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Investigation on the diffusion of chlorides into concrete

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ABSTRACT

This paper discusses on Rapid Chloride Permeability Test investigations on penetration of chloride ions into the concrete. Concrete samples of M40 and M50 Grades have been tested. The concrete specimens are made using standard moulds of 100mm diameter x 50mm height. After curing the concrete samples are experimented. Specimens were casted and tested for 28 days. One chamber is filled with sodium chloride (NaCl) and another sodium hydroxide solution is filled. The strength of sodium chloride solution is varied from 1000ppm-35000ppm and the strength of sodium hydroxide solution is 0.04N. For all the combinations, RCPT was carried out and the charge passed through the specimens was noted. The Rapid Chloride Permeability Test values are found, the penetration charge through the concrete decreased with increase in grade of concrete.

Keywords— *Rapid Chloride Permeability Test (RCPT), Sodium Chloride, 0.04N NAOH, PH.*

1. INTRODUCTION

The most important and costly deterioration mechanism affecting the reinforced concrete structures is the corrosion of steel reinforcement. In good quality concrete reinforcement steel is unlikely to corrode even if sufficient moisture and oxygen are available due to formation of a protective oxide film (passive film) in the highly alkaline environment However, this passive film can be disrupted and corrosion initiated by carbonation, due to the penetration of carbon dioxide into the concrete, which lowers the alkalinity of the environment or by the presence of high concentrations of aggressive ions, mainly chlorides. The deuteriation can be broken down in one of two ways, carbonation or chloride attack While corrosion due to carbonation occurs relatively infrequently, a much more prevalent problem is chloride induced corrosion in structures exposed to marine conditions and Deicing salts. Once the chloride concentration at the steel has reached a sufficient level (chloride threshold) it will attack the passive layer and reduce its ability to protect the underlying steel. The volume of the corrosion products is much larger than that of the reactants, therefore the formation of these products produces expansive forces on the concrete. These forces lead to cracking, spalling and delamination's, severely reducing the service life of the structure. The Rapid Chloride Permeability test was created to develop techniques to nondestructively measure the chloride permeability of in-place concrete. Prior to the development of the test, chloride permeability of concrete was measured by a ponding test, such as AASHTO T259-80, "Resistance of Concrete to Chloride Ion Penetration." Ponding tests typically take 90 days or longer and involve taking samples of the concrete at various depths to determine the chloride profile Chloride migration through concrete, even in high water/cement ratio concrete, is a very slow process. So, researchers looked for a test method that would accelerate this migration They found that when an electrical current was applied to a concrete specimen it increased and accelerated the rate at which the chlorides migrated into concrete. The researchers also found that if one measured the coulombs (the integral of current vs. time plot) that were passed through the sample and then compared these numbers to results from a ponding test a good correlation existed. From these findings, researchers developed the test procedures that are currently specified in AASHTO T277 and ASTM C1202.

2. LITERATURE REVIEW

Donald W. Pfeifer, S.E. et.al,[1] reviews documents referenced by ASTM C1202, "Electrical Indication of Concrete's Ability to Resist Chloride ion Penetration," and explores the correlation of **ASTM C1202** to **AASHTO T259**, "Resistance of Concrete to Chloride ion Penetration." The procedure outlined in ASTM C1202 is based on the AASHTO Test Method T277, "Rapid Determination of the Chloride Permeability of Concrete," initially developed in 1981. Chloride penetration in both ASTM C1202 and AASHTO T277 is expressed as charge passed, or coulombs. The scope of ASTM C1202 states that this method is applicable to concretes in which a correlation has been established between the coulomb value and the amount of chloride ingress. This correlation test- rarely performed by specifiers or researchers. Thus, selection or rejection of concrete based solely on ASTM C1202 can result in improper decisions and the rejection of concrete known to be durable. Based on the review of the documents referenced in ASTM C1202, it is concluded that reliable and proper correlations do not exist between the rapid test procedure results and 90-day ponding test results. The ASTM C1202 or AASHTO T277 test procedures should not be used in specifications without proper correlation to long-term tests. It is recommended that the table relating chloride penetration to coulomb values in these test procedures be removed since it is inaccurate and can be misleading.

Peter Claisse et.al,[2] describes "The effect of other ions on chloride migration in concrete" Measuring chloride migration is essential for predicting the durability of embedded steel in concrete. The "Rapid Chloride Permeability Test" to ASTM C1202 is gaining popularity as a method for this but it has severe limitations, particularly when pozzolanic admixtures are used. The NTBuild-492 Migration test overcomes some of these but still does not take full account of the complex processes involved. An overview of a major experimental program to test and validate the models will be presented. The programs concluded that even in diffusion tests in which there is no electric field applied or electrical measurements made, there are still significant effects of charge build up from hydroxyl, sodium and potassium ions as well as the chloride.

Stanish K.D, et.al[3] in his paper "Testing the Chloride Penetration Resistance of Concrete" conducted a review of the current common methods for determining chloride penetrability of concrete is presented. First, some theoretical background of what influences the penetration of chlorides into concrete is presented in Section 3. The different mechanisms of chloride penetration are presented followed by a further elaboration of the chloride diffusion theory. The influence of basic properties of concrete on its chloride penetrability is also discussed. In Section 4, individual test procedures are presented. First, the existing long-term procedures are discussed, namely the salt ponding (AASHTO T259) test and the Nordtest (NTBuild 443) bulk diffusion test. The existing short-term tests are then presented. For each test, the procedure, the theoretical basis, and any advantages and disadvantages are presented.

Yunping Xi et.al[4], proposed "Modeling Chloride Penetration In Saturated Concrete" A mathematical model is established for chloride penetration in saturated concrete. The model takes into account various influential parameters such as water-to-cement ratio**,** The model considers several influencing parameters, such as the ratio of cement to water, curing time, cement type and addition amount. Two material models have been developed for chloride ion binding capacity and diffusivity. They play a leading role in the chloride diffusion process. The chloride ion binding capacity is modeled by the chloride ion adsorption isotherm. The chloride diffusivity is modeled by a composite material theory in which concrete is considered as a two-phase material with the cement paste as one phase and the aggregate as another. To take into account the effect of aggregate content, the three-phase model for diffusivity of a two-phase composite developed by Christensen is used. The diffusivity for cement paste is characterized by the Kozeny- Carman model as modified by Martys et al. The influences of temperature and chloride ion concentration are also handled in the model. The model prediction agrees quite well with available test results.

Caijun Shi[5], discusses "Another Look At The Rapid Chloride Permeability Test (ASTM C1202)" the effects of several factors, such as cement composition, replacement of cement with supplementary cementing materials and inclusion of aggregate, on the electrical conductivity or RCPT results of hardened cement mortars and concrete. Analyses based on published results have indicated that all the three factors may have significant effects on the chemistry and specific conductivity of concrete pore solution, which has little to do with the transport of ions in the solution. Thus, RCPT is not a valid test for evaluation of permeability of concretes made with different materials or different proportions.

Dr. Ghalib Mohsin Habeeb[6], **"**Determination of Apparent Chloride Diffusion Coefficient For Self-Compacting Concrete Containing Nano Silica Under Effect Of Sulfate Attack" determine the apparent chloride diffusion coefficient of self-compacting concrete (SCC) with Nano Silica which is subjected to severe saline conditions contain sulfates and chlorides at concentrations similar to those existing in soils and ground water of the middle and southern parts of Iraq. Four basic mixes of SCC were performed with and without addition of Nano Silica, and with two types of cement (ordinary Portland cement and sulfate resistance Portland cement). The workability properties of mixes were evaluated by fresh tests such as slump-flow test, T50cm, L-box and V-funnel tests. The apparent chloride diffusion coefficient was determined at90 and 180 days. Test results exhibited that the presence of Nano Silica in concrete decreases the apparent chloride diffusion coefficient at age of 180 days which was ranged between (50.83 54.40) % measured relative to its reference mixes without Nano silica addition. Also, the results revealed that SRPC specimens have higher chloride content than OPC mixes especially at 90 days. While at 180 days, SRPC specimens have lower chloride content than OPC specimens.

3. EXPERIMENTAL PROGRAM

3.1 Materials

In this study 53 grade of Ordinary Portland Cement (OPC) is used. The fine aggregate was M sand having a nominal size of 4.75 mm. 20mm and 12mm size of coarse aggregates are used. Fosroc conplast SP430 DIS is used as Admixture.

3.2 Other Materials Used:

- PVC PIPE – 4 inch, 5cm diameter pipe are used as moulds
- PVC BLEND – used for filling of solution
- STAINLESS STEEL – Acts as electrode

3.3 Mix Proportions

In the present work, M40 and M50 concretes are casted. The mixed proportion of M40 and M50 is presented in the Table 3.1 given below

Table 3.1. Mix Proportions of Concrete

Grade	Cement	Fine Aggregate	20mm Coarse Aggregate	12mm Coarse Aggregate	W/C Ratio
M40	1	1.94	1.66	1.11	0.37
M50	1	1.76	1.51	1.0	0.32

Table 3.2. Basic Tests of Material

Tests	Results
Initial Setting Time	35 Minutes
Final Setting Time	6 Hours
Specific Gravity of Cement	3.10
Specific Gravity of Fine Aggregate	2.56
Specific Gravity of Coarse Aggregate	2.7
Finest Modulus of Fine Aggregate	3.16

3.4 Preparation of specimen

The concrete specimens are made using standard moulds of 100mm diameter x 50mm height. After curing the concrete samples are experimented.

Figure 3.1. Preparation of Moulds

3.5 Preparation of solutions

The diffuser cell consists of two chambers. One chamber is filled with sodium chloride (NaCl) and another sodium hydroxide solution is filled. The strength of sodium chloride solution is varied from 1000ppm-35000ppm and the strength of sodium hydroxide solution is 0.04N. Na sodium - 22.989 O oxygen – 15.999 H hydrogen – 1.0079 To make 3% solution of NaCl.30 grams of salt is mixed with 1000ml of distilled water. To make molar 0.3M NaOH solution. 0.3x40gms = 12gms of NaOH is dissolved with 1000ml of distilled water

Table 3.3. Preparation of Solution

Test	No of concrete sample	Cathodic Solution	Anodic solution
1	3	0.04n naoh	0.04n naoh+1000 ppm nacl
2	3	0.04n naoh	0.04n naoh+5000 ppm nacl
3	3	0.04n naoh	0.04n naoh+10000 ppm nacl
4	3	0.04n naoh	0.04n naoh+20000 ppm nacl
5	3	0.04n naoh	0.04n naoh+35000 ppm nacl

3.6 Procedure

The specimen was fixed in between the halves of the test cell. One cell is overfilled with of 3% NaCl solution which is attached to power supply of negative terminal and the further side is loaded with 0.3M NaOH solutions which are attached to the power supply of positive terminal. These test cells are sealed together by the boundaries of specimen and cell with the help of sealant. Wires are attached to the cell. Turn on power supply, set the voltage into 60V, and initial reading is recorded as I0, Record the reading at every 30 min up to 6 hours. Each cell contains appropriate solution must remained in the whole period of the test.

Figure 3.2a, 3.2b. Experimental Setup

3.7 Methodology

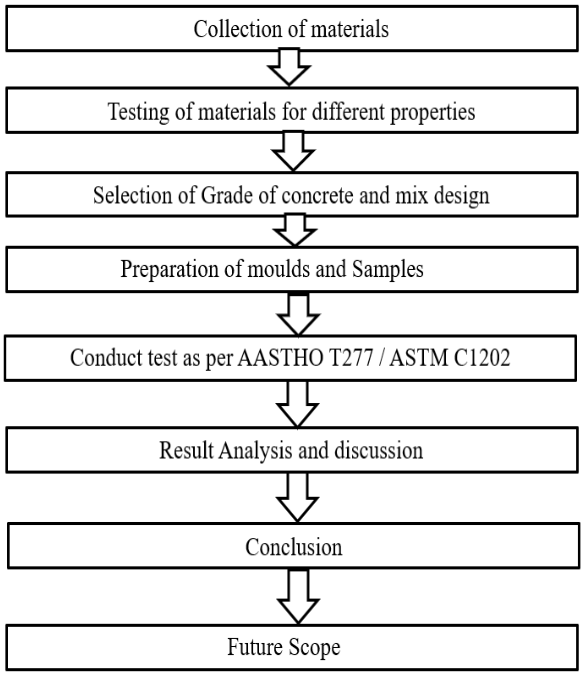

Figure 3.4. Flow Chart

4. RESULT AND DISCUSSION

As can be seen from the work presented above, the diffusion of chloride ions into concrete is a complicated, multi-mechanistic phenomenon. It is important to understand some of the basic concepts underlying chloride ingress into concrete to enable the proper consideration of this eventuality when designing concrete. A multitude of tests has been proposed and used to test the resistance of concrete to chloride ingress, and reveals that each test procedure has advantages and disadvantages. The different test methods depends on different situations. Limitation of each test procedure should be properly understood and along with the requirement for the situation will allow the correct selection of testing procedure at each case.

Table 4.1. RCPT Test result for M40 Concrete

1000 PPM NACL		1000 PPM NACL		1000 PPM NACL		1000 PPM NACL		1000 PPM NACL	
TIME	CHARGE	TIME	CHARGE	TIME	CHARGE	TIME	CHARGE	TIME	CHARGE
0	1.1	0	1.6	0	2.3	0	3.9	0	4
30	1.1	30	1.5	30	2.3	30	3.7	30	3.8
60	1	60	1	60	1	60	1.7	60	2
90	0.9	90	0.7	90	0.8	90	1.1	90	1
120	0.7	120	0.5	120	0.7	120	0.8	120	0.8
150	0.6	150	0.4	150	0.6	150	0.7	150	0.6
180	0.4	180	0.4	180	0.3	180	0.6	180	0.5
210	0.2	210	0.3	210	0.2	210	0.3	210	0.4
240	0.2	240	0.2	240	0.2	240	0.2	240	0.4
270	0.1	270	0.2	270	0.2	270	0.1	270	0.4
300	0.1	300	0.1	300	0.2	300	0.1	300	0.3
330	0.1	330	0.1	330	0.1	330	0.1	330	0.3
360	0.1	360	0.1	360	0.1	360	0.1	360	0.3

Table 4.2. RCPT Test result for M50 Concrete

1000 PPM NACL		1000 PPM NACL		1000 PPM NACL		1000 PPM NACL		1000 PPM NACL	
TIME	CHARGE	TIME	CHARGE	TIME	CHARGE	TIME	CHARGE	TIME	CHARGE
0	0.1	0	0.2	0	0.4	0	1.3	0	2.2
30	0.2	30	0.2	30	0.5	30	0.9	30	1.6
60	0.1	60	0.1	60	0.4	60	0.7	60	1.2
90	0.1	90	0.1	90	0.4	90	0.6	90	0.9
120	0.1	120	0.1	120	0.3	120	0.5	120	0.8
150	0.1	150	0.1	150	0.3	150	0.4	150	0.6
180	0.2	180	0.1	180	0.3	180	0.4	180	0.6
210	0.1	210	0.1	210	0.3	210	0.3	210	0.5
240	0.1	240	0.1	240	0.2	240	0.3	240	0.4
270	0.1	270	0.1	270	0.2	270	0.3	270	0.4
300	0.1	300	0.1	300	0.2	300	0.2	300	0.4
330	0.1	330	0.1	330	0.2	330	0.2	330	0.3
360	0.1	360	0.1	360	0.2	360	0.2	360	0.3

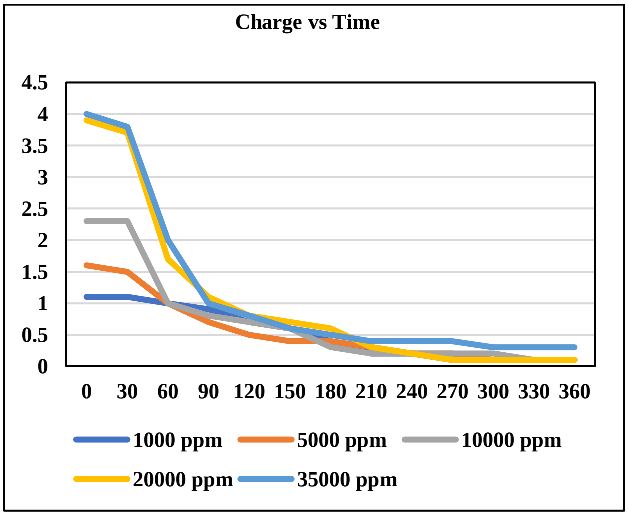

Figure 4.1. RCPT Test result for M40 Concrete

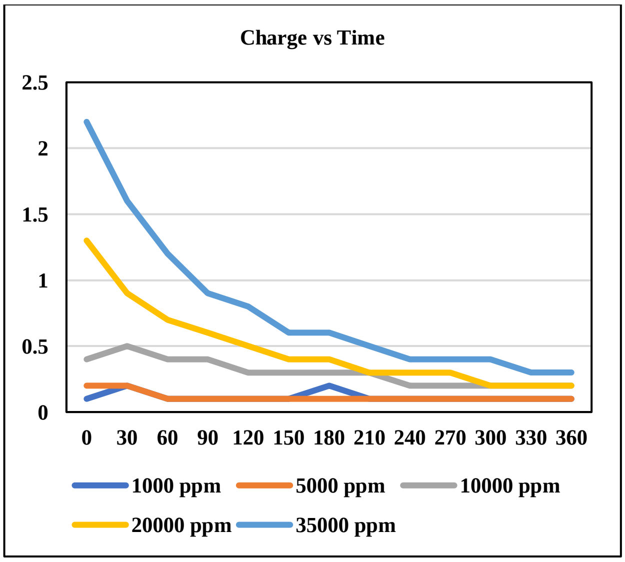

Figure 4.2. RCPT Test result for M50 Concrete

Due to cathodic reaction at chloride contaminated sodium Na+ combined with hydroxyl's ions to form NaOH correspondingly Cl- migrate to anode through the cathode side. Migration of OH-ions into to the concrete the deflection of OH-ion at the cathode side reduces the pH at cathodic face of the concrete during diffusion experiment

Table 4.3. PH of solution before testing

PH	NACL	NAOH
M40-S1	9.25	12.5
M40-S2	9.25	12.5
M40-S3	9.25	12.5
M40-S4	9.25	12.5
M40-S5	9.25	12.5
M50-S1	9.25	12.5
M50-S2	9.25	12.5
M50-S3	9.25	12.5
M50-S4	9.25	12.5
M50-S5	9.25	12.5

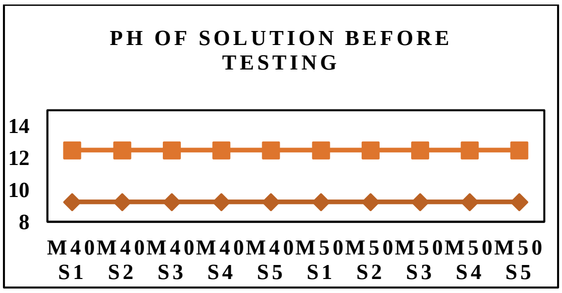

Figure 4.3. PH of solution before testing

Table 4.4.PH of solution after testing

PH	NACL	NAOH
M40-S1	9.99	10.57
M40-S2	9.9	10.12
M40-S3	10.24	10.76
M40-S4	9.8	10.5
M40-S5	9.94	11.15
M50-S1	9.41	10.4
M50-S2	9.75	10.6
M50-S3	9.94	10.67
M50-S4	10.12	10.82
M50-S5	10	10.62

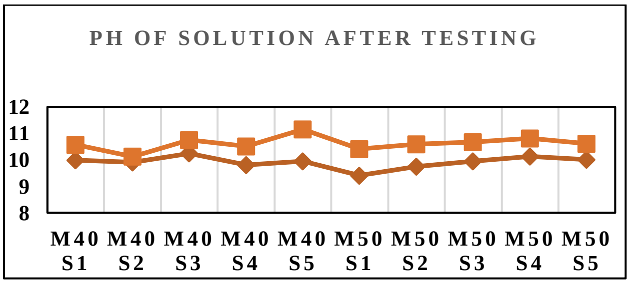

Figure 4.4. PH of solution after testing

5. CONCLUSION

As seen in the present work the transportation of chloride ion into the concrete is a phenomenon it is an important factor in designing of a durable reinforced concrete by understanding the rate of chloride penetration The penetration charge through the concrete decreased with increase in grade of concrete. Due to cathodic reaction at chloride contaminated sodium Na+ combined with hydroxyl's ions to form NaOH correspondingly Cl- migrate to anode through the cathode side. Migration of OH-ions into to the concrete the deflection of OH-ion at the cathode side reduces the pH at cathodic face of the concrete during diffusion experiment. The penetration charge through the concrete increased with increase in percentage of NaCl.

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