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ANALYSIS OF CHLORIDE PENETRATION IN PRE-CONDITIONED CONCRETE SLABS

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Abstract: *In winter season, ice accumulates on the top surface of concrete slabs and bridge decks. For the purpose of removing the snow and ice, de-icing agents are applied. These salts migrate down to the reinforcing steel through small pores in the concrete. Over time, the chlorides in these salts can react with the reinforcing steel, breaking down the passive layer and causing the steel to corrode. Reinforcement corrosion in concrete is one of the most encountered causes of premature failure of infrastructure concrete structures as well as has serious economic and safety implications. Moreover, carbon dioxide from the atmosphere can gradually migrate into the concrete and react with the alkaline pore solution. Chloride ions from winter maintenance operations, marine environment/other contamination can penetrate through the concrete pores to the passive layer on the reinforcement and de-passivate the passive film. Thus in turn chloride ingress, carbonation, and low quality of the concrete cover can induce steel corrosion in concrete. This causes a build-up stress in concrete and leads to concrete deterioration and dangerous loss of structural durability.*

There is a need to quantify the chloride concentration in concrete slabs which is of most important factor. The present research work was made an attempt to interpret the concrete chloride concentration at different drill depths (30,40 and 50 mm) in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete slabs such as dry/fully/partially saturated condition which were salt ponded with chloride solution for about 160 days. Thus the objectives of this present research are such as, First, this research will examine the influence of conditioning such as dry/fully/partially saturated condition on the results of chloride concentration performed on concrete slabs at various drill depths with different mixtures proportion in which slump, and w/c ratio value was 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. Eighteen concrete slabs (450x450x100) mm with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride concentration under different exposure condition. It's concluded from the results that, in dry/saturated conditioned concrete slabs, the chloride concentration value were increased in all designed mixtures type at lesser drill depth as when compared to higher drill depth. Similarly, the average chloride concentration was decreased in solvent/water based impregnation DCC/PSC/FSC slabs as when compared to control DCC/PSC/FSC slabs for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value.

Keywords: *Concrete, mixture proportion, grade of concrete, pre-conditioning, w/c ratio, chloride penetration, drill depth*

1.0 Introduction

During winter, salt is used for road de-icing. The chlorides dissolved in the melt water are scattered around the reinforced concrete structure mainly due to vehicle circulation. Once the impermeability of the sealing is compromised, the water containing chlorides penetrates into the underlying concrete during wet seasons. During dry seasons water evaporates without mobilizing chlorides that remain in the concrete. The alternation of weathering cycles causes the chlorides to gradually migrate through the pores of the concrete by capillarity and diffusion [Conciatori 2005]. Thus, one can expect to encounter chloride and water concentration gradients within a concrete structure. Reinforced concrete structures and specifically bridge decks contain several layers of steel reinforcing bars (rebars) for bearing resistance. Once chlorides reach the first rebar layer, generally located at 2-4 cm depth, the chloride ions remove the protecting passivation layer on the steel rebar surface and localized corrosion pitting, is initiated. Pitting corrosion induces localized areas to become anodic, while the rest of the bar becomes cathodic. This creates an electric potential that increases the corrosion process. Different studies have shown that the probability of the initiation increases steadily with increasing chloride levels. This probability is considered high when exceeding 0.5% chloride content [Böhni 2005]. Once initiated, the corrosion process does not stop and the rebars lose progressively their mechanical resistance until possible structural failure. Chloride-induced reinforcement corrosion is one of the most important degradation processes in reinforced concrete structures exposed to a marine environment and road environment where de-icing salt is used in the winter [Hobbs, 2001]. Concrete is a porous material in which the pores are partially filled with water. When concrete is exposed to salt solutions chloride ions migrate into to the concrete changing the environment around the reinforcement, and causing a degradation of the reinforcement with time [Bamforth *et al*., 1997]. The degradation of reinforced concrete structures, especially infrastructures, has very important economic and social consequences due to the need for diverting resources for repairing damaged structures and sometimes the need to close the facility for carrying out the repair work.

The two governing equations that describe the diffusion of chloride ions into non-saturated concrete are established. Material models for the four material parameters involved in the governing equations are developed, including chloride binding capacity, chloride diffusion coefficient, moisture capacity, and moisture diffusion coefficient. The planned attempt is to establish material models based on analytical results first, and if this is not possible, to develop empirical models based on dominant physical or chemical mechanism at different scale levels and calibrate the individual model by related test data. The alternating-direction implicit finite-difference method was employed for solving coupled two-dimensional moisture diffusion and chloride penetration equations. The numerical solutions are compared with the experimental results obtained by the 90-day ponding test [AASHTO T259-80]. The numerical prediction agrees very well with the test data. Free chloride concentration profiles at different depths and different ages of concrete slab are presented. Two limiting cases for different initial relative humidity levels are analyzed in detail to study the dependence of the chloride diffusion on the moisture diffusion in non-saturated concrete [Ayman Ababneh *et al.* 2003]. This paper presents analysis and evaluation of experimental results of chloride ingress and chloride-induced corrosion resistance of concrete made with Portland limestone cement (PLC). The results were mined from 169 globally published studies from 32 countries since 1989, yielding a matrix of 20 500 data points. This review showed that chloride ingress in concrete increases with increasing limestone (LS) content, within the range permitted in BS EN 197-1:2011. However, this effect is less for PLC concrete mixes designed for strength equal to corresponding Portland cement concrete mixes than those designed on an equal water/cement (w/c) basis. The results also showed that Eurocode 2 specifications for chloride exposure, in terms of characteristic cube strength of concrete or w/c ratio, may need to be reviewed for the use of LS with PC. This study also investigated other influencing factors such as cement content, LS fineness, the method of producing PLC, aggregate volume content and particle size, combined chloride and sulfate environment, curing and exposure temperature. A comparison was made for the performance of PLC concrete in terms of pore structure and related properties, strength, carbonation and chloride ingress. Procedures to improve the resistance of PLC to chloride ingress in concrete are proposed [Elgalhud *et al*.2017]. The corrosion of reinforcing steel is one of the major causes of deterioration, reduced durability/even failure of reinforced concrete structures. The German Committee for Structural Concrete (DAfStB-Deutscher Ausschuss für Stahlbeton) reported in the project report [Schießl, and Mayer, 2007] that 66% of structural failures of German infrastructure building resulted from chloride-induced corrosion of reinforcement and 5% resulted from carbonation-induced corrosion.

The overall aim of this paper is to establish the process and amount of chlorides penetrating reinforced concrete elements when exposed to a salt-laden environment. For this purpose, a number of slabs were subjected to 70 cycles of wetting-drying regime with a 4% sodium chloride solution over a period of 2-3 years. To examine the direction of transportation of the chlorides, some of the slabs were partially coated with a surface coating system known to be highly resistant to chloride penetration. The amount and depth of penetration of chlorides in the coated and uncoated parts of the slab were then determined. The results show conclusively that, in large exposed areas of concrete, chlorides diffuse both in the direction of depth and in a direction lateral to the depth of the element. The amount of chlorides and the distance of their lateral diffusion depend on the w/c ratio of the concrete and the duration of exposure. Concrete mixes with a high w/c ratio (0.75) are highly conducive to this lateral diffusion of chlorides. Although concrete mixes of lower w/c ratios (0.45 and 0.60) are less conducive to lateral diffusion of chlorides, in practice, all concretes should be considered to be prone to chloride diffusion in both the direction of gravity and the lateral direction because of the effects of cracking. In unprotected concrete, reducing the w/c ratio from 0.60 to 0.45 is far more effective in decreasing chloride penetration than that achieved by reducing the w/c ratio from 0.75 to 0.60. The acrylic-based surface coating system is totally resistant to chloride penetration [Suryavanshi *et al*. 1998]. Work presents an investigation of chloride penetration of HC-500 pre-stressed concrete slabs made of precast concrete. This type of concrete slabs is widely used to construct floors in steel or reinforced concrete framing buildings. In such solutions ceiling can be considered as a simple-supported beam. Considered precast concrete was made of C50/C60 concrete with use of Portland cement CEM II 52.5 R. Investigated specimens were sampled directly from the upper part of pre-stressed concrete slabs. The process of chloride penetration in concrete can be described by the non-linear diffusion equation. In the paper Bayesian inverse technique was applied to estimate diffusion coefficient of chloride in concrete treated as a saturated porous material. Unknown distribution of estimated parameters was sampled with use of Metropolis-Hastings algorithm which allowed us to obtain unknown values and their error bounds. Obtained values of diffusion coefficient were confronted against values obtained with use of norms: NT BUILD 443 and ASTM C 1556 - 03 and against previously developed methodology based on the analytical solution of the diffusion equation [Zofia Szweda and Zbigniew Buliński, 2018]. In marine and coastal environments, penetration of chloride ions is one of the main mechanisms causing concrete reinforcement corrosion. Currently, most of experimental investigations about submerged penetration of chloride ions are started after the four-week standard curing of concrete. The further hydration of cement and reduction of chloride diffusivity during submerged penetration period are ignored. To overcome this weak point, this paper presents a numerical procedure to analyse simultaneously cement hydration reaction and chloride ion penetration process. First, using a cement hydration model, degree of hydration and phase volume fractions of hardening concrete are determined. Second, the dependences of chloride diffusivity and chloride binding capacity on age of concrete are clarified. Third, chloride profiles in hardening concrete are calculated. The proposed numerical procedure is verified by using chloride submerged penetration test results of concrete with different mixing proportions [Wei-Jie Fan and Xiao-Yong Wang, 2015].

The ingress of chloride ions constitutes a major source of durability problems affecting reinforced concrete structures which are exposed to marine environments. Once a sufficient quantity of chloride ions has accumulated around the embedded steel, pitting corrosion of the metal is liable to occur unless the environmental conditions are strongly anaerobic. In the design of concrete structures, the influence of chloride ingress on service life must be considered [Metha and Monteiro, 2006]. The development of chloride penetration models is essential for the assessment of the service life of concrete structures exposed to marine environment. Simple models derived from Fick's second law of diffusion are at present the best way to predict the chloride penetration in practical situations. However these models need to be calibrated with experimental results. This paper presents an experimental study where the parameters used in the penetration model were calibrated to allow the prediction of long term chloride content in concrete. The results showed that both the concrete cover and concrete quality requirements stated in the present codes need to be increased so that an acceptable service life can be achieved [Costa and Appleton, 1999]. This keynote paper deals with the durability of reinforced concrete (RC) structures exposed to aggressive environments characterized by high concentration of chloride ions, namely, marine environments or the use of de-icing salts. The mechanism of chloride-induced corrosion of steel in concrete is introduced, and its influence on the service life of RC structures is analyzed. Factors affecting the time to corrosion initiation are described with regard to both concrete properties and environmental exposure conditions. Design approaches available for achieving durability targets associated with the design service life are analyzed, focusing on studies carried out by the authors in recent years at the mCD Concrete Durability lab of Politecnico di Milano, which were aimed at improving the protection provided to the steel bars by the concrete cover, investigating the advantages of using corrosion-resistant stainless steel bars and developing the electrochemical technique of cathodic prevention [Luca Bertolini *et al*. 2016]. This paper presents the current development of the numerical model ClinConc for predicting chloride penetration into concrete. In the beginning of the 1990's, as a part of the work in a Swedish national research project, some 40 types of concrete specimens were exposed to sea water at the field station on the west coast of Sweden. The chloride profiles in concrete were measured after exposure for 0.6, 1, 2 and 5 years. These data of chloride profiles together with the transport properties of concrete measured in the laboratory are greatly useful for modeling of chloride penetration into concrete. In the middle of the 1990's a numerical model for predicting chloride penetration into concrete, called ClinConc, was developed from our previous work. The model is essentially based on the current knowledge of physical and chemical processes involved in the chloride transport and binding in concrete. In this model most of the factors affecting chloride penetration are considered in a relevant and scientific way. The ambition is to predict chloride penetration profiles by using those parameters as input data that can be measured independently without relying upon any curve-fitting procedure. After tracing five years field exposure, it is proved that the model could predict field chloride profiles fairly well, especially in the penetration depth. It has been found, on the other hand, that the model somewhat underestimates the total chloride content in the surface zone. This discrepancy could be solved by simply including a factor describing the time effect of chloride binding [Tang Luping, and Lars-Olof Nilsson, 2000]. The removal of ice from transport infrastructure can be accomplished by a combination of several methods, such as plowing, natural melting, traffic movement, and chemical treatment. And these infrastructures maintenance depends on chemicals and fine aggregates for de-icing and anti-icing [Kuemmel, 1994]. In fact, various de-icing chemical agents are available commercially at market. The most cost-effective chemical agent is sodium chloride. However, by using chloride as de-icing agent has caused damage to concrete infrastructure such as concrete bridge decks. In addition to that, the de-icing agent may induce damage to an automobile bodies, roadside soils and water runoff [Mcelroy *et al.* 1988]. Moreover, de-icing agent may induce osmotic pressure which causes water to move upward the slab layer where freezing takes place [Neville, 1996]. Corrosion of ordinary/pre-stressed reinforcement (concrete cover, concrete poor quality, and aggressive salts) was confirmed by many researchers [Zenonas Kamaitis, 2002]. In addition to that, the de-icing agents may also cause scaling on roads in many cold countries. As a result of accelerated ingress of aggressive substances which may cause reinforcement corrosion in concrete [Bertolini *et al*. 2005]. The de-icing salts may also induced strength loss due to frost action in different structural members with the presence of higher degree of saturation as well as de-icing agent [Scherer, and Valenza, 2005]. Thus both the scaling frost action was considered to be the most important factors which were reduce the service life of concrete infrastructure [Vesikari, and Ferreria, 2011]. There is a need to interpret chloride concentration in designed concrete slabs under pre-conditions such as dry/fully/partially saturated condition which was salt ponded with chloride solution for about long term time duration.

2.0 Research Objectives

The importance of chloride concentration as a durability-based material property has received greater attention only after the revelation that chloride-induced corrosion is the major problem for concrete durability. The present research work was made an attempt to interpret the concrete chloride concentration in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete slabs such as dry/fully/partially saturated condition which was salt ponded with chloride solution for about 160 days. Thus the objectives of this present research is to examine the influence of conditioning such as dry/fully/partially saturated condition on the results of chloride concentration performed on concrete slabs with different mixtures proportion in which slump, and w/c ratio value was 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. Eighteen concrete slabs (450x450x100) mm with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the chloride concentration under different exposure condition at various drill depth (30-40-50) mm.

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 slabs of size (450x450x100) mm. Thus totally 18 concrete slabs of size (450x450x100) mm were fabricated with different six mixtures type (M1-M6). Out of which three mixtures type with constant compressive strength (40 N/mm^2) and varied slump (0-10, 10-30, and 60-180 mm) were designed as one group (M1-M3). In second group (M4-M6), rest of three mixtures type were designed as with different compressive strength (25 N/mm^2, 30 N/mm^2, and 40 N/mm^2), and constant slump (10-30 mm). Actually the mixture ingredients quantities were found to be more or less same/equivalent that is why, the mixture proportions were adopted in dry conditioned concrete slabs (DCC) as mixture type (M1=M2), (M3=M5), and (M4=M6) for in case of partially saturated (PSC) as well as fully saturated conditioned concrete (FSC) slabs. As concern to DCC concrete slabs, the control/impregnation concrete slabs were represented as (M1CS, M2CS) with solvent based/water based concrete slabs as (M1S1, M2S3) and (M1S2, M2S4). For in case of PSC concrete slabs, the control/impregnation concrete slabs were represented as (M3CS, M5CS) with solvent based/water based concrete slabs as (M3S5, M5S7) and (M3S6, M5S8). With reference to FSC concrete slabs, the control/impregnation concrete slabs were represented as (M4CS, M6CS) with solvent based/water based concrete slabs as (M4S9, M6S11) and (M4S10, M6S12). After 28 days of initial curing in water, the concrete slabs were subjected to different exposure conditions such as drying/fully/partially saturated conditions for specified time duration. Hence it's possible to develop a better understanding of the long-term tests to assess the resistance of concrete to chloride concentration under different pre-conditions such as drying/partially/fully saturated conditions with/without impregnation. In which totally 12 concrete slabs were treated with two different impregnation materials such as Solvent based (M1S1, M2S3, M3S5, M5S7, M4S9, M6S11) and Water based (M1S2, M2S4, M3S6, M5S8, M4S10, M6S12). The other 6 concrete slabs were left untreated as control concrete slabs (M1CS, M2CS, M3CS, M4CS, M5CS, and M6CS). The overall details of the mixture proportions were to be represented in Table.1-2. Three concrete slabs of size (450x450x100) mm were cast for each mixture and overall eighteen concrete slabs were casted for six types of concrete mixture. The coarse aggregate used was crushed stone with maximum nominal size of 10 mm with grade of cement 42.5 N/mm^2 and fine aggregate used was 4.75 mm sieve size down 600 microns for this research work. As concern to impregnation materials, Water based (WB) and Solvent based (SB) impregnate materials were used in this present research work. To avoid criticizing or promoting one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclosed and they will be referred to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

Table 1 Concrete slabs mixture proportion (M1-M3)

Mix ID	Comp/mean target strength (N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg)	Mix Proportions
M1	40/47.84	0-10	0.45	18.23	8.20	29.70	94.16	1:1.63:5.17
M2	40/47.84	10-30	0.44	22.05	9.72	28.49	85.47	1:1.29:3.88
M3	40/47.84	60-180	0.43	27.51	11.85	32.50	72.41	1:1.18:2.63

Table 2 Concrete slabs mixture proportion (M4-M6)

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

3.1 Salt ponding test

The unidirectional salt ponding was adopted as per [AASHTO T 259] method. In which the slabs are typically moist cured for a length of time followed by a period of drying at 50% relative humidity before ponding with a 10% sodium chloride solution. AASHTO T 259 calls for 14 days moist curing followed by 28 days of drying. The ponded slabs are stored to allow air circulation around the slabs in a room at 50% relative humidity. A cover is placed over the solution pond to prevent evaporation of water from the solution. AASHTO T 259 stipulates for a ponding period of 90 days. For low-permeability concretes, this is typically found to be too short for significant penetration of chloride ions into the concrete, and ponding is often extended for longer periods. But in this present research work, certain concrete slabs were pre-conditioned such as fully saturated (60 days)/partially saturated (40 days) conditioned in water for certain time duration and dry pre-conditioning for specified time duration (28 days) before salt ponding test which was carried out for about 160 days at 10% Nacl solution. The chloride profiles were analysed by drilling the slabs. The drilling was done with a diameter of 20 mm (max aggregate size) and drill depths of (30, 40, and 50) mm. The dust sample were collected, weighted between 1-5 grams as specified by [BS EN 15629:2007] for the determination of the chloride penetration. The chloride concentration for each of the dust samples, including from the control specimens was determined in accordance with [BS EN 15629:2007] in hardened concrete. The chloride content was calculated as a percentage of chloride ion by mass of the sample of concrete. Volhard's method was used for the determination of the total chloride content in the concrete. Samples of dust powder drilled from the concrete specimens at different drill depths (30 mm, 40 mm, and 50 mm) were used for the determination of the chloride penetration in the concrete samples for in case of six mixtures type (M1-M6).The chloride salt ponding, and analysis in pre-conditioned concrete slabs as shown in Fig.1.

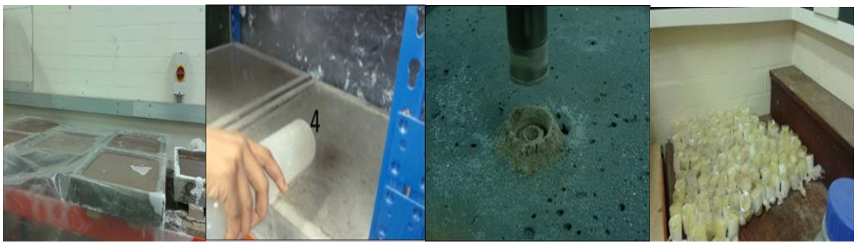


Fig.1 Cl^- profile analysis in pre-conditioned concrete slabs

The variation of chloride concentration in pre-conditioned control/impregnation concrete slabs was represented in Table.3. As observed from the results that (Table.3), the chloride concentration were found to be increased at drill depth (30 mm) in DCC/PSC/FSC control/impregnation concrete slabs as when compared to DCC/PSC/FSC control/impregnation concrete slabs at drill depths (40 mm, and 50 mm) respectively.

Table 3 Chloride concentration in different pre-conditioned concrete slabs

Final CC (%) results for DCC Slabs				Final CC (%) results for PSC Slabs				Final CC (%) results for FSC Slabs			
Mixture type [M1=M2]				Mixture type [M3=M5]				Mixture type [M4=M6]			
Slab ID	30 mm	40 mm	50 mm	Slab ID	30 mm	40 mm	50 mm	Slab ID	30 mm	40 mm	50 mm
M1CS	0.092	0.086	0.082	M3C5	0.079	0.0731	0.069	M4CS	0.072	0.071	0.0650
M1S1	0.0894	0.084	0.075	M3S5	0.074	0.0711	0.066	M4S9	0.069	0.067	0.0624
M1S2	0.0915	0.085	0.080	M3S6	0.075	0.0722	0.067	M4S10	0.070	0.069	0.0634
M2CS	0.0821	0.078	0.065	M5CS	0.085	0.0736	0.062	M6CS	0.065	0.060	0.0558
M2S3	0.0773	0.067	0.061	M5S7	0.080	0.0613	0.058	M6S11	0.063	0.052	0.0501
M2S4	0.0783	0.068	0.063	M5S8	0.081	0.0705	0.059	M6S12	0.064	0.055	0.0536

4.0 Discussion about Results

The variation of chloride concentration is interpreted by chemical analysis at different drill depths (30-40-50) mm and it's as shown in Fig.2-3 for in case of control/impregnation (SB/WB) pre-conditioned concrete slabs in order to characterize various designed mixtures type. Its varied average chloride concentration at different drill depths is increased for in case of DCC slabs as when compared to PSC concrete slabs. Its varied values are represented as M1CS (15.23%), M1S1 (15.23%), M1S2 (16.61%), M2CS (2.55%), M2S3 (3.08%), M2S4 (0.8%) respectively. In addition to that, the chloride concentration is also increased in case of DCC concrete slabs as when compared to FSC concrete slabs and its varied average chloride concentration at drill depths are interpreted as M1CS (19.73%), M1S1 (19.78%), M1S2 (21.21%), M2CS (19.74%), M2S3 (19.39%), M2S4 (17.38%) respectively. Similarly the chloride concentration is also increased in PSC concrete slabs as when compared to FSC concrete slabs in which its average variation of chloride concentration at different drill depths were represented as M3CS (5.30%), M3S5 (5.36%), M3S6 (5.52%), M5CS (17.64%), M5S7 (16.82%), and M5S6 (18.04) respectively.

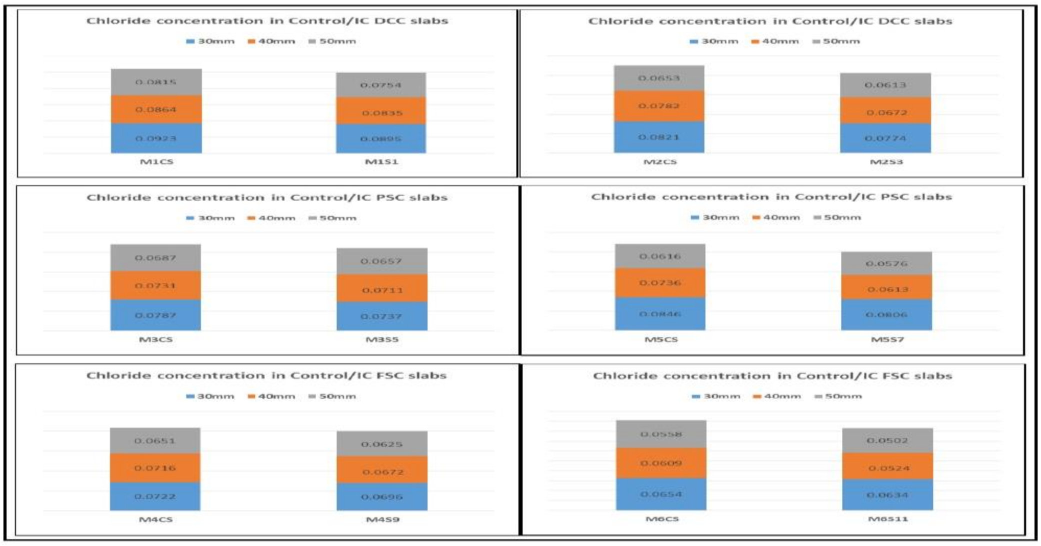


Fig.2 Cl^- penetration in pre-conditioned control/IC slabs (SB)

The average chloride concentration at different drill depths from (30-50) mm is found to be slightly increased in control concrete slabs for in case of mixtures type (M1CS-M2CS). As concerned to the average chloride concentration at different drill depths from (30-50) mm is reduced in solvent based impregnation concrete slabs as when compared to control concrete. Furthermore, the chloride concentration in water based impregnation concrete slabs is slightly increased as when compared to solvent based impregnation concrete slabs in all mixtures type (M1CS-M2CS). The chloride concentration is also increased at drill depth 30 mm for in case of control, solvent, and water based impregnation concrete cubes as when compared to drill depths (40-50) mm and its varied values were represented as M1CS (6.42%, 11.66%), M1S1 (6.65%, 15.77%), M1S2 (6.67%, 12.82%), M2CS (4.84%, 20.46%), M2S3 (13.20%, 20.74%), M2S4 (12.79%, 20%) respectively. The chloride concentration in solvent based impregnation concrete slabs was decreased as when compared to control concrete slabs at different drill depths (30-50) mm and in which its varied values were determined as M1S1 (96.95%, 96.71%, 92.44%), and M2S3(94.20%, 85.92%, 93.87%) respectively. Whereas the chloride concentration in water based impregnation concrete slabs was reduced at different drill depths (30-50) mm as when compared to control concrete slabs for in case of all mixtures type (M1CS-M2CS) in its varied values are at different drill depths (30, 40, and 50) mm as M1S2 (99.16%, 98.90%, 97.86%), and M2S4 (95.42%, 87.44%, 95.97%) respectively. Similarly, the chloride concentration in solvent based impregnation concrete slabs is decreased as when compared to water based impregnation concrete cubes in which its varied values at different drill depths (30-50) mm as M1S1 (97.77%, 97.78%, 94.46%), M2S3 (98.72%, 98.25%, 97.81%) respectively.

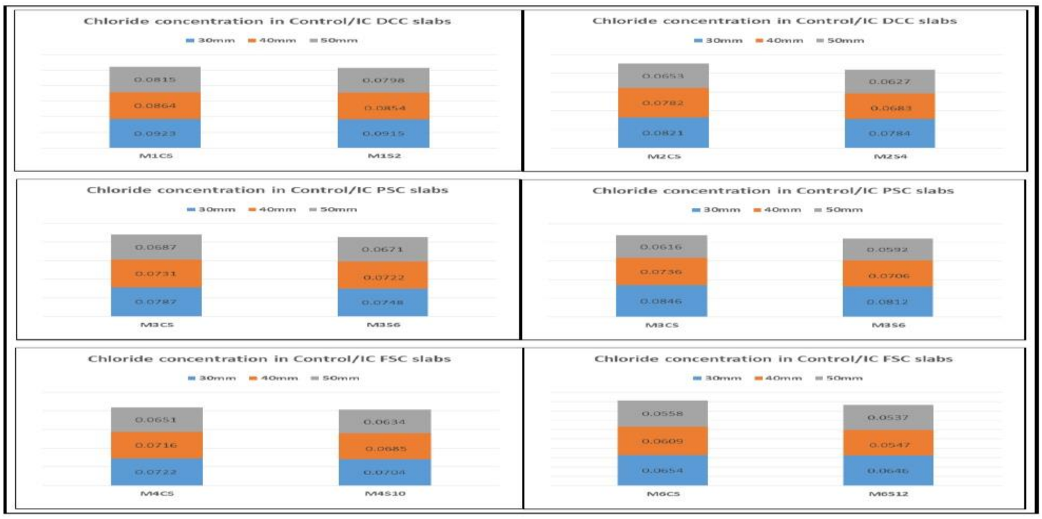
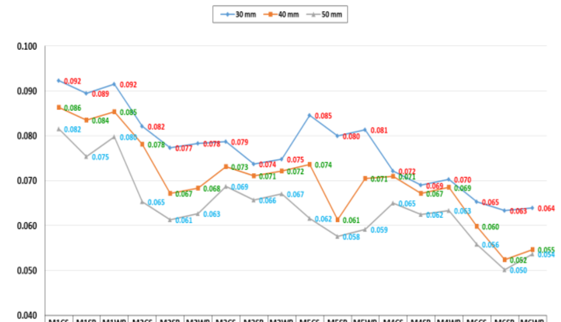
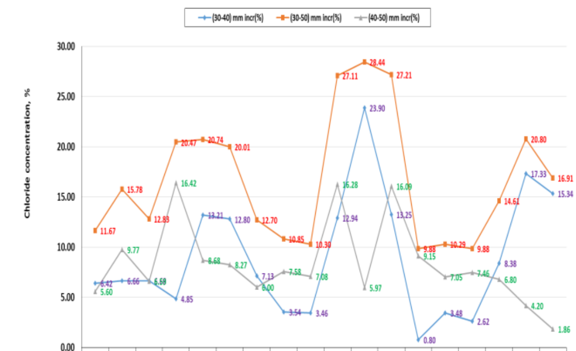


Fig.3 Cl^- penetration in pre-conditioned control/IC slabs (WB)

The average chloride concentration is increased in control concrete slabs for in case of mixtures type (M3CS, and M5CS) at different drill depths (30-40-50) mm as when compared to impregnation concrete slabs. The average chloride concentration at different drill depths from (30-50) mm is reduced in solvent based impregnation concrete slabs as when compared to control concrete slabs for in case of mixture type (M3CS) and (M5CS). Furthermore, the chloride concentration in water based impregnation concrete slabs was slightly increased as when compared to solvent based impregnation concrete slabs in all mixtures type (M3CS-M5CS). The chloride concentration is also increased at drill depth 30 mm for in case of control, solvent, and water based impregnation concrete slabs as when compared to drill depths (40-50) mm and its varied values were represented as M3CS (7.12%, 12.70%), M3S5 (3.54%, 10.85%), M3S6 (3.46%, 10.29%), M5CS (12.93%, 27.11%), M5S7 (23.89%, 28.44%), M5S8 (13.25%, 27.21%) respectively. The chloride concentration in solvent based impregnation concrete slabs is decreased as when compared to control concrete slabs at different drill depths (30-50) mm and in which its varied values were determined as M3S5 (93.64%, 97.26%, 95.63%), and M5S7 (95.24%, 83.25%, 93.51%) respectively. Whereas the chloride concentration in water based impregnation concrete slabs is reduced at different drill depths (30-50) mm as when compared to control concrete slabs for in case of all mixtures type (M3CS-M5CS) and its varied values are at different drill depths (30, 40, and 50) mm as M3S6 (95%, 98.75%, 97.62%), and M5S8 (96.16%, 95.81%, 96.04%) respectively. Similarly the chloride concentration in solvent based impregnation concrete slabs was decreased as when compared to water based impregnation concrete cubes in which its varied values at different drill depths (30-50) mm as M3S5 (98.56%, 98.49%, 97.95%), M5S7 (99.04%, 86.88%, 97.36%) respectively. The variation of chloride concentration in control concrete slabs (M1CS-M6CS), and impregnation concrete slabs (M1SB-M6SB and M1WB-M6WB) for in case of designed mixtures type at different drill depths (30-40-50) mm as representing in the Fig.4. The chloride concentration were higher in control concrete slabs (M1CS:0.092-0.082; M2CS:0.082-0.065; M3CS:0.079-0.069; M4CS:0.072-0.065; M5CS:0.086-0.062; and M6CS:0.065-0.056) and impregnation concrete slabs (M1SB:0.089-0.075; M2SB:0.077-0.061; M3SB:0.074-0.066; M4SB:0.069-0.062; M5SB:0.080-0.058; and M6SB:0.063-0.050 M1WB:0.092-0.080; M2WB:0.078-0.063; M3WB:0.075-0.067; M4WB:0.070-0.063; M5WB:0.081-0.059; and M6WB:0.064-0.054) at lower drill depth (30 mm) as when compared to higher drill depth (40-50 mm). The variation of chloride concentration in control concrete slabs (M1CS-M6CS), and impregnation concrete slabs (M1SB-M6SB and M1WB-M6WB) for in case of designed mixtures type at different drill depths (30-40-50) mm as representing in the Fig.5.The chloride concentration were higher in control concrete slabs (M1CS:6.42; M2CS:4.85; M3CS:7.83; M4CS:0.80; M5CS:12.94; and M6CS:8.38) and impregnation concrete slabs (M1SB:6.66; M2SB:13.21; M3SB:3.54; M4SB:3.48; M5SB:23.90; and M6SB:17.33; M1WB:6.68; M2WB:12.80; M3WB:3.46; M4WB:2.62; M5WB:13.25; and M6WB:15.34) at lower drill depth (30 mm) as when compared to higher drill depth (40 mm).



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
30 mm	0.092	0.089	0.092	0.082	0.077	0.078	0.079	0.074	0.075	0.085	0.080	0.081	0.072	0.069	0.070	0.065	0.063	0.064
40 mm	0.086	0.084	0.085	0.078	0.067	0.068	0.073	0.071	0.072	0.074	0.061	0.071	0.071	0.067	0.069	0.060	0.052	0.055
50 mm	0.082	0.075	0.080	0.065	0.061	0.063	0.069	0.066	0.067	0.062	0.058	0.059	0.065	0.062	0.063	0.056	0.050	0.054



	M1CS	M1SB	M1WB	M2CS	M2SB	M2WB	M3CS	M3SB	M3WB	M5CS	M5SB	M5WB	M4CS	M4SB	M4WB	M6CS	M6SB	M6WB
(30-40) mm incr(%)	6.42	6.66	6.68	4.85	13.21	12.80	7.13	3.54	3.46	12.94	23.90	13.25	0.80	3.48	2.62	8.38	17.33	15.34
(30-50) mm incr(%)	11.67	15.78	12.83	20.47	20.74	20.01	12.70	10.85	10.30	27.11	28.44	27.21	9.88	10.29	9.88	14.61	20.80	16.91
(40-50) mm incr(%)	5.60	9.77	6.59	16.42	8.68	8.27	6.00	7.58	7.08	16.28	5.97	16.09	9.15	7.05	7.46	6.80	4.20	1.86

Fig.4 Cl^- penetration in pre-conditioned control/IC slabs

Fig.5 Cl^- penetration in pre-conditioned control/IC slabs

The average chloride concentration is increased in control concrete slabs for in case of mixtures type (M4-M6) at different drill depths (30-40-50) mm as when compared to impregnation concrete slabs and their varied values were interpreted as M4CS (0.072%, 0.071%, 0.065%), M6CS (0.065%, 0.059%, 0.055%). Similarly, the average chloride concentration at different drill depths from (30-50) mm is reduced in solvent based impregnation concrete slabs as when compared to control concrete slabs for in case of mixture type (M4CS) and (M6CS). The interpreted average values of chloride concentration at different drill depth from (30-50) mm is represented as M4S9 (0.069%, 0.067%, 0.062%), M6S11 (0.063%, 0.052%, 0.050%) respectively. Furthermore, the chloride concentration in water based impregnation concrete slabs is slightly increased as when compared to solvent based impregnation concrete slabs in all mixtures type (M4CS-M6CS). Its varied values is found to be as MS10 (0.070%, 0.068%, 0.063%), M6S12 (0.064%, 0.054%, 0.053%) respectively. The chloride concentration is also increased at drill depth 30 mm for in case of control, solvent, and water based impregnation concrete slabs as when compared to drill depths (40-50) mm and its varied values were represented as M4CS (0.80%, 9.87%), M4S9 (3.47%, 10.28%), M4S10 (2.61%, 9.87%), M6CS (8.38%, 14.61%), M6S11 (17.32%, 20.80%), M6S12 (15.33%, 16.91%) respectively. The chloride concentration in solvent based impregnation concrete slabs is decreased as when compared to control concrete slabs at different drill depths (30-50) mm and in which its varied values were determined as M4S9 (96.42%, 93.82%, 95.98%), and M6S11 (96.94%, 87.47%, 89.91%) respectively. Whereas the chloride concentration in water based impregnation concrete slabs is reduced at different drill depths (30-50) mm as when compared to control concrete slabs for in case of all mixtures type (M4-M6) in its varied values are at different drill depths (30, 40, and 50) mm as M4S10 (97.45%, 95.67%, 97.44%), and M6S12 (98.85%, 91.34%, 96.18%) respectively. Similarly, the chloride concentration in solvent based impregnation concrete slabs is decreased as when compared to water based impregnation concrete cubes in which its varied values at different drill depths (30-50) mm as M4S9 (98.94%, 98.07%, 98.50%), M6S11 (98.06%, 95.76%, 93.47%) respectively. The chloride concentration in control concrete slabs (M1CS-M6CS) were increased as when compared to impregnation concrete slabs (M1SB-M6SB and M1WB-M6WB) for in case of designed mixtures type at different drill depths (30-40-50) mm as representing in the Fig.6. Chloride concentration in impregnation concrete slabs (M1WB-M6WB) were increased as when compared to impregnation concrete slabs (M1SB-M6SB) for in case of designed mixtures type at different drill depths (30-40-50) mm as representing in the Fig.7.

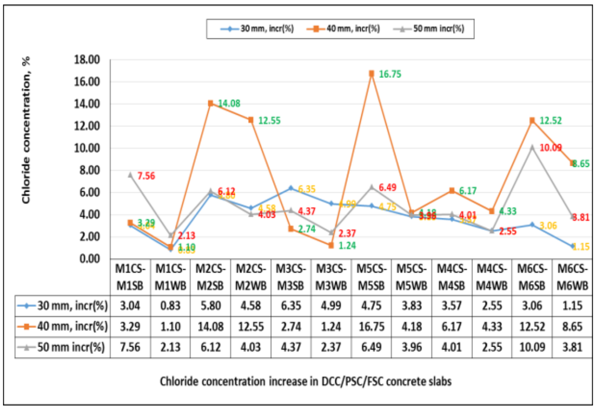


Fig.6 Cl^- penetration in pre-conditioned control/IC slabs

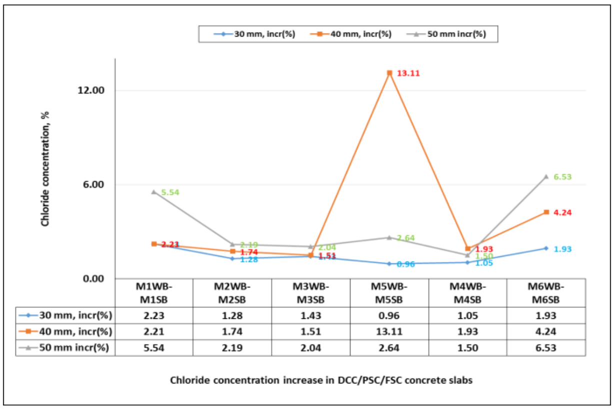


Fig.7 Cl^- penetration in pre-conditioned control/IC slabs

Chloride concentration in impregnation concrete slabs (M1SB:96.96%, M2SB:94.20%, M3SB:93.65%, M4SB:96.43%, M5SB:95.25%, M6SB:96.94%) were decreased as when compared to control concrete slabs (M1CS-M6CS) for in case of designed mixtures type at different drill depths as representing in the Fig.8. Chloride concentration in impregnation concrete slabs (M1SB:97.77%, M2SB:98.72%, M3SB:98.57%, M4SB:98.95%, M5SB:99.04%, M6SB:98.07%) were decreased as when compared to control concrete slabs (M1WB-M6WB) for in case of designed mixtures type at different drill depths.

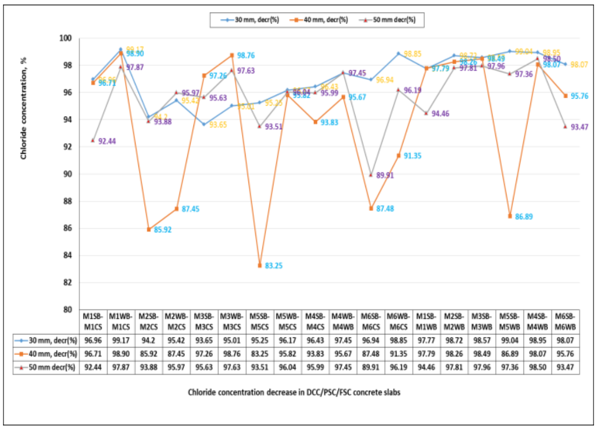


Fig.8 Cl^- penetration in pre-conditioned control/IC slabs

5.0 Conclusions

- The chloride concentration is increased in DCC pre-conditioned concrete slabs at different drill depths (30-40-50) mm as when compared to PSC/FSC pre-conditioned concrete slabs at different drill depths.

- The chloride concentration is decreased in solvent/water based impregnation DCC/PSC/FSC concrete slabs as when compared to control DCC/PSC/FSC concrete slabs.

- In addition to that, the chloride concentration is decreased in solvent based impregnation DCC/PSC/FSC as when compared to water based impregnation DCC/PSC/FSC concrete slabs.

- It's also observed from the results that, the chloride concentration is slightly increased in control/ impregnation PSC (SB/WB) as when compared to control/impregnation FSC (SB/WB) concrete slabs.

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