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EVALUATION OF CHLORIDE ABSORPTION IN PRE-CONDITIONED CONCRETE CUBES

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Abstract: The chloride contamination will occur from an application of de-icing salts. It was confirmed that, the application of de-icing salts caused a significant reduction in structural and serviceability reliabilities. The chemicals used in the snow and ice control operations (de-icers) may cause corrosion damage to the transportation infrastructure such as reinforced/pre-stressed concrete structures/steel bridges. There are many ways to manage the corrosive effects of de-icers, such as selection of high-quality concrete, adequate concrete cover and alternative reinforcement, control of an ingress and accumulation of deleterious species, injection of beneficial species into concrete, and use of non-corrosive de-icer alternatives and optimal application rates. In fact, snow and ice on streets and highway are a major threat to human life and limb. Traffic accidents and fatalities climb as snow and ice reduce traction on roadways. Lengthened emergency response times create additional risks for persons in urgent need of medical care, particularly in cases of heart attacks, burns, childbirth and poisoning. Thus the de-icing salts are necessary to provide safe winter driving conditions and save lives by preventing the freezing of a layer of ice on concrete infrastructure. However, the safety and sense of comfort provided by these salts is not without a price, as these salts can greatly contribute to the degradation and decay of reinforced concrete transportation systems. An 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. Therefore, there is a need to quantify the chloride concentration in concrete which is of paramount importance. The present research work was made an attempt to interpret the concrete chloride absorption 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 was salt ponded with chloride solution for about 160 days. Thus the objectives of this present research are such as: First, this research will examine an influence of conditioning such as dry/fully/partially saturated condition on the results of chloride absorption performed on 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 mm3) with Grades of concrete ranges from 25 to 40 N/mm2 were prepared and evaluate the chloride absorption under different exposure condition. It's concluded from the results that, in dry/saturated conditioned concrete cubes, the chloride absorption value was increased in all designed mixtures type. Similarly, average chloride absorption 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 average chloride absorption 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 absorption was goes on decreases with an increased compressive strength and constant slump value.

Keywords: *Concrete, mixture proportion, grade of concrete, pre-conditioning, slump, water-cement ratio, chloride absorption, de-icer, snow and ice control, reinforcing steel, corrosion.*

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1.0 Introduction

The prolonged periods of snowfall in countries with an advanced infrastructure and transport systems have rendered the use of de-icing agents to a common occurrence on roads and highway structures. They are necessary in order to maintain a good level of service with respect to the transport systems, thus avoiding traffic jams and disruptions, as well as to provide a high level of road safety. Today, chloride-based products, such as rock salt, are the most commonly encountered de-icers as they are easy to apply and store but mostly because they efficiently melt ice at an affordable price (TRB, 1991). However, their widespread use over a long period has left the construction industry and the engineering community with a grave problem regarding the durability of highway reinforced concrete bridges and multi-storey parking structures (Pullar-Strecker, 2002), due mainly to the fact that they cause corrosion of the reinforcement and steel components (Pullar-Strecker, 2002). In cold-climate regions, snow and ice control operations are crucial to maintaining highways that endure cold and snowy weather. The growing use of de-icers has raised concerns about their effects on motor vehicles, transportation infrastructure, and the environment. The deleterious effect of chloride-based de-icers on reinforcing steel bar in concrete structures is well known (Shi *et al*., 2009). De-icers may also pose detrimental effects on concrete infrastructure through their reactions with cement paste/aggregates and thus reduce concrete integrity and strength, which in turn may foster the ingress of moisture, oxygen and other aggressive agents onto the rebar surface and promote rebar corrosion. Large amounts of solid and liquid chemicals (de-icers) as well as abrasives are applied onto winter highways to keep them clear of ice and snow. De-icers applied onto highways often contain chlorides because of their cost-effectiveness, including mainly sodium chloride (NaCl), magnesium chloride ($MgCl_2$), and calcium chloride ($CaCl_2$), sometimes blended with proprietary corrosion inhibitors. The rock salt/sodium chloride (NaCl), is the most commonly used de-icing agent. It was first used to control snow and ice on roadways to improve transportation safety in the 1930s, and became widespread by the 1960s.

The salt works by dissolving into precipitation on roadways and lowering the freezing point, thereby melting ice and snow. Eliminating the ice has enormous safety benefits, but depending on the amount of chemicals used, the dissolved salt can have negative effects on the surrounding environment. The melting snow and ice carries de-icing chemicals onto vegetation and into soils along the roadside where they eventually enter local waterways. Elevated salt levels in soils can inhibit the ability of vegetation to absorb both water and nutrients, which can slow plant growth and ultimately affect animal habitats. This degradation also affects the ability of these areas to act as buffers to slow the runoff of other contaminants into the watershed. Once the salt enters freshwater it can build up to concentration levels that further affect aquatic plants and other organisms. Salt deposits along roadways also attract birds, deer, and other animals which increases the chance of animal-vehicle accidents. While the major effect on public drinking water supplies for humans is merely an alteration of taste, high concentrations of sodium in drinking water can lead to increased dietary intake and possibly hypertension. Since salt is corrosive to automobiles, bridge decks, and other roadway infrastructure, de-icing chemicals are often combined with other substances to block corrosion. While eliminating ice is of great benefit to commerce and human safety, these drawbacks must be taken into consideration by communities as they plan for regular maintenance of the concrete infrastructure, as well as the health of the local ecosystem.

The costs of maintaining reinforced concrete infrastructure (bridges, tunnels, harbours, parking structures) are increasing due to aging of structures, which are being exposed to aggressive environment. Corrosion of reinforcement due to chloride ingress is the main problem for existing structures in marine and de-icing salt environments (Bertolini, 2013). In The Netherlands 5% of motorway bridges, built predominantly between 1960 and 1980, shows cracking and spalling of the concrete cover due to chloride induced corrosion (Gaal, 2004). This corresponds to 10% of the bridges showing corrosion initiation at an age of 40 years (Polder, 2012). Older structures have been built according to older codes, which may not have provided sufficient protection. Moreover, for new infrastructure corrosion cannot be ruled out completely, even with today's emphasis on design for long service life (typically 100 years), either by composition requirements (Euro codes) or based on service life modelling and performance testing (Fib, 2006). This may be due to various factors, such as unforeseen aggressive loads, e.g. leakage of joints; or to deviations from the intended concrete quality or cover thickness; or to modelling inadequacies (carbonation induced corrosion (Bertolini, 2011). Repair of corrosion damage is possible, but costly, potentially disruptive and not necessarily long lived. A European study has shown that 50% of repairs fail within 10 years (Tilly, 2011). These results were confirmed by a study in the Netherlands (Visser, 2012). In the worst case, this means that after about ten years the structure must again be repaired, involving more costs; and possibly this will go on until the structure is taken out of service. Thus in the present research work, an attempt was made to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures type for in case of 72 pre-conditioned concrete cubes (100 mm^3) such as dry/fully/partially saturated condition which was salt ponded with chloride solution for about 160 days. This research will examine an influence of conditioning such as dry/fully/partially saturated condition on the results of chloride absorption performed on concrete cubes with different mixtures proportion in which slump (0-10, 10-30, 60-180) mm, and w/c ratio value was varied with constant compressive strength (40 N/mm^2) as in the First case and compressive strength (25-40 N/mm^2), and w/c ratio value varied with constant slump (10-30) mm as in the Second case.

2.0 Research Objectives

An interpretation of the performance of a concrete mix is not limited to the determination of its mechanical properties since it is of paramount importance to characterize the material in terms of the parameters that rate its durability. An importance of chloride absorption 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 absorption 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 was salt ponded with chloride solution for about 160 days. An objectives of this present research is to examine an influence of pre-conditioning on the results of chloride absorption performed on 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 different Grades of concrete were prepared to evaluate the chloride absorption under different exposure condition.

3.0 Experimental Program

In the present research work, six different mixtures type were prepared in total as per BRE, 1988 (Teychenné, 1988) code standards with a 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 cubes have been tested for crushing strength in a 2000 KN compression-testing machine as per IS 516-1999. Bearing surfaces of the testing machine were wiped up (loose sand, dust) and any other material was removed from the surface of cube to be tested. The cube was placed in the machine in such a manner that open face of cube (in mould) appears on front side. The axis of the specimen was carefully aligned with the centre of thrust of the spherically seated platen. No packing was used between the faces of test specimen and the steel platen of the testing machine. As the spherically seated block was brought to bear on the specimen, the movable portion was rotated gently by hand so that uniform seating is obtained. The load was applied continuously at the rate of approximately 140 kg/cm^2/min until the resistance of specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen was then recorded. An overall detail 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.

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

Mix ID	*Comp/mean target stg, N/mm^2*	*Slump (mm)*	*w/c*	*C (kg)*	*W (kg)*	*FA (kg)*	*CA (kg) 10 mm*	*Mixture proportions*
M	40/47.84	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M	40/47.84	10-	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M	40/47.84	60-	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 ID	*Comp/mean target stg, N/mm^2*	*Slump (mm)*	*w/c*	*C (kg)*	*W (kg)*	*FA (kg)*	*CA (kg) 10 mm*	*Mixture proportions*
M	25/32.84	10-	0.50	3.84	1.92	5.98	17.04	1:1.55:4.44
M	30/37.84	10-	0.45	4.27	1.92	6.09	16.50	1:1.42:3.86
M	40/47.84	10-	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87

4.0 Interpretation of Chloride Solution Absorption

The primary aim of this research was to interpret an effectiveness of wetting/drying pre-conditioned concrete cubes on chloride absorption, which was exposed to different pre-determined conditions such as dry/fully saturated/partially saturated condition was evaluated in control/impregnation concrete cubes for about 160 days salt ponding test in all designed six mixtures type (M1-M6). The chloride solution was prepared by using (10 gm) of sodium chloride powder/litre of water (10% Nacl) as per manufacturer (100 gm/m^3 per litre). 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. The chloride ingress in to the concrete can only take place if the concrete pores are totally/partly filled with water. The penetration occurs either through the capillary pores/through cracks by permeation, capillary suction, and diffusion. In the exposure conditions, the concrete moisture content, and the pore structure will determine the relative importance of those penetration mechanisms. The variation of weight loss/weight gain (water) in pre-conditioned concrete cubes such as DCC/PSC/FSC was represented in the following Tables.3-5.

Table 3: Interpretation of weight loss (water) in DCC concrete cubes

Mix ID	*Average, (%)*	*STD*	*Min, value*	*Max, value*
M1CC	-0.561	0.570	-	-
M2CC	-0.697	0.742	-	-
M3CC	-0.516	0.530	-	-
M4CC	-0.994	1.058	-	-
M5CC	-0.538	0.553	-	-
M6CC	-0.663	0.675	-	-

Table 4: Interpretation of weight gain (water) in PSC concrete cubes

Mix ID	*Average, (%)*	*STD*	*Min, value*	*Max, value*
M1CC	0.617	0.712	0.049	1.817
M2CC	0.567	0.625	0.050	1.445
M3CC	0.565	0.622	0.050	1.397
M4CC	0.657	0.749	0.051	1.856
M5CC	0.138	0.101	0.050	0.334
M6CC	0.113	0.064	0.050	0.236

Table 5: Interpretation of weight gain (water) in FSC concrete cubes

Mix ID	*Average, (%)*	*STD*	*Min, value*	*Max, value*
M1CC	1.091	1.159	0.063	2.933
M2CC	1.152	1.401	0.063	4.088
M3CC	1.261	1.602	0.063	4.428
M4CC	1.417	1.827	0.063	5.070
M5CC	0.965	1.457	0.070	4.393
M6CC	0.665	0.971	0.065	2.926

The concrete is a porous material with a wide range of pore sizes. Nano-pores are predominant in the hydration products of cements. In fact the concrete was just as other similar porous systems which have an intense interaction with moisture of its environment. If the concrete surface is in contact with liquid water or with aqueous salt solutions, significant quantities of water are absorbed by capillary suction. Under drying conditions, the moisture content is reduced again with a marked hysteresis. All changes of moisture content will induce volume changes which are at the origin of crack formation. The durability of a concrete structure depends essentially on this complex interaction between the porous material and its surrounding. It has been shown by a number of authors that, the deep impregnation of the concrete surfaces with water repellent agents forms an efficient and long lasting barrier with respect to chloride ingress (Zhao *et al*., 2006; Zhan *et al*., 2003; and Zhan, 2005). In this way service life of reinforced concrete structures situated in an aggressive environment such as marine climate/de-icing performance can be significantly extended/improved in different concrete infrastructures. Thus in the present research work that, an effectiveness of impregnation materials such as solvent/water based impregnation materials was evaluated in pre-conditioned concrete cubes in ordered to reduce chloride absorption for in case of designed mixtures type. The variation of average (1-160) days concrete chloride absorption, standard deviation, minimum, as well as maximum values under various pre-conditioned concrete cubes such as DCC/PSC/FSC was represented in Tables.6-8.

The variation of an average chloride absorption was compared in pre-conditioned control/impregnation concrete cubes at different time duration such as 31th, 61th, 91th, 121th, and 160th days to determine an effectiveness of impregnation materials (solvent/water) based impregnation material for long time duration. The variation of an average chloride absorption in pre-conditioned control/impregnation concrete cubes was recorded at different time duration as represented in Table.9. An average chloride absorption in DCC control/impregnation concrete cubes was pre-dominantly increased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned DCC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. An average chloride absorption in DCC control/impregnation concrete cubes was pre-dominantly increased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned DCC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength.

Table 6: Interpretation of chloride absorption in DCC/IC concrete cubes

Mix ID	*Average, (%)*	*STD*	*Min, value*	*Max, value*	*Mix ID*	*Average, (%)*	*STD*	*Min, value*	*Max, value*
M1CC	1.97	0.75	0.31	2.89	M4CC	3.17	0.68	1.61	4.04
M2SB	1.59	0.61	0.21	2.38	M4SB	2.62	0.63	1.24	3.42
M1W	1.72	0.62	0.25	2.50	M4W	2.82	0.68	1.45	3.71
M2CC	2.66	0.75	0.67	3.55	M5CC	2.38	0.72	0.71	3.27
M2SB	1.75	0.62	0.41	2.56	M5SB	1.63	0.66	0.31	2.48
M2W	1.88	0.64	0.51	2.72	M5W	1.89	0.63	0.46	2.68
M3CC	2.45	0.75	0.43	3.37	M6CC	2.19	0.66	0.48	3.02
M3SB	1.94	0.64	0.33	2.78	M6SB	1.66	0.64	0.34	2.50
M3W	2.06	0.69	0.34	2.92	M6W	2.00	0.67	0.40	2.84

Table 7: Interpretation of chloride absorption in PSC/IC concrete cubes

Mix ID	*Average, (%)*	*STD*	*Min, value*	*Max, value*	*Mix ID*	*Average, (%)*	*STD*	*Min, value*	*Max, value*
M1CC	0.75	0.39	0.23	1.40	M4CC	0.82	0.42	0.24	1.63
M2SB	0.63	0.35	0.15	1.21	M4SB	0.63	0.35	0.16	1.25
M1W	0.65	0.34	0.19	1.24	M4W	0.67	0.35	0.21	1.36
M2CC	0.76	0.41	0.21	1.46	M5CC	0.73	0.40	0.21	1.52
M2SB	0.61	0.35	0.16	1.25	M5SB	0.62	0.35	0.15	1.23
M2W	0.64	0.36	0.20	1.33	M5W	0.64	0.36	0.16	1.33
M3CC	0.77	0.46	0.17	1.62	M6CC	0.66	0.35	0.18	1.32
M3SB	0.60	0.35	0.12	1.22	M6SB	0.61	0.34	0.15	1.24
M3W	0.62	0.35	0.14	1.23	M6W	0.63	0.35	0.16	1.25

Table 8: Interpretation of chloride absorption in FSC/IC concrete cubes

Mix ID	*Average, (%)*	*STD*	*Min, value*	*Max, value*	*Mix ID*	*Average, (%)*	*STD*	*Min, value*	*Max, value*
M1CC	0.37	0.32	0.10	1.16	M4CC	0.43	0.29	0.21	1.31
M2SB	0.11	0.04	0.06	0.22	M4SB	0.22	0.10	0.12	0.44
M1W	0.13	0.05	0.07	0.28	M4W	0.25	0.12	0.14	0.53
M2CC	0.34	0.29	0.07	1.10	M5CC	0.31	0.25	0.12	1.03
M2SB	0.16	0.09	0.06	0.31	M5SB	0.19	0.12	0.09	0.45
M2W	0.21	0.16	0.07	0.59	M5W	0.21	0.16	0.10	0.64
M3CC	0.25	0.20	0.10	0.78	M6CC	0.24	0.17	0.10	0.74
M3SB	0.14	0.09	0.08	0.36	M6SB	0.17	0.10	0.05	0.40
M3W	0.19	0.11	0.09	0.43	M6W	0.20	0.13	0.09	0.53

Table 9: Variation of chloride absorption in pre-conditioned concrete cubes

Mix ID	*31 day*	*61 day*	*91 day*	*121 day*	*160 day*	*Mix ID*	*31 day*	*61 day*	*91 day*	*121 day*	*160 day*
Average chloride absorption (%) in DCC/IC concrete cubes											
M1C	1.13	1.65	2.27	2.68	2.89	M4C		2.90	3.36	3.81	4.04
M2SB	1.04	1.35	1.75	2.16	2.38	M4SB		2.36	2.78	3.23	3.42
M1W	1.10	1.49	1.92	2.31	2.50	M4W		2.55	3.01	3.47	3.71
M2C	1.86	2.36	2.94	3.37	3.55	M5C		2.17	2.61	3.06	3.27
M2SB	1.12	1.46	1.89	2.35	2.56	M5SB		1.37	1.82	2.26	2.48
M2W	1.21	1.62	2.05	2.49	2.72	M5W		1.65	2.09	2.50	2.68
M3C	1.62	2.25	2.72	3.13	3.37	M6C		1.93	2.38	2.79	3.02
M3SB	1.26	1.71	2.09	2.54	2.78	M6SB		1.47	1.78	2.24	2.50
M3W	1.27	1.81	2.28	2.69	2.92	M6W		1.82	2.22	2.61	2.84
Mix ID	*31 day*	*61 day*	*91 day*	*121 day*	*160 day*	*Mix ID*	*31 day*	*61 day*	*91 day*	*121 day*	*160 day*
Average chloride absorption (%) in PSC/IC concrete cubes											
M1C	0.31	0.52	0.87	1.06	1.40	M4C	0.29	0.70	0.98	1.11	1.63
M2SB	0.19	0.46	0.74	0.93	1.20	M4SB	0.21	0.52	0.76	0.90	1.25
M1W	0.24	0.50	0.75	0.93	1.24	M4W	0.26	0.58	0.76	0.92	1.36
M2C	0.26	0.56	0.87	1.10	1.46	M5C	0.26	0.56	0.88	0.99	1.52
M2SB	0.20	0.42	0.73	0.83	1.25	M5SB	0.19	0.50	0.72	0.87	1.22
M2W	0.24	0.42	0.74	0.92	1.33	M5W	0.21	0.48	0.74	0.87	1.33
M3C	0.21	0.53	0.94	1.11	1.62	M6C	0.23	0.50	0.77	0.93	1.32
M3SB	0.17	0.47	0.74	0.84	1.21	M6SB	0.20	0.43	0.69	0.89	1.24
M3W	0.18	0.48	0.74	0.88	1.23	M6W	0.21	0.47	0.74	0.89	1.25
Mix ID	*31 day*	*61 day*	*91 day*	*121 day*	*160 day*	*Mix ID*	*31 day*	*61 day*	*91 day*	*121 day*	*160 day*
Average chloride absorption (%) in FSC/IC concrete cubes											
M1C	0.13	0.14	0.30	0.54	1.16	M4C	0.25	0.26	0.39	0.45	1.31
M2SB	0.07	0.08	0.10	0.13	0.22	M4SB	0.14	0.16	0.21	0.25	0.44
M1W	0.09	0.09	0.12	0.14	0.28	M4W	0.15	0.16	0.23	0.29	0.53
M2C	0.17	0.18	0.27	0.41	1.10	M5C	0.14	0.16	0.30	0.35	1.03
M2SB	0.07	0.09	0.11	0.24	0.31	M5SB	0.10	0.11	0.19	0.22	0.45
M2W	0.08	0.10	0.23	0.28	0.59	M5W	0.10	0.11	0.19	0.23	0.64
M3C	0.11	0.13	0.23	0.28	0.78	M6C	0.12	0.14	0.22	0.29	0.74
M3SB	0.08	0.09	0.12	0.14	0.36	M6SB	0.08	0.10	0.18	0.22	0.40
M3W	0.10	0.12	0.20	0.24	0.43	M6W	0.10	0.11	0.18	0.23	0.53

An average chloride absorption in PSC control/impregnation concrete cubes was slightly increased/decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned PSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in PSC control/impregnation concrete cubes was slightly decreased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned PSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength. Whereas an average chloride absorption in FSC control/impregnation concrete cubes was slightly decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned FSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in FSC control/impregnation concrete cubes was slightly increased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned FSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength as observed from Table 9.

5.0 Discussion

Thus in the present research work, an effectiveness of 72 preconditioned concrete cubes of size (100) mm on chloride absorption under various pre-conditions was evaluated for in case of six designed mixtures type (M1-M6). The variation of weight loss/gain (water) in pre-conditioned concrete cubes such as dry/partially/fully saturated conditioned concrete cubes was represented in Figs.1-3. The variation of an average water weight loss in control DCC cubes was more/less more with constant higher compressive strength and varied slump value as when compared to variation of an average water weight loss in control DCC cubes with varied compressive strength and constant slump value. But, the variation of an average water weight loss in DCC cubes was pre-dominantly increased with lesser compressive strength and constant slump value and goes on decreased somewhat with increased compressive strength.

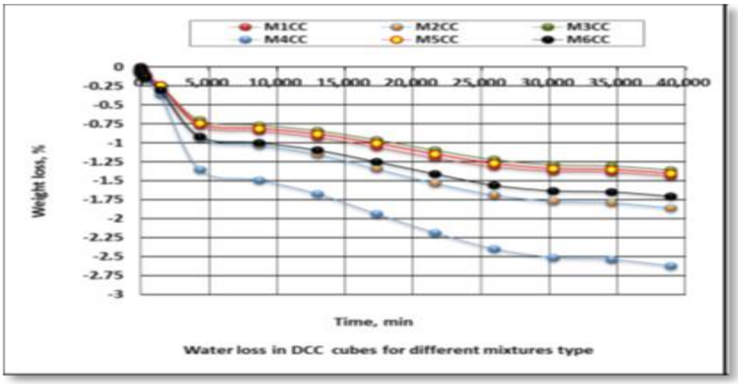


Figure 1: Water weight loss in DCC cubes

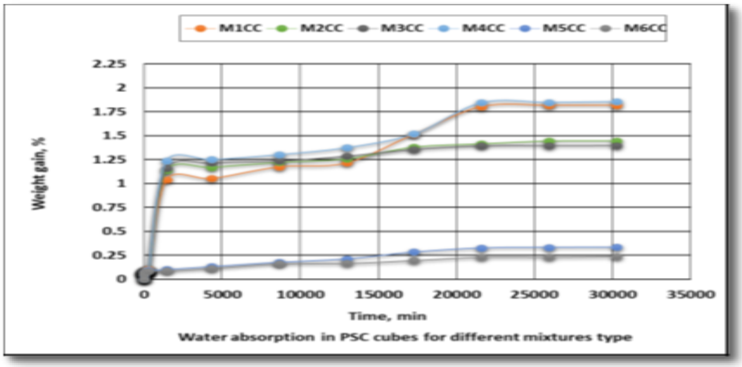


Figure 2: Water weight gain in PSC cubes

The variation of an average water weight gain in control PSC cubes was lesser with constant higher compressive strength and varied slump value/varied compressive strength and constant slump value as when compared to variation of an average water weight gain in control FSC cubes with constant compressive strength and varied slump value/varied compressive strength and constant slump value.

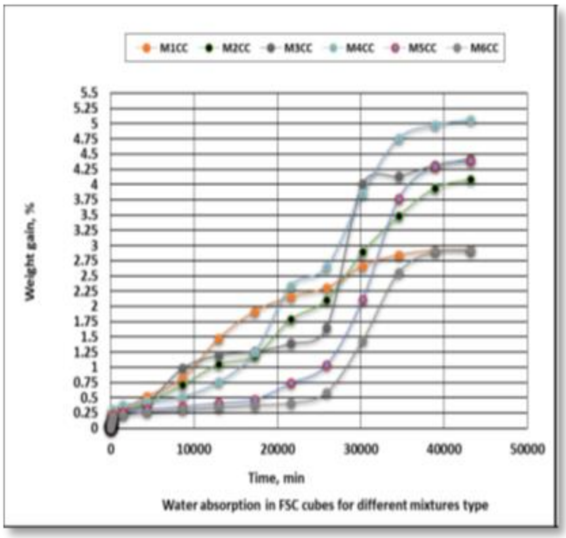


Figure 3: Water weight gain in FSC cubes

The variation of an average water weight gain in control PSC/FSC cubes was predominantly depends on saturation time duration and mixture proportioning method, pore structure, packing density of concrete, cement content, concrete matrix and cement paste interface zone, as well as aggregate volume fraction ratio in the concrete matrix. In fact, an average chloride absorption value in control and impregnation DCC/SB/WB cubes was found to be higher with higher constant concrete compressive strength, and varied slump values, as well as varied concrete compressive strength and constant slump value as when compared to an average chloride absorption in control and impregnation PSC and FSC/SB/WB cubes at longer time duration (160 day). An average chloride absorption was pre-dominantly increased in control and impregnation DCC/SB/WB cubes for lesser compressive strength and constant slump value and the chloride absorption value was decreases with an increased compressive strength and constant slump value for in case of designed mixtures type at longer time duration (160 day). Similarly, an average chloride absorption was decreased in solvent/water based impregnation DCC cubes as when compared to control DCC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value at longer time duration.

The variation of an average chloride absorption in control/solvent/water based impregnation DCC cubes at longer time duration (160 day) was represented in Fig.4 for different designed mixtures type (M1-M6). In fact, the average chloride absorption value in control and impregnation PSC/SB/WB cubes was found to be higher with higher constant concrete compressive strength, and varied slump values, as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control and impregnation FSC/SB/WB cubes at longer time duration (160 day). The average chloride absorption was pre-dominantly increased in control and impregnation PSC/SB/WB cubes for lesser compressive strength and constant slump value and the chloride absorption value was decreases with increased compressive strength and constant slump value for in case of designed mixtures type at longer time duration (160 day). Similarly, the average chloride absorption was decreased in solvent and water based impregnation PSC cubes as when compared to control PSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value at longer time duration. The variation of average chloride absorption in control/solvent/water based impregnation PSC cubes at longer time duration (160 day) was represented in Fig.5 for different designed mixtures type (M1-M6).

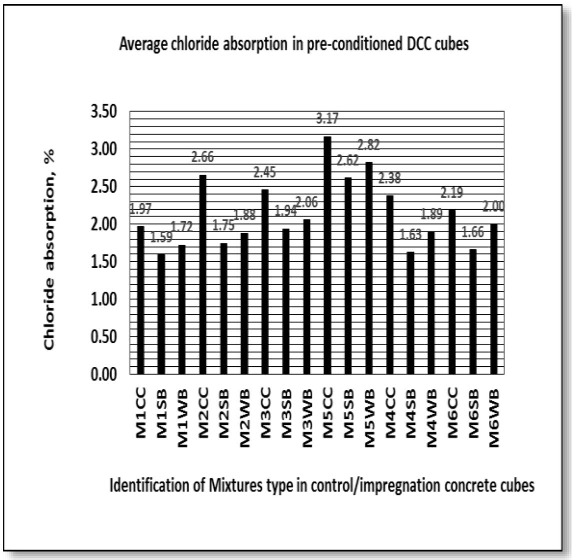


Figure 4: Chloride absorption in DCC cubes

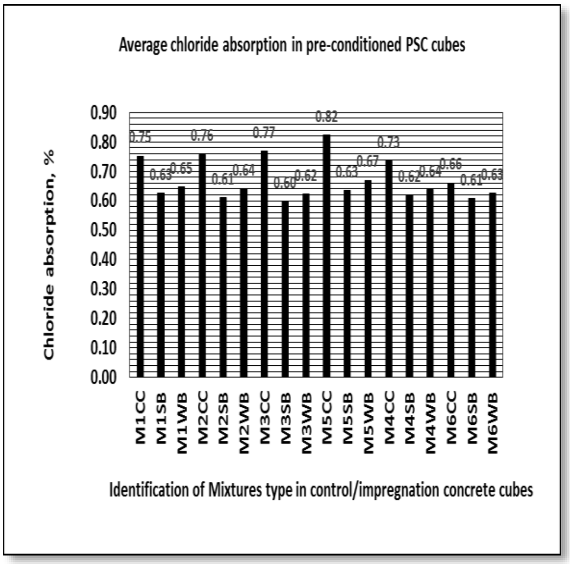


Figure 5: Chloride absorption in PSC cubes

The average chloride absorption value in control/impregnation FSC/SB/WB cubes was found to be pre-dominantly decreased with constant higher concrete compressive strength and varied slump values as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control/impregnation DCC/SB/WB cubes. The average chloride absorption was more increased in control/impregnation FSC/SB/WB cubes for lesser compressive strength and constant slump value. Whereas the average chloride absorption in control/impregnation FSC/SB/WB cubes was goes on decreases with increased compressive strength and constant slump value. The variation of average chloride absorption in control/solvent/water based impregnation FSC cubes at longer time duration (160 day) was represented in Fig.6 for different designed mixtures type (M1-M6). The transport mechanism of chloride absorption in concrete cubes during wetting/drying pre-conditioned concrete cubes is evaluated in this research work. The dry-wet pre-condition accelerate the transport process of chloride absorption within a certain distance from the surface, beyond this distance, chloride absorption in the complete immersion specimens migrate more rapidly than those under dry-wet pre-condition (Xu Gang, 2015). Especially, in case of absolute dry condition, the penetration rate of chloride ion will be much larger because of advection process than that in diffusion process in mortar with water saturated condition. Moreover, at the surface part of mortar, additional chloride content due to diffusion process can be also confirmed on distribution of chloride content due to advection process during absorption test. Therefore, in order to assess the penetration of chloride ion, effects of both advection and diffusion processes depending on moisture condition of mortar should be considered.

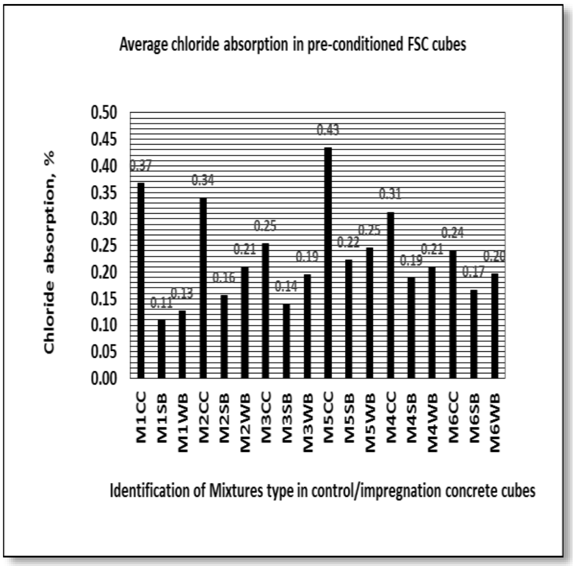
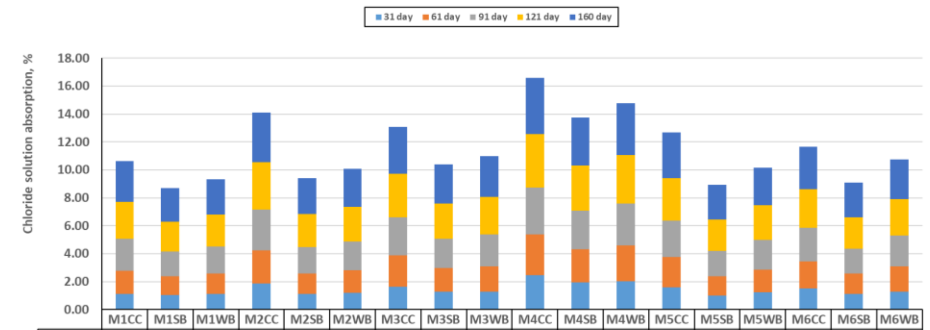


Figure 6: Chloride absorption in FSC cubes

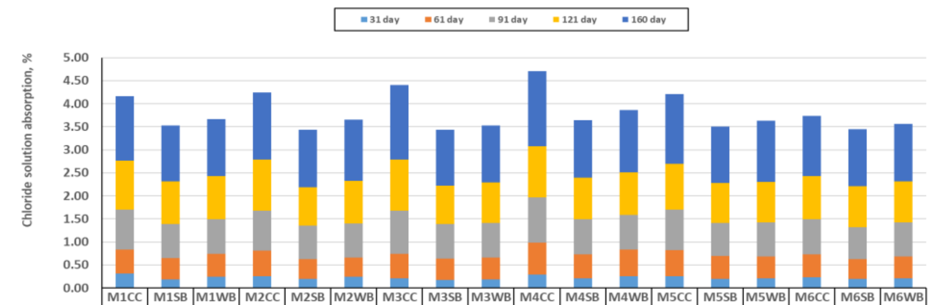
The chloride absorption was increased in pre-conditioned control/impregnation DCC (SB/WB) cubes as when compared to control/impregnation PSC (SB/WB), and control/impregnation FSC (SB/WB) conditioned cubes as represented in Figs.7-9. In fact, the chloride absorption was predominately increased in control/impregnation DCC (SB/WB) cubes at lesser compressive strength and constant slump value. But, the chloride was decreased in control/impregnation PSC (SB/WB) cubes with lower compressive strength and constant slump value, whereas in control/impregnation FSC (SB/WB) cubes was increases with lower compressive strength and constant slump value.



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
160 day	2.89	2.38	2.50	3.55	2.56	2.72	3.37	2.78	2.92	4.04	3.42	3.71	3.27	2.48	2.68	3.02	2.50	2.84
121 day	2.68	2.16	2.31	3.37	2.35	2.49	3.13	2.54	2.69	3.81	3.23	3.47	3.06	2.26	2.50	2.79	2.24	2.61
91 day	2.27	1.75	1.92	2.94	1.89	2.05	2.72	2.09	2.28	3.36	2.78	3.01	2.61	1.82	2.09	2.38	1.78	2.22
61 day	1.65	1.35	1.49	2.36	1.46	1.62	2.25	1.71	1.81	2.90	2.36	2.55	2.17	1.37	1.65	1.93	1.47	1.82
31 day	1.13	1.04	1.10	1.86	1.12	1.21	1.62	1.26	1.27	2.47	1.94	2.04	1.57	0.99	1.22	1.53	1.11	1.28

Chloride solution absorption in DCC concrete cubes

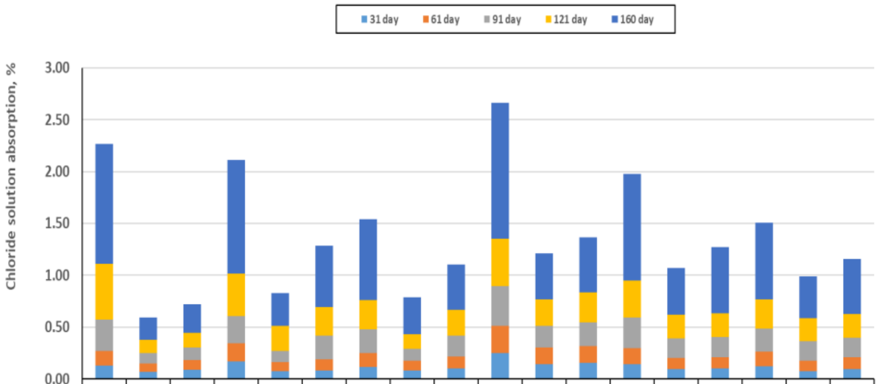
Figure 7: Chloride solution absorption in DCC cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
160 day	1.40	1.20	1.24	1.46	1.25	1.33	1.62	1.21	1.23	1.63	1.25	1.36	1.52	1.22	1.33	1.32	1.24	1.25
121 day	1.06	0.93	0.93	1.10	0.83	0.92	1.11	0.84	0.88	1.11	0.90	0.92	0.99	0.87	0.87	0.93	0.89	0.89
91 day	0.87	0.74	0.75	0.87	0.73	0.74	0.94	0.74	0.74	0.98	0.76	0.76	0.88	0.72	0.74	0.77	0.69	0.74
61 day	0.52	0.46	0.50	0.56	0.42	0.42	0.53	0.47	0.48	0.70	0.52	0.58	0.56	0.50	0.48	0.50	0.43	0.47
31 day	0.31	0.19	0.24	0.26	0.20	0.24	0.21	0.17	0.18	0.29	0.21	0.26	0.26	0.19	0.21	0.23	0.20	0.21

Chloride solution absorption in PSC concrete cubes

Figure 8: Chloride solution absorption in PSC cubes



	M1CC	M1SB	M1WB	M2CC	M2SB	M2WB	M3CC	M3SB	M3WB	M4CC	M4SB	M4WB	M5CC	M5SB	M5WB	M6CC	M6SB	M6WB
160 day	1.16	0.22	0.28	1.10	0.31	0.59	0.78	0.36	0.43	1.31	0.44	0.53	1.03	0.45	0.64	0.74	0.40	0.53
121 day	0.54	0.13	0.14	0.41	0.24	0.28	0.28	0.14	0.24	0.45	0.25	0.29	0.35	0.22	0.23	0.29	0.22	0.23
91 day	0.30	0.10	0.12	0.27	0.11	0.23	0.23	0.12	0.20	0.39	0.21	0.23	0.30	0.19	0.19	0.22	0.18	0.18
61 day	0.14	0.08	0.09	0.18	0.09	0.10	0.13	0.09	0.12	0.26	0.16	0.16	0.16	0.11	0.11	0.14	0.10	0.11
31 day	0.13	0.07	0.09	0.17	0.07	0.08	0.11	0.08	0.10	0.25	0.14	0.15	0.14	0.10	0.10	0.12	0.08	0.10

Chloride solution absorption in FSC concrete cubes

Figure 9: Chloride solution absorption in FSC cubes

6.0 Conclusion

The corrosion of reinforcement is the most significant cause of premature deterioration of reinforced concrete structures. The problem is particularly complicated where corrosion is initiated by chloride ingress, for in case of coastal environments and highway infrastructures subjected to the application of de-icing salts. The transport of chloride ions into concrete can take place by several different methods, in which major transport mechanisms are capillary absorption, diffusion and, where relevant, flow under hydrostatic pressure. Capillary absorption is driven by moisture gradients in the concrete and significantly influences the extent of chloride ion take-up. It therefore influences the concentration gradient within the concrete. The diffusion processes then encourage the ingress of chloride ions through the cover, as long as there is a continuous liquid phase in the concrete. Permeation occurs through hydrostatic pressure if a solution containing chloride ions is present under an applied hydraulic head on at least one face of the concrete. The effectiveness of impregnation of concrete cubes in resisting chloride absorption under pre-conditions such as dry/partially/fully saturated condition for long term time duration in ordered to characterize the designed mixtures type in this present research work. Based on the results represented in this contribution it can be concluded that:

i. The variation of average water weight loss in control DCC cubes was more/less more with constant higher compressive strength and varied slump value as when compared to variation of average water weight loss in control DCC cubes with varied compressive strength and constant slump value. But, the variation of average water weight loss in DCC cubes was pre-dominantly increased with lesser compressive strength and constant slump value and goes on decreased somewhat with increased compressive strength.

ii. The variation of average water weight gain in control PSC cubes was lesser with constant higher compressive strength and varied slump value/varied compressive strength and constant slump value as when compared to variation of average water weight gain in control FSC cubes with constant compressive strength and varied slump value/varied compressive strength and constant slump value.

iii. In fact, the variation of average water weight gain in control PSC/FSC cubes was pre-dominantly depends on saturation time duration and mixture proportioning method, pore structure, packing density of concrete, cement content, concrete matrix and cement paste interface zone, as well as aggregate volume fraction ratio in the concrete matrix.

iv. The average chloride absorption value in control/impregnation DCC/SB/WB cubes was found to be higher with higher constant concrete compressive strength, and varied slump values, as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control/ impregnation PSC and FSC/SB/WB cubes at longer time duration.

v. The average chloride absorption was pre-dominantly increased in control/impregnation DCC/SB/WB cubes for lesser compressive strength and constant slump value and the chloride absorption value was decreases with increased compressive strength and constant slump value for in case of designed mixtures type at longer time duration. Similarly, the average chloride absorption was decreased in solvent/water based impregnation DCC cubes as when compared to control DCC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value at longer time duration. In fact, the average chloride absorption value in control and impregnation PSC/SB/WB cubes was found to be higher with higher constant concrete compressive strength, and varied slump values, as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control and impregnation FSC/SB/WB cubes at longer time duration.

vi. The average chloride absorption was increased in control/impregnation PSC/SB/WB cubes for lesser compressive strength and constant slump value and the chloride absorption value was decreases with increased compressive strength and constant slump value for in case of designed mixtures type at longer time duration. Similarly, the average chloride absorption was decreased in impregnation PSC/SB/WB cubes as when compared to control PSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value at longer time duration.

vii. The average chloride absorption value in control/impregnation FSC/SB/WB cubes was found to be pre-dominantly decreased with constant higher concrete compressive strength and varied slump values as well as varied concrete compressive strength and constant slump value as when compared to average chloride absorption in control/impregnation DCC/SB/WB cubes. The average chloride absorption was more increased in control FSC/SB/WB cubes for lesser compressive strength and constant slump value. Whereas the average chloride absorption in control FSC/SB/WB cubes was goes on decreases with increased compressive strength and constant slump value.

viii. The chloride absorption was increased in pre-conditioned control/impregnation DCC (SB/WB) cubes as when compared to control PSC (SB/WB), and control FSC (SB/WB) conditioned cubes. In fact, the chloride absorption was predominately increased in control DCC (SB/WB) cubes at lesser compressive strength and constant slump value. But, the chloride was decreased in control PSC (SB/WB) cubes with lower compressive strength and constant slump value, whereas in control FSC (SB/WB) cubes was increases with lower compressive strength and constant slump value.

ix. It's concluded from the results that, in dry/saturated conditioned concrete cubes, the chloride absorption value was increased in all designed mixtures type. Similarly, the average chloride absorption 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 absorption 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 absorption was goes on decreases with increased compressive strength and constant slump value.

x. The variation of average chloride absorption was compared in pre-conditioned control/impregnation concrete cubes at different time duration such as 31^{th}, 61^{th}, 91^{th}, 121^{th}, and 160^{th} days to determine the effectiveness of impregnation materials (solvent/water) based impregnation material for long time duration. The variation of average chloride absorption in pre-conditioned control/impregnation concrete cubes was recorded at different time duration. The average chloride absorption in DCC control/impregnation concrete cubes was pre-dominantly increased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned DCC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in DCC control/impregnation concrete cubes was pre-dominantly increased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned DCC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength.

xi. The average chloride absorption in PSC control/impregnation concrete cubes was slightly increased/decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned PSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in PSC control/impregnation concrete cubes was slightly decreased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned PSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength.

xii. The average chloride absorption in FSC control/impregnation concrete cubes was slightly decreased with constant higher concrete compressive strength and varied slump values as when compared to pre-conditioned FSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength. The average chloride absorption in FSC control/impregnation concrete cubes was slightly increased with lesser concrete compressive strength and constant slump value as when compared to pre-conditioned FSC control/impregnation concrete cubes with constant slump value and varied concrete compressive strength as well as it goes on decreases with increased concrete compressive strength.

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