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## Study on the Degradation of Concrete by Chloride Diffusion

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**ABSTRACT:** Chloride ions and other aggressive substances penetrate through concrete via different mechanisms depending on the driving force involved. Diffusion, permeability and absorption are the most well-known chloride transport mechanisms through concrete. The fresh state of concrete and the service environment determine the driving force and thus the mechanisms by which chloride penetrates into concrete. In saturated concrete which is continuously immersed in an aqueous solution, chloride transport occurs by diffusion through the pore solution. Movement into and through unsaturated concrete, a common state for concrete with surfaces exposed to the atmosphere, is largely controlled by absorption through the capillary pore system and diffusion of chlorides through pore solution. In highway structures and bridges, concrete is subjected to intermittent wetting events due to rain or condensation and dries out in between these wetting events. The most important and costly deterioration mechanism affecting the reinforced concrete structures is the corrosion of steel reinforcement. Liquid in the pores evaporates progressively from the surface. In this situation, the most likely scenario is that chloride will enter the concrete initially by absorption and produce a reservoir of chloride ions a relatively short distance from the concrete surface from which diffusion can occur. If the concrete dries out to a greater depth, subsequent wettings carry the chlorides deeper into the concrete. Thus it would appear that absorption and diffusion are important transport mechanisms associated with chloride ingress in highway structures and bridges and marine structures. However, before discussing these two mechanisms of chloride ingress in detail, the following gives a brief description of permeability which is necessary for an understanding of the theory of absorption. Chloride penetration using ASTM C 1202 & AASTHO T277 (Standard Test Method for of Concretes Ability to Resist Chloride Ion Penetration).

**KEYWORDS:** Diffusion, Chloride penetration, concrete mix design, concrete pumping, curing, finishing, permeability, salt-ponding, temperature control, correlation, coulomb

### I. INTRODUCTION

Concrete is one of the most widely used construction materials in the world. It is a versatile and economical material that generally performs its intended use well over its service life. 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 transport of chloride ions through concrete has very severe ramifications on the service life of reinforced concrete structures, not because of its effect on the concrete, but because of its effect on the reinforcing steel.

In a high alkaline environment, such as concrete, a passive layer is formed on the surface of reinforcing steel. This layer is a very dense, slowly reacting corrosion product that essentially prevents further corrosion of the steel bars. However, this layer can be broken down in one of two ways, carbonation or chloride attack. Carbonation lowers the  $p^H$

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of the concrete to a level where the passive layer is no longer stable, allowing corrosion to occur. This attack is common in balconies, soffits and other exposed concrete that is sheltered from direct precipitation. 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. These lead to cracking, spalling and delaminations, severely reducing the service life of the structure. Due to the risk of corrosion, many owners of new structures that will be exposed to chlorides, either through deicing salts or marine environments, have specified the use of low permeability concrete to reduce the rate at which the chlorides ingress into the concrete, thus extending the life of their structure.

The concept Rapid Chloride Permeability test was developed in a FHWA Research program. The program was created to develop techniques to non-destructively 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. The FHWA wanted a test that could be done in place and have a good correlation to data that was developed from chloride ponding tests.

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.

The work in this paper is divided in two stages. 1) Determine if a relationship exists between concrete current flow and the rate of diffusion of chloride ions through concrete. 2) Examine the chloride diffusion rate in various grade of concrete.

The work in this paper describes the laboratory studies undertaken. The laboratory work consisted of two Phases.

Phase I is designed to investigate the effect of different variables such as basic material testing, that is specific gravity of cement, aggregates establish the relationships.

Phase II is intended for casting the specimen by using the critical variables identified in phase I and exposing concrete specimens for a curing period of time i.e. 28 days. And conduct the test as per the AASHTO T277 & ASTM C 1202. present and discuss the findings in Phases I and II of the laboratory work, Respectively. Presents two proposed numerical prediction models for chloride penetration in Concrete. Summarizes the findings and makes recommendations for future work on Modelling chloride penetration in concrete.

## II. MATERIAL AND METHODOLOGY

**DIRECT CHLORIDE TESTING:** Direct testing of chloride diffusion typically includes some form of specimen exposure to a chloride solution. After a period of time, samples are taken from the concrete to determine the chloride content. The methods of exposure and sampling vary. Direct testing methods are typically considered to be long-term tests taking more than 30 days.

The AASHTO T 259 (2002) and the ASTM C1543 (2002) are ponding test methods that provide a direct measure of chloride ingress into non-saturated concrete. Small slab specimens are exposed to an aqueous chloride ion solution of known concentration by ponding for 3 months or more. After the exposure period, samples are taken from the specimens at various depths and tested for chloride ion concentration. A profile of chloride concentration levels throughout the depth of the concrete is established. Concrete properties, such as the effective diffusion coefficient and the apparent surface concentration, can be mathematically estimated using Fick's Second Law. The chloride profile and the effective diffusion coefficient serve as a measure of the material's ability to resist ingress of chloride ions in the uncracked condition. Chloride concentration levels of samples from these tests are determined using methods such as ASTM C1152/C 1152M (2004) or AASHTO T 260 (2001).

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**INDIRECT CHLORIDE TESTING:** Because of the long-term nature of direct testing, faster testing methods are often desired. Indirect testing methods can be used based on the assumption that the indirect measures correlate with a concrete's ability to resist chloride ion penetration. Measurement of the electrical conductivity of concrete is a popular method for evaluating potential chloride ingress. ASTM C1202/AASHTO T 277, Test Method of Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (2007) is the most commonly used electrical conductivity testing method, particularly in the United States. developed as an in-situ field test, the method is based on the ability of a specimen to conduct electrical current. The test consists of measuring the amount of electrical charge (**in Coulombs**) passed through a vacuum-saturated concrete core over a 6-hour period. The specimen is sandwiched between two solutions, sodium chloride and sodium hydroxide, and a constant potential difference is maintained across the specimen. The total charge passed through the specimen is recorded and considered to be an indication of the concrete's permeability or resistance to chloride ion penetration. Premature deterioration of reinforced concrete bridges is a worldwide problem. Corrosion of embedded reinforcing steel caused by the use of de-icing salts on highways is the root cause of the problem in many countries. Chloride ions derived from de-icing salts penetrate into concrete and in the presence of oxygen and moisture can cause corrosion. The penetration of **chloride** into concrete occurs via different mechanisms depending on the exposure environment. In order to tackle this problem it is necessary to understand how much quantity chloride ions are passed through concrete.

## III. TESTING ON MATERIAL

Material	Properties	Results	Grade of Mix	Proportion
cement	Specific gravity	3.10	M20	1 : 1.54 : 3.05
	Finess of Cement	3%	M25	1 : 1.4 : 2.65
Coarse aggregate	Specific gravity	2.7	M30	1 : 1.1 : 2.3
	Water absorption	0.7%	M40	1 : 1: 1.99
Fine aggregate	Specific gravity	2.65		
	Fineness modulus	3.16(Zone III)		
Initial setting time	35 minutes			
Final setting time	6 hours			

## IV. RESULTS AND DISCUSSION



Fig. 1. Experimental setup

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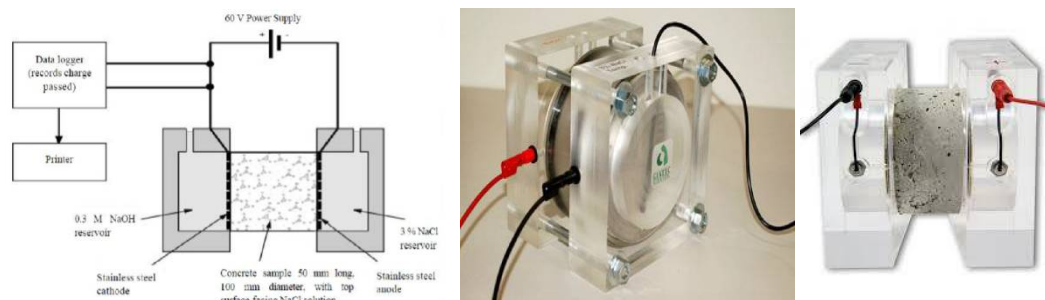


Fig. 2 Block diagram for experiment

The large majority of the work done in this project was conducted on saturated concrete specimens under laboratory conditions. It is realized that many other factors influence resistivity, however it is not within the scope of this project to quantify the impact of these factors. However, once it was found that resistivity could be used as a quality control method, a small-scale study was conducted to determine if the depth of variation in surface saturation, due to natural exposure, was significant enough to impact the resistivity results obtained.

Table 1. Represents various test methods for chloride diffusion method

Test Method	Sample Thickness	Measurement	Test Duration	Precision	Evaluation
Ponding Test	Any	Chloride Profile	Long	Approximate	Penetration Depth, Diffusion Coefficient
Diffusion Cell	Thin	Diffused Cl	Long	Accurate	Diffusion Coefficient
Penetration Depth	Any	Penetration Front	Short	Approximate	Penetration Depth, Diffusion Coefficient
Conductivity	50 mm Any	Current vs Time	Very Short	Approximate	Passed Charges Conductivity

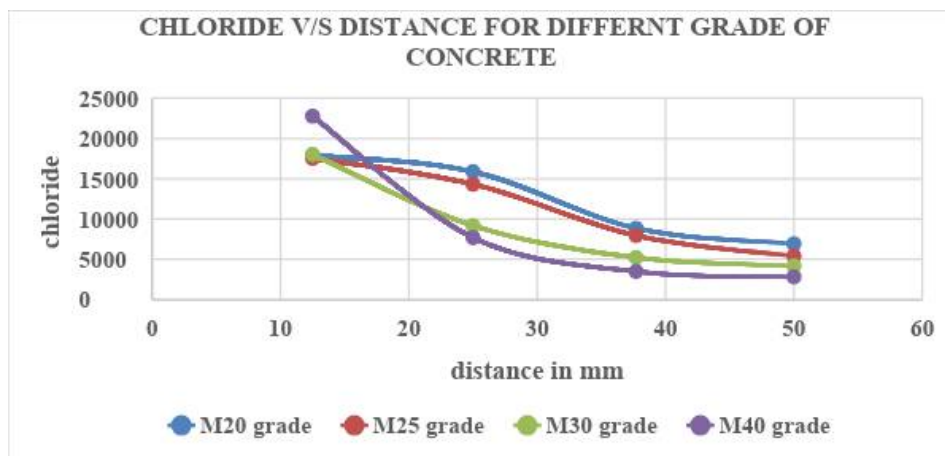


Fig. 4 represents chloride v/s distance for different grade of concrete

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The large majority of the work done in this project was conducted on saturated concrete specimens under laboratory conditions. It is realized that many other factors influence resistivity, however it is not within the scope of this project to quantify the impact of these factors. However, once it was found that It is evident that the chloride ions migrations with different grade where obtained through concrete in cathodic side concentration face higher concentration of chloride than anodic face of concrete this has produced diffusion gradient from cathodic face to anodic face. used as a quality control method, a small-scale study was conducted to determine if the depth of variation in surface saturation, due to natural exposure, was significant enough to impact the resistivity results obtained.

Table 2. Chloride diffusion rate

Grade	Average (NaOH)	Average (NaCl)	Difference In PPM	Duration In sec	Diffusion rate
M20	8486.3	20082.7	11596.4	43200	$5.36 \times 10^{-3}$
M25	8530.7	20771.3	12240.6	43200	$5.66 \times 10^{-3}$
M30	7997.5	22348.6	14351.1	43200	$6.64 \times 10^{-3}$
M40	6375.8	23370.5	16994.7	43200	$7.86 \times 10^{-3}$

With the widespread specification of concrete, it is necessary, for quality control measures, to have a test that gives an indication of the concrete's quality. The currently accepted method is ASTM C 1202 & AASHTO T277 Standard Test method for of Concrete's ability to Chloride Diffusion Method, more commonly known as the Chloride Diffusion Method While its name suggests it, the CDM is anything but rapid. It is for this reason that there is a need for a new rapid test quality control and assurance test. Problem is the need for a rapid test to give an accurate prediction of the chloride diffusion coefficient of concrete. This value is vital in service life prediction of structures. The current method is a long, labour intensive test, and must be performed at several different ages to have confidence in predicting how the diffusion coefficient of that particular concrete will change with time.

Table 3 Rapid chloride penetrability test for ordinary concrete

Grade	Trial I	Trail II	Trail III	RESULTS	Dia other than 95 mm	Penetrability
M20	18586	29067	30959	26204	23649.11	High
M25	28651.27	12805.06	23201.92	21552	19450.68	High
M30	30461.9	36004.1	31644.5	32703.5	29514.90	High
M40	11356.3	1939.48	3946.99	5747	5186.67	High

## IV. CONCLUSIONS

- As seen in the present work the transportation of chloride ion into the concrete is a phenomena 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  $\text{Na}^+$  combined with hydroxyl's ions to form NaOH correspondingly  $\text{Cl}^-$  migrate to anode through the cathode side.
- Migration of  $\text{OH}^-$  ions into to the concrete the deflection of  $\text{OH}^-$  ion at the cathode side reduces the  $\text{p}^{\text{H}}$  at cathodic face of the concrete during diffusion experiment.



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- It is evident that the chloride ions migrations with different grade where obtained through concrete in cathodic side concentration face higher concentration of chloride than anodic face of concrete this has produced diffusion gradient from cathodic face to anodic face.
- The diffusion rate is in order of  $M_{20} 5.36 \times 10^{-3}$ ,  $M_{25} 5.66 \times 10^{-3}$ ,  $M_{30} 6.64 \times 10^{-3}$ ,  $M_{40} 7.86 \times 10^{-3}$  PPM/mm/sec.

We have implemented an chloride diffusion rate technique from experimental work. Our experimental successfully done as per ASTHO T277 standards, the result obtained it as our experimental setup it may varying as AASHTO T277 states that the results of companion Samples tested by the same operator should not vary by more than 19.5%. This is an extremely large variation in allowable results. The ASTM method shows that the results of two properly conducted tests by the same operator on concrete samples from the same batch may differ as much as 42%. On companion samples tested by different laboratories, this percentage is raised to 51%. This large variability in test results indicates the relative inaccuracy of the test method while maintaining that concrete samples which lie within this large acceptable range are essentially equal in quality.

## V. RECOMMENDATION FOR FUTURE WORK

- Different grade of concrete higher than M40, with reinforcement.
- Diffusion coefficient can be determined on the basis of Nernst-planck equation and Ficks law.
- Theoretical analysis of concrete chloride diffusion can be compared with the experimental methods.
- Suitable design coefficient for concrete chloride diffusion can be obtained and incorporated in design of RCC structures in marine environment.
- Chloride diffusion can be studied on reinforced uncrate specimen to study the bond behaviours of reinforced at the interface of concrete.
- It would be beneficial for structural engineers to establish the correlation between equilibrium sorptivity and compressive strength of concrete, allowing the depth of chloride penetration to be predicted using compressive strength of concrete. In order to establish this correlation it is necessary to carry out a comprehensive study on the effect of mix design (e.g. cement type, w-c ratio, cement content, etc.) and exposure condition (e.g. salt solution concentration, temperature, etc.) on this correlation.
- The assumption that 3% or 10% salt solution concentration exposures are representative of field exposure needs to be examined. More data needs to be collected from concretes exposed to different salt solution concentrations in the laboratory and compared with measurements taken from the field.

## VI. ACKNOWLEDGMENT

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