COMPARATIVE STUDY OF CHLORIDE ABSORPTION IN PRE-CONDITIONED CONCRTE CUBES

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Abstract: *An increasing amount prematurely deteriorating concrete infrastructure/steel structures such as concrete bridge decks, car parking places, airport pavement, railway platforms, and steel bridges at worldwide in cold country regions. The present research will interpret the influence of concrete ingredients on the chloride absorption in concrete cubes with different concrete mixtures design. For which slump, and w/c ratio is varied with same 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 with different grades of concrete were prepared and evaluate the differential rate of chloride absorption under different pre-conditioned exposure from 160 days salt ponding test with 10% Nacl solution for in designed different mixtures type. The chloride absorption is pre-dominantly gradually increased at an initial stage as when compared to longer time duration for in case of all mixtures type. It's also confirmed from the results that, the chloride absorption in control concrete cubes is significantly increased for in case of higher/lower compressive grade and varied/constant slump. But in the case of lower compressive strength and constant slump, the variation of chloride absorption with time is slightly higher and goes on decreases with increased compressive strength. Finally, from this research work that, it's possible to mitigate the effectiveness of chloride absorption in control concrete cubes/impregnation concrete cubes for in case of pre-conditioned DCC, FSC and PSC cube by proper concrete mixture design.*

Keywords: *Concrete mixtures type, pre-condition, water-cement ratio, grade of concrete, impregnation*

1.0 Introduction

The reinforced concrete is one of the most pre-dominant construction techniques in the world. In fact that, it was found that reinforced concrete are not maintenance-free structural elements. Chloride-induced corrosion is generally more pernicious and expensive to repair carbonation-induced corrosion of rebar may affect a wider range of RC structures at a larger scale. The penetration of gas/solutions can cause damage to the cement matrix/steel reinforcement. Many relationships have been proposed between the transport properties and the performance of concrete exposed to aggressive conditions [Basheer, *et al*, 2001].Concrete is relatively cheap, versatile with high compressive strength. Cracking of reinforced concrete is inevitable due to mechanical/environmental actions. Steel corrosion can be induced chemically from sulfates/sea water/acids. It results in the formation of expansive products, which result in further cracking of the concrete. In extreme cases, this eventually causes spalling, and infiltration as a result of an increase in permeability. It is estimated that around 40-60% of the European construction budget is devoted to repair and maintenance of existing structures as noted by [De Rooij, *et al*, 2013]. In the UK, the size of the UK repair industry is in excess of £1 billion [BRE, 2003]. In the US alone, the annual cost for repair, protection and strengthening of concrete structures is estimated to be between US$ 18 billion-US $21 billion [International concrete repair institute, 2006]. In fact that, various techniques have been explored to protect the steel from these aggressive substances. They include surface waterproofing/epoxy coated reinforcement/stainless steel reinforcement/fibre-reinforced plastic reinforcement/cathodic protection. However, none of these techniques have solved this present problem, either due to technical/economical/limitations [Kepler, *et al*, 2000]. Researchers [Chanakya Arya, *et al*, 2014] investigates the factors that influence absorption of chloride ions into concrete and how this affects distribution of chloride at different depths from the surface. Results show that the quantity of chloride entering the concrete, and in particular surface chloride content, is very sensitive to effective porosity/drying conditions immediately before wetting and as much as 31% of the protection provided by concrete cover can be lost after exposure to one wet/dry cycle. Chloride exposure is the primary cause of corrosion in reinforced concrete as investigated by [Bottenberg, 2008]. Corrosion is a natural process of material degradation though means of an electrochemical process called oxidation. External chloride ion exposure, such as dissolved de-icing salts or seawater mist, remains the most prominent source of chlorides; the chlorides ingress the concrete as an aqueous solution, diffuse through the pore network, and eventually reach the reinforcing steel [Bottenberg, 2008].Corrosion depends on the permeability of the concrete/clear cover depth/relative humidity/ambient temperature. Carbonation of the concrete has a synergistic effect when combined with chlorides. More chlorides accumulate at the carbonation front and are more likely to initiate corrosion when the carbonation front reaches the reinforcing steel [ACI Committee, 2010]. Concrete must be performing adequately throughout its service life, and concrete surface characteristics strongly influence concrete longevity, but sometimes surface treatments are needed. Surface treatments can be the most cost-effective solution for delaying time to corrosion initiation [Broomfield, 2007]. Protective surface treatments for concrete are commonly used to prevent the ingress of carbon dioxide, water, and waterborne containments into concrete in order to prevent corrosion initiation. An influence of moisture condition in concrete on the rate of water transport and characterization of chloride ingress into concrete is investigated by [Koike, *et al*, 2012]. From these experimental results, penetration property of chloride ion shows different trend depending on the internal water condition in mortar. 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. However, there are a few case studies about relationship between water movement and chloride ion movement, and those are not enough to clarify the mechanism of chloride penetration in actual phenomena. Furthermore several experimental investigations are carried out to build the assessment method that links water movement to chloride ion migration. In this study, moisture condition in concrete is focused upon, because it is expected that moisture condition influences on rate of water movement and penetration property of chloride ion. From the results of experimental study, effectiveness of moisture and internal water transport on chloride ingress in concrete structures are examined. It has been shown by a number of authors that deep impregnation of the concrete surfaces with water repellent agents forms an efficient and long lasting barrier with respect to chloride ingress [Wittmann, *et al*, 2006].

2.0 Research Objectives

The present research work is aim to determine the concrete chloride absorption to differentiate concrete mixtures design for in pre-conditioned control/impregnation concrete cubes under dry/fully/partially saturated condition which is salt ponded with chloride solution for about 160 days with 10% Nacl solution. Examine the influence of pre-conditioning on chloride absorption in control/impregnation concrete cubes. Slump, and w/c ratio value was vary with constant compressive strength as in the first case and compressive strength, and w/c ratio value varied with same slump as in the second case. Seventy-two concrete cubes with different grades of concrete were prepared and evaluate the chloride absorption under different exposure condition at different time interval.

3.0 Experimental program

In the present pilot program, 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 types were concrete cubes with a same compressive strength, differential slump, and different w/c. These mixtures were designate as M1, M2, and M3. Another three of the mixtures type were concrete cubes with a differential compressive strength, constant slump, and different w/c. These mixtures were designate as M4, M5, and M6. The overall details of the mixture proportions were to be representing in Table.1-2. Overall seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crush stone (10 mm) with grade of cement 42.5 N/mm^2, and fine aggregate used was 4.75 mm sieve size down 600 microns. As concern to impregnation materials, Water based (WB)/Solvent based (SB), impregnate materials were used for this research work. To avoid criticizing one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclosed. WB is water borne acrylic co-polymer based impregnation material, which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10mm.

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

Mix ID	Comp/mean target stg,N/mm^2	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10 mm	Mix 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

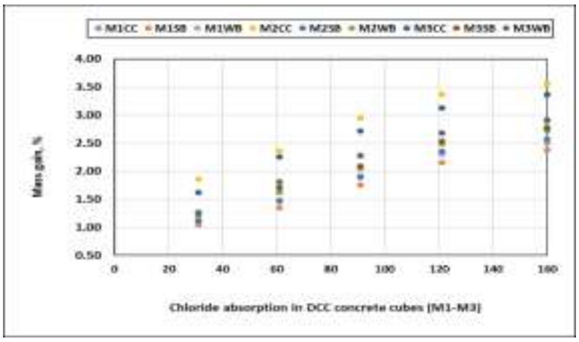
Table: 2 (Variable: Compressive strength & W/C value; Constant: Slump)

Mix ID	Comp/mean target stg,N/mm^2	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10mm	Mix 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 Discussion about Results

The primary aim of this research is to interpret the effectiveness of wetting/drying pre-conditioned concrete cubes on chloride absorption at different time duration, which is exposing to different pre-determined conditions such as dry/fully saturated/partially saturated condition. In which, it is evaluate 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 induce in order to achieve desired dry condition in specified 24 concrete cubes. In which all 24 concrete cubes were expose to natural room temperature for about 28 days. The pre-conditioned fully saturated condition was achieve 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 assess in specified 24 concrete cubes by partially submerged in water with one surface exposed for about 21 days. Finally chloride absorption was assessed in pre-conditioned concrete cubes at each time interval in control/impregnation concrete cubes until long-term duration (160 days). The chloride absorption (mass gain) were analysed in control/impregnation concrete cubes at different time interval in pre-conditioned concrete cubes for in concrete mixtures design (M1-M6).

The chloride absorption (mass gain) were analysed in the control/impregnation concrete cubes at different time interval (31-61-91-121-160) days in pre-conditioned concrete cubes for in the concrete mixtures design (M1-M6) as shown in Figs.1-15. Its observed from the results that, the chloride solution absorption in DCC cubes was varied depending upon the exposure condition in control/impregnation concrete cubes, concrete compressive strength, slump, w/c ratio, cement content. For instance the chloride solution absorption was varied in control DCC cubes in the range as M1CC (31.55-61.05 %), M2CC (21.05-47.61%), M3CC (28.18-51.98%), M4CC (14.81-38.69%), M5CC (27.50-51.87%), and M6CC (20.97-49.48%). The chloride solution absorption was varied in solvent based impregnate DCC cubes in the range as M1SB (22.69-56.12%), M2SB (23.70-56.44%), M3SB (26.27-54.54%), M4SB (17.91-43.31%), M5SB (27.37-59.96%), and M6SB (24.31-55.56%). Chloride solution absorption was further more varied in water based impregnate DCC cubes in the range as M1WB (20.41-56.10 %), M2WB (24.99-55.39%), M3WB (30.25-56.59%), M4WB (20.12-45.16%), M5WB (25.80-54.35%), and M6WB (29.69-55.04%) at interval 31th to 160th day as indicated in Figs.1-5. In which the chloride absorption was increased in the control/impregnation DCC cubes as against to the normal/impregnation PSC and FSC cubes at different time intervals. Chloride solution absorption was varied in control PSC cubes in the range as M1CC (40.42-77.63 %), M2CC (54.13-82.44%), M3CC (59.34-51.86.75%), M4CC (58.60-82.18%), M5CC (54.81-83.18%), and M6CC (53.57-82.45%). The chloride solution absorption was varied in solvent based impregnate PSC cubes in the range as M1SB (58.61-84.08%), M2SB (52.28-83.90%), M3SB (64.12-85.99%), M4SB (59.91-83.17%), M5SB (61.28-84.21%), and M6SB (52.51-83.66%). Chloride solution absorption was further more varied in water based impregnate PSC cubes in the range as M1WB (51.52-80.51 %), M2WB (42.59-81.77%), M3WB (62.20-85.20%), M4WB (55.51-81.14%), M5WB (56.08-84.32%), and M6WB (55.30-83.25 %) at interval 31th to 160th day as representing in Figs.6-10.



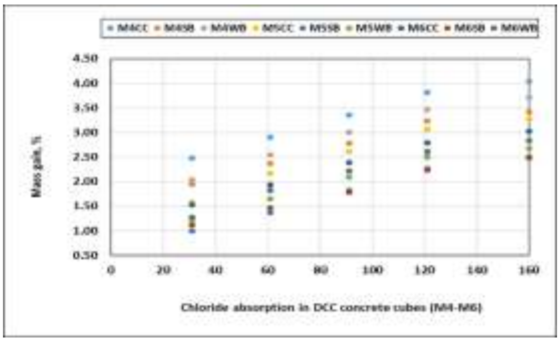
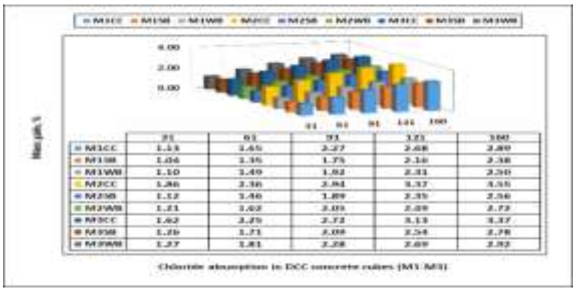


Fig.1 Mass gain in DCC control/IC cubes Fig.2 Mass gain in DCC control/IC cub



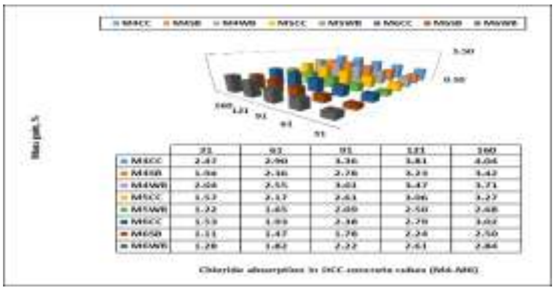
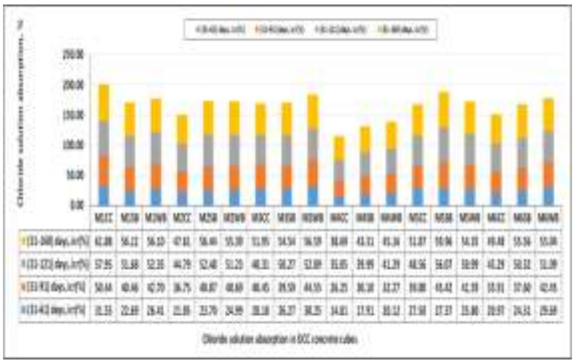


Fig.3 Mass gain in DCC control/IC cubes Fig.4 Mass gain in DCC control/IC cubes



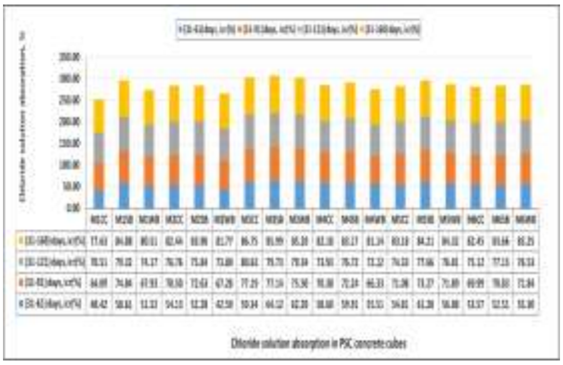
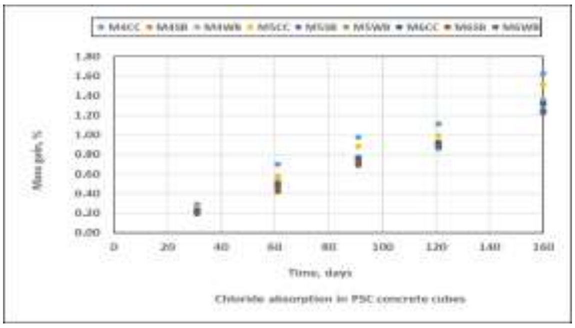


Fig.5 Mass gain in DCC control/IC cubes Fig.6 Mass gain in PSC control/IC cubes



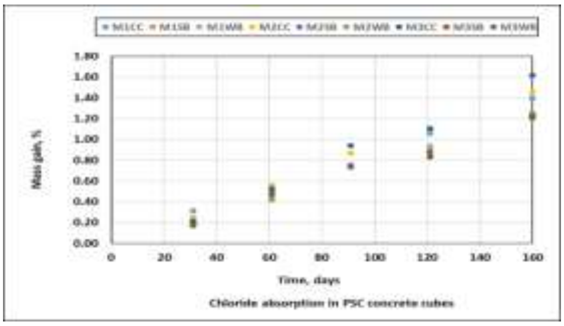
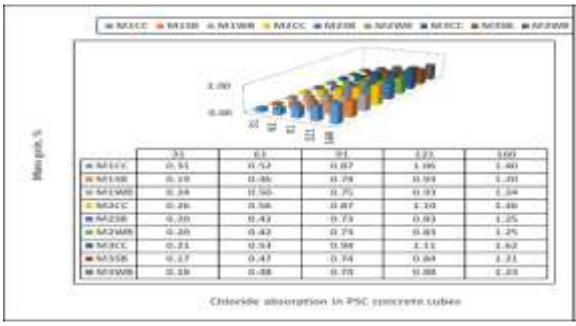


Fig.7Mass gain in PSC control/IC cubes Fig.8Mass gain in PSC control/IC cubes



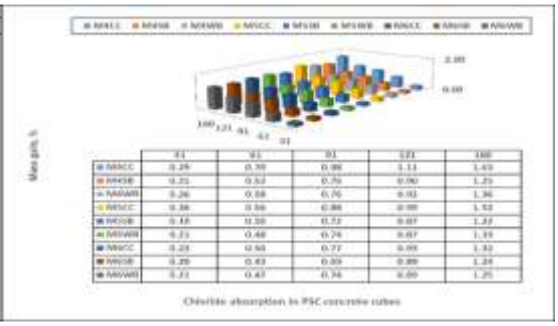
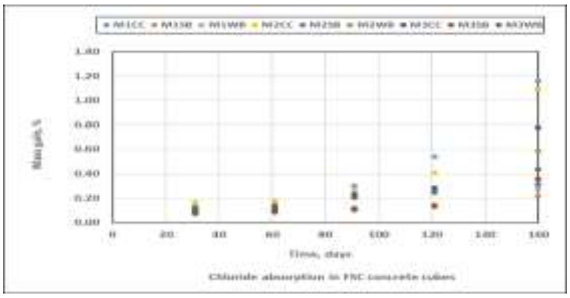


Fig.9 Mass gain in PSC control/IC cubes Fig.10 Mass gain in PSC control/IC cubes

Chloride solution absorption was varied in control FSC cubes in the range as M1CC (6.66-88.76%), M2CC (5.97-84.80%), M3CC (15.19-85.34%), M4CC (4.41-80.96%), M5CC (9.71-86.37%), and M6CC (13.90-83.61%). The chloride solution absorption was varied in solvent based impregnate FSC cubes in the range as M1SB (13.71-67.28%), M2SB (15.57-76.45%), M3SB (9.02-76.28%), M4SB (13.21-67.80%), M5SB (6.45-78.26%), and M6SB (26.47-81.12%). Chloride solution absorption was further more varied in water based impregnate FSC cubes in the range as M1WB (7.22-68.13 %), M2WB (19.68-85.79%), M3WB (14.45-76.99%), M4WB (6.59-71.25%), M5WB (6.31-83.87%), and M6WB (12.70-81.25%) at interval 31th to 160th day as shown in Figs.11-15. In which the chloride absorption was increased in the control/impregnation DCC cubes as against to the control/impregnation PSC and FSC cubes at different time intervals.



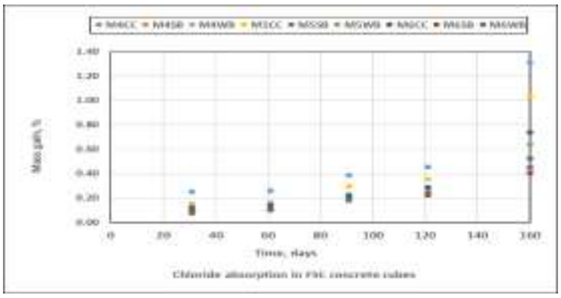
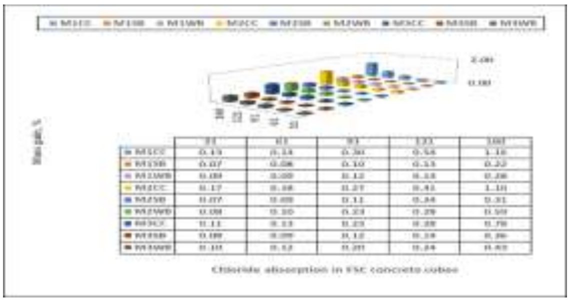


Fig.11 Mass gain in FSC control/IC cubes Fig.12 Mass gain in FSC control/IC cubes



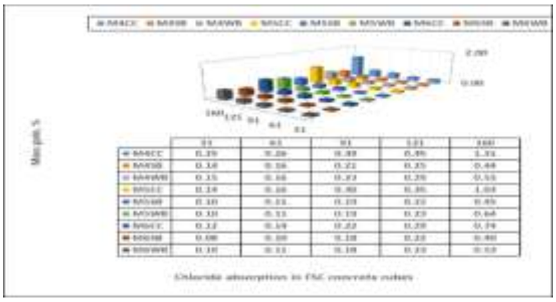


Fig.13Mass gain in FSC control/IC cubes Fig.14Mass gain in FSC control/IC cubes

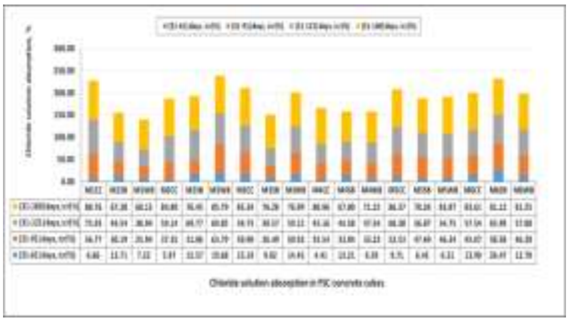


Fig.15Mass gain in FSC control/IC cubes

5.0 Conclusions

- The chloride absorption is gradually increased at initial time as against to longer for in case of (control/impregnation concrete cubes) in designed concrete mixtures type.

- The chloride absorption in control concrete cubes is significantly increased for in case of higher/lower grade of concrete and varied/same slump. But in case of lower grade of concrete and constant slump, the variation of chloride absorption with time is slightly higher and goes on decreases with increased compressive strength for in case of designed concrete mixtures type.

- Chloride absorption was increased in the control/impregnation DCC concrete cubes as against to the control/impregnation partially saturated and fully saturated conditioned concrete cubes at different time intervals.

- Finally, from this research work that, it's possible to mitigate the effectiveness of chloride absorption in control concrete cubes and impregnation concrete cubes for in case of pre-conditioned DCC, FSC and PSC cube.

6.0 References

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