0.99	0.78	0.68	0.60	0.57	0.54	0.52	0.50	0.49
M4WB	1.05	0.82	0.68	0.63	0.59	0.56	0.53	0.51	0.50
M5CC	0.98	0.79	0.65	0.61	0.58	0.55	0.52	0.51	0.49
M5SB	1.18	0.91	0.68	0.70	0.66	0.62	0.61	0.59	0.57
M5WB	0.90	0.73	0.63	0.57	0.53	0.51	0.49	0.47	0.46
M6CC	0.95	0.77	0.67	0.60	0.56	0.54	0.52	0.50	0.48
M6SB	0.89	0.69	0.68	0.54	0.55	0.53	0.52	0.51	0.48
M6WB	0.92	0.74	0.67	0.60	0.56	0.53	0.51	0.50	0.48

4. 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 (2.23 min) as when compared to time interval (173.89 min) for in case of all designed control mixtures type (M1CC-M2CC:4.13-0.14, M1CC-M3CC:3.32-0.10, M1CC-M4CC:9.95-0.80, M1CC-M5CC:7.60-1.55, M1CC-M6CC:8.51-0.04, M2CC-M3CC:-0.84-0.03, M2CC-M4CC:6.08-0.67, M2CC-M5CC:3.62-1.69, M2CC-M6CC:4.57-0.10, M3CC-M4CC:6.86-0.70, M3CC-M5CC:4.42-1.66, M3CC-M6CC:5.37-0.06, M4CC-M5CC:2.62-2.37, M4CC-M6CC:1.60-0.77, and M5CC-M6CC:0.99-1.57)%. The diffusion coefficient is initially increased, may be due to concentration gradient. Actually the 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 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).

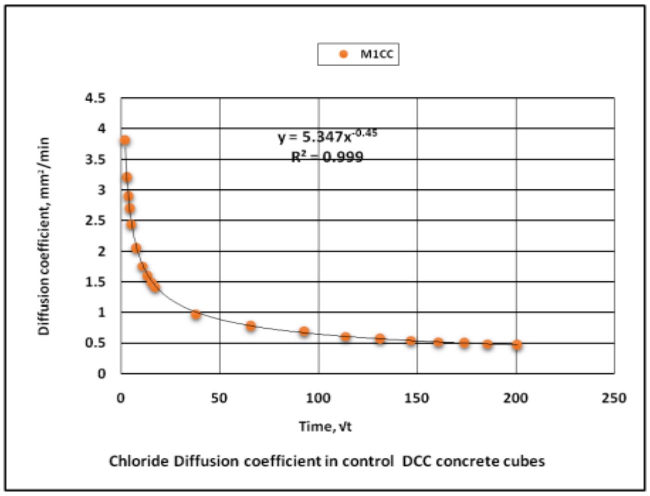


Fig.1a Cl^- diffusion coefficient in mix M1

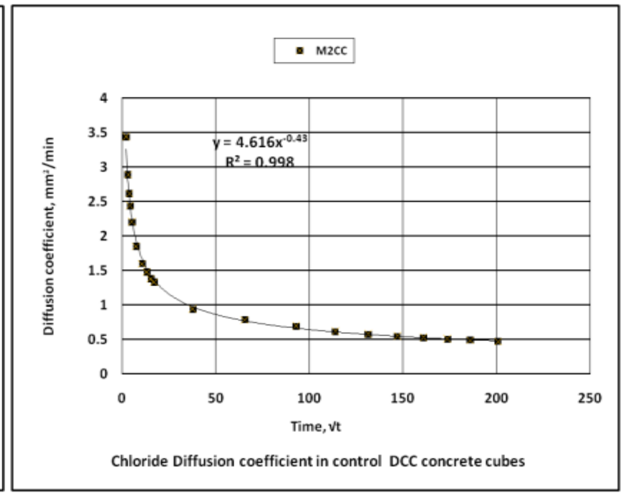


Fig.1b Cl^- diffusion coefficient in mix M2

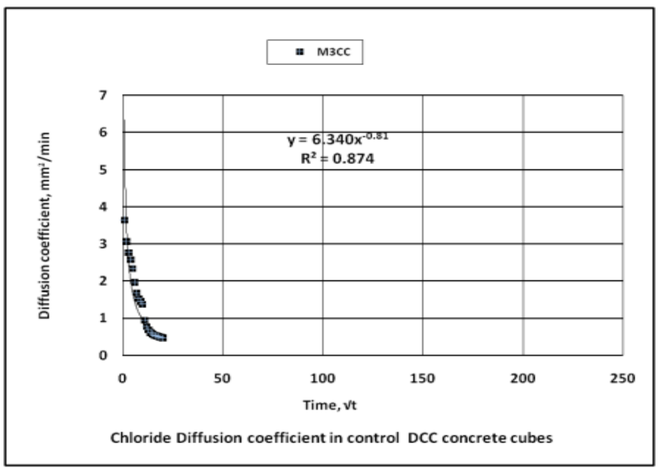


Fig.1c Cl^- diffusion coefficient in mix M3

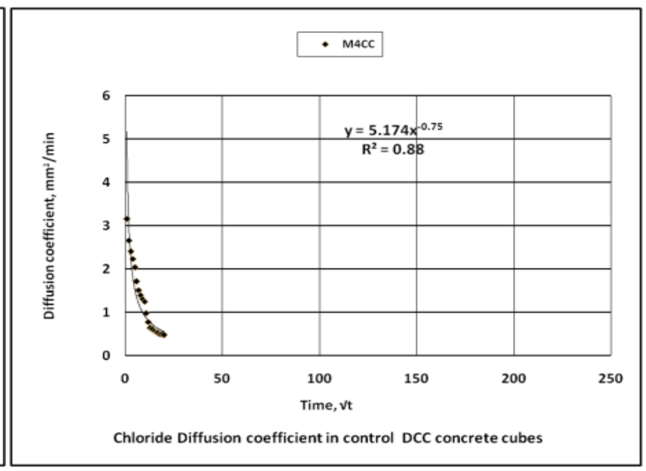


Fig.1d Cl^- diffusion coefficient in mix M4

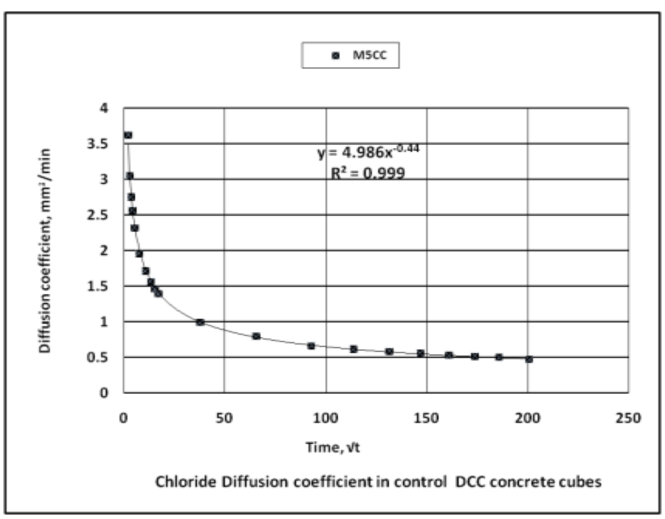


Fig.1e Cl^- diffusion coefficient in mix M5

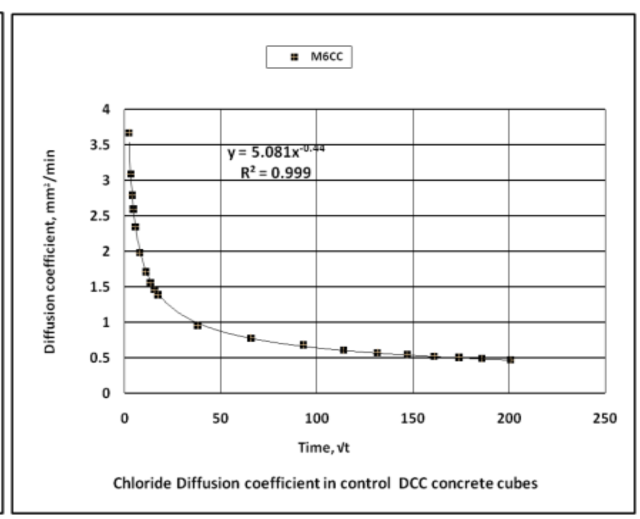


Fig.1f Cl^- diffusion coefficient in mix M6

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 (2.23 min) as when compared to time interval (173.89 min) for in case of all designed control mixtures type as when compared to impregnation concrete cubes (M1CC-M1SB:4.13-0.67, M1CC-M1WB:3.32-0.20, M2CC-M2SB:2.62-0.53, M2CC-M2WB:1.50-0.25, M3CC-M3SB:0.23-0.11, M3CC-M3WB:-0.32-0.12, M4CC-M4SB:4.77-0.90, M4CC-M4WB:13.65-4.03, M5CC-M5SB:28.33-16.07, M5CC-M5WB:7.93-6.32, M6CC-M6SB:13.10-0.11, M6CC-M6WB:6.07-0.39, and M1WB-M1SB:0.83-0.87, M2WB-M2SB:1.00-0.29, and M3WB-M3SB:0.55-0.01, M4WB-M4SB: 7.81-3.00, M5WB-M5SB: 39.38-23.90, M6WB-M6SB: 7.49-0.28)%. 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).

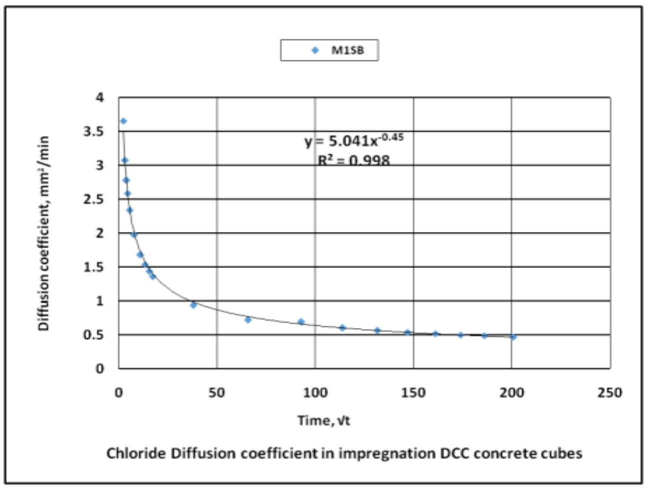


Fig.2a Cl^- diffusion coefficient in mix M1

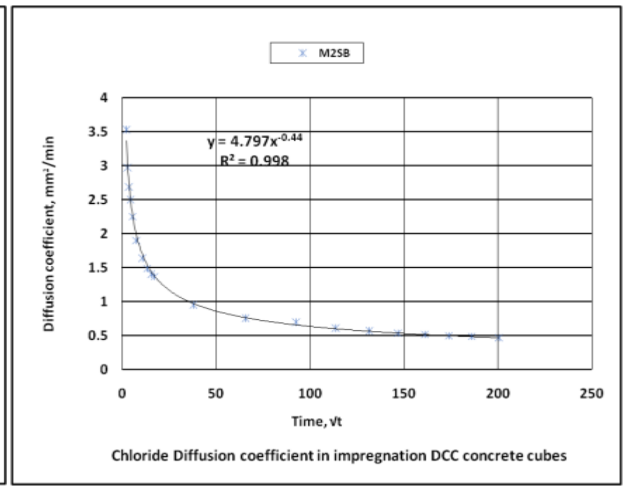


Fig.2b Cl^- diffusion coefficient in mix M2

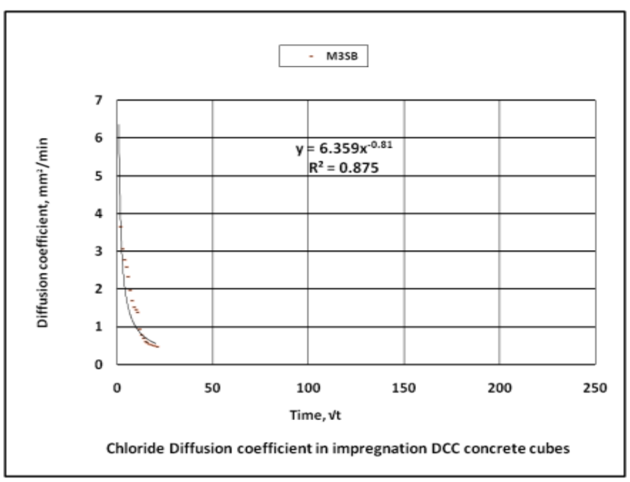


Fig.2c Cl^- diffusion coefficient in mix M3

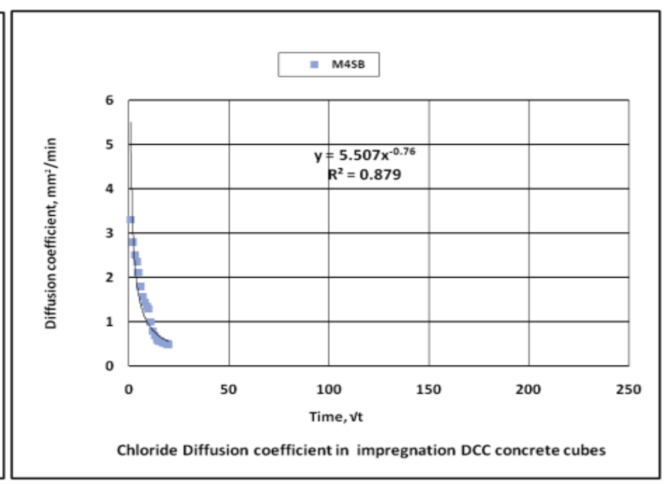


Fig.2d Cl^- diffusion coefficient in mix M4

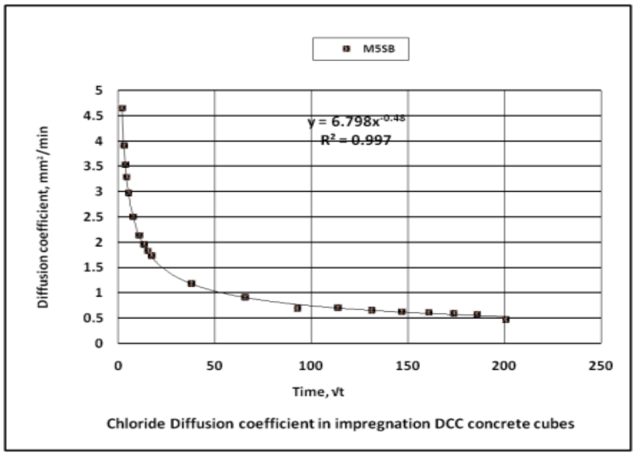


Fig.2e Cl$^-$ diffusion coefficient in mix M5

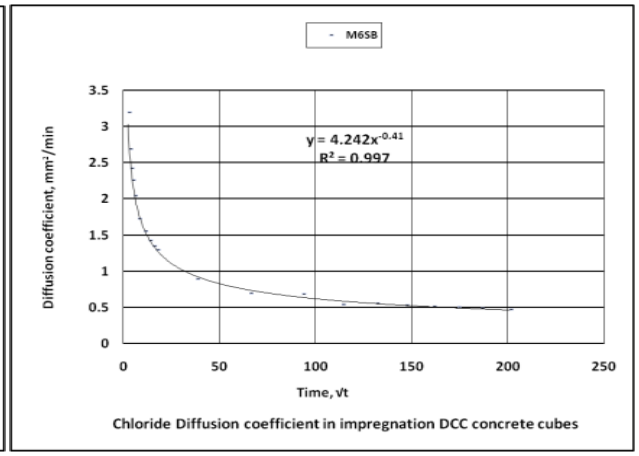


Fig.2f Cl$^-$ diffusion coefficient in mix M6

The chloride diffusion coefficient is increased at time interval (2.23 min) as when compared to time interval (173.89 min) for in case of all designed control mixtures type as when compared to impregnation concrete cubes (M1WB-M2WB:5.37-0.58, M1WB-M3WB:1.60-0.43, M1WB-M4WB:2.66-2.98, M1WB-M5WB:9.55-5.06, M1WB-M6WB:6.47-0.63, M2WB-M3WB:-3.98-0.16, M2WB-M4WB:2.87-3.59, M2WB-M5WB:4.42-4.50, M2WB-M6WB:1.17-0.05, M3WB-M4WB:1.07-3.42, M3WB-M5WB:8.07-4.66, M3WB-M6WB:4.95-0.21, and M4WB-M6WB:7.08-7.81, M4WB-M6WB:3.92-3.51, and M5WB-M6WB:3.40-4.67)%. 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).

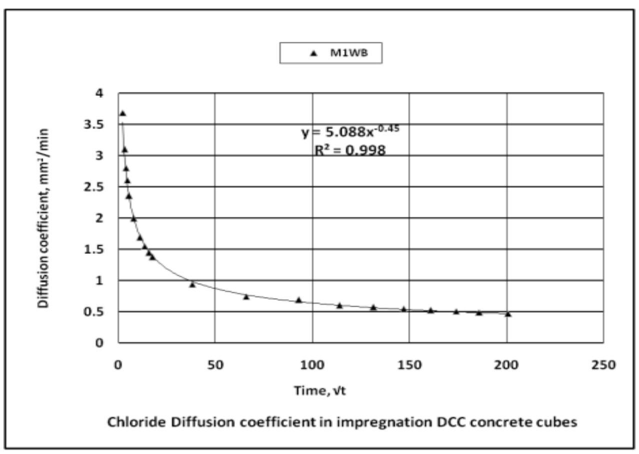


Fig.3a Cl$^-$ diffusion coefficient in mix M1

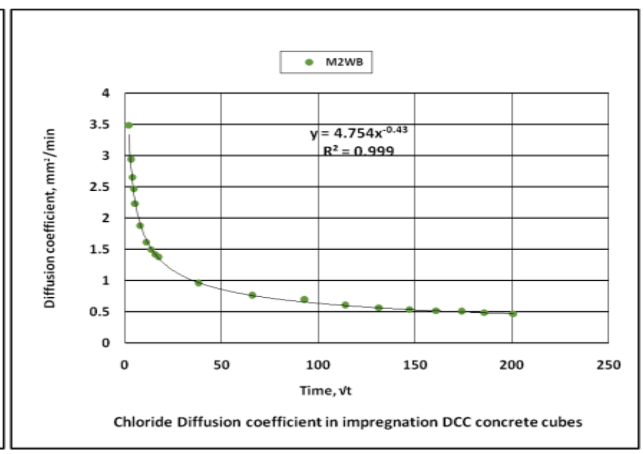


Fig.3b Cl$^-$ diffusion coefficient in M2

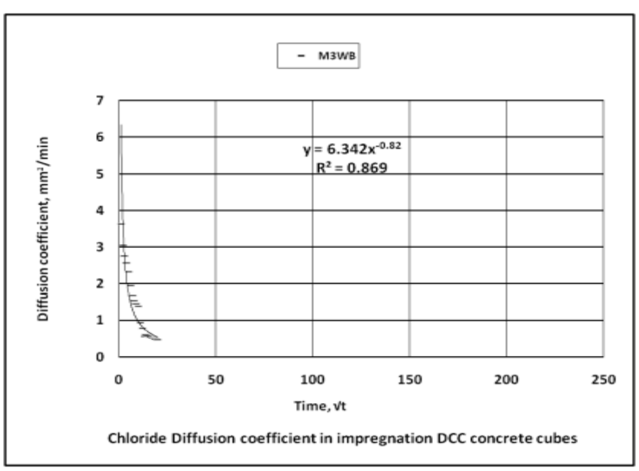


Fig.3c Cl$^-$ diffusion coefficient in M3

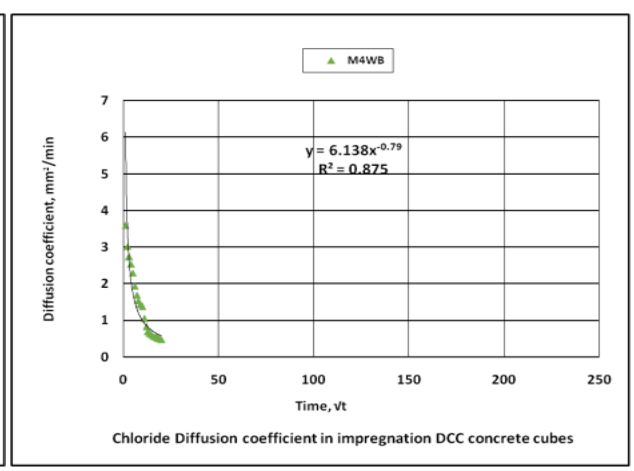
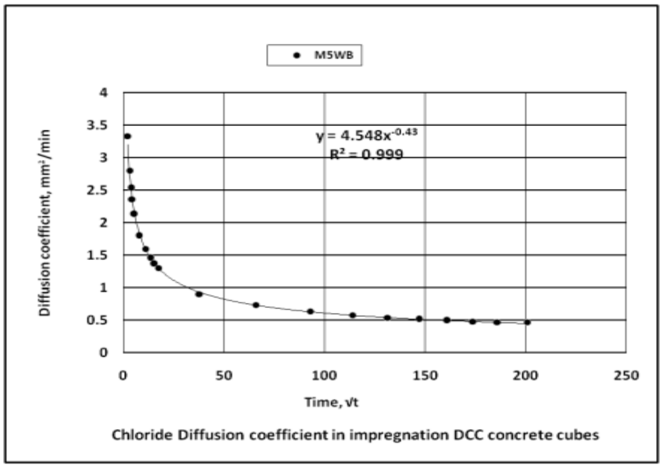


Fig.3d Cl$^-$ diffusion coefficient in mix M4



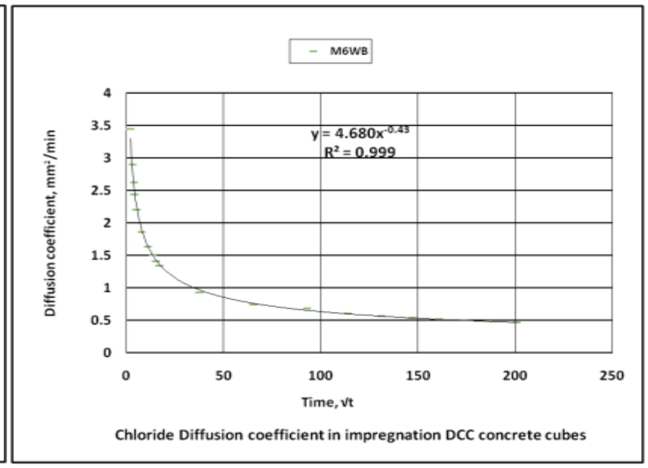
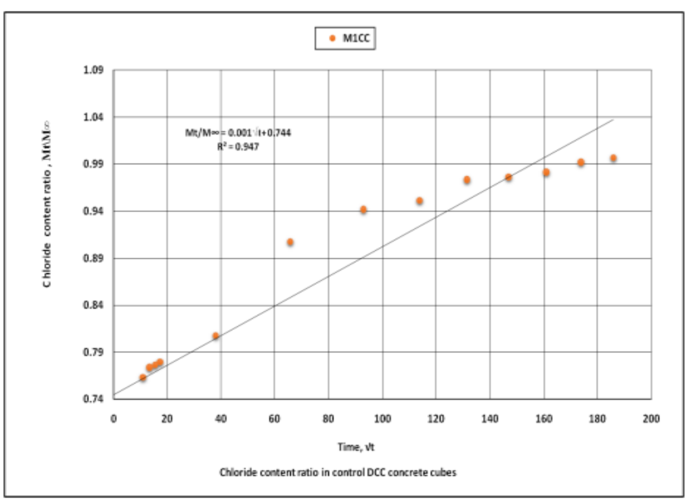


Fig.3e Cl^- diffusion coefficient in mix M5 **Fig.3f** Cl^- diffusion coefficient in mix M6

The variation of chloride solution absorption content (Mt) at any particular time duration to chloride solution absorption content (M∞) at an infinite time duration is studied in the present research work for in the case of designed control mixtures type (M1CC-M6CC) at different time duration in ordered to obtain chloride diffusion coefficient which is represented as shown in Fig.4a-4f and this chloride solution absorption content ratio is correlated with square root of time by linear type of equation in all control designed mixtures type (M1CC-M6CC). The chloride solution absorption content ratio was depends on factors such as square root of time, and material thickness, diffusion coefficient, mixture proportion, compactness of concrete matrix, quantity of fine and coarse aggregate, slump value, and fineness of cement. The chloride solution absorption content (Mt) at particular time duration depends on time, lesser/more the time, lesser/more chloride solution content availability in concrete matrix which depends on the pore structure formation, aggregates volume fraction, w-c ratio, slump, and compressive strength. As observed from the results that, the chloride solution absorption content ratio was varied and compared at different time duration (0 min) to time interval (34560 min) for in case of control mixtures type [M1CC-M2CC:18.92-0.27, M1CC-M3CC:8.93-0.20, M1CC-M4CC:31.42-1.59, M1CC-M5CC:9.78-(-3.13), M1CC-M6CC:7.33-0.08, M2CC-M3CC:-12.32-(-0.07), M2CC-M4CC:15.42-1.33, M2CC-M5CC:11.26-(-3.41), M2CC-M6CC:-14.29-(-0.19), M3CC-M4CC:24.70-1.39, M3CC-M5CC:0.94-(-3.34), M3CC-M6CC:-1.75-(-0.12), M4CC-M5CC:31.55-(-4.80), M4CC-M6CC:-35.12-(-1.54), and M5CC-M6CC:-2.72-3.11] respectively.



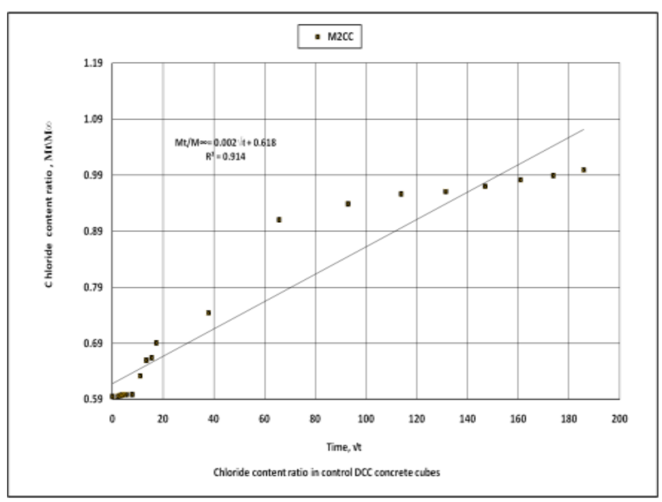


Fig.4a Cl^- content ratio-time in mix M1 **Fig.4b** Cl^- content ratio-time in mix M2

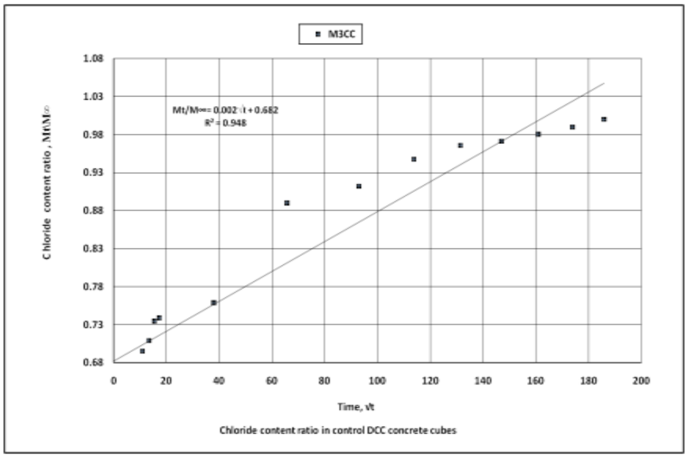


Fig.4c Cl^- content ratio-time in mix M3

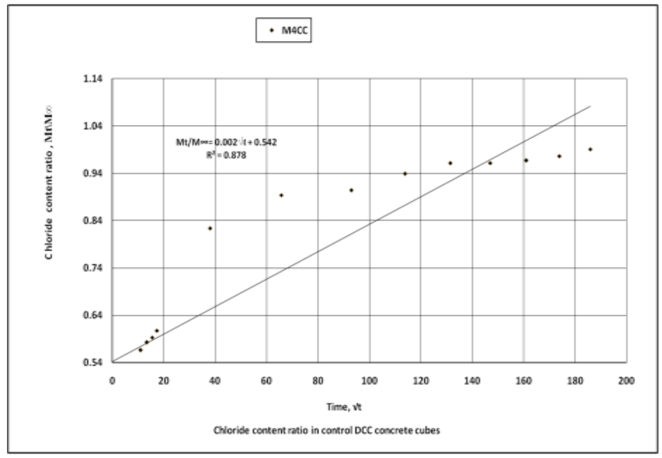


Fig.4d Cl^- content ratio-time in mix M4

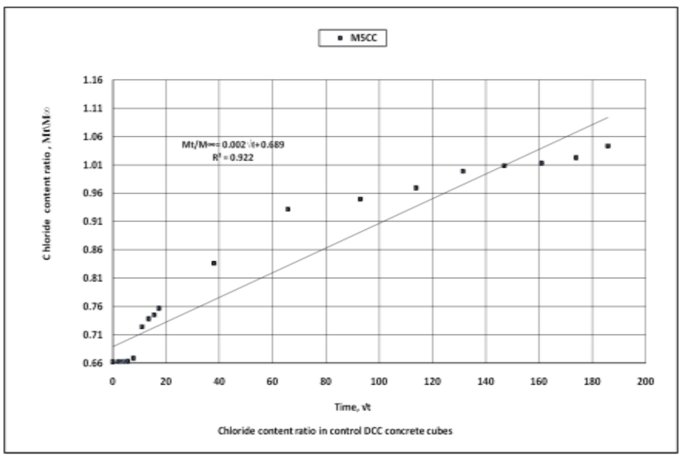


Fig.4e Cl^- content ratio-time in mix M5

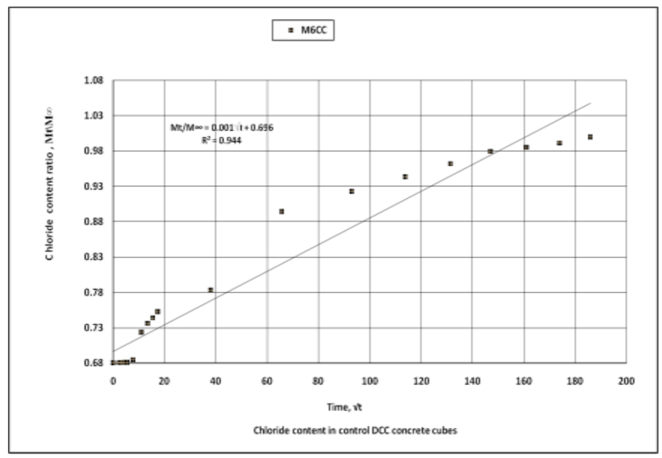


Fig.4f Cl^- content ratio-time in mix M6

The chloride solution absorption content (Mt) at particular time duration depends on time, lesser/more the time, lesser/more chloride solution content availability in concrete matrix which depends on the pore structure formation, aggregates volume fraction, w-c ratio, slump, and compressive strength. As observed from the results that, the chloride solution absorption content ratio was varied and compared at time duration (0 min) to time interval (34560 min) for in case of control mixtures type [M1SB-M2SB:7.11-0.00, M1SB-M3SB:0.46-(-0.93), M1SB-M4SB:18.10-(-1.55), M1SB-M5SB:61.64-(-40.82), M1SB-M6SB:-23.87-(-1.05), M2SB-M3SB:-7.16-(-0.92), M2SB-M4SB:-11.83-(-1.55), M2SB-M5SB:74.01-(-40.82), M2SB-M6SB:-18.05-(-1.05), M3SB-M4SB:17.72-(-0.62), M3SB-M5SB:62.39-(-39.53), M3SB-M6SB:-23.52-(-0.12), M4SB-M5SB:97.37-(-38.67), M4SB-M6SB:7.05-0.49, and M5SB-M6SB:-52.90-28.24] respectively. The variation of chloride solution absorption content (Mt) at any particular time duration to chloride solution absorption content (M∞) at an infinite time duration is studied in the present research work for in the case of designed impregnation mixtures type (M1SB-M6SB) at different time duration which is represented as shown in Fig.5a-5f.The variation of chloride solution absorption content ratio coefficient is co-related with square root of time by linear type of equation in impregnation concrete cubes for in case of all impregnation designed mixtures type (M1SB-M6SB) .

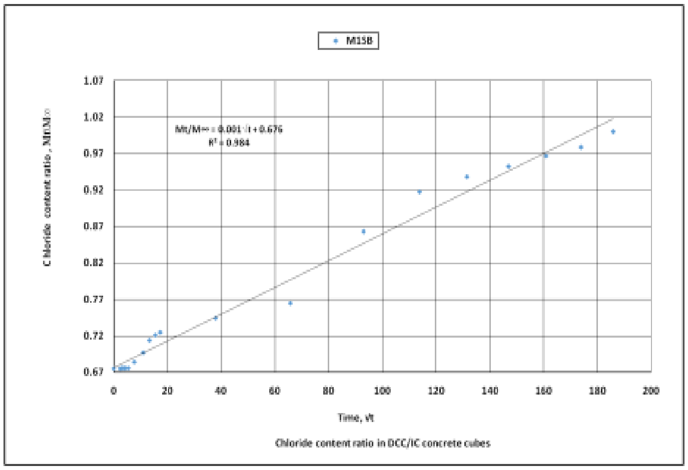


Fig.5a Cl^- content ratio-time in mix M1

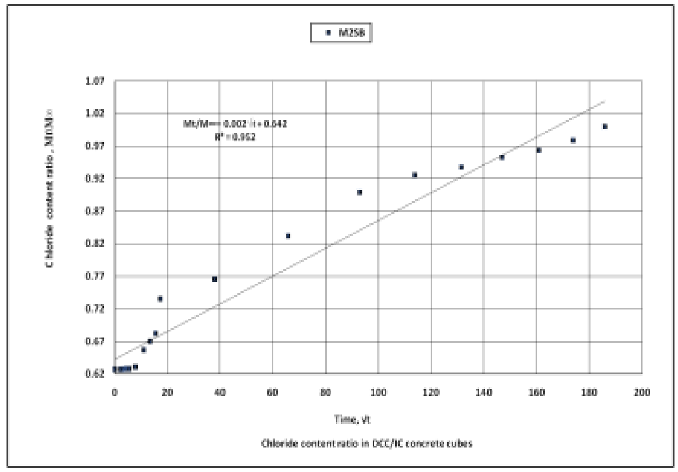


Fig.5b Cl^- content ratio-time in mix M2

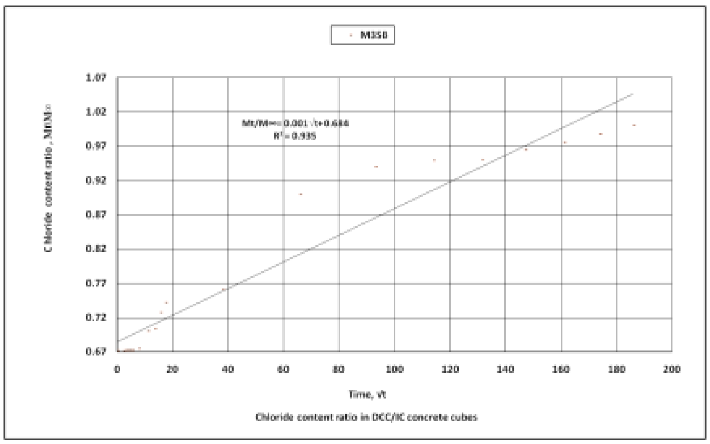


Fig.5c Cl^- content ratio-time in mix M3

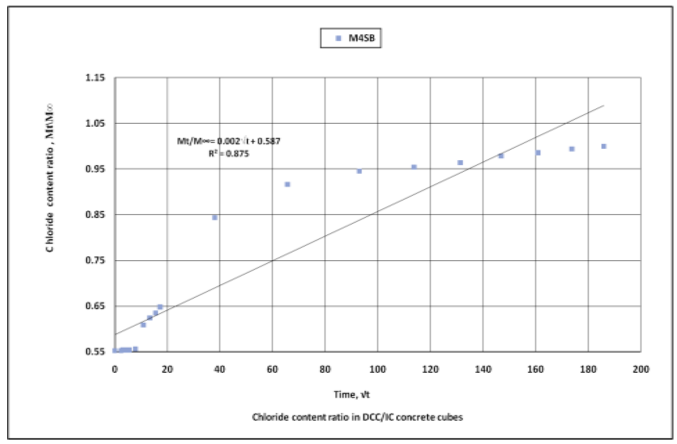


Fig.5d Cl^- content ratio-time in mix M4

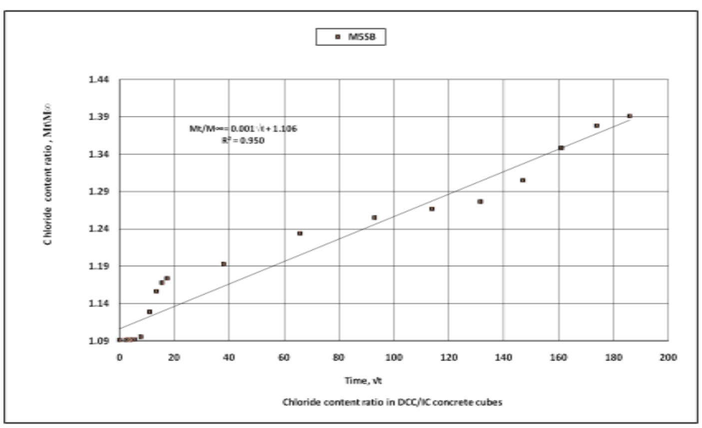


Fig.5e Cl^- content ratio-time in mix M5

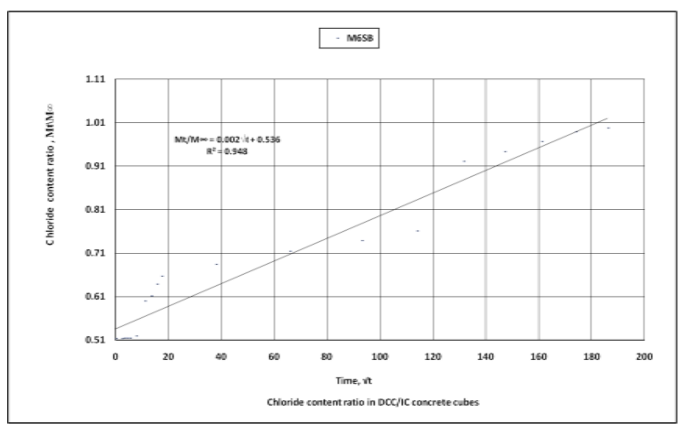


Fig.5f Cl^- content ratio-time in mix M6

As observed from the results that, the chloride solution absorption content ratio was varied and compared at time duration (0 min) to time interval (34560 min) for in case of control mixtures type [M1WB-M2WB:10.45-1.17, M1WB-M3WB:3.18-0.85, M1WB-M4WB:5.24-(-6.06), M1WB-M5WB:18.18-9.87), M1WB-M6WB:12.53-1.26, M2WB-M3WB:-8.11-(-0.32), M2WB-M4WB:-5.81-(-7.31), M2WB-M5WB:8.64-8.80), M2WB-M6WB:2.32-0.09, M3WB-M4WB:2.12-(-6.97), M3WB-M5WB:15.49-9.09, M3WB-M6WB:9.65-0.41, M4WB-M5WB:13.66-15.02, M4WB-M6WB:7.69-6.90, and M5WB-M6WB:-6.91-(-9.55)] respectively. The variation of chloride solution absorption content (Mt) at any particular time duration to chloride solution absorption content (M∞) at an infinite time duration is interpreted and compared in this present research work for in the case of designed impregnation mixtures type (M1WB-M6WB) at different time duration which is represented as shown in Fig.6a-6f.The variation of chloride solution absorption content ratio coefficient is co-related with square root of time was represented by linear type of equation in all impregnation designed concrete mixtures type (M1WB-M6WB).

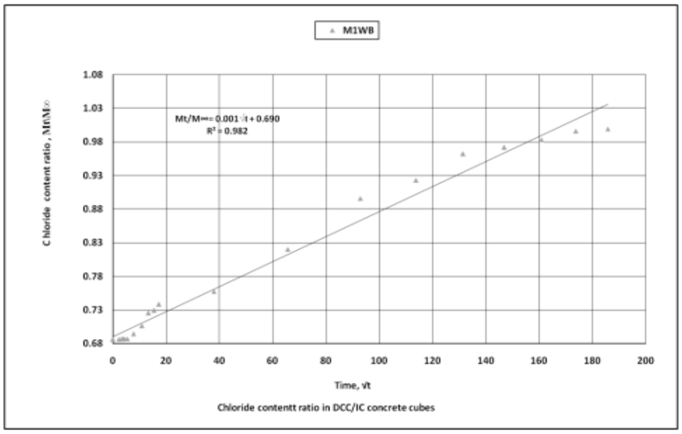


Fig.6a Cl^- content ratio-time in mix M1

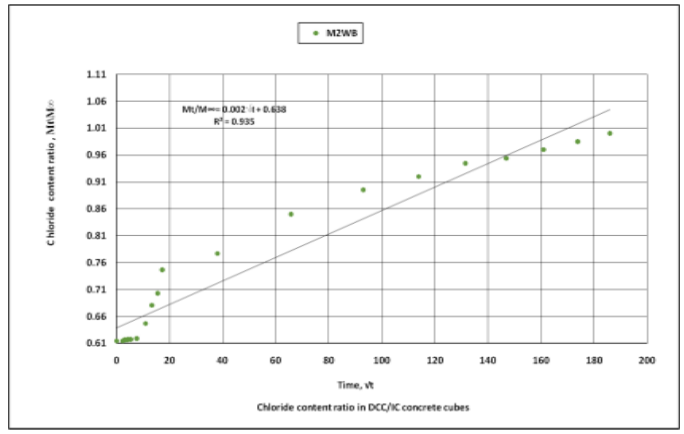


Fig.6b Cl^- content ratio-time in mix M2

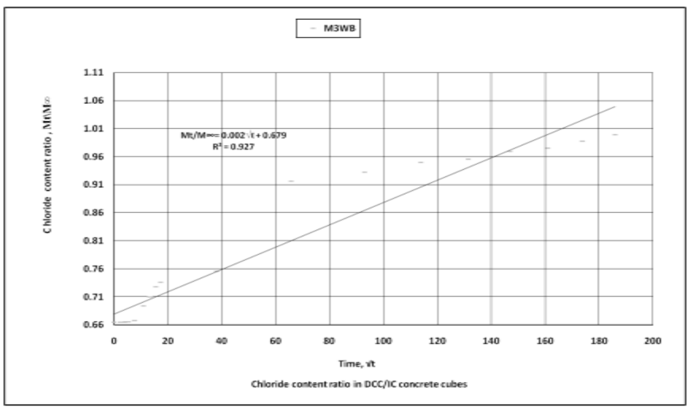


Fig.6c Cl^- content ratio-time in mix M3

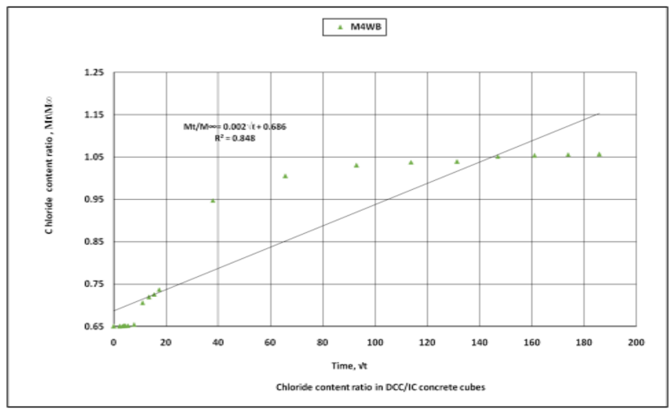


Fig.6d Cl^- content ratio-time in mix M4

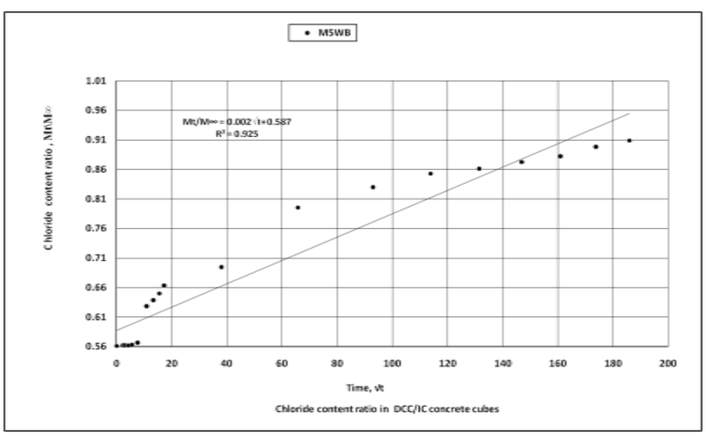


Fig.6e Cl^- conent ratio-time in mix M5

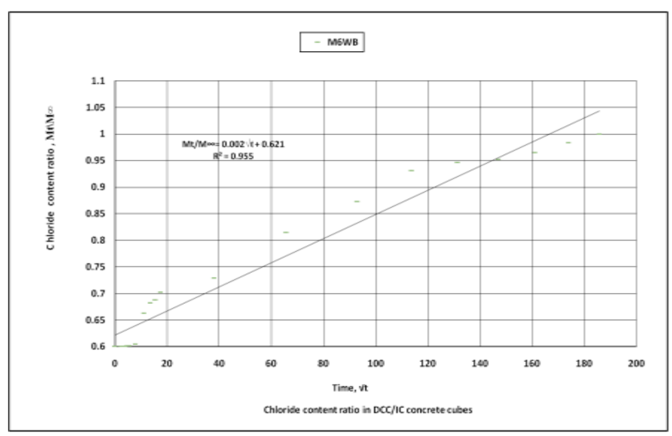
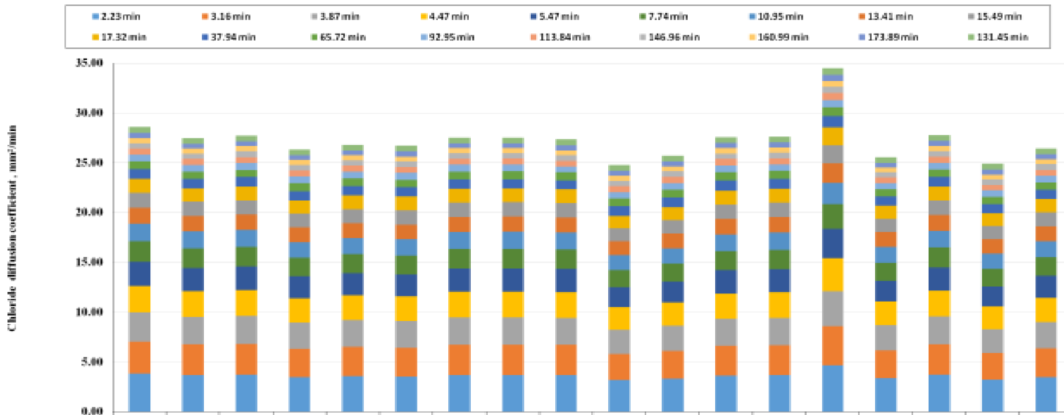


Fig.6f Cl^- content ratio-time in mix M6

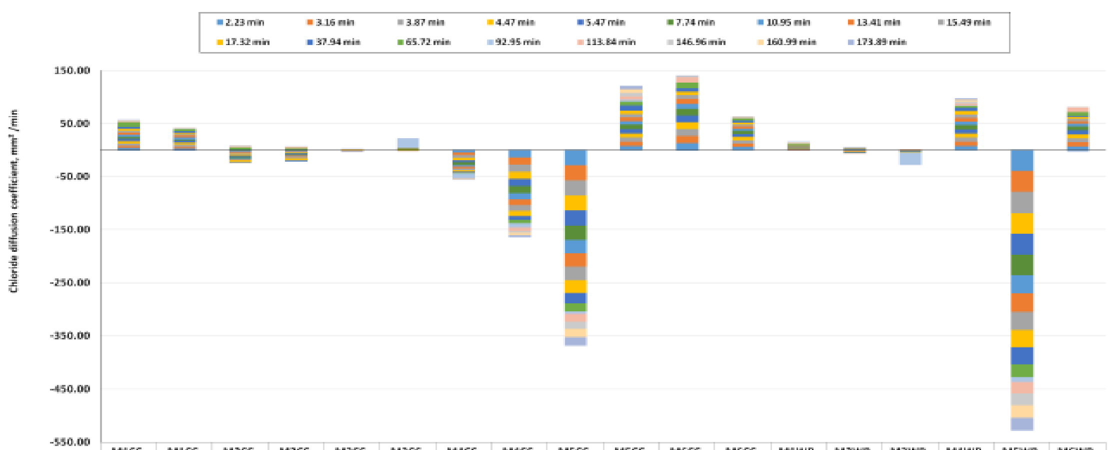
As observed from the results that, the chloride diffusion coefficient was predicted based on chloride solution absorption at particular time duration (Mt) to chloride solution absorption at infinite time duration (M∞) for different time duration (0 min) up to time interval (34560 min). The chloride diffusion coefficient was varied in the control concrete cubes (M1CC:3.81-0.50, M2CC:3.43-0.50, M3CC:3.64-0.50, M4CC:3.16-0.50, M5CC:3.62-0.51, and M6CC:3.67-0.50), impregnation concrete cubes [(M1SB:3.61-0.50, M2SB:3.52-0.50, M3SB:3.65-0.50, M4SB:3.31-0.50), M5SB:4.65-0.59, M6SB:3.19-0.50, M1WB:3.69-0.50, M2WB:3.49-0.50, M3WB:3.63-0.50, M4WB:3.59-0.52, M5WB:3.34-0.48, M6WB:3.45-0.50] mm^2/min respectively.



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
131.45 min	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
173.89 min	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
160.99 min	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
146.96 min	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
113.84 min	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
92.95 min	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
65.72 min	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
37.94 min	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
17.32 min	1.41	1.36	1.37	1.33	1.37	1.38	1.37	1.38	1.37	1.25	1.29	1.37	1.39	1.73	1.30	1.39	1.30	1.34
15.49 min	1.49	1.44	1.44	1.38	1.40	1.42	1.45	1.44	1.44	1.30	1.35	1.44	1.46	1.83	1.36	1.46	1.35	1.40
13.41 min	1.60	1.54	1.55	1.48	1.49	1.50	1.53	1.52	1.53	1.39	1.44	1.54	1.56	1.95	1.45	1.56	1.42	1.50
10.95 min	1.76	1.68	1.69	1.60	1.63	1.62	1.68	1.68	1.67	1.51	1.57	1.69	1.71	2.14	1.59	1.71	1.56	1.64
7.74 min	2.05	1.98	1.99	1.85	1.90	1.88	1.97	1.96	1.95	1.71	1.78	1.93	1.96	2.50	1.80	1.98	1.72	1.86
5.47 min	2.44	2.34	2.36	2.20	2.25	2.23	2.34	2.33	2.32	2.03	2.12	2.30	2.32	2.97	2.13	2.35	2.04	2.20
4.47 min	2.70	2.59	2.61	2.43	2.49	2.47	2.57	2.58	2.57	2.23	2.34	2.54	2.56	3.29	2.36	2.60	2.26	2.44
3.87 min	2.90	2.78	2.80	2.61	2.68	2.65	2.77	2.77	2.76	2.40	2.52	2.73	2.75	3.53	2.54	2.79	2.43	2.62
3.16 min	3.21	3.08	3.10	2.89	2.96	2.94	3.06	3.07	3.05	2.66	2.78	3.02	3.05	3.91	2.81	3.09	2.68	2.90
2.23 min	3.81	3.66	3.69	3.43	3.52	3.49	3.64	3.65	3.63	3.16	3.31	3.59	3.62	4.65	3.34	3.67	3.19	3.45

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

Fig.7a Cl^- diffusion coefficient in DCC/CC/SB/WB 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
173.89 min	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
160.99 min	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
146.96 min	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
113.84 min	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
92.95 min	-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
65.72 min	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
37.94 min	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
17.32 min	3.60	2.70	-3.19	-3.94	-0.21	0.18	-3.20	-10.14	-24.52	6.42	6.58	3.40	0.93	0.72	-0.40	6.30	-33.07	3.29
15.49 min	3.65	3.10	-1.34	-2.84	0.51	0.48	-3.47	-10.60	-25.21	6.60	7.34	3.85	0.57	1.46	0.03	6.45	-34.06	3.63
13.41 min	3.93	3.16	-0.79	-1.62	0.35	-0.04	-3.50	-11.08	-25.14	7.04	8.86	3.75	0.80	0.81	0.39	6.83	-34.61	5.31
10.95 min	4.45	3.81	-1.98	-1.23	-0.35	0.11	-3.72	-11.64	-24.84	6.90	8.93	4.27	0.67	-0.74	-0.46	7.10	-34.09	4.86
7.74 min	3.61	2.90	-2.66	-1.64	0.05	0.59	-4.29	-13.06	-27.99	8.00	12.89	6.03	0.73	-1.00	-0.55	7.76	-39.12	7.30
5.47 min	4.20	3.40	-2.45	-1.55	0.19	0.74	-4.08	-12.95	-28.32	7.91	13.06	6.05	0.83	-0.88	-0.55	7.86	-39.34	7.46
4.47 min	4.20	3.40	-2.44	-1.55	-0.24	0.31	-4.77	-13.68	-28.33	7.92	13.07	6.05	0.83	-0.88	-0.55	7.84	-39.36	7.47
3.87 min	4.21	3.40	-2.47	-1.53	-0.24	0.31	-4.77	-13.68	-28.33	7.92	13.09	6.06	0.83	-0.93	-0.55	7.84	-39.37	7.48
3.16 min	4.18	3.38	-2.54	-1.60	-0.23	0.32	-4.77	-13.66	-28.33	7.93	13.10	6.06	0.83	-0.93	-0.55	7.82	-39.38	7.49
2.23 min	4.13	3.32	-2.62	-1.60	-0.23	0.32	-4.77	-13.65	-28.33	7.93	13.10	6.07	0.83	-1.00	-0.55	7.81	-39.38	7.49

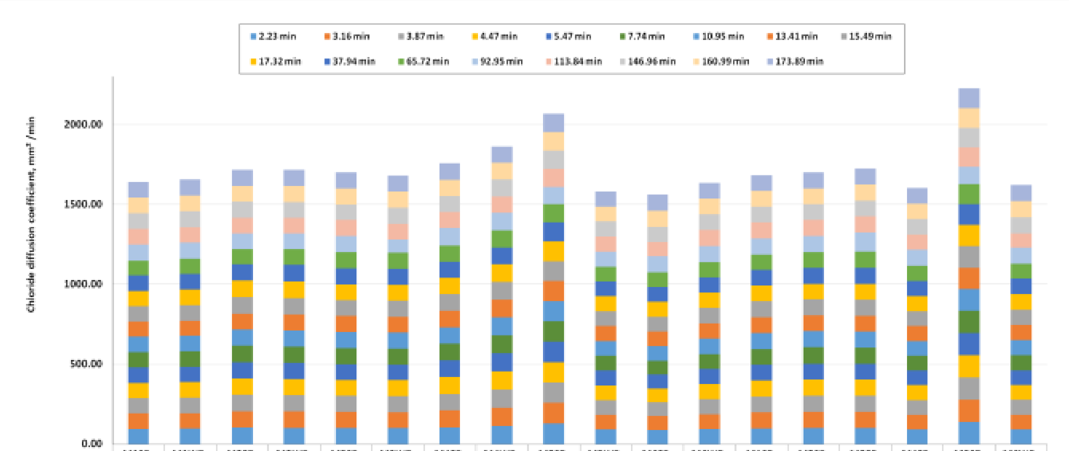
Chloride diffusion coefficient increase in control DCC/SB/WB concrete cubes

Fig.7b Cl^- diffusion coefficient in DCC/CC/SB/WB cubes

The variation of chloride diffusion coefficient at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1CC-M6CC) and impregnation (M1SB-M6SB, M1WB-M6WB) concrete cubes at different time duration as shown in Fig.7a. The chloride diffusion coefficient was predicted based on chloride solution absorption at different time duration (0 min) up to time interval (34560 min). The chloride diffusion coefficient was increased in the control concrete cubes as when compared to impregnation concrete cubes (M1CC-M1SB:4.13-0.67, M2CC-M2SB:2.62-0.53, M3CC-M3SB:-0.23-0.53, M4CC-M4SB:-4.77-(-0.90), M5CC-M5SB:-28.33-(-16.07, and M6CC-M6SB:13.10-0.11, M1CC-M1WB:3.32-(-0.20), M2CC-M2WB:-1.60-0.25, M3CC-M3WB:0.32-0.12, M4CC-M4WB:-13.65-(-4.03), M5C-M5WB:7.93-6.32, M6CC-M6WB:6.07-0.39, M1WB-M1SB:0.83-0.07, M2WB-M2SB:-1-0.29, M3WB-M3SB:-0.55-(-0.01), M4WB-M4SB:7.81-3.00, M5WB-M5SB:-39.28-(-23.90), M6WB-M6SB:7.49-(-0.28)] mm^2/min respectively. The variation of chloride diffusion coefficient at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1CC-M6CC) and impregnation (M1SB-M6SB, M1WB-M6WB) concrete cubes at different time duration as shown in Fig.7b.

The chloride diffusion coefficient was decreased in the impregnation concrete cubes as when compared to control concrete cubes (M1SB-M1CC:95.87-99.33, M1WB-M1CC:96.68-100.20, M2SB-M2CC:102.62-99.47, M2WB-M2CC:101-99.75, M3SB-M3CC:100.23-99.89, and M3WB-M3CC:99.68-99.88, M4SB-M4CC:104.77-100.90, M4WB-M4CC:113.65-104.03, M5SB-M5CC:128.33-116.07, M5WB-M5CC:92.07-93.68, M6SB-M6CC:86.90-99.89, M6WB-M6CC:99.93-99.61, M1SB-M1WB:99.17-99.13, M2SB-M2WB:101-99.71, M3SB-M3WB:100.55-100.01, M4SB-M4WB:92.19-97.00, M5SB-M5WB:139.38-123.90, M6SB-M6WB:92.51-100.28) mm^2/min respectively. The variation of chloride diffusion coefficient at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1CC-M6CC) and impregnation (M1SB-M6SB, M1WB-M6WB) concrete cubes at different time duration as shown in Fig.7c. The chloride diffusion coefficient was increased in the control concrete cubes [(M1CC-M2CC:4.13-0.14, M1CC-M3CC:3.32-0.10, M1CC-M4CC:-9.95-0.80, M1CC-M5CC:-7.60-(-1.55), M1CC-M6CC:8.51-0.04, and M2CC-M3CC:-0.84-(-0.03), M2CC-M4CC:6.08-0.67, M2CC-M5CC:3.62-(-1.69), M2CC-M6CC:4.57-(-0.10), M3CC-M4CC:6.86-0.70, M3CC-M5CC:4.42-(1.66), M3CC-M6CC:5.33-(-0.06), M4CC-M5CC:-2.62-(-2.37), M4CC-M6CC:-1.60-(-0.77), M5CC-M6CC:0.99-1.57)] mm^2/min respectively. The variation of chloride diffusion coefficient at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1CC-M6CC) concrete cubes as shown in Fig.7d. The chloride diffusion coefficient was increased in the impregnation concrete cubes as when compared to different impregnation concrete cubes [(M1SB-M2SB:3.62-0.00, M1SB-M3SB:0.23-(-0.46), M1SB-M4SB:9.50-(-0.77), M1SB-M5SB:-27.14-(-18.67), M1SB-M6SB:12.75-(-0.52), and M2SB-M3SB:-3.52-(-0.46), M2SB-M4SB:6.10-(-0.77), M2SB-M5SB:-31.91-(-18.67), M2SB-M6SB:9.47-(-0.52), M3SB-M4SB:9.29-(-0.31), M3SB-M5SB:-27.43-(-18.12), M3SB-M6SB:12.55-(-0.61), M4SB-M5SB:-40.49-(-17.76), M4SB-M6SB:3.59-0.25, M5SB-M6SB:31.37-15.29)] mm^2/min respectively. The variation of chloride diffusion coefficient at specified time duration (2.23 min up to 173.89 min) was interpreted in the impregnation (M1SB-M6SB) concrete cubes at different time duration as shown in Fig.7e. The chloride diffusion coefficient was increased in the impregnation concrete cubes [(M1WB-M2WB:5.37-0.58, M1WB-M3WB:1.60-0.43, M1WB-M4WB:2.66-(-2.98), M1WB-M5WB:9.55-5.06, M1WB-M6WB:6.47-0.63, and M2WB-M3WB:-3.98-(-0.16), M2WB-M4WB:-2.87-(-3.59), M2WB-M5WB:-4.42-4.50, M2WB-M6WBB:1.17-0.05, M3WB-M4WB:1.07-(-3.42), M3WB-M5WB:8.07-4.66, M3WB-M6WB:4.95-0.21, M4WB-M5WB:7.08-7.81, M4WB-M6WB:3.92-3.51), M5WB-M6WB:3.48-(-4.67)] mm^2/min respectively. The variation of chloride diffusion coefficient at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1WB-M6WB) concrete cubes as shown in Fig.7f.

The chloride solution absorption ratio was increased in the control concrete cubes as when compared to impregnation concrete cubes [M1CC-M1SB:8.08-1.34, M1CC-M1WB:6.53-(-0.41), M2CC-M2SB:-5.30-1.07, M2MCC-M2WB:-3.24-0.49, M3CC-M3SB:-0.46-0.22, and M3CC-M3WB:0.63-0.24, M4CC-M4SB:-9.77-(-1.81), M4CC-M4WB:-29.15-(-8.22), M5CC-M5SB:-64.69-(-24.73), M5CC-M5WB:15.23-12.24, M6CC-M6SB:24.49-0.22, M6CC-M6WB:11.77-0.77, M1WB-M1SB:1.66-1.74, M2WB-M2SB:-2.00-0.58, M3WB-M3SB:-1.10-(-0.02), M4WB-M4SB:15.01-5.92), M5WB-M5SB:-94.28-(-53.52), M6WB-M6SB:14.42-(-0.66)] mm^2/min respectively. The variation of chloride solution absorption ratio at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1CC-M6CC) and impregnation concrete cubes (M1SB-M6SB and M1WB-M6WB) concrete cubes as shown in Fig.7g. The chloride solution absorption ratio was decreased in the impregnation concrete cubes [(M1SB-M1CC:91.92-98.66, M1WB-M1CC:93.47-100.41, M2SB-M2CC:105.30-98.93), M2WB-M2CC:103.24-99.51, M3SB-M3CC:100.46-99.78, and M3WB-M3CC:99.37-99.76, M4SB-M4CC:100.77-101.81, M4WB-M4CC:-129.15-108.22, M5SB-M5CC:164.69-134.73, M5WB-M5CC:84.77-87.76, M6SB-M6CC:75.51-99.78, M6WB-M6CC:88.23-99.23, M1SB-M1WB:98.34-99.26, M2SB-M2WB:102.00-99.42, M3SB-M3WB:101.10-100.02, M4SB-M4WB:84.79-94.08, M5SB-M5WB:194.28-153.52, and M6SB-M6WB:85.58-100.56] mm^2/min as when compared to control concrete cubes (M1CC-M6CC) respectively. The variation of chloride diffusion coefficient at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1WB-M6WB) concrete cubes as shown in Fig.7h.



	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
173.89 min	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
160.99 min	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
146.96 min	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
113.84 min	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
92.95 min	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
65.72 min	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
37.94 min	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
17.32 min	96.40	97.30	103.19	103.94	100.21	99.82	103.20	110.14	124.52	93.58	93.42	96.60	99.07	99.28	100.40	93.70	133.07	96.71
15.49 min	96.35	96.90	101.34	102.84	99.49	99.52	103.47	110.60	125.21	93.40	92.66	96.15	99.43	98.54	99.97	93.55	134.06	96.37
13.41 min	96.07	96.84	100.79	101.62	99.65	100.04	103.50	111.08	125.14	92.96	91.14	96.25	99.20	99.19	99.61	93.17	134.61	94.69
10.95 min	95.55	96.19	101.98	101.23	100.35	99.89	103.72	111.64	124.84	93.10	91.07	95.73	99.33	100.74	100.46	92.90	134.09	95.14
7.74 min	96.39	97.10	102.66	101.64	99.95	99.41	104.29	113.06	127.99	92.00	87.11	93.97	99.27	101.00	100.55	92.24	139.12	92.70
5.47 min	95.80	96.60	102.45	101.55	99.81	99.26	104.08	112.95	128.32	92.09	86.94	93.95	99.17	100.88	100.55	92.14	139.34	92.54
4.47 min	95.80	96.60	102.44	101.55	100.24	99.69	104.77	113.68	128.33	92.08	86.93	93.95	99.17	100.88	100.55	92.16	139.36	92.53
3.87 min	95.79	96.60	102.47	101.53	100.24	99.69	104.77	113.68	128.33	92.08	86.91	93.94	99.17	100.93	100.55	92.16	139.37	92.52
3.16 min	95.82	96.62	102.54	101.60	100.23	99.68	104.77	113.66	128.33	92.07	86.90	93.94	99.17	100.93	100.55	92.18	139.38	92.51
2.23 min	95.87	96.68	102.62	101.60	100.23	99.68	104.77	113.65	128.33	92.07	86.90	93.93	99.17	101.00	100.55	92.19	139.38	92.51

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

Fig.7c Cl^- diffusion coefficient-time in DCC/SB/WB/CC 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
173.89 min	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
160.99 min	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
146.96 min	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
131.45 min	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
113.84 min	-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
92.95 min	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
65.72 min	-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
37.94 min	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
17.32 min	5.90	2.66	11.73	1.48	1.75	-3.45	6.19	-4.70	-4.41	9.32	-1.21	-0.93	-11.61	-11.30	0.28
15.49 min	7.55	2.74	12.59	2.07	2.13	-5.20	5.46	-5.93	-5.86	10.13	-0.69	-0.63	-12.04	-11.97	0.06
13.41 min	7.67	4.28	13.20	2.30	2.45	-3.68	5.99	-5.81	-5.66	9.32	-2.06	-1.91	-12.55	-12.39	0.15
10.95 min	9.05	4.57	13.86	2.59	2.64	-4.92	5.29	-7.10	-7.05	9.74	-2.07	-2.02	-13.08	-13.03	0.05
7.74 min	9.86	4.22	16.64	4.71	3.58	-6.25	7.52	-5.71	-6.97	12.96	0.51	-0.67	-14.31	-15.67	-1.19
5.47 min	9.87	4.24	16.70	5.10	3.82	-6.24	7.58	-5.29	-6.71	13.01	0.90	-0.44	-13.93	-15.46	-1.34
4.47 min	9.87	4.65	17.26	5.10	3.82	-5.78	8.20	-5.29	-6.71	13.22	0.47	-0.87	-14.69	-16.24	-1.35
3.87 min	9.90	4.65	17.26	5.10	3.82	-5.82	8.17	-5.33	-6.74	13.22	0.47	-0.87	-14.69	-16.24	-1.35
3.16 min	9.94	4.63	17.24	5.08	3.80	-5.90	8.10	-5.40	-6.82	13.22	0.47	-0.87	-14.69	-16.24	-1.35
2.23 min	4.13	3.32	9.95	7.60	8.51	-0.84	6.08	3.62	4.57	6.86	4.42	5.37	-2.62	-1.60	0.99

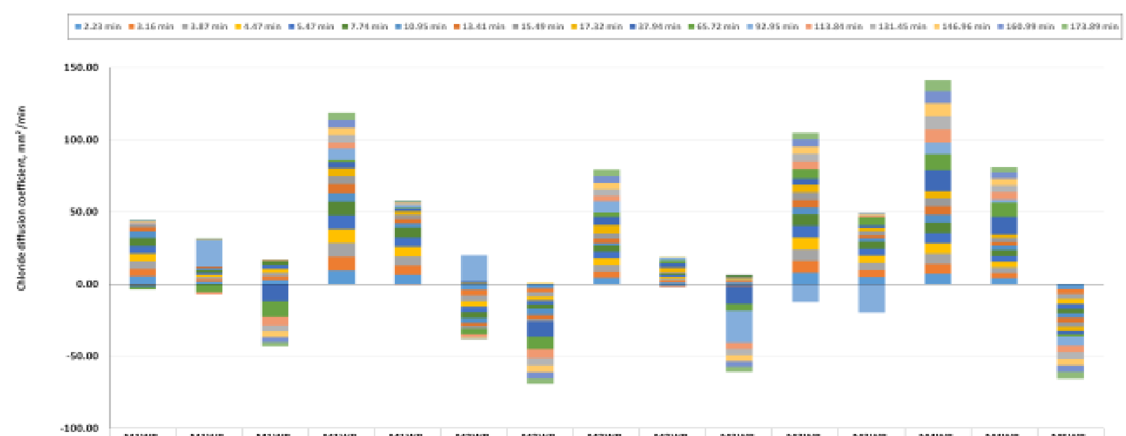
Chloride diffusion coefficient in control DCC cubes

Fig.7d Cl^- diffusion coefficient-time in DCC/CC cubes

	M1SB-M2SB	M1SB-M3SB	M1SB-M4SB	M1SB-M5SB	M1SB-M6SB	M2SB-M3SB	M2SB-M4SB	M2SB-M5SB	M2SB-M6SB	M3SB-M4SB	M3SB-M5SB	M3SB-M6SB	M4SB-M5SB	M4SB-M6SB	M5SB-M6SB
173.89 min	0.00	-0.46	-0.77	-18.67	-0.52	-0.46	-0.77	-18.67	-0.52	-0.31	-18.12	-0.06	-17.76	0.25	15.29
160.99 min	0.17	-0.46	-0.94	-18.11	0.03	-0.63	-1.12	-18.32	-0.14	-0.49	-17.58	0.48	-17.01	0.97	15.36
146.96 min	0.01	-0.64	-1.37	-17.06	0.48	-0.64	-1.38	-17.06	0.47	-0.73	-16.31	1.11	-15.48	1.82	14.98
131.45 min	0.05	-0.65	-1.37	-16.65	0.95	-0.70	-1.42	-16.70	0.90	-0.71	-15.89	1.59	-15.07	2.28	15.08
113.84 min	-0.43	-1.69	-1.98	-17.49	8.92	-1.25	-1.54	-16.99	9.31	-0.29	-15.55	10.43	-15.22	10.68	22.48
92.95 min	0.14	-0.06	0.02	0.02	0.03	-0.20	-0.12	-0.13	-0.12	0.08	0.08	0.09	-0.01	0.00	0.01
65.72 min	-4.28	-8.42	-9.45	-27.01	3.40	-3.97	-4.95	-21.79	7.37	-0.95	-17.14	10.90	-16.04	11.74	23.94
37.94 min	-1.39	-1.10	-6.47	-26.60	4.11	0.29	-5.01	-24.86	5.43	-5.31	-25.22	5.15	-18.91	9.94	24.26
17.32 min	-0.74	-1.20	5.49	-27.27	4.78	-0.46	6.18	-26.34	5.48	6.61	-25.76	5.91	-34.67	-0.75	25.19
15.49 min	2.76	-0.43	6.14	-27.27	5.88	-3.28	3.48	-30.87	3.21	6.54	-26.72	6.28	-35.59	-0.28	26.04
13.41 min	3.13	0.71	6.48	-27.26	7.45	-2.50	3.46	-31.37	4.46	5.82	-28.17	6.79	-36.08	1.04	27.28
10.95 min	2.93	-0.22	6.51	-27.26	7.20	-3.25	3.68	-31.11	4.40	6.72	-26.98	7.41	-36.12	0.75	27.08
7.74 min	3.99	0.68	9.81	-26.53	12.86	-3.45	6.06	-31.79	9.24	9.19	-27.40	12.27	-40.29	3.39	31.13
5.47 min	3.62	0.24	9.50	-27.12	12.72	-3.50	6.11	-31.89	9.44	9.29	-27.42	12.51	-40.47	3.55	31.34
4.47 min	3.62	0.24	9.50	-27.12	12.73	-3.51	6.11	-31.89	9.45	9.29	-27.42	12.52	-40.47	3.56	31.35
3.87 min	3.62	0.23	9.50	-27.13	12.74	-3.51	6.11	-31.90	9.46	9.29	-27.43	12.53	-40.48	3.57	31.36
3.16 min	3.62	0.23	9.50	-27.13	12.75	-3.51	6.10	-31.91	9.47	9.29	-27.43	12.54	-40.48	3.59	31.37
2.23 min	3.62	0.23	9.50	-27.14	12.75	-3.52	6.10	-31.91	9.47	9.29	-27.43	12.55	-40.49	3.59	31.37

Chloride diffusion coefficient increase in impregnation DCC cubes

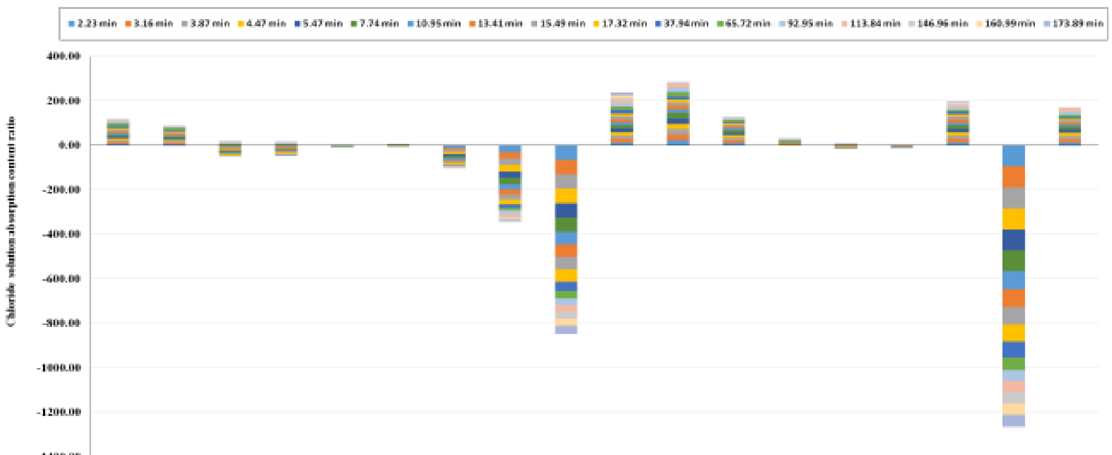
Fig.7e Cl^- diffusion coefficient-time in DCC/SB cubes



	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
173.89 min	0.58	0.43	-2.98	5.06	0.63	-0.16	-3.59	4.50	0.05	-3.42	4.66	0.21	7.81	3.51	-4.67
160.99 min	0.65	0.40	-3.55	5.29	0.92	-0.25	-4.22	4.67	0.27	-3.96	4.91	0.52	8.53	4.31	-4.61
146.96 min	0.91	0.11	-4.03	5.23	1.03	-0.80	-4.98	4.37	0.12	-4.15	5.13	0.91	8.90	4.86	-4.44
131.45 min	0.95	0.34	-3.93	5.43	0.85	-0.61	-4.92	4.52	-0.10	-4.28	5.10	0.51	9.00	4.59	-4.84
113.84 min	0.15	-1.45	-6.04	3.88	-0.44	-1.61	-6.20	3.73	-0.59	-4.52	5.26	1.00	9.36	5.29	-4.49
92.95 min	0.05	18.11	-0.07	8.00	1.88	18.07	-0.12	7.95	1.83	-22.20	-12.35	-19.82	8.06	1.95	-6.65
65.72 min	-1.76	-5.68	-10.71	1.51	0.33	-3.85	-8.79	3.21	2.06	-4.76	6.80	5.69	11.04	9.97	-1.20
37.94 min	-1.29	0.11	-11.85	4.28	1.92	1.38	-10.42	5.49	3.17	-11.97	4.17	1.81	14.42	12.31	-2.46
17.32 min	-0.52	0.14	0.08	5.25	2.46	0.66	0.59	5.74	2.97	-0.06	5.12	2.33	5.17	2.39	-2.94
15.49 min	1.88	0.11	0.24	5.61	2.89	-1.80	-1.67	3.80	1.03	0.13	5.50	2.78	5.38	2.65	-2.88
13.41 min	3.12	1.11	0.43	6.21	3.05	-2.07	-2.77	3.19	-0.08	-0.69	5.16	1.96	5.80	2.62	-3.38
10.95 min	4.29	0.90	0.04	5.73	3.11	-3.54	-4.44	1.50	-1.23	-0.88	4.87	2.23	5.69	3.08	-2.77
7.74 min	5.64	1.94	2.94	9.71	6.68	-3.92	-2.87	4.32	1.11	1.01	7.92	4.83	6.98	3.86	-3.35
5.47 min	5.25	1.61	2.60	9.53	6.46	-3.85	-2.80	4.51	1.28	1.01	8.05	4.94	7.11	3.97	-3.39
4.47 min	5.25	1.61	2.63	9.54	6.47	-3.85	-2.77	4.53	1.28	1.04	8.06	4.94	7.10	3.94	-3.40
3.87 min	5.10	1.60	2.62	9.54	6.47	-3.90	-2.82	4.48	1.24	1.04	8.07	4.94	7.10	3.95	-3.40
3.16 min	5.10	1.60	2.64	9.54	6.47	-3.90	-2.81	4.48	1.24	1.06	8.07	4.95	7.09	3.93	-3.40
2.23 min	5.37	1.60	2.66	9.55	6.47	-3.98	-2.87	4.42	1.17	1.07	8.07	4.95	7.08	3.92	-3.40

Chloride diffusion coefficient increase in impregnation DCC cubes

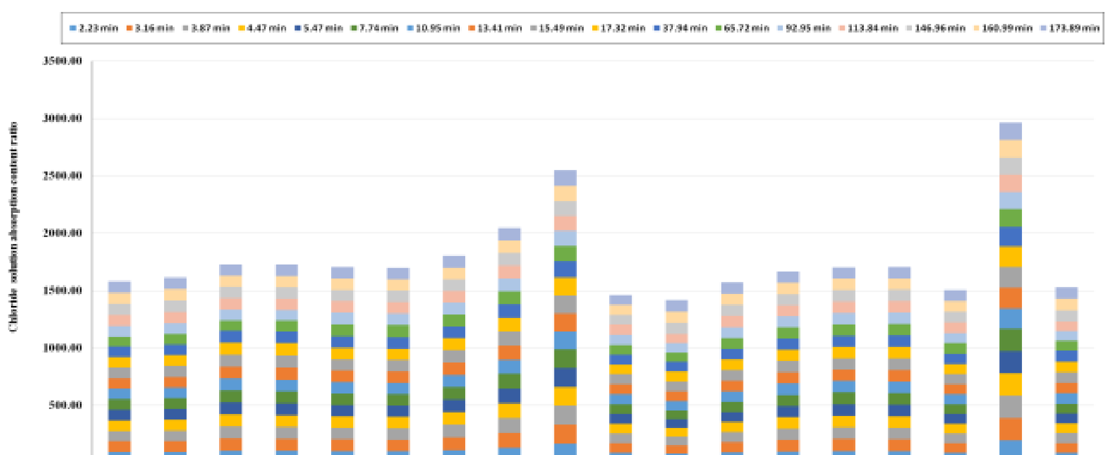
Fig.7f Cl^- diffusion coefficient-time in DCC/WB cubes



	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
173.89 min	1.34	-0.41	1.07	0.49	0.22	0.24	-1.81	-8.22	-34.73	12.24	0.22	0.77	1.74	0.58	-0.02	5.92	-53.52	-0.56
160.99 min	1.52	-0.14	1.86	1.15	0.52	0.56	-1.87	-9.00	-33.10	12.97	1.95	2.06	1.66	0.72	-0.03	6.54	-52.94	-0.11
146.96 min	2.44	0.46	1.84	1.64	0.69	0.17	-1.75	-9.34	-29.38	13.48	3.68	2.80	2.00	0.21	0.52	6.95	-49.53	0.91
113.84 min	3.58	3.00	3.26	3.80	-0.15	-0.28	-1.64	-10.56	-30.66	12.03	19.32	1.30	0.60	-0.57	0.14	8.07	-48.53	18.25
92.95 min	8.36	4.87	4.25	4.69	-3.04	-2.18	-4.61	-14.02	-32.15	12.67	19.95	5.41	3.66	-0.46	-0.84	8.26	-51.32	15.38
65.72 min	15.73	9.64	8.64	6.72	-1.05	-2.94	-2.51	-12.45	-32.43	14.61	20.18	8.89	6.74	2.05	1.83	8.84	-55.10	12.39
37.94 min	7.87	6.21	-2.81	-4.44	-0.23	0.41	-2.47	-15.11	-42.60	17.02	12.67	7.00	1.76	1.56	-0.64	10.98	-71.84	6.10
17.32 min	7.08	5.32	-6.49	-8.04	-0.43	0.36	-6.51	-21.32	-55.06	12.42	12.73	6.69	1.85	1.43	-0.79	12.21	-77.06	6.47
15.49 min	7.17	6.10	-2.71	-5.76	1.01	0.96	-7.05	-22.32	-56.78	12.76	14.14	7.55	1.14	2.89	0.06	12.48	-79.71	7.13
13.41 min	7.71	6.22	-1.59	-3.26	0.70	-0.09	-7.13	-23.40	-56.60	13.58	16.94	7.36	1.59	1.61	0.78	13.19	-81.19	10.33
10.95 min	8.70	7.47	-3.99	-2.47	-0.71	0.22	-7.57	-24.63	-55.86	13.32	17.06	8.37	1.33	-1.49	-0.93	13.69	-79.81	9.48
7.74 min	7.09	5.72	-5.40	-3.31	0.09	1.18	-8.76	-27.82	-63.82	15.36	24.12	11.70	1.46	-2.02	-1.10	14.91	-93.55	14.07
5.47 min	8.22	6.68	-4.95	-3.12	0.39	1.47	-8.32	-27.58	-64.67	15.19	24.41	11.73	1.65	-1.77	-1.10	15.10	-94.16	14.36
4.47 min	8.23	6.69	-4.94	-3.12	-0.48	0.62	-9.77	-29.23	-64.67	15.21	24.44	11.74	1.65	-1.77	-1.10	15.06	-94.22	14.38
3.87 min	8.24	6.69	-5.01	-3.08	-0.47	0.63	-9.77	-29.24	-64.68	15.22	24.46	11.75	1.66	-1.86	-1.10	15.06	-94.24	14.40
3.16 min	8.19	6.64	-5.15	-3.23	-0.47	0.63	-9.77	-29.19	-64.68	15.23	24.48	11.76	1.66	-1.86	-1.10	15.03	-94.26	14.41
2.23 min	8.08	6.53	-5.30	-3.24	-0.46	0.63	-9.77	-29.15	-64.69	15.23	24.49	11.77	1.66	-2.00	-1.10	15.01	-94.28	14.42

Chloride solution absorption content ratio increase in control DCC/SB/WB concrete cubes

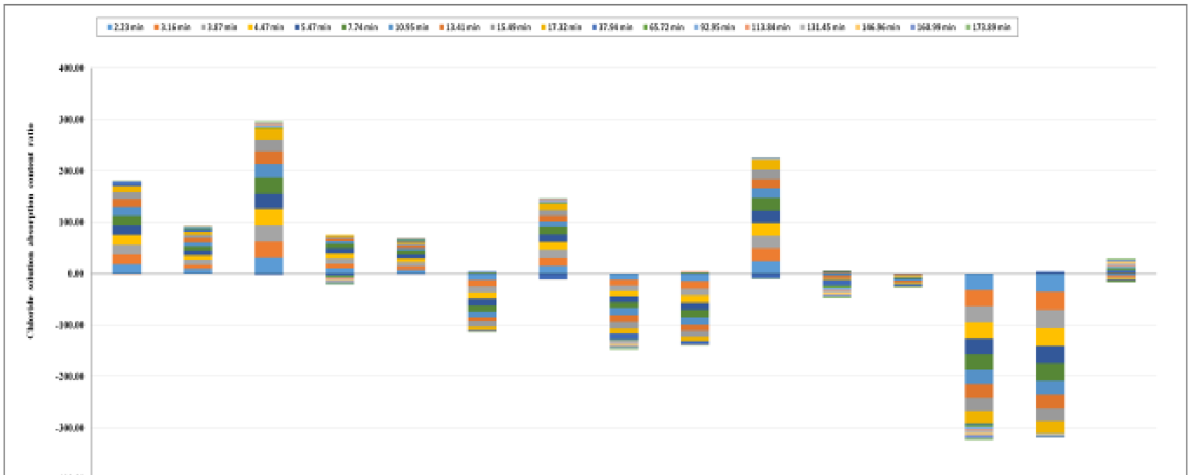
Fig.7g Cl⁻ solution absorption ratio-time in DCC/WB/SB cubes



	M1SB-M1CC	M1WBC-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	M6SB-M6WB
173.89 min	98.66	100.41	98.93	99.51	99.78	99.76	101.81	108.22	134.73	87.76	99.78	99.23	98.26	99.42	100.02	94.08	153.52	100.56
160.99 min	98.48	100.14	98.14	98.85	99.48	99.44	101.87	109.00	133.10	87.03	98.05	97.94	98.34	99.28	100.03	93.46	152.94	100.11
146.96 min	97.56	99.54	98.16	98.36	99.31	99.83	101.75	109.34	129.38	86.52	96.32	97.20	98.00	99.79	99.48	93.05	149.53	99.09
113.84 min	96.42	97.00	96.74	96.20	100.15	100.28	101.64	110.56	130.66	87.97	80.68	98.70	99.40	100.57	99.86	91.93	148.53	81.75
92.95 min	91.64	95.13	95.75	95.31	103.04	102.18	104.61	114.02	132.15	87.33	80.05	94.59	96.34	100.46	100.84	91.74	151.32	84.62
65.72 min	84.27	90.36	91.36	93.28	101.05	102.94	102.51	112.45	132.43	85.39	79.82	91.11	93.26	97.95	98.17	91.16	155.10	87.61
37.94 min	92.13	93.79	102.81	104.44	100.23	99.59	102.47	115.11	142.60	82.98	87.33	93.00	98.24	98.44	100.64	89.02	171.84	93.90
17.32 min	92.92	94.68	106.49	108.04	100.43	99.64	106.51	121.32	155.06	87.58	87.27	93.31	98.15	98.57	100.79	87.79	177.06	93.53
15.49 min	92.83	93.90	102.71	105.76	98.99	99.04	107.05	122.32	156.78	87.24	85.86	92.45	98.86	97.11	99.94	87.52	179.71	92.87
13.41 min	92.29	93.78	101.59	103.26	99.30	100.09	107.13	123.40	156.60	86.42	83.06	92.64	98.41	98.39	99.22	86.81	181.19	89.67
10.95 min	91.30	92.53	103.99	102.47	100.71	99.78	107.57	124.63	155.86	86.68	82.94	91.63	98.67	101.49	100.93	86.31	179.81	90.52
7.74 min	92.91	94.28	105.40	103.31	99.91	98.82	108.76	127.82	163.82	84.64	75.88	88.30	98.54	102.02	101.10	85.09	193.55	85.93
5.47 min	91.78	93.32	104.95	103.12	99.61	98.53	108.32	127.58	164.67	84.81	75.59	88.27	98.35	101.77	101.10	84.90	194.16	85.64
4.47 min	91.77	93.31	104.94	103.12	100.48	99.38	109.77	129.23	164.67	84.79	75.56	88.26	98.35	101.77	101.10	84.94	194.22	85.62
3.87 min	91.76	93.31	105.01	103.08	100.47	99.37	109.77	129.24	164.68	84.78	75.54	88.25	98.34	101.86	101.10	84.94	194.24	85.60
3.16 min	91.81	93.36	105.15	103.23	100.47	99.37	109.77	129.19	164.68	84.77	75.52	88.24	98.34	101.86	101.10	84.97	194.26	85.59
2.23 min	91.92	93.47	105.30	103.24	100.46	99.37	109.77	129.15	164.69	84.77	75.51	88.23	98.34	102.00	101.10	84.99	194.28	85.58

Chloride solution absorption content ratio decrease in control DCC/SB/WB concrete cubes

Fig.7h Cl⁻ solution absorption ratio-time in DCC/SB/WB 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
173.89 min	0.27	0.20	1.59	-3.13	0.08	-0.07	1.33	-3.41	-0.19	1.39	-3.34	-0.12	-4.80	-1.54	3.11
160.99 min	0.00	0.10	1.49	-3.22	-0.38	0.09	1.49	-3.23	-0.38	1.40	-3.32	-0.47	-4.79	-1.90	2.76
146.96 min	0.62	0.51	1.48	-3.32	-0.32	-0.12	0.86	-3.97	-0.95	0.98	-3.85	-0.83	-4.87	-1.82	2.91
131.45 min	1.31	0.79	1.24	-2.60	1.19	-0.52	-0.07	-3.96	-0.12	0.45	-3.42	0.40	-3.89	-0.05	3.69
113.84 min	-0.53	0.45	1.34	-1.88	0.86	0.97	1.86	-1.35	1.38	0.90	-2.33	0.42	-3.26	-0.49	2.69
92.95 min	0.33	3.15	4.00	-0.86	1.99	2.82	3.68	-1.19	1.66	0.88	-4.13	-1.20	-5.06	-2.10	2.82
65.72 min	-0.30	1.97	1.53	-2.64	1.49	2.27	1.82	-2.34	1.78	-0.46	-4.71	-0.50	-4.24	-0.04	4.02
37.94 min	7.87	6.05	-1.92	-3.56	3.00	-1.98	-10.63	-12.40	-5.29	-8.48	-10.22	-3.25	-1.60	4.83	6.33
17.32 min	11.46	5.24	22.08	2.94	3.47	-7.02	12.00	-9.62	-9.02	17.77	-2.43	-1.87	-24.57	-23.88	0.55
15.49 min	14.52	5.40	23.60	4.09	4.21	-10.67	10.62	-12.20	-12.06	19.24	-1.38	-1.25	-25.53	-25.38	0.13
13.41 min	14.75	8.37	24.66	4.55	4.84	-7.49	11.62	-11.97	-11.63	17.78	-4.17	-3.86	-26.69	-26.31	0.30
10.95 min	17.28	8.93	25.80	5.12	5.21	-10.09	10.51	-14.70	-14.59	18.53	-4.18	-4.09	-27.88	-27.76	0.09
7.74 min	18.74	8.26	30.51	9.19	7.02	-12.90	14.47	-11.75	-14.42	24.24	1.01	-1.35	-30.67	-33.79	-2.39
5.47 min	18.76	8.30	30.61	9.94	7.50	-12.88	14.59	-10.86	-13.86	24.33	1.78	-0.87	-29.79	-33.31	-2.71
4.47 min	18.76	9.09	31.54	9.94	7.50	-11.90	15.72	-10.86	-13.86	24.69	0.93	-1.75	-31.54	-35.11	-2.71
3.87 min	18.82	9.09	31.54	9.94	7.50	-11.98	15.67	-10.93	-13.94	24.69	0.93	-1.75	-31.55	-35.11	-2.71
3.16 min	18.90	9.04	31.50	9.89	7.45	-12.15	15.54	-11.10	-14.11	24.69	0.94	-1.75	-31.55	-35.12	-2.71
2.23 min	18.92	8.93	31.42	9.78	7.33	-12.32	15.42	-11.26	-14.29	24.70	0.94	-1.75	-31.55	-35.12	-2.72

Fig.7i Cl^- solution absorption ratio-time in DCC/CC cubes

	M1SB-M2SB	M1SB-M3SB	M1SB-M4SB	M1SB-M5SB	M1SB-M6SB	M2SB-M3SB	M2SB-M4SB	M2SB-M5SB	M2SB-M6SB	M3SB-M4SB	M3SB-M5SB	M3SB-M6SB	M4SB-M5SB	M4SB-M6SB	M5SB-M6SB
173.89 min	0.27	0.20	1.59	-3.13	0.08	-0.07	1.33	-3.41	-0.19	1.39	-3.34	-0.12	-4.80	-1.54	3.11
160.99 min	0.00	0.10	1.49	-3.22	-0.38	0.09	1.49	-3.23	-0.38	1.40	-3.32	-0.47	-4.79	-1.90	2.76
146.96 min	0.62	0.51	1.48	-3.32	-0.32	-0.12	0.86	-3.97	-0.95	0.98	-3.85	-0.83	-4.87	-1.82	2.91
131.45 min	1.31	0.79	1.24	-2.60	1.19	-0.52	-0.07	-3.96	-0.12	0.45	-3.42	0.40	-3.89	-0.05	3.69
113.84 min	-0.53	0.45	1.34	-1.88	0.86	0.97	1.86	-1.35	1.38	0.90	-2.33	0.42	-3.26	-0.49	2.69
92.95 min	0.33	3.15	4.00	-0.86	1.99	2.82	3.68	-1.19	1.66	0.88	-4.13	-1.20	-5.06	-2.10	2.82
65.72 min	-0.30	1.97	1.53	-2.64	1.49	2.27	1.82	-2.34	1.78	-0.46	-4.71	-0.50	-4.24	-0.04	4.02
37.94 min	7.87	6.05	-1.92	-3.56	3.00	-1.98	-10.63	-12.40	-5.29	-8.48	-10.22	-3.25	-1.60	4.83	6.33
17.32 min	11.46	5.24	22.08	2.94	3.47	-7.02	12.00	-9.62	-9.02	17.77	-2.43	-1.87	-24.57	-23.88	0.55
15.49 min	14.52	5.40	23.60	4.09	4.21	-10.67	10.62	-12.20	-12.06	19.24	-1.38	-1.25	-25.53	-25.38	0.13
13.41 min	14.75	8.37	24.66	4.55	4.84	-7.49	11.62	-11.97	-11.63	17.78	-4.17	-3.86	-26.69	-26.31	0.30
10.95 min	17.28	8.93	25.80	5.12	5.21	-10.09	10.31	-14.70	-14.59	18.53	-4.18	-4.09	-27.88	-27.76	0.09
7.74 min	18.74	8.26	30.51	9.19	7.02	-12.90	14.47	-11.75	-14.42	24.24	1.01	-1.35	-30.67	-33.79	-2.39
5.47 min	18.76	8.30	30.61	9.94	7.50	-12.88	14.59	-10.86	-13.86	24.33	1.78	-0.87	-29.79	-33.31	-2.71
4.47 min	18.76	9.09	31.54	9.94	7.50	-11.90	15.72	-10.86	-13.86	24.69	0.93	-1.75	-31.54	-35.11	-2.71
3.87 min	18.82	9.09	31.54	9.94	7.50	-11.98	15.67	-10.93	-13.94	24.69	0.93	-1.75	-31.55	-35.11	-2.71
3.16 min	18.90	9.04	31.50	9.89	7.45	-12.15	15.54	-11.10	-14.11	24.69	0.94	-1.75	-31.55	-35.12	-2.71
2.23 min	18.92	8.93	31.42	9.78	7.33	-12.32	15.42	-11.26	-14.29	24.70	0.94	-1.75	-31.55	-35.12	-2.72

Fig.7j Cl^- solution absorption ratio-time in DCC/SB cubes

The chloride solution absorption ratio was increased in the control concrete cubes as when compared to different control concrete mixture types [M1CC-M2CC:18.92-0.27, M1CC-M3CC:8.93-0.20, M1CC-M4CC:31.42-1.59, M1CC-M5CC:-9.78-(-3.13), M1CC-M6CC:.7.33-0.08, and M2CC-M3CC:-12.32-(-0.07), M2CC-M4CC:15.42-1.33, M2CC-M5CC:-11.26-(-3.41), M2CC-M6CC:-14.29-(-0.19), M3CC-M4CC:24.70-1.39, M3CC-M5CC:0.94-(-3.34), M3CC-M6CC:-1.75-(-0.12), M4CC-M5CC:-31.55-(-4.80), M4CC-M6CC:-31.12-(-1.54), M5CC-M6CC:-2.72-3.11] mm²/min respectively. The variation of chloride solution absorption ratio at specified time duration (2.23 min up to 173.89 min) was interpreted in the control (M1CC-M6CC) concrete cubes as shown in Fig.7i. The chloride solution absorption ratio was increased in the impregnation concrete cubes as when compared to different designed impregnation concrete cubes [M1SB-M2SB:7.11-0.00, M1SB-M3SB:0.46-(-0.93), M1SB-M4SB:18.10-(-1.56), M1SB-M5SB:-61.64-(-40.82), M1SB-M6SB:23.87-(-1.05), and M2SB-M3SB:-7.16-(-0.92), M2SB-M4SB:11.83-(-1.55), M2SB-M5SB:-74.07-(-40.82), M2SB-M6SB:18.05-(-1.05), M3SB-M4SB:17.72-(-0.62), M3SB-M5SB:-62.39-(-39.53), M3SB-M6SB:23.52-(-0.12), M4SB-M5SB:-97.37-(-38.67), M4SB-M6SB:7.05-0.49, M5SB-M6SB:52.90-28.24] mm²/min respectively. The variation of chloride solution absorption ratio at specified time duration (2.23 min up to 173.89 min) was interpreted in the impregnation concrete cubes (M1SB-M6SB) as shown in Fig.7j.

	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
173.89 min	1.17	0.85	-6.86	9.87	1.26	-0.32	-7.31	8.80	0.09	-6.97	9.09	0.41	15.02	6.90	-9.55
160.99 min	1.29	0.80	-7.22	10.30	1.83	-0.50	-8.62	9.12	0.55	-8.08	9.58	1.04	16.34	8.44	-9.44
146.96 min	1.81	0.22	-8.22	10.19	2.04	-1.61	-10.21	8.54	0.24	-8.46	9.99	1.82	17.02	9.48	-9.08
131.45 min	1.89	0.69	-8.00	10.56	1.69	-1.22	-10.08	8.84	-0.20	-8.75	9.94	1.01	17.19	8.97	-9.92
113.84 min	0.51	-2.92	-12.45	7.61	-0.87	-3.24	-12.79	7.32	-1.19	-9.25	10.23	1.99	17.84	10.29	-9.18
92.95 min	0.14	-4.04	-15.06	7.41	2.54	-6.18	-15.22	7.28	2.40	-10.60	11.00	6.32	19.53	15.30	-5.26
65.72 min	-3.55	-11.68	-22.56	3.00	0.67	-7.85	-18.36	6.32	4.07	-9.74	13.15	11.06	20.86	18.95	-2.41
37.94 min	-2.59	0.23	-25.10	8.37	3.81	2.75	-21.94	10.69	6.24	-25.38	8.16	3.59	26.75	23.00	-4.98
17.32 min	-1.04	0.28	0.15	10.22	4.96	1.31	1.19	11.14	5.84	-0.12	9.97	4.60	10.08	4.71	-5.96
15.49 min	3.73	0.22	0.48	10.90	5.69	-3.64	-3.37	7.45	2.04	0.26	10.70	5.48	10.47	5.24	-5.84
13.41 min	6.14	2.21	0.87	12.04	6.00	-4.19	-5.62	6.29	-0.15	-1.38	10.05	3.87	11.27	5.18	-6.87
10.95 min	8.39	1.80	0.07	11.12	6.13	-7.20	-9.09	2.98	-2.47	-1.76	9.50	4.41	11.06	6.06	-5.62
7.74 min	10.96	3.85	5.79	18.48	12.92	-7.99	-5.81	8.45	2.20	2.02	15.22	9.44	13.47	7.57	-6.82
5.47 min	10.22	3.18	5.13	18.15	12.51	-7.84	-5.67	8.83	2.54	2.01	15.46	9.63	13.72	7.78	-6.89
4.47 min	10.23	3.18	5.18	18.17	12.51	-7.85	-5.62	8.85	2.55	2.06	15.48	9.64	13.70	7.73	-6.91
3.87 min	10.31	3.18	5.18	18.17	12.52	-7.95	-5.73	8.76	2.46	2.06	15.48	9.64	13.71	7.74	-6.91
3.16 min	10.32	3.18	5.22	18.18	12.52	-7.96	-5.69	8.76	2.46	2.10	15.49	9.65	13.67	7.71	-6.91
2.23 min	10.45	3.18	5.24	18.18	12.53	-8.11	-5.81	8.64	2.32	2.12	15.49	9.65	13.66	7.69	-6.91

Fig.7k Cl^- solution absorption ratio-time in DCC/WB cubes

The chloride solution absorption ratio was increased in the impregnation concrete cubes as when compared to different designed impregnation concrete cubes [M1WB-M2WB:10.45-1.17, M1WB-M3WB:3.18-0.85, M1WB-M4WB:5.24-(-6.06), M1WB-M5WB:18.18-9.87, M1WB-M6WB:12.63-1.26, and M2WB-M3WB:-8.11-(-0.32), M2WB-M4WB:-5.81-(-7.31), M2WB-M5WB:8.64-8.80, M2WB-M6WB:2.32-0.09, M3WB-M4WB:2.12-(-6.97), M3WB-M5WB:15.49-9.09, M3WB-M6WB:9.65-0.41, M4WB-M5WB:13.66-15.02, M4WB-M6WB:7.69-6.90, M5WB-M6WB:-6.91-(-9.55)] mm²/min respectively. The variation of chloride solution absorption ratio at specified time duration (2.23 min up to 173.89 min) was interpreted in the impregnation concrete cubes (M1WB-M6WB) as shown in Fig.7k.

5. CONCLUSION

The chloride diffusion coefficient is co-related with square root of time by power type of equation in control/impregnation concrete cubes. Chloride diffusion coefficient is initially increased, which may be 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. It's also possible to correlate the variation of chloride solution absorption content ratio with square root of time by linear type of equation. From this relationship it's possible to predict chloride diffusion coefficient at any time duration based on chloride solution absorption in control/impregnation concrete cubes.

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REFERENCE

1. Alexander, M. and Thomas, M. (2015). *Service life prediction and performance testing*- Current developments and practical application. Cement and Concrete Research. 78:155-164.
2. ASTM C1556-04. (2004). Standard test method for determining the apparent chloride diffusion coefficient of cementitious mixtures by Bulk diffusion. ASTM International, USA.
3. 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.
4. 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).
5. Bazant, Z.P., and Najjar, L.J. (1972). *Nonlinear water diffusion in non-saturated concrete,* Matriaux et Constructions, 5: 3-20.
6. Ballim, Y., Alexander, M. and Beushausen, H. (2009). *Durability of concrete. In Fulton's Concrete Technology*, 9th ed. Ed:
7. G. Owens. Midrand, South Africa: Cement and Concrete Institute, pp. 155-188.
8. Fujiwara, T., Sato, K. and Konishi, T. (1988). *Water movement within concrete due to drying and wetting*, Review of 42 General meeting, CAJ, 427-430pp (In Japanese).
9. Fujiwara, T., Kayaba, M. and Akita, H. (1992). *Water movement within concrete due to drying under various temperature conditions*, CAJ Proceedings of Cement & Concrete, 46:428-433 (In Japanese).
10. Gjorv, O. E. (2009). *Durability design of concrete structures in severe environments*. London, UK: Taylor and Francis.
11. Hamilton, H. R., Boyd, A. J. and Vivas, E. (2007). Permeability of concrete - Comparison of conductivity and diffusion methods. UF Project No. 00026899. Florida, USA: Engineering and Industrial Experiment Station, University of Florida.
12. Mehta, P. K. and Monteiro, P. J. M. (2006). *Concrete microstructure, properties and materials*, 3rd ed. USA: McGraw-Hill.
13. Nilsson, L.-O. (2003). *Durability concept; pore structure and transport processes*. In advanced concrete technology, Concrete Properties. Eds: J. Newman and B. S. Choo. Oxford, UK: Butterworth-Heinemann, pp. 8/3-8/29.
14. Oh, B. H. and Jang, S. Y. (2007). *Effects of material and environmental parameters on chloride penetration profiles in concrete structures*. Cement and Concrete Research. 37:47-53.
15. Pack, S., Jung, M., Song, H., Kim, S. and Ann, Y. (2010). *Prediction of time dependent chloride transport in concrete structures exposed to a marine environment*. Cement and Concrete Research. 40:302-312.
16. Roziere, E., Loukili, A. and Cussigh, F. (2009). *A performance based approach for durability of concrete exposed to carbonation.* Construction and Building materials. 23:190-199.
17. 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.
18. Savija, B. (2014). *Experimental and numerical investigation of chloride ingress in cracked concrete*. PhD Thesis. Technische Universiteit Delft.
19. Stanish, K. and Thomas, M. (2003). *The use of bulk diffusion tests to establish time dependent concrete chloride diffusion coefficients*. Cement and Concrete Research. 33:55-62.
20. Sakata, K. (1983). *A Study on moisture diffusion in Drying and drying shrinkage of concrete*, Cement and Concrete Research, 13:216-224.

21. 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.
22. 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.
23. Teychenné. D. C, Franklin. R. E. and Erntroy. H. C. (1988). *Design of normal concrete mixes,* Second edition, BRE.
24. Wegen, G., Polder, R. B. and Breugel, K. (2012). A guideline for service life design of structural concrete – A performance based approach with regard to chloride induced corrosion, 57(3):153-167.
25. Xiao Zhang, and Hongduo Zhao (2015). *Characterization of moisture diffusion in cured concrete slabs at early ages*, Advances in materials science and Engineering, Article ID 154394, 10 pages.
26. 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.