CHLORIDE DIFFUSION COEFFICIENT IN PARTIALLY SATURATED 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 withstand water 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 water diffusion coefficient the within concrete structures. Therefore, there is a need to quantify the water diffusion coefficient in concrete cubes which is of most important factor. The present research work is made an attempt to interpret the concrete water 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 water 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 water diffusion coefficient under different. It's confirmed from the results that, the water diffusion coefficient is co-related with square root of time, in turn the average variation of water diffusion coefficient is more for in case of higher compressive strength and varied slump for in first three set of mixtures type. But in the case of lower compressive strength and constant slump, the water diffusion coefficient was slightly higher in case of second three set of mixture type. It's possible to establish logarithmic relationship between water diffusion coefficient and square root of time. The water diffusion coefficient is lesser at an initial stage when the rate of absorption is lesser at an initial stage for in case of all mixtures type.*

The moisture content ratio coefficient is co-related with square root of time, in turn the average variation of moisture content ratio coefficient 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 ratio coefficient 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. It's possible to establish tri-polynomial relationship between moisture content ratio coefficient and square root of time. It's also confirmed from the results that, the average variation of moisture content is slightly higher 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.

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

1.0 Introduction

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 [1-3] 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 [4]. There is a major difficulty in establishing reliable diffusion parameters, because diffusion of moisture inside cementitious materials is basically controlled by the microstructure 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 [5]. 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 [6-8]. They used different approaches to obtain the relationship between water content and water diffusion coefficient, and obtained consistent results to those by [5]. 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 [9]. 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 [10] 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. Its confirmed by investigators [11] that, the moisture diffusion coefficient of concrete at an early age is significantly dependent on age and the coefficient may vary from 10-10 from 3-28 days starting from concrete casting. The variation law of the coefficient with age can be described as a rapidly decreasing stage within 7-10 days from concrete casting followed by a slow decreasing stage.

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 [12] 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 [13].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 [14] 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

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 water diffusion coefficient in concrete structures. The present research work is made an attempt to interpret the concrete water 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 water 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 to 40 N/mm^2 were prepared and evaluate the concrete water 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.

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 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 water diffusion coefficient, moisture content ratio coefficient, and moisture content with their average, minimum, maximum, and standard deviation in concrete cubes for in case of different mixtures type is represented as in Table.3-5.

Table: 3Water diffusion coefficient in concrete cubes

Mix ID	Average	Min,value	Max,value	STD
M1	1.09	0.47	2.20	0.56
M2	1.17	0.47	2.37	0.61
M3	1.15	0.47	2.27	0.56
M4	1.20	0.47	2.44	0.57
M5	1.13	0.47	2.20	0.55
M6	1.05	0.47	2.07	0.54

Table : 4 Moisture content ratio coefficient (M_t/M_∞) in concrete cubes

Mix ID	Average	Min,value	Max,value	STD
M1	0.654	0.353	0.134	1.064
M2	0.780	0.427	0.148	1.310
M3	0.632	0.351	0.125	1.027
M4	0.967	0.543	0.154	1.626
M5	0.667	0.366	0.137	1.083
M6	0.638	0.341	0.109	1.019

Table: 5 Moisture content in concrete cubes for different mixtures type

Mix ID	Average,%	Min,value(%)	Max,value(%)	STD
M1	2.61	1.41	4.19	0.44
M2	3.15	1.75	5.23	0.59
M3	2.52	1.41	4.10	0.50
M4	3.97	2.22	6.48	0.64
M5	2.75	1.53	4.45	0.55
M6	2.63	1.40	4.20	0.45

4.0 Discussion about Results

The water diffusion coefficient is gradually increased which in turn follows linearity of proportion at an 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 water diffusion coefficient is varied approximately in between 2.2-0.5 mm^2/min in all mixtures type (M1-M6). The water diffusion coefficient is initially increased in all mixtures type (M1-M6). The diffusion coefficient is increased at shorter time duration (5 min) which is about 9.70% in mixtures type (M1-M3) as when compared to time duration at 10 min. Also the diffusion coefficient is increased at shorter time duration (5 min) which is about 10.32% in mixtures type (M4-M6) as when compared to time duration at 10 min. Similarly, water diffusion is more varied at initial time duration 5 min which is in the range of about 57.21% as when compared to 1day (1440 min). Furthermore it is still increased at initial time (5 min) duration of about 76.50% as when compared to 185.90 min in all mixtures type. But at an initial stage (5 min), the observed diffusion coefficient is found to be increased in case of mixtures type (M1-M3) as about 76.92% as well as (76.02%) for in mixtures type (M4-M6) as when compared to longer time duration (185.90 min).The diffusion coefficient is an 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 combined water diffusion coefficient, in concrete cube in case of different mixtures type (M1-M6) as shown in Fig.1. Similarly the variation of water diffusion coefficient in different mixture type is as shown in separate Figs.2-7 respectively. Water diffusion coefficient is directly proportional to the negative logarithm of square root of time and constant value in all designed mixtures type (M1-M6).

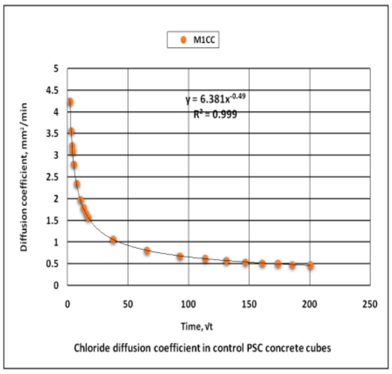

Fig.1a Cl^- diffusion coefficient

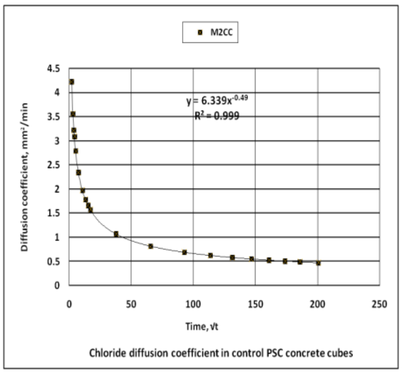

Fig.1b Cl^- diffusion coefficient

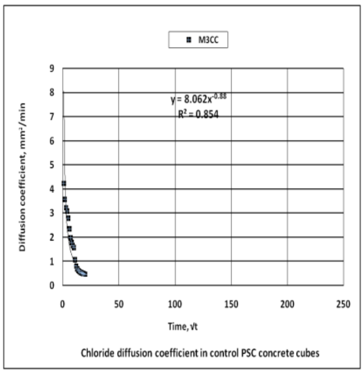

Fig.1c Cl^- diffusion coefficient

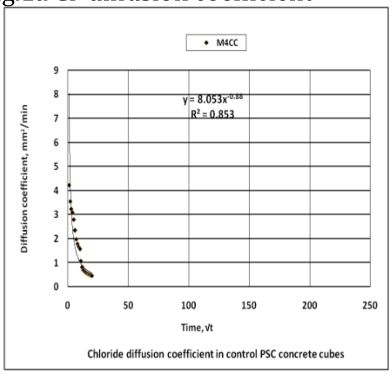

Fig.2a Cl^- diffusion coefficient

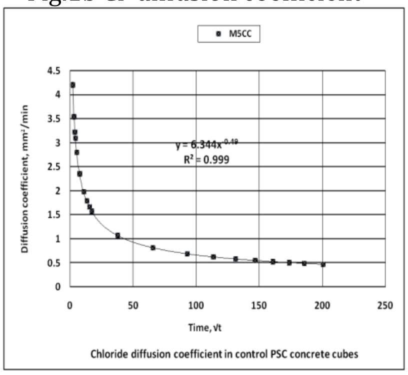

Fig.2b Cl^- diffusion coefficient

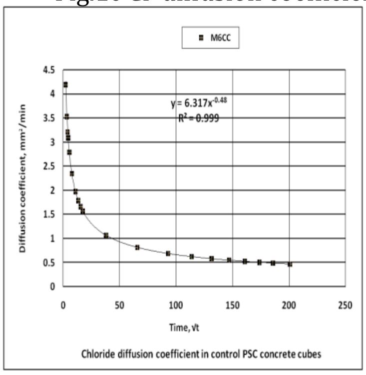

Fig.2c Cl^- diffusion coefficient

The moisture content ratio coefficient is depends on factors such as square root of material thickness, diffusion coefficient, and time. As observed from the research work that, the moisture content ratio varies linearly at initial time duration, afterwards the curve follows non-linear trend, and finally reaches equilibrium conditions in all mixtures type. In addition to that, the moisture content ratio varies between 1-1.2 for in case of mixtures type (M1-M3). Whereas the moisture content ratio varies more 1.6 for in case of mixture type M4 as when compared to mixtures type (M5-M6). This may be due to the Grade of concrete in turn it's indicate that, higher the grade of concrete, and lesser the moisture content ratio. In fact the moisture content ratio depends up on the mixture proportion, compactness of concrete matrix, quantity of fine and coarse aggregate, slump value, and fineness of cement. The variation of moisture content at any particular time duration to moisture content at an infinite time duration is studied in the present research work for in case of designed mixtures type (M1-M6) at different time duration which is represented as shown in Fig.8.The moisture content (Mt) depends on time, lesser/more the time, lesser/more moisture content availability in concrete matrix which depends on the pore structure formation, aggregates volume fraction, w-c ratio, slump, and compressive strength. From this ratio, it's possible to predict the time duration for that ratio and in turn able to predict diffusion coefficient at that ratio. As observed from the results that, the moisture content ratio varied at different time duration, the ratio variation is lesser in case of mixtures type (M1-M3) as well as (M4-M6) at an initial time duration (5 min) is as 0.255, and 0.284. Similarly, it's varied in mixtures type such as (M1-M3) with (M4-M6) as 1.107 and 1.23 at time duration (185.90 min). The variation of moisture content (Mt) at any particular time duration to moisture content (M∞) at an infinite time duration is studied in the present research work for in the case of designed mixtures type (M1-M6) at different time duration which is represented as shown in Fig.9-14.The variation of moisture content ratio coefficient is co-related with square root of time by tri-polynomial equation.

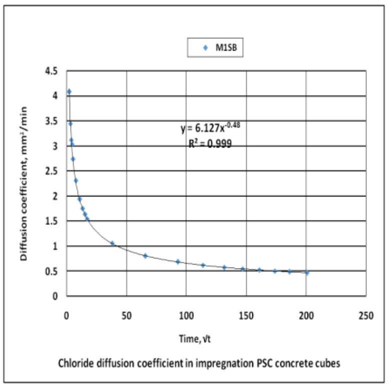

Fig.3a Cl^- diffusion coefficient

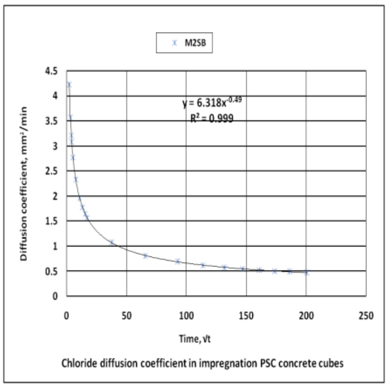

Fig.3b Cl^- diffusion coefficient

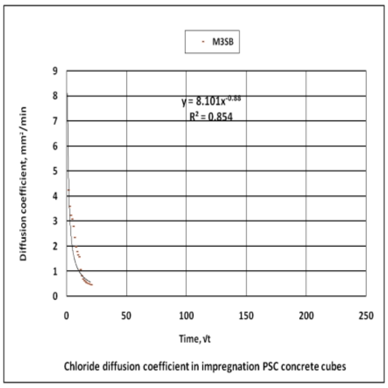

Fig.3c Cl^- diffusion coefficient

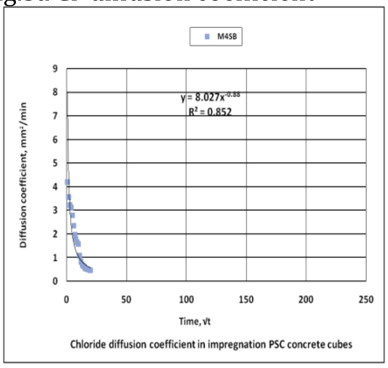

Fig.4a Cl^- diffusion coefficient

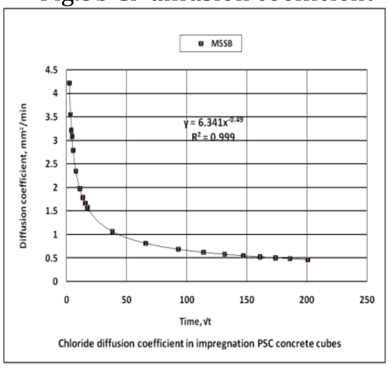

Fig.4b Cl^- diffusion coefficient

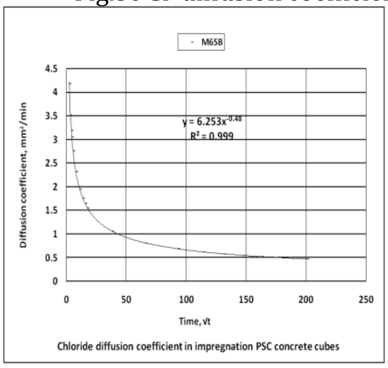

Fig.4c Cl^- diffusion coefficient

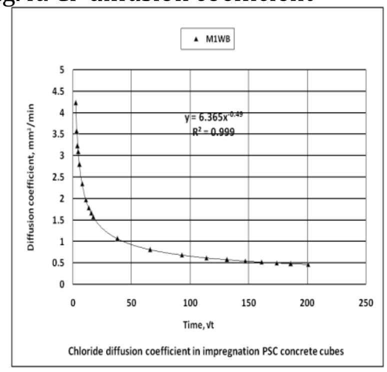

Fig.5a Cl^- diffusion coefficient

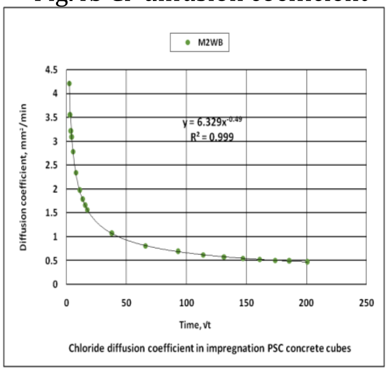

Fig.5b Cl^- diffusion coefficient

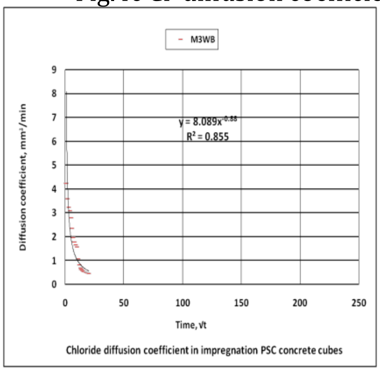

Fig.5c Cl^- diffusion coefficient

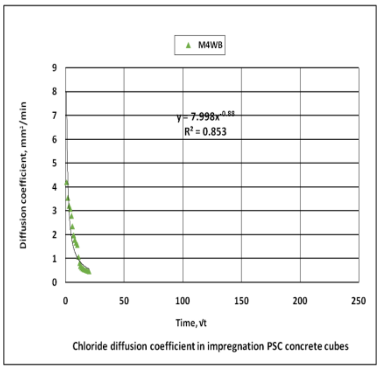

Fig.6a Cl^- diffusion coefficient

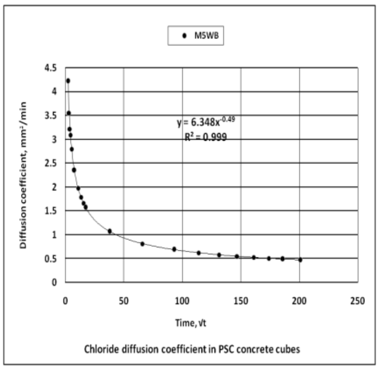

Fig.6b Cl^- diffusion coefficient

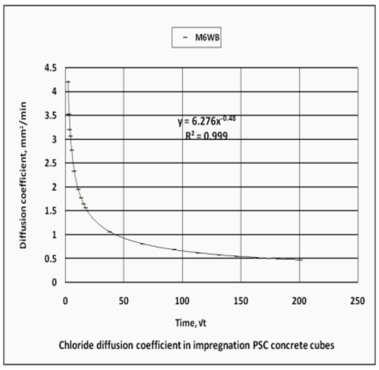

Fig.6c Cl^- diffusion coefficient

5.0 Conclusions

- *The water diffusion coefficient is co-related with square root of time, in turn the average variation of water diffusion coefficient is more for in case of higher compressive strength and varied slump for in first three set of mixtures type. But in the case of lower compressive strength and constant slump, the water diffusion coefficient was slightly higher in case of second three set of mixture type. In fact, from this research work that, it's possible to establish logarithmic relationship between water diffusion coefficient and square root of time. The water diffusion coefficient is lesser at an initial stage when the rate of absorption is lesser at an initial stage for in case of all mixtures type.*

- *The moisture content ratio coefficient is co-related with square root of time, in turn the average variation of moisture content ratio coefficient 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 ratio coefficient 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. In fact, from this research work that, it's possible to establish tri-polynomial relationship between moisture content ratio coefficient and square root of time.*

- *It's also confirmed from the results that, the average variation of moisture content is slightly higher 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.*

6.0 References

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