CHLORIDE PENETRATION AT DIFFERENTIAL MATRIX IN PRE-CONDITIONED CONCRETE CUBES

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Abstract: *The concrete structures were deteriorating in various ways such as their operating environment under the combined action of harsh environmental conditions and external loading. In fact, the main long-term time duration deterioration mechanism involves moisture movement and the transport of chlorides within concrete. In order to build durable oriented and practicable concrete structures, it is needed to be able to accurately predict the movement of moisture and chlorides within concrete. Therefore, there is a need to quantify the chloride concentration in concrete cubes which is of most important factor. 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 cubes such as dry/fully/partially saturated condition which is salt ponded with chloride solution for about 160 days at 10% Nacl solution. 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 in concrete cubes 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. Seventy-two concrete cubes (100 mm^3) 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 cubes, 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 cubes as when compared to control DCC/PSC/FSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride concentration was increased in solvent/ water based impregnation DCC/PSC/FSC cubes for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride concentration was goes on decreases with increased compressive strength and constant slump value.*

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

1.0 Introduction

The durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion/any other deterioration process to retain its original form, quality, and serviceability when exposed to harsh environment [Mehta and Monteiro, 2006]. To a large extent, it is commonly accepted that concrete durability is governed by concrete's resistance to the penetration of aggressive media. This media may be present in a liquid or gaseous state and that may be transported by various mechanisms such as permeation, diffusion, absorption, capillary suction, and combinations of the items. Hence, for concrete in service, a combined action of various media may prevail and mixed modes of transport processes occur. Moreover, there are correlations between transport parameters of concrete and the following durability characteristics: carbonation, sulphate attack, alkali-aggregate reaction, frost resistance, leaching, soft water attack, acid attack, abrasion, chloride ingress, and reinforcement corrosion. When steel is exposed to the acidic environment created by dissolved chloride salts and water, the effect is that of a giant battery. As oxygen diffuses into the concrete, it reacts with water to form hydroxide ions at the surface of the steel, creating the cathode, or negative pole of the battery. At the anode, the positive pole, iron ions migrate away from the rebar, leaving a pit in the surface, and travel toward the cathode by way of an electrolyte solution, usually composed of dissolved chloride salts in water. Under the acidic conditions of the salt solution, these iron ions combine with the hydroxide ions at the cathode to form hydrated ferric oxide, or rust, which is deposited at the interface between the steel and the surrounding concrete. As the steel corrodes, it expands up to eight times its original volume. Expansive forces cause extreme pressures within the concrete, which eventually are relieved when the concrete cracks. These cracks in turn admit more water and chloride salts, accelerating the corrosion process, leading to more cracking, then more corrosion, in a progressive cycle of damage. Over time, the cumulative process reduces the cross-sectional area of the reinforcing steel, compromising structural integrity of the parking structure. Advanced-stage corrosion results in spalls or large chunks of concrete falling away from the structure, which makes deterioration hard to ignore and there are signs the prudent building owner can look for to identify incipient problems. Rust-colored stains at the surface of concrete can indicate corrosion below the surface. Hairline cracks and fissures that develop over time might also be indicative of expansive stress, as an increasing volume of rust exerts pressure on the surrounding concrete. Standing water and leaks, as well as accumulated de-icing chemicals on deck surfaces, may be early warning signs that conditions conducive to corrosion are present. High levels of calcium hydroxide in concrete make it a highly alkaline material, with a pH typically above 12.5. Values for pH ordinarily range from 0-14, with 0 being most acidic, 14 most basic/alkaline, and 7 being neutral; for comparison, household bleach has a similar pH to that of concrete, while lemon juice has a pH of around 2.2. This alkaline environment protects the embedded reinforcement by creating a passivating film around the steel. Since the electrochemical reaction of corrosion can only take place in a neutral or acidic setting, the alkaline concrete prevents oxidation of the steel and guards against deterioration. The most common de-icing material is rock salt (sodium chloride), which is extremely corrosive to steel and destructive to concrete. Calcium chloride is a more effective de-icing chemical that tends to be less damaging than rock salt, but it is still a corrosive compound. Potassium chloride and magnesium chloride are better options, but they are only effective down to about 5-10°F, as compared with the -20°F minimum temperature for calcium chloride. To reduce the amount of de-icing chemical needed, property owners should apply grit/sand to increase traction, and consider a preventative application of the ice-loosening chemical calcium magnesium acetate, which does not contribute to chloride contamination. As chloride-containing de-icing salts accumulate on parking deck surfaces, the variation in chloride ion concentration from the top to the bottom of the slab establishes a difference in electrical potential between the upper and lower rebar mats, leading to corrosion. In cold climates, de-icing agents are used to reduce traffic problems due to ice and snowdrifts. However, the use of de-icing salts results in accelerated scaling of concrete surfaces on account of damage caused by salt combined with rapid freeze–thaw cycles. These cycles reduce user safety and the service life of concrete pavement. Moreover, scaling is the deterioration of concrete due to the general loss of surfa ce mortar or the mortar surrounding aggregates in concrete. Numerous methods have been proposed and evaluations have been conducted to predict the degree of deterioration caused by scaling and freeze–thaw cycles. In the present study, several previously proposed test methods were experimentally investigated and their differences were examined. Although the water tightness and durability properties of fly ash concrete were observed to be excellent, the scaling resistance decreased. Therefore, it is considered that scaling resistance has a direct effect on cement paste strength. Furthermore, measurement of the scaling resistance varies according to the saline solution, surface finishing treatment, and freeze–thaw environments. In this study, saline solutions that combined the de-icing agents NaCl and $CaCl_2$ were used. The surfaces of the test specimens were given the same finish as the field samples using a stiff brush after bleeding. It was determined that these conditions must be considered to simulate conditions that are similar to those of roads, and a critical experimental assessment must be undertaken [Hongseob Oh *et al*. 2018]. The damaging impact of various de-icing chemicals and exposure conditions on concrete materials was investigated. Five de-icing chemicals (sodium chloride, calcium chloride with and without a corrosion inhibitor, potassium acetate, and an agricultural product) were studied. Freezing–thawing and wetting–drying exposure conditions were considered. Mass loss, scaling, compressive strength, chemical penetration, and micro-structure of the paste and concrete subjected to these de-icing chemicals and exposure conditions were evaluated. Results indicated that the various de-icing chemicals penetrated at different rates into a given paste and concrete, resulting in different degrees of damage. Among the de-icing chemicals tested, two calcium chloride solutions caused the most damage. Addition of a corrosion inhibitor into the calcium chloride solution delayed the onset of damage, but it did not reduce the ultimate damage. Chloride-related de-icing chemicals often brought about leaching of calcium hydroxide, as well as chemical alterations in concrete. Potassium acetate caused minor scaling, associated with alkali carbonation of the surface layer of concrete. Although producing a considerable number of micro-pores on the surface of the samples, the agricultural deicing product resulted in the least chemical penetration and scaling damage of paste and concrete [Kejin Wang *et al*. 2006].

Sixty samples from three concrete mixes (same components) were prepared and subjected to frost salt scaling cycles. A set of 20 samples from the same mix was tested according to the French standard XP P18-420. Another set was exposed to different chloride concentrations. Different numbers of freeze/thaw cycles were applied to the last set. The mass of scaled-off particles follows a lognormal distribution. Despite high standard deviation, this scaling test enables to separate high resistant from very low resistant concrete. A combined analysis reveals that the scaling and the chloride penetration front are independent from a phenomenological point of view and that the chloride concentration on the exposed surface directly influences the amount of scaled mass according to the typical pessimum effect. These results raise two main questions: is the amount of chloride on the surface solution a direct or indirect parameter and what happens to this pessimum effect if we take into account the scaling test dispersion [Bouteille *et al*. 2010]. Chloride attack on concrete is a mechanism of deterioration which causes corrosion of steel reinforcement. Geopolymer, an alternative aluminosilicate binder material, has attracted attention for its structural and durability performance as well as for environmental benefits in reducing the CO2 emissions associated with concrete production. However, the understanding of its behaviour in the chloride resistance of geo-polymer concrete especially from mixtures of pulverized fuel ash (PFA) and palm oil fuel ash (POFA) is scarce. In this study, geopolymer concrete using blended ashes from agro-industrial waste were tested for chloride content using ASTM 1543-10a (Standard Test Method for Determining the Penetration of Chloride Ion into Concrete). The geo-polymer concrete samples were prepared using a mix of the PFA and POFA as the main binder components at the range of alkaline/binder ratio of 0.4 together mixed with coarse and fine aggregates. The ambient temperature (26-30°C) of curing regimes was used. The specimens were cast in 100mm^3 molds. After achieving the targeted compressive strength (25-30 MPa), the specimens were immersed for 18 months to 2.5% solution of sodium chloride. The normal OPC concrete with similar compressive strength were also prepared for direct comparison. X-ray diffraction (XRD), Fourier Transformed Infrared Spectrometer, Thermogravimetry analyser (TGA-DTG) and Field Emission Scanning electron microscopy images with energy dispersive X-ray (FESEM-EDX) were performed to analyse the microstructural characterisation of the materials. In particular, geopolymer concrete had shown a better resistance to chloride penetration as compared to OPC concrete [Mohd Azreen Mohd Ariffin, Mohd Warid Hussin, 2015].

The concrete infrastructures were deteriorated in different regions of the world without satisfying the stipulated service life. Therefore there is a need to predict service life which is a major task in the design of concrete infrastructures. In fact, the chloride concentration is a major cause of any early deterioration of reinforced concrete infrastructures. As a result of this concrete deterioration, it may lead to cracking, spalling, and de-lamination of concrete cover, reduce load carrying capacity, and cross sectional area of reinforcement. Whereas, in the cold countries region it may lead to pre-mature deterioration of concrete infrastructures due to the application of de-icing salts on roads and concrete infrastructures. In fact, the bridge-decks were simultaneously exposed to wetting-drying condition and it's also subjected to direct impact as well as repeated loading by continuous flow of traffic. Almost all the concrete structures were working under dry conditions. Even though most of the researchers have dedicated their efforts to study transport of chloride in concrete under wet conditions with limited publication data on dry concrete. In fact major diffusion models are applicable to the concrete structures that remains fully wet condition at all the times. They underestimate the amount of chloride penetrating a concrete structure which is subjected to wetting/drying for in case of splash/tidal zones of structures exposed to marine environment/highway structures exposed to de-icing salts. An experimental study is carried out on the influence of water absorption in ordered to evaluate the effectiveness of durability of concrete by researchers [Zhang and Zong, 2014]. It's confirmed that, there is no clear relationship exists between surface sorptivity and internal sorptivity with compressive strength. It's also showed that, the surface water absorption is related to the performance of concrete which is includes permeability, sulfate attack, and chloride diffusion. Furthermore, it's possible to establish relationship between non-permeability and resistance to sulfate attack which is linearly associated with surface sorptivity. An investigation by researchers [Chanakya Arya *et al*. 2014] that, there is an influence of chloride absorption on concrete and interpret how this affects chloride distribution at different depths from the concrete surface. Results show that the surface chloride content is very sensitive to effective porosity/drying conditions immediately before wetting. It also has as much as 31% of the protection provided by concrete cover can be lost after exposure to just one wet/dry cycle, and thereby significantly reducing time to corrosion of concrete structures. It's confirmed from results that the most significant effect of sorptivity on long-term chloride ingress to concrete is its effect on surface chloride content. It's decided to consider an effective amount of absorption when modelling chloride ingress under cyclic wetting and drying conditions. It's also possible from research work to produce higher surface chloride contents (0·29–0·62%) that would lower the time to corrosion using the cover depths recommended in the code. Its confirmed long time ago that [Zhao *et al*. 2008], young and uncontaminated concrete can be surface impregnated by liquid silanes in order to provide a protective barrier against ingress of chloride ions and moderate chloride content allows to apply surface impregnation of silanes successfully as a protective measure as well as to avoid further chloride ingress. It's also confirmed that, higher chloride concentration and low water-cement ratio make surface impregnation more difficult. Therefore it is recommended to test the efficiency of application of silane on concrete surfaces before a protective measure is carried out. It's confirmed that deep impregnation of the concrete surfaces with water repellent agent's forms an efficient and long lasting barrier with respect to chloride ingress [Wittmann *et al*. 2006]. In this way service life of reinforced concrete structures erected in an aggressive environment such as marine climate can be significantly extended for long time duration. It's cited by investigators [Brandt, 2009] that, the corrosion of steel reinforcement induces expansion in volume due to corrosion products, cracking, and spalling of concrete from the reinforcement. Furthermore, chloride concentration together with frost attack can cause another form of concrete deterioration such as concrete scaling. As confirmed that [Hall, 1994], the pore space of concrete is not fully saturated. If the moisture content inside concrete is less than the saturation moisture content, it may be absorbed by the concrete through large capillary forces arising from the contact of the very small pores of the concrete with the liquid phase. Therefore, determination of the moisture retention function is necessary for the modelling of moisture flow and transport of chlorides in concrete. In fact, there has been very little effort to establish relationships for the capillary pressure as a function of degree of saturation for concrete.

The chloride diffusion can only occur for a continuous water phase is present in the capillary pores of concrete in order to provide a path for diffusion. Therefore, in the case of dry concrete, the diffusion process is lessened since the number of water filled pores decreases and that decreases the continuity of pore solution [Saetta, *et al*. 1993]. Under dry conditions, the effective diffusion coefficient is no longer a constant but a function of saturation [Garboczi, 1990] and therefore cannot be described by simple diffusion theory. This is noted by researchers that [De Vriesl *et al.* 1998], hydrophobic treatment makes a concrete surface absorb lesser water and chloride. It's confirmed that, the corrosion which had already started before application of the hydrophobic agent was not influenced by hydrophobic treatment. No effect of hydrophobic treatment is measured on carbonation. It's also shown that, long term absorption tests with drinking and salt water showed significantly less absorption by hydrophobic concrete. Furthermore, its highlighted by researchers [Jacob, and Hermann,1998] that, hydrophobic agents could be effective for at least 10 years when applied to a 6-month-old concrete façade provide that, the concrete of the substrate needs to have a minimum age of 28 days or more. In addition to that, some conditions must be avoided when applying hydrophobic agents such as high or low temperatures, high air humidity and high construction element humidity. Therefore there is a need to investigate about the rapid deterioration of concrete structures due to reinforcement corrosion has now become a day-day growing problem in recent years at all over the world in so many cold countries region. Considerable resources are used to repair and rehabilitate deteriorated structures around the world. In addition to that, consequently, an extensive research [McCarter, 1996] has been conducted to evaluate the effectiveness of sealers and other concrete surface treatment materials. Among the various procedures used to protect concrete surfaces, hydrophobic impregnations are the least harmful to essential concrete appearance, mainly inhibiting capillary water absorption of the concrete.

2.0 Research Objectives

The present research work is 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 cubes such as dry/fully/partially saturated condition which is 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 in concrete cubes 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. Seventy-two concrete cubes (100 mm^3) 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 respectively.

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 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 10 mm.

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

4.0 Interpretation of chloride penetration

The primary aim of this research is to interpret the effectiveness of wetting/drying pre-conditioned concrete cubes on chloride absorption/chloride concentration at different time duration and drill depths (30-40-50) mm, which is exposed to different pre-determined conditions such as dry/fully saturated/partially saturated condition is evaluated in 72 control/impregnation concrete cubes for about 160 days salt ponding test in all designed six mixtures type (M1-M6).The pre-conditioning was induced in order to achieve desired dry condition in specified 24 concrete cubes. In which all 24 concrete cubes were exposed to natural room temperature for about 28 days. The pre-conditioned fully saturated condition was achieved in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 31 days. The pre-conditioned partially saturated condition was assessed in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 21 days. Then finally assessed the chloride absorption in pre-conditioned concrete cubes at each and every time duration is monitored in control/impregnation concrete cubes until long term duration (160 days). The chloride profiles were analysed by drilling the concrete cubes for chloride concentration at different drill depths in preconditioned concrete cubes. The drilling was done with a diameter of 20 mm (max aggregate size) and drill depths of (30, 40, and 50) mm. The dust sample were collected, weighted between 1-5 grams as specified by [BS EN 15629:2007] for the determination of the chloride concentration. The chloride concentration for each of the dust samples, including from the control/impregnation concrete cube specimens was determined in accordance with [BS EN 15629:2007] in hardened concrete. The chloride content was calculated as a percentage of chloride ions 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 of 30 mm, 40 mm, and 50 mm were used for the determination of the chloride concentration in the concrete samples for in case of six mixtures type (M1-M6).The chloride salt ponding, and analysis in pre-conditioned concrete cubes as shown in Fig.1.

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

The variation of chloride concentration in pre-conditioned control/impregnation concrete cubes is 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 cubes as when compared to DCC/PSC/FSC control/impregnation concrete cubes at drill depths (40 mm, 50 mm) respectively.

Table: 3 Cl^- concentration in pre-conditioned control/impregnation concrete cubes

Final CC, % results for DCC cubes				Final CC, % results for PSC cubes			Final CC, % results for FSC cubes		
Mix ID	30 mm	40 mm	50 mm	30 mm	40 mm	50 mm	30 mm	40 mm	50 mm
M1CC	0.070	0.066	0.064	0.066	0.064	0.061	0.059	0.056	0.054
M1SB	0.060	0.053	0.053	0.059	0.059	0.056	0.054	0.052	0.049
M1WB	0.064	0.064	0.061	0.061	0.061	0.059	0.056	0.055	0.053
M2CC	0.066	0.064	0.063	0.064	0.061	0.061	0.059	0.056	0.054
M2SB	0.061	0.058	0.056	0.059	0.059	0.056	0.054	0.052	0.049
M2WB	0.063	0.061	0.059	0.061	0.061	0.059	0.056	0.054	0.052
M3CC	0.074	0.072	0.072	0.073	0.071	0.071	0.068	0.066	0.063
M3SB	0.071	0.068	0.066	0.068	0.066	0.064	0.061	0.056	0.054
M3WB	0.072	0.071	0.068	0.071	0.068	0.066	0.063	0.061	0.059
M4CC	0.075	0.067	0.064	0.061	0.056	0.061	0.060	0.054	0.052
M4SB	0.061	0.059	0.057	0.059	0.056	0.056	0.054	0.052	0.049
M4WB	0.061	0.061	0.059	0.061	0.059	0.059	0.056	0.052	0.051
M5CC	0.071	0.068	0.067	0.068	0.067	0.066	0.063	0.062	0.061
M5SB	0.064	0.061	0.059	0.061	0.058	0.057	0.054	0.051	0.052
M5WB	0.068	0.066	0.066	0.066	0.064	0.059	0.056	0.054	0.054
M6CC	0.068	0.066	0.064	0.066	0.065	0.062	0.061	0.059	0.056
M6SB	0.064	0.061	0.061	0.061	0.058	0.057	0.056	0.052	0.049
M6WB	0.066	0.064	0.062	0.064	0.063	0.061	0.059	0.056	0.054

5.0 Discussion about Results

In worldwide the use of de-icing salts has been common since 1960 in areas where snow and ice is a seasonal roadway safety hazard, automobile, and highway bridge corrosion, and ecosystem changes caused by de-icing salt is well documented and focus of considerable study until now in recent years. The salts are necessary to provide safe winter driving conditions and save lives by preventing the freezing of a layer of ice on roads and bridge decks. However, the safety and sense of comfort provided by the salts is not without a price, as these salts can greatly contribute to the degradation and decay of reinforced concrete transportation systems. Most salts are chloride based and when the applied salts diffuse into the concrete and reach the level of the steel reinforcement, the chloride ions can quickly de-passivate the steel and activate corrosion reactions that can ultimately result in the loss of functionality of the concrete structure. Furthermore, research has indicated that these same salts attack the concrete itself, through reactions and phase changes, producing dimensional changes and cracking of the concrete. The further penetration of the salts into these cracks sets up a vicious cycle of concrete spalling and degradation. The corrosion of reinforcement bars due to chloride ingress is a well-known problem in reinforced concrete. Several methods have been adopted to protect reinforced concrete, and one of them is to provide added protection to the concrete surface in the form of surface treatments. They react with the cement matrix and form a hydrophobic layer on the walls of the pores within the concrete. This protects the concrete from the ingress of water and water-born salts. However, too much water in the pores of concrete will prevent the treatments from penetrating deeper into the pores. Actually the depth of penetration and therefore the durability of the treatment is adversely affected when the concrete is near saturation. In fact, billions of dollars are spent annually to replace defective infrastructure that needs replacement only because of concrete failing to attain its expected service life. Much of this cost is due to the effects of chloride ingress into the concrete removing protective sheaths from steel reinforcement leading to destructive corrosion of the infrastructure. Thus accurate prediction of the rate of chloride ingress into concrete would lead to the establishment of proper specification in turn achieve designed service life. There are currently many types of protective materials for reinforced concrete structures and the influence of these materials in the chloride concentration still needs more research. The primary focus of this present study is to examine the effects of wetting and drying with 10% sodium chloride solution in concrete cubes with/without impregnation material (solvent/water based) for about 160 days. Chloride profiles of samples exposed to wetting and drying cycles were determined. From these profiles, the rate and depths of chloride ingress were calculated and compared for six different mixtures type of concrete. In this present research work, chloride concentration at different drill depths such as 30-40-50 mm is interpreted in order to evaluate designed six different mixtures type. The chloride concentration in pre-conditioned impregnation DCC (SB/WB) concrete cubes is as shown in Fig.2.

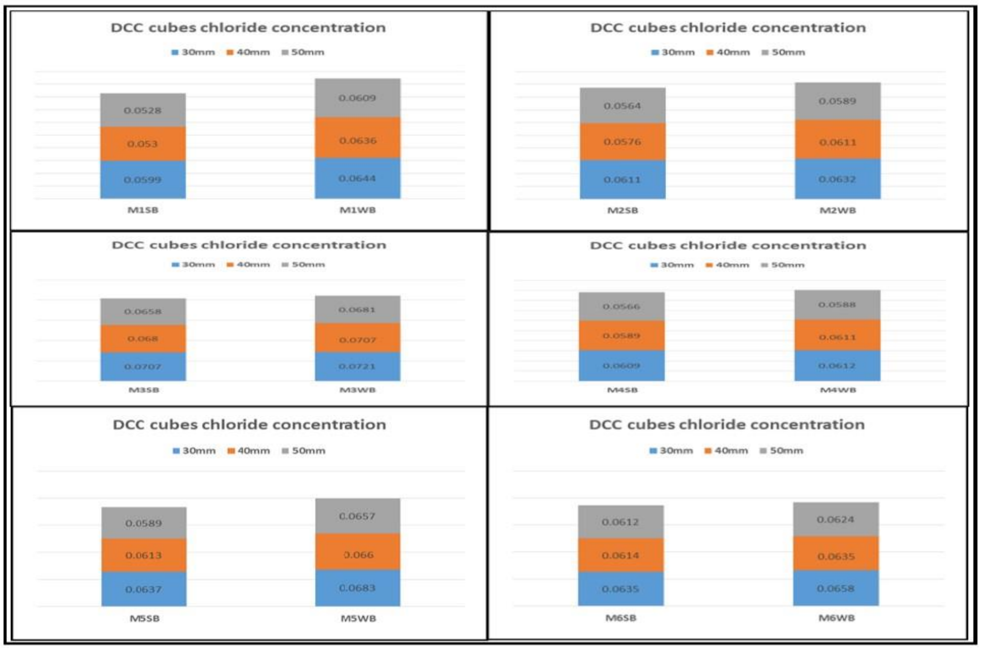

Fig.2 Cl^- concentration in pre-conditioned DCC concrete cubes

It's confirmed from DCC concrete cubes that for higher compressive strength and varied slump value, the chloride concentration was found to be slightly higher in magnitude as when compared to solvent/water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride concentration was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). The average chloride concentration at different drill depths from (30-50) mm was found to be slightly lesser in all control concrete cubes for in case of mixtures type (M1-M3). Similarly, the average chloride concentration at different drill depths from (30-50) mm was increased with lower compressive strength and constant slump value for in case of mixture type (M4) and goes on reduced with increased compressive strength for in case of mixtures type (M5-M6). The chloride concentration in solvent based impregnation concrete cubes was reduced as when compared to control concrete cubes for in case of all mixtures type (M1-M6). Furthermore, the chloride concentration in water based impregnation concrete cubes was slightly increased as when compared to solvent based impregnation concrete cubes in all mixtures type (M1-M6). The chloride concentration was also increased at drill depth 30 mm as when compared to drill depths (40-50) mm. Chloride concentration in water based impregnation concrete cubes was reduced at different drill depths (30-50) mm as when compared to control concrete cubes for in case of all mixtures type (M1-M6). The chloride concentration in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes at drill depth (30 mm). Furthermore the chloride concentration at 50 mm drill depth in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes. It's confirmed that for higher compressive strength and varied slump value, the chloride concentration for in case control concrete cubes was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride concentration was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). The chloride concentration in pre-conditioned impregnation PSC (SB/WB) concrete cubes is as shown in Fig.3.

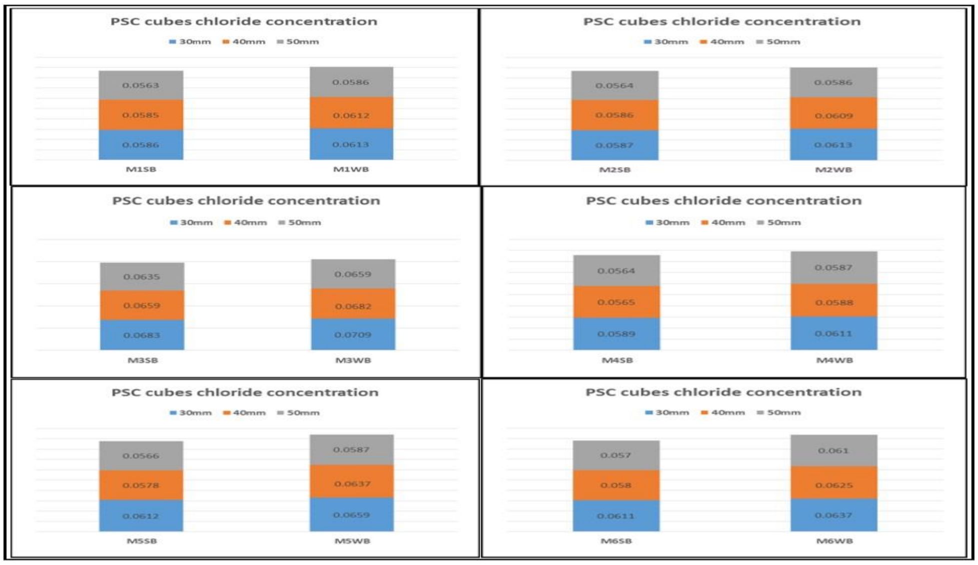

Fig.3 Cl^- concentration in pre-conditioned PSC concrete cubes

The average chloride concentration at different drill depths from (30-50) mm was found to be slightly lesser in all control concrete cubes for in case of mixtures type (M1-M3) such that their varied valued were interpreted as M1CC (0.066%, 0.063%, 0.061%), M2CC (0.063%, 0.061%, 0.061%), and M3CC(0.073%, 0.071%, 0.070%). Similarly, the average chloride concentration at different drill depths from (30-50) mm was somewhat decreased with lower compressive strength and constant slump value for in case of mixture type (M4) and goes on reduced with increased compressive strength for in case of mixtures type (M5-M6). Thus the interpreted average values of chloride concentration at different drill depth from (30-50) mm was represented as M4CC (0.061%, 0.056%, 0.061%), M5CC (0.068%, 0.067%, 0.066%), and M6CC (0.065%, 0.065%, 0.062%) respectively. The chloride concentration in solvent based impregnation concrete cubes was reduced as when compared to control concrete cubes for in case of all mixtures type (M1-M6) in which the variation of average chloride concentration at different drill depths from (30-50) mm in different mixtures type. Furthermore, the chloride concentration in water based impregnation concrete cubes was slightly increased as when compared to solvent based impregnation concrete cubes in all mixtures type (M1-M6). The chloride concentration was also increased at drill depth 30 mm as when compared to drill depths (40-50) mm. The chloride concentration in solvent based impregnation concrete cubes was decreased/increased as when compared to control concrete cubes at different drill depths (30-50) mm. Whereas the chloride concentration in water based impregnation concrete cubes was reduced at different drill depths (30-50) mm as when compared to control concrete cubes for in case of all mixtures type (M1-M6) in its varied values are at different drill depths (30, 40, and 50) mm. The chloride concentration in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes at drill depth (30 mm). Similarly, the chloride concentration at drill depth 40 mm in solvent based impregnation concrete cubes was decreased as when compared to water based impregnation concrete cubes. Furthermore, the chloride concentration at 50 mm drill depth in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes. The chloride concentration in pre-conditioned impregnation FSC (SB/WB) concrete cubes is as shown in Fig.4. It's confirmed from results that for higher compressive strength and varied slump value, the chloride concentration for in case of control concrete cubes was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride concentration was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). Thus the effectiveness of the different mixtures type (M1-M6) for in case of control concrete cube as well as impregnation concrete cubes was interpreted from 160 days and its average value such as chloride concentration as well as their standard deviation was varied in all mixtures type.

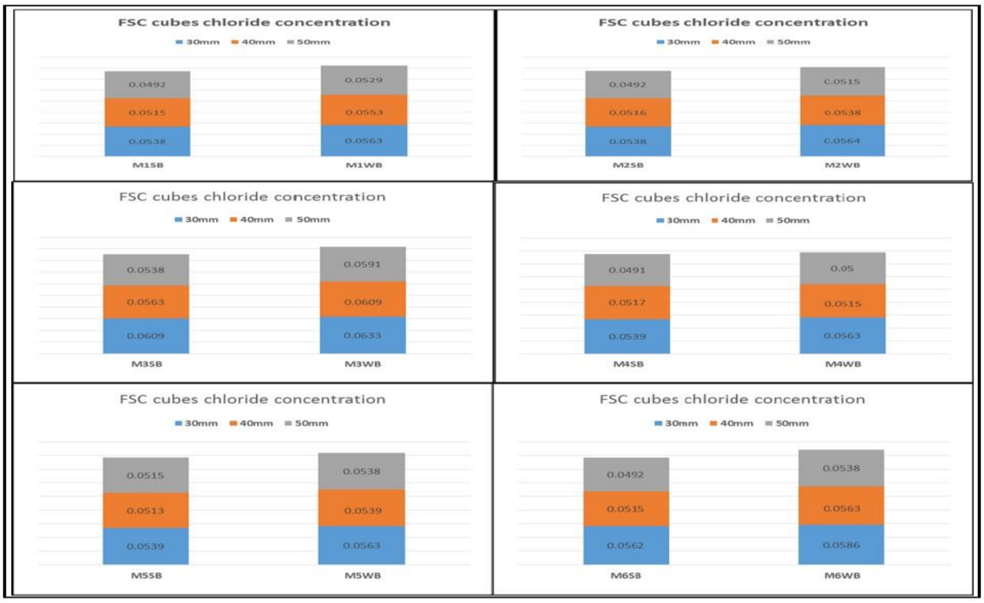

Fig.4 Cl^- concentration in pre-conditioned FSC concrete cubes

The average chloride concentration at different drill depths from (30-50) mm was found to be slightly lesser in all control concrete cubes for in case of mixtures type (M1-M3). Similarly, the average chloride concentration at different drill depths from (30-50) mm was somewhat increased with lower compressive strength and constant slump value for in case of mixture type (M4) and goes on reduced with increased compressive strength for in case of mixtures type (M5-M6).The chloride concentration in solvent based impregnation concrete cubes was reduced as when compared to control concrete cubes for in case of all mixtures type (M1-M6) in which the variation of average chloride concentration at different drill depths from (30-50) mm in different mixtures type. Furthermore, the chloride concentration in water based impregnation concrete cubes was slightly increased as when compared to solvent based impregnation concrete cubes in all mixtures type (M1-M6). The chloride concentration in solvent based impregnation concrete cubes was decreased/increased as when compared to control concrete cubes at different drill depths (30-50) mm. Chloride concentration in water based impregnation concrete cubes was reduced at different drill depths (30-50) mm as when compared to control concrete cubes for in case of all mixtures type (M1-M6). The chloride concentration in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes at drill depth (30 mm). Similarly, the chloride concentration at drill depth 40 mm in solvent based impregnation concrete cubes was decreased as when compared to water based impregnation concrete cubes. Furthermore, the chloride concentration at 50 mm drill depth in solvent based impregnation concrete cubes was found to be decreased as when compared to water based impregnation concrete cubes. The chloride concentration in pre-conditioned control DCC/PSC concrete cubes as well as pre-condition control DCC/FSC concrete cubes is as shown in Fig.5 and Fig.6.

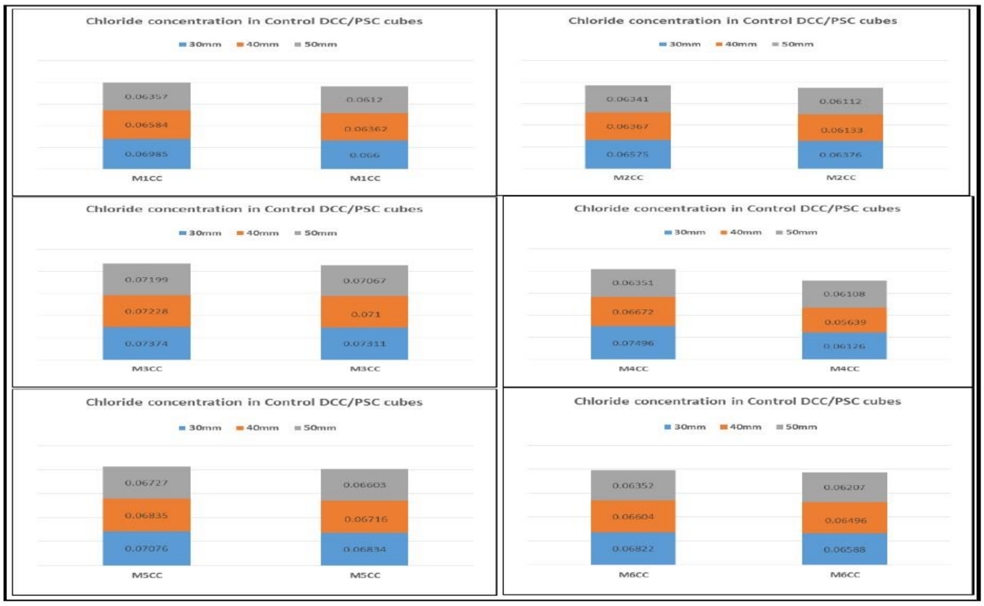

Fig.5 Cl^- concentration in pre-conditioned DCC/PSC concrete cubes

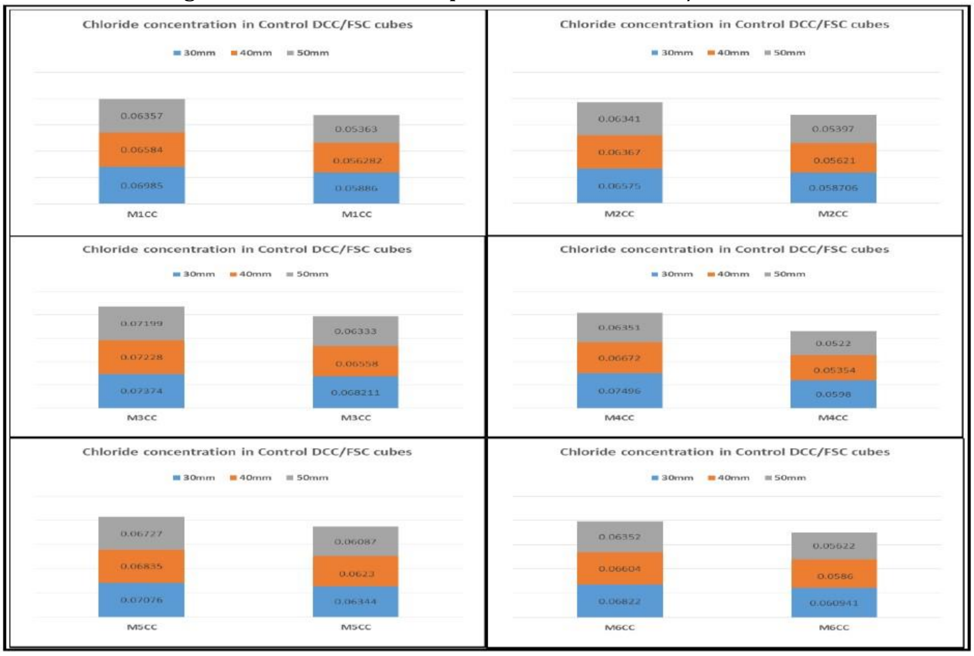

Fig.6 Cl^- concentration in pre-conditioned DCC/FSC concrete cubes

Actually the penetration of chloride in concrete due to wet/dry environment occurs by diffusion and absorption. The drying temperature was found to be the most critical factors influencing rate of absorption (sorptivity) and depth of chloride penetration. In fact, the salt solution concentration also had a significant effect on chloride penetration through the apparent surface chloride content. The drying temperature had the most significant effect on weight sorptivity, depth of chloride penetration, and, apparent chloride diffusion coefficient. This is due to the fact that, drying temperature influences the effective porosity of concrete. Furthermore, in the drying period, the water is evaporating from the concrete, leaving the chloride ions in the concrete. Thus the continuously increasing amount of chloride ions at the penetration depth by capillary suction is creating a high concentration gradient over the remaining concrete. In fact, if there are no chlorides in the environment, there is of course no chloride induced corrosion. As a known fact that, in cold countries region, de-icing salts are applied to the concrete infrastructure in turn the chloride ions migrate into structures through joints exposed, caps, girders, and through defected parts of the structure. Actually the wetting-drying of the concrete increases the rate of accumulation of chlorides inside the concrete and can lead to chloride concentrations in concrete that are higher than in the external environment because evaporation increases the chloride concentrations on the surface of the concrete. In real concrete structure, the chloride ions from the service environment can penetrate into concrete and deposit in the surface layer to form the boundary conditioning for further diffusion towards the interior and in fact the w/c ratio influences the surface chloride concentration in concrete matrix. The variation of chloride concentration in control DCC concrete cubes (M1CC-M6CC), and impregnation concrete cubes (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.7.

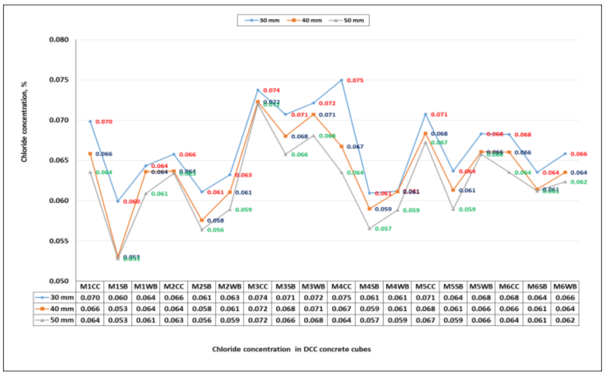

Fig.7 Cl- concentration in DCC concrete cubes

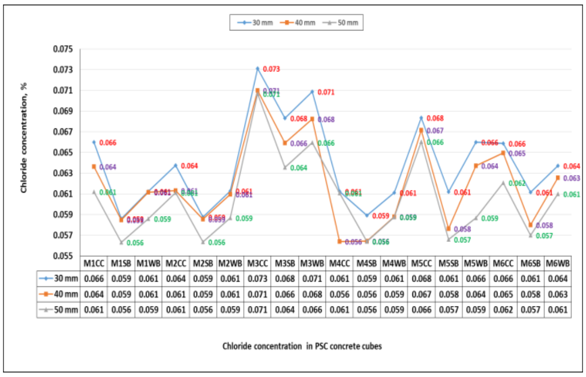

Fig.8 Cl- concentration in PSC concrete cubes

The chloride concentration were higher in control concrete cubes (M1CC:0.070-0.064; M2CC:0.066-0.063; M3CC:0.074-0.072; M4CC:0.075-0.064; M5CC:0.071-0.067; and M6CC:0.068-0.064) and impregnation concrete cubes (M1SB:0.060-0.053; M2SB:0.061-0.056; M3SB:0.071-0.066; M4SB:0.061-0.057; M5SB:0.064-0.059; and M6SB:0.064-0.061 M1WB:0.064-0.061; M2WB:0.063-0.059; M3WB:0.072-0.068; M4WB:0.061-0.059; M5WB:0.068-0.066; and M6WB:0.066-0.062) at lower drill depth (30 mm) as when compared to higher drill depth (40-50 mm). Chloride concentration in control PSC concrete cubes (M1CS-M6CS), and impregnation concrete cubes (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.8.The chloride concentration were higher in control concrete cubes (M1CC:0.066-0.061; M2CC:0.066-0.061; M3CC:0.073-0.071; M4CC:0.061-0.061; M5CC:0.068-0.066; and M6CC:0.066-0.062) and impregnation concrete slabs (M1SB:0.059-0.056; M2SB:0.059-0.056; M3SB:0.068-0.064; M4SB:0.059-0.056; M5SB:0.061-0.057; and M6SB:0.061-0.057; M1WB:0.061-0.059; M2WB:0.061-0.051; M3WB:0.071-0.066; M4WB:0.061-0.059; M5WB:0.066-0.059; and M6WB:0.064-0.061) at lower drill depth (30 mm) as when compared to higher drill depth (40 mm and 50 mm). Whereas chloride concentration in control FSC concrete cubes (M1CC-M6CC), and impregnation concrete cubes (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.9. The chloride concentration were higher in control concrete cubes (M1CC:0.059-0.054; M2CC:0.059-0.054; M3CC:0.068-0.063; M4CC:0.060-0.052; M5CC:0.063-0.061; and M6CC:0.061-0.056) and impregnation concrete cubes (M1SB:0.054-0.049; M2SB:0.054-0.049; M3SB:0.061-0.054; M4SB:0.054-0.049; M5SB:0.054-0.052; and M6SB:0.056-0.049; M1WB:0.056-0.053; M2WB:0.066-0.062; M3WB:0.063-0.059; M4WB:0.056-0.051; M5WB:0.056-0.054; and M6WB:0.059-0.054) at lower drill depth (30 mm) as when compared to higher drill depth (40-50 mm). Chloride concentration in control DCC concrete cubes (M1CC-M6CC), and impregnation concrete cubes (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.10.The chloride concentration were higher in control concrete cubes (M1CC:5.74; M2CC:3.16; M3CC:1.98; M4CC:10.99; M5CC:3.41; and M6CC:3.20)% and impregnation concrete slabs (M1SB:11.48; M2SB:5.76; M3SB:0.068-3.83; M4SB:3.17; M5SB:3.71; and M6SB:3.32; M1WB:1.18; M2WB:3.42; M3WB:1.98; M4WB:0.10; M5WB:3.31; and M6WB:3.52) at lower drill depth (30 mm) as when compared to higher drill depth (40 mm and 50 mm). Chloride concentration variations in control PSC, FSC concrete cubes (M1CC-M6CC), and impregnation concrete cubes (M1SB-M6SB and M1WB-M6WB) were indicated for in case of designed mixtures type at different drill depths (30-40-50) mm as representing in the Figs.11-12.

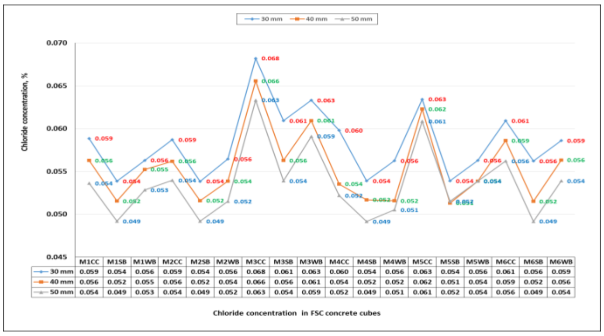

Fig.9 Cl^- concentration in FSC concrete cubes

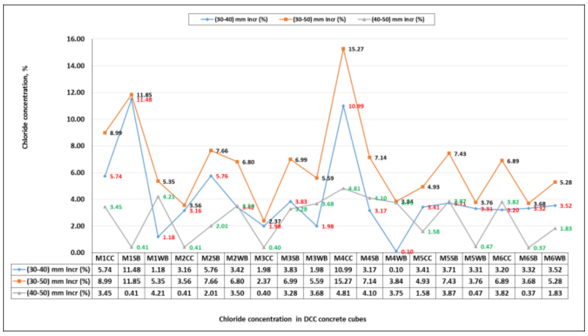

Fig.10 Cl^- concentration in DCC concrete cubes

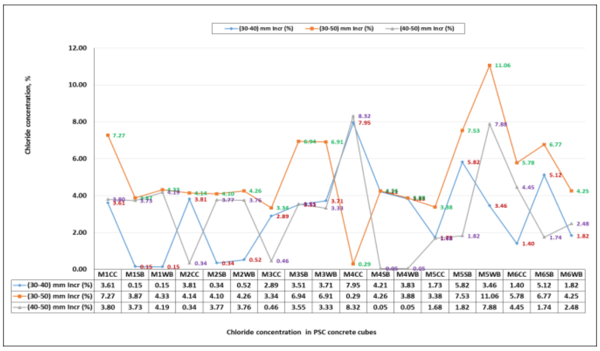

Fig.11 Cl^- concentration in PSC concrete cubes

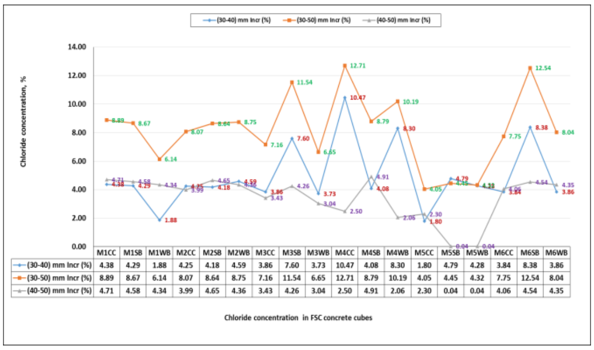

Fig.12 Cl^- concentration in FSC concrete cubes

It's possible to compare the variation (%, decrease) in chloride concentration for in case of impregnation concrete cubes (M1SB-M6SB) as against impregnation (M1WB-M6WB) and control concrete cubes (M1CC-M6CC) at different drill depths (30-40-50 mm) as indicated in the Fig.13.

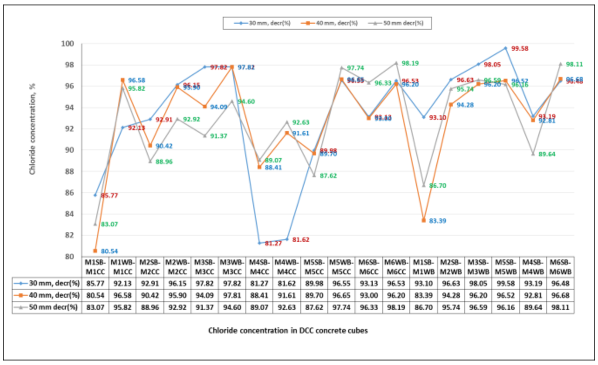

Fig.13 Cl^- concentration in DCC concrete cubes

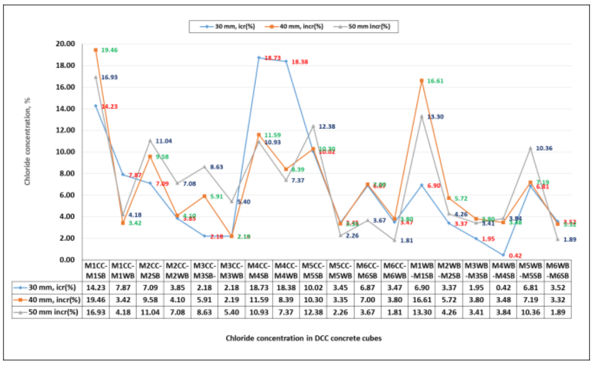

Fig.14 Cl^- concentration in DCC concrete cubes

Chloride concentration were decreased in DCC impregnation concrete cubes as when compared to control concrete cubes (M1SB-M1CC:85.77; M2SB-M2CC:92.91; M3SB-M3CC:97.82; M4SB-M4CC:81.27; M5SB-M5CC:89.98; and M6SB-M6CC:93.13) and impregnation concrete cubes (M1SB-M1WB:93.10; M2SB-M2WB:96.63; M3SB-M3WB:98.05; M4SB-M4WB:99.88; M5SB-M5WB:93.19; and M6SB-M6WB:96.48; M1WB-M1CC:92.13; M2WB-M2CC:96.15; M3WB-M3CC:97.82; M4WB-M4CC:89.62; M5WB-M5CC:96.55; and M6WB-M6CC:96.53) at different drill depth (30 mm) as against drill depths (40-50 mm) as noted in the (Fig.13). Similarly the chloride concentrations were increased in DCC control concrete cubes (M1CC-M6CC) and impregnation concrete cubes (M1WB-M6WB) at different drill depths (30-40-50 mm) as representing in the Fig.14. It's also possible to interpret the variations in chloride concentrations in PSC and FSC concrete cubes at different drill depths (30-40-50 mm) as indicated in the Figs.15-18 for in case of control concrete cubes (M1CC-M6CC) and impregnation concrete cubes (M1SB-M6SB, M1WB-M6WB).

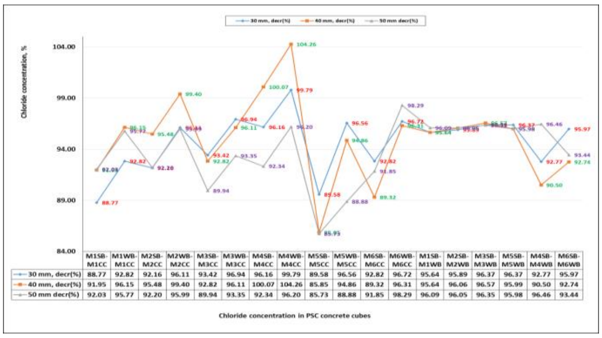

Fig.15 Cl- concentration in PSC concrete cubes

Fig.16 Cl- concentration in PSC concrete cubes

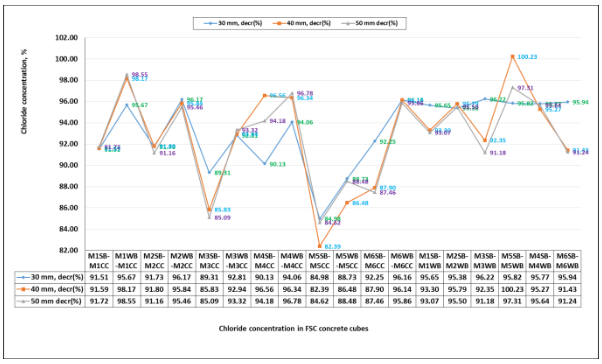

Fig.17 Cl- concentration in FSC concrete cubes

Fig.18 Cl- concentration in FSC concrete cubes

6.0 Conclusions

- From this lesser/more weight loss in water under pre-dry conditioned concrete cubes, it's confirmed that for higher compressive strength and varied slump value, the weight loss was found to be lesser in magnitude. Also it's observed that, for lower compressive strength and constant slump value, the weight loss was found to be more as when compared to higher compressive strength and constant slump value.

- For lower compressive strength and constant slump value, the weight gain in water under pre-fully/partially saturated concrete cubes was found to be higher in magnitude. In fact, its goes on decreases slightly with increase in compressive strength and constant slump value. But the weight gain in water was increased for higher compressive strength and varied slump.

- For higher compressive strength and varied slump value, the average chloride concentration at drill depths (30-50) mm in control concrete cubes was found to be slightly higher in magnitude as when compared to solvent/water based impregnation concrete cubes. It's observed from the results that, for lower compressive strength and constant slump value, the average chloride concentration at drill depths (30-50) mm in control concrete cubes was found to be slightly more as when compared to higher compressive strength.

- It's confirmed that for higher/lower compressive strength and varied/constant slump value, the average chloride concentration at drill depths (30-50) mm in control/solvent/water based impregnation partially/fully saturated concrete cubes was found to be slightly lower in magnitude as when compared to dry conditioned control/solvent/water based impregnation concrete cubes.

- It's also clear that for higher/lower compressive strength and varied/constant slump value, the average chloride concentration at drill depths (30-50) mm in partially saturated control/solvent/water based impregnation concrete cubes was found to be slightly higher in magnitude as when compared to fully saturated conditioned control/solvent/water based impregnation concrete cubes.

7.0 References

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