KICEM Journal of Construction Engineering and Project Management
Online ISSN 2233-9582

www.jcepm.org
http://dx.doi.org/10.6106/JCEPM.2017.3.30.026

Experimental Investigation of Chloride Ion Penetration and Reinforcement Corrosion in Reinforced Concrete Member

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ABSTRACT: This paper represents the experimental investigation of chloride penetration into plain concretes and reinforced concretes. The main objective of this work is to study the main influencing parameters affecting corrosion of steel in concrete. Plain cement concrete and reinforced cement concrete with different water-cement ratios and different cover depth were subjected to ponding test. Ponding of specimens were done for different periods into 10% NaCl solution. Depth of penetration of chloride solution into specimens was measured after ponding. Specimens were crushed and reinforcements were washed using HNO_3 solution and weight loss due to corrosion was calculated accordingly. There was a linear relationship between depth of penetration and water-cement ratio. It was also observed that, corrosion of reinforcing steel increases with chloride ponding period and with water-cement ratio. Corrosion of steel in concrete can be minimized by providing good quality concrete and sufficient concrete cover over the reinforcing bars. Water-cement ratio has to be low enough to slow down the penetration of chloride salts into concrete.

Keywords: Water-cement ratio, Cover depth, Chloride ponding test, Reinforcement, Corrosion

I. INTRODUCTION

Reinforced concrete is relatively cheap and available building material. It can be widely applicable and durable if designed and casted in a proper way. For its wide variety of applications, reinforced concrete structures are subjected to a range of exposure conditions, including marine, industrial or other severe environments. Corrosion of steel reinforcement in concrete is the most common problem affecting the durability of reinforced concrete structures, in particular when exposed to such environments where attack of chloride happened.

The service life of reinforced concrete structures is, according to the classic model by [1], divided into two periods: initiation and propagation. Initiation is defined as the period until depassivation of steel is detected. In order to properly design this period, knowledge of the chloride ingress rate and the critical condition for depassivation is necessary. The propagation period on the other hand, requires knowledge of the corrosion rate so as to be able to make predictions concerning the structural integrity. Concrete provides physical and chemical protection to the reinforcing steel from penetrating chlorides. The chloride penetration depends on the permeability of the concrete and the thickness of concrete cover to the reinforcement.

In any case, the presence of air voids at the concrete-steel interface has been found to strongly influence the resistance to chloride induced corrosion [2].

The rate of steel corrosion depends on the availability of water, oxygen, and aggressive ions, as well as the pH and temperature of the surrounding environment and on the internal properties of the steel, such as composition, grain structure and entrained fabrication stresses [3]. Dissolved chloride ions are a big contributor to corrosion in concrete because they impair the passivity of the reinforcement and increase the active corrosion rate of steel. Oxidation is enhanced through the formation of an iron chloride complex, which is subsequently converted to iron oxide and chloride ions, which are then available to combine again with iron in the reinforcement. When corrosion products are deposited, they induce tensile stresses on the surrounding concrete, which cause cracking to occur [4]. Thus, the influence of the binder in concrete, the water-cement ratio and protective concrete cover were investigated in this study to make a model for chloride ion penetration and reinforcement corrosion in reinforced concrete member.

II. THEORETICAL BACKGROUND

Corrosion of reinforcement in concrete occurs as a result of chloride ion penetration and carbonation of the concrete. Poor construction practices and lack of cover enhance the corrosion probabilities [5].

To reduce porosity of concrete it should be designed with lower water-cement ratio so that the compressive strength increased [6].

To test the effects of water-cement ratio and concrete cover on corrosion loss of reinforcing steel due to chloride penetration, test of chloride penetration was done in laboratory.

According to [7] test is commonly referred to as the salt ponding test. In these test specimens of three slabs of at least 75 mm thick and surface area of 300 mm square

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are tested. These slabs are moist cured for 14 days; then stored in a drying room at 50 percent relative humidity for 28 days. The sides of the slabs are sealed except the bottom and top face. After the conditioning period, a 3 percent NaCl solution is ponded on the top surface for 90 days, while the bottom face is left exposed to the drying environment. At the end of this time the slabs are removed from the drying environment and the chloride concentration of 0.5-inch thick slices is then determined [7].

Bulk Diffusion Test (NordTest NTBuild 443) [8], is the method of immersion of concrete specimen into chloride solution (2.8 M) for 35 days, and finally fit the chloride profile.

For experimental need a modified salt ponding test was done in laboratory, where specimens were made of 75 mm diameter with 150 mm height cylinder, which were of different size than [7] test specimens. Concentration of NaCl was kept 10% throughout the test instead of 3%. Specimens were subjected to immersion in NaCl solution for 30 days, 60 days and 90 days successively.

III. Experimental Procedure

A. Materials Selection & Specimen Preparation

The coarse aggregates used in specimen were maximum 20 mm size crushed gravel. River sand (coarse sand) and Ordinary Portland Cement (OPC) were used. Five water-cement ratios (0.40, 0.45, 0.50, 0.55 and 0.60) were used in each series. All mixes were designed to achieve compressive strength of 25 MPa. For each mix, 3 specimens (75 mm diameter with 150 mm height) were casted without reinforcement, cured in water for 28 days and compressive strength of those specimens was tested according to [9]. The mixing proportion and physical properties of concrete used in this test are shown in Table I.

For each mix a number of cylindrical specimens (75 mm diameter with 150 mm height) were casted placing reinforcement at different concrete cover depth (10 mm, 20mm and 30mm). These specimens were also cured in water for 28 days and dried into sun and then prepared for salt ponding test.

TABLE I
PHYSICAL PROPERTIES OF CONCRETE

W/C ratio	Cement Kg	Water Kg	Sand Kg	Crushed Gravel Kg	Average Compressive Strength, MPa
0.40	461.25	184.5	582	1204	42.95
0.45	410.00	184.5	598	1230	38.5
0.50	369.00	184.5	608.13	1253.45	32.3
0.55	335.45	184.5	617.5	1269.5	28.7
0.60	307.5	184.5	623.79	1287.9	25.1

B. Salt Ponding Test

After curing in water for 28 days, all specimens were dried in air and lateral surfaces of specimens were coated with epoxy and allowed to harden for 24 hr as shown in Figure I. Then the specimens were subjected to continuous ponding with 10% NaCl solution for 30 days, 60 days and 90 days. Because of sealing of all lateral surface and bottom of cylindrical specimens, penetration of salt into specimens occurred only from top surface.

C. Determination of Depth of Salt Penetration

After 30 days some of specimens were taken out from salt ponding reservoir and sliced into two pieces vertically. Then 0.05N $AgNO_3$ solution was sprayed over the slices and recorded the depth of penetration of salt by noticing white AgCl product as shown in Figure II. Similar process was done after 60 and 90 days salt ponding of other specimens successively. This process is known as colorimetric process ([10], [11]) which is less time consuming and simpler than other methods.

FIGURE I
Preparation of Specimen for Salt Ponding

FIGURE II
Measurement of Depth of Chloride Penetration

D. Determination of Weight Loss of Steel

After determining the salt penetration depth, specimens were broken and the reinforcements were taken out separately. Then all the rods were placed in the solution of HNO3 to remove loose rust particles. The rods were placed in the solution for 5 minutes and were taken out, cleaned and wiped. The weight of rods were determined to estimate the weight loss in reinforcing steel rods and are given in Table II, Table III and Table IV.

TABLE II
30 Days Salt Ponding Test Results

W/C Ratio	Clear Cover of Steel	Average Depth of Chloride Penetration	Average Weight loss of Steel
	mm	mm	%
0.40	10	12.5	0.072
0.45	10	13.0	0.087
0.50	10	14	0.089
0.55	10	15.5	0.091
0.60	10	17	0.094

TABLE III
60 Days Salt Ponding Test Results

W/C Ratio	Clear Cover of Steel	Average Depth of Chloride Penetration	Average Weight loss of Steel
	mm	mm	%
0.40	10	23	0.084
	20	24	0.068
0.45	10	25	0.094
	20	25	0.076
0.50	10	27	0.098
	20	27	0.085
0.55	10	30	0.11
	20	30	0.089
0.60	10	31	0.12
	20	31	0.096

TABLE IV
90 Days Salt Ponding Test Results

W/C Ratio	Clear Cover of Steel	Average Depth of Chloride Penetration	Average Weight loss of Steel
	mm	mm	%
0.40	10	35	0.115
	20	35	0.094
	30	35	0.076
0.45	10	35	0.124
	20	36	0.098
	30	36	0.086
0.50	10	35	0.132
	20	37	0.103
	30	36	0.089
0.55	10	36	0.137
	20	37	0.108
	30	37	0.093
0.60	10	38	0.141
	20	38	0.118
	30	38	0.107

IV. RESULTS AND DISCUSSIO

1. Chloride Penetration in Relation with Water-Cement Ratio:

Concrete is a porous material as a result of the cement hydration and the pore structure dependent on several factors such as the water-cement ratio or curing temperature [12]. Porosity of concrete increased with increasing water-cement ratio and simultaneously, more chloride penetration occurred into specimen. In this experiment for 0.1 increases in water-cement ratio, minimum 1mm more penetration of chloride solution occurred. In some cases penetration increased by 2 mm to 3 mm also. Therefore there is a linear relation between water-cement ratio and chloride penetration. The relations are shown in figure III.

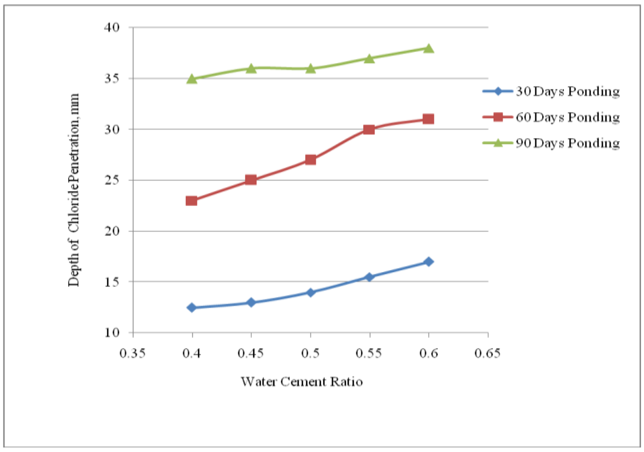

FIGURE III
Depth of Chloride Penetration with W/C Ratio

2. Corrosion Losses with Water-Cement Ratio of Concrete:

Concrete is protecting cover of steel reinforcements. Chloride solution reaches rapidly to steel reinforcement for high water-cement ratio concrete than low ones. More losses in reinforcement will occur for more contact with chloride. It is also observed that, high concentration of chloride penetration occur for high water-cement ratio concrete. In conclusion, for high water-cement ratio concrete, more corrosion loss was found. These relations are shown in figure IV.

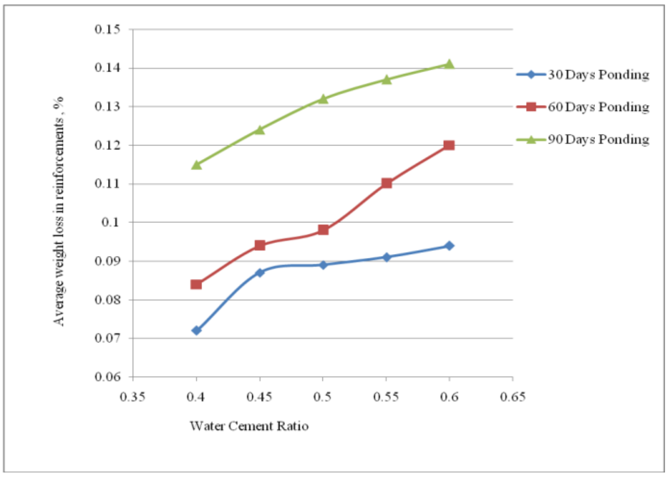

FIGURE IV
Weight Loss in Steel Reinforcement with W/C Ratio
(Clear Cover 10 mm)

3. Corrosion Losses with Concrete Cover of Reinforcing Steel:

Concrete cover in reinforced concrete structure is needed to protect reinforcing steel from adverse environment. In this experiment it is observed that, more corrosion loss occur for smaller concrete cover. When protective cover depth increased, low concentration chloride solution could reach to steel and take more time to produce corrosion. These relations can be described by figure V.

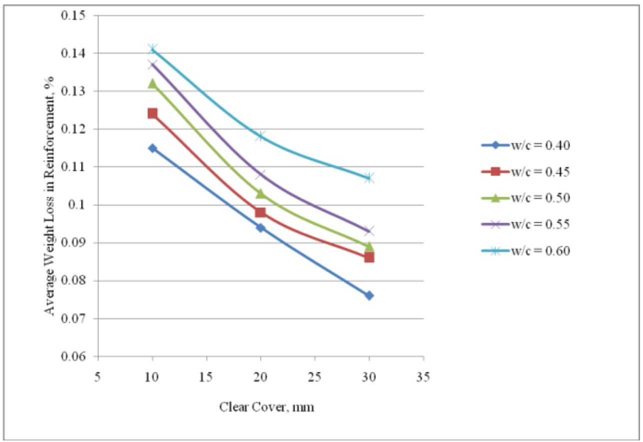

FIGURE V
Weight Loss in Steel Reinforcement with Concrete Clear Cover (90 Days Salt Ponding test)

V. CONCLUSIONS

This study describes general concepts on penetration of chloride and corrosion of reinforcement in concrete member. By studying the controlling parameter in this experimental study the following conclusions can be drawn:

1. Chloride penetration increases with increase in water-cement ratio in concrete. Chloride spread over more distances for high water-cement ratio concrete.
2. Water-cement ratio influences the compressive strength of concrete. Lower water-cement ratio in concrete possesses higher compressive strength.
3. High strength concrete permits less penetration of salts.
4. Corrosion losses in steel reinforcements increase with water content in concrete. Water-cement ratio is influencing factor to corrosion control in reinforcement.
5. Larger concrete covers give more protection of reinforcement from chloride corrosion.
6. More contact with chloride causes more corrosion losses.

ACKNOWLEDGMENT

The experimental work was carried out in Rajshahi University of Engineering & Technology, Bangladesh. The authors are highly grateful to the Management, Secretary, Head of the Department and Faculty Members of Civil Engineering for the facilities provided and co-operation rendered.

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