Influence of microbiologically induced corrosion of steel embedded in ordinary Portland cement and Portland pozzolona cement

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Abstract

Purpose – The acceleration of corrosion of rebars in concrete are due to several reasons such as carbonation, chloride attack, influence of microorganisms, etc. The aim of this investigation mainly focused on how the microorganism was involved in the corrosion process and thereby affect a mechanical property of mortar and accelerate the corrosion of steel in mortar. ordinary portland cement (OPC) and portland pozzolona cement (PPC) was used for making mortar specimens. Sodium citrate was used as an inhibitor for the corrosion of steel in mortar.

Design/methodology/approach – Compressive strength measurements were conducted for mortar at different ages in the presence of microorganisms to understand the mechanical property of mortar. Potential-time behavior studies were carried out to determine the status of rebars inside the mortar. Weight loss measurements were adopted to quantify the corrosion level due to microorganisms. The microbial count in the water samples at the initial and final exposure period was also examined.

Findings – All these studies showed that additions of sodium citrate level of greater than 1 percent by weight of OPC and PPC severely affected both the mechanical and the corrosion resistance properties of OPC and PPC. Microbiological examination reveals that bacteria consume citrates for their survival and thereby increasing the permeability of mortar specimens.

Originality/value – Generally, citrates are considered as being good corrosion inhibitor for steel in concrete. However, results from the present study indicated that sodium citrate concentrations only of less than 1 percent by weight of OPC and PPC are suitable for use in concretes that are exposed to heterotrophic bacterial environments.

Keywords Portland cement, Corrosion, Bacteria

Paper type Research paper

1. Introduction

The term microbiologically influenced corrosion (MIC) is usually interpreted as to indicate an increase in corrosion activity due to the presence of bacteria (Nagiub and Mansfeld, 2002). MIC can occur in any aqueous environment and it is now-a-days a commonly occurring phenomenon because of the omnipresent nature of microbes, adequate nutrients and by-products in today's industrial and municipal process (Stott, 1993; Sanchez Del Junco *et al.*, 1992). A number of recently developed techniques, which may be used for rapid quantification of total microbial activity or of specific microorganisms involved in corrosion, were reviewed by Gaylarde (1990). The relationship between microbial metabolic activity and bio-corrosion of carbon steel was reported (Dzierzewicz *et al.*, 1997). A number of metals such as structural steels, mild carbon steels, ductile iron, etc., are prone to corrode on the entire surface in the absence of crevices or galvanic effects. On the other hand, MIC is caused by localized corrosion because most organisms do not form in a continuous film on the metal surface and the mechanism for MIC of steel and iron was proposed (Pope and Morris, 1995). The heterotrophic bacteria and fungi microorganisms are present in their environments are responsible for initiating the bio-deterioration process of the concrete (Nica *et al.*, 2000; Roberts *et al.*, 2002). Heterotrophic bacteria cannot make its own food and is therefore wholly depends on other substances for nutrition. All animals and humans are considering its heterotrophs because they need to eat other plants and animals in order to survive. Bacteria and yeast are also heterotrophs, as they are unable to make the nutrients need to live and grow. Hence, the protection of concrete structures

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against MIC has therefore become very critical in many industries including marine, municipal, storage vessels and sewage treatment plants. All the works focused on the influence of heterotrophic bacteria on the direct attack on the metal surface. The present investigation deals with the systematic studies on the role of heterotrophic bacteria on the strength property of mortar and the corrosion of steel embedded in mortar made by using two types of cements namely ordinary portland cement (OPC) and portland pozzolona cement (PPC). Studies also were carried out to understand the influence of bacteria on the mortar specimens admixed with various sodium citrate levels.

2. Experimental procedure

2.1 Materials used

OPC : 43 Grade OPC – IS 8112

PPC: IS-1489 (Part-1)

Graded fine aggregates: Local clean river sand (fineness modulus of medium sand of 2.6) conforming to grading zone III of IS-383-1970 was used as fine aggregates.

2.2 Methodology

2.2.1 Compressive strength measurements

Mortar cube specimens of size 10 × 10 × 10 cm were cast using OPC and PPC containing 0, 0.5, 1, 1.5, 2 and 2.5 percent premixed sodium citrates. Mortar specimens were prepared using 1 : 1 and 1 : 3 mixes with a water cement ratio of 0.45. The specimens were vibrated mechanically to assist compaction. After 24 h of setting, the specimens were demoulded and cured for 28 days in distilled water in order to avoid any contamination. After the curing period was over, the specimens were immersed in heterotrophic bacteria for 120 days. The pond water containing heterotrophic bacteria was collected from nearby place. The compressive strength was measured at the age of 28 and 90 days by using AIMIL compressive strength testing machine. Triplicate specimens were cast and the average compressive strengths were reported (Saraswathy *et al.*, 2003).

2.2.2 Open circuit potential measurements

The Open Circuit Potentials (OCPs) for the different systems were periodically monitored using a voltmeter with a high input impedance of 10 MΩ. A saturated calomel electrode (SCE) was used as the reference. The positive terminal of the voltmeter was connected to the working electrode i.e. CTD rods. The common terminal was connected to the reference electrode. The corresponding potentials were recorded. The OCPs for all of the specimens were monitored over an exposure period of 120 days. In this study, triplicate specimens were used for each system and the average of these values were reported and interpreted based on ASTM C-876-1994.

2.2.3 Weight loss measurements

Cylindrical mortar specimens of size 55 mm diameter and 60 mm height were cast using OPC and PPC containing 0, 0.5, 1, 1.5, 2 and 2.5 percent premixed citrates. CTD rebar of 8 mm diameter and 35 mm long was embedded centrally. Initially, the CTD rebar samples were cleaned in acid solution as follows. HCl: 100 percent; $SnCl_2$: 35 gpl; Sb_2O_3: 25 gpl, washed with water, degreased with acetone, washed with double-distilled water and dried. The initial weight of rebar sample was taken before casting for gravimetric weight loss measurements. Mortar specimens were prepared as described previously. At the end of the exposure period, the concrete specimens were split open and the corrosion rate of CTD anodes embedded in control and specimens containing various percentage of citrates were measured by gravimetric weight loss method and expressed in millimeter per year (mmpy) (Saraswathy *et al.*, 2000).

2.2.4 Microbiological examination

The heterotrophic plate count (HPC) is a procedure used to estimate the number of live heterotrophic bacteria that are present in a water sample. A sample of water is put on a plate that contains nutrients that the bacteria need to survive and grow. The nutrient media that most often used for this test is called R2A Agar, which is a gelatin-like substance that is best suited to the needs of water bacteria. After 5-7 days, the number of small spots on the plate, called colonies, is counted, and a measure of how many bacteria are present in each milliliter of water can be determined. The HPC results generally are reported as CFU/ml (colony forming units per milliliter). Each CFU represents an initial single, live bacterium that was capable of multiplying until it could be observed on the plate.

3. Results

3.1 Compressive strength measurements

The compressive strength data for 1 : 1 OPC and PPC mortar specimens after 28 and 90 days of curing in inoculation with heterotrophic bacteria are given in Table I. Mortar specimens were made with different percentages of sodium citrate ranging from 0.5 to 2.5 percent by weight of cement. The compressive strength for plain OPC after 28 and 90 days of curing was found to be 23 and 30 MPa, respectively. Similarly, the compressive strength for PPC plain was found to be 27 MPa and 38 MPa, respectively, after 28 and 90 days of curing. It can be observed from the Table I that for plain OPC, the compressive strength had increased after 90 days of curing. However, the addition of citrate up to 1.0 percent did not affect the compressive strength values, though for greater concentrations the compressive strength values decreased. The same observation was noticed in the PPC system also. Table II present the data for 1 : 3 OPC and PPC mortar specimens after 28 and 90 days of curing in heterotrophic bacteria. As observed previously, additions of citrate of greater than 1.0 percent resulted in a decrease in the compressive strength values of both OPC and PPC specimens. It can be observed from the compressive strength measurements that, in both OPC and PPC, the average compressive strength at both ages was inversely proportional to the percentage of admixed citrate.

3.2 Potential-time behavior studies

Figures 1-4 relate the potential-time behavior of CTD rebars embedded in 1 : 1 and 1 : 3 ratio for OPC and PPC mortars immersed in heterotrophic bacteria. The OCP was monitored continuously for 120 days of exposure. The OPC and PPC control specimen showed OCP values less than − 275 mV vs SCE throughout the exposure period, indicating that the rebars were in a passive condition. The addition of up to citrate 1.0 percent resulted in potential measurements of less than − 275 mV up to 90 days of exposure. On the other hand, the sodium citrate levels namely 1.5, 2.0 and 2.5 percent shifted the OCP values in a more negative direction even after

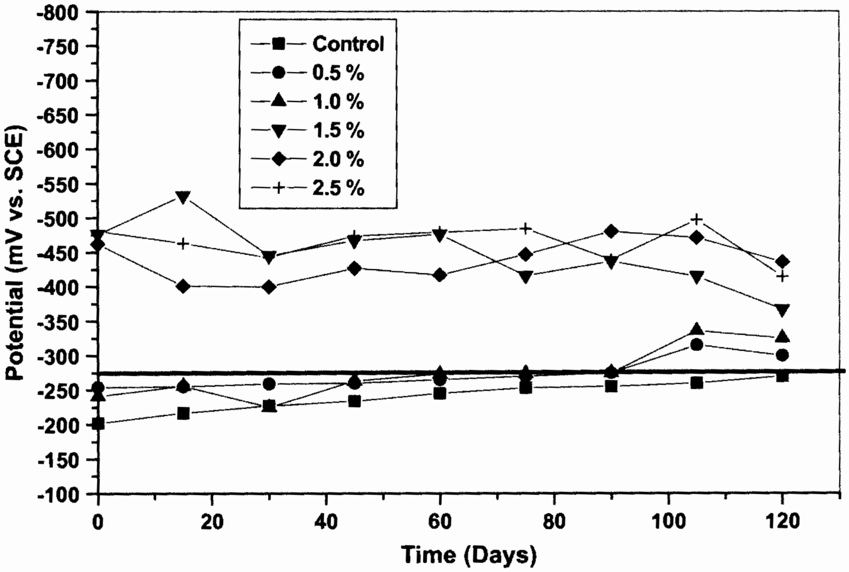
Table I Compressive strength data for 1 : 1 OPC and PPC mortar specimens after 28 and 90 days of curing in inoculation with heterotrophic bacteria

		OPC		PPC	
Sl. No	System (percent)	Compressive strength (MPa) at 28 days	Compressive strength (MPa) at 90 days	Compressive strength (MPa) at 28 days	Compressive strength (MPa) at 90 days
1	0	23	30	27	38
2	0.5	13	25	21	30
3	1.0	10	20	13	24
4	1.5	7	12	5	12
5	2.0	5	7	5	10
6	2.5	4	5	4	9

Table II Compressive strength data for 1 : 3 OPC and PPC mortar specimens after 28 days and 90 days of curing in inoculation with heterotrophic bacteria

		OPC		PPC	
Sl. No	System (percent)	Compressive strength (MPa) at 28 days	Compressive strength (MPa) at 90 days	Compressive strength (MPa) at 28 days	Compressive strength (MPa) at 90 days
1	0	23	28	21	31
2	0.5	18	20	18	21
3	1.0	14	18	6	17
4	1.5	9	12	5	12
5	2.0	4	6	4	5
6	2.5	3	5	4	2

Figure 1 Potential-time behavior of CTD rebars embedded in 1 : 1 OPC mortar



only 10 days of exposure indicating the active condition of rebars. This behavior was observed with both types of cements.

3.3 Weight loss measurements

The corrosion rate of rebars embedded in mortars made with OPC and PPC, with 0.5, 1.0, 1.5, 2.0 and 2.5 percent citrate levels are reported in Table III. From this table it can be observed that steel embedded in OPC and PPC showed a corrosion rate of 0.0014 and 0.0012 mmpy, respectively. Systems that showed less than 0.0014 mmpy for OPC and 0.0012 mmpy for PPC may be considered an improvement in the corrosion resistant properties of the steel. Addition of up to 1 percent citrate resulted in corrosion rate that were lower than had been the case for OPC and PPC (plain). For concentrations of greater than 1.0 percent, there was an increase in corrosion rate, compared to the situation for both untreated systems.

3.4 Microbiological examination

The enumeration of citrate bacteria in the OPC and PPC systems are shown in Table IV. The bacterial counts were

Figure 2 Potential-time behavior of CTD rebars embedded in 1 : 3 OPC mortar

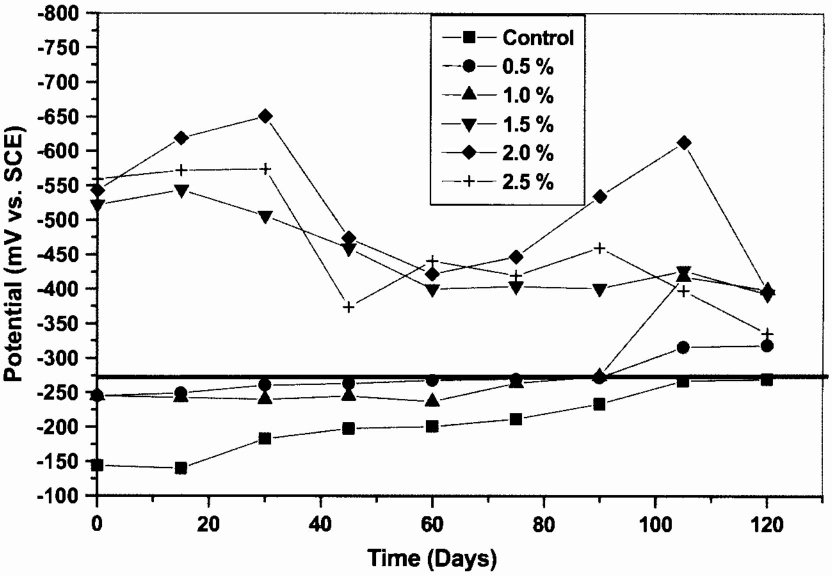
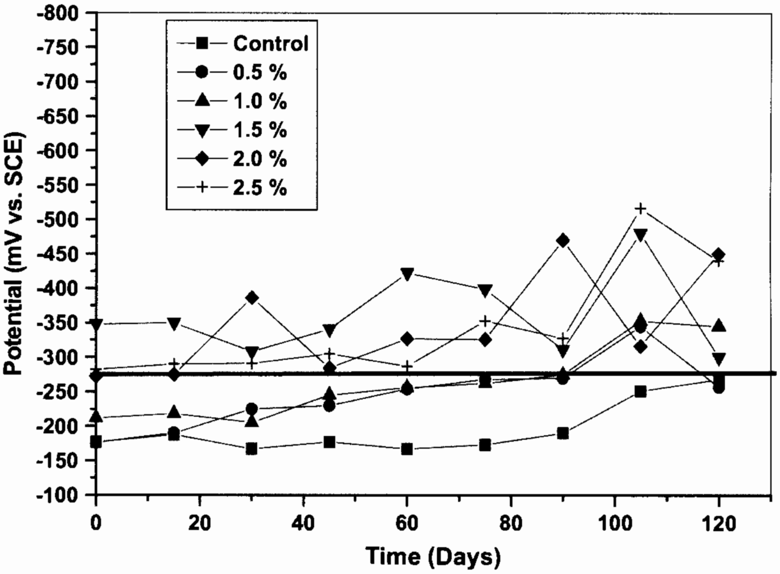


Figure 3 Potential-time behavior of CTD rebars embedded in 1 : 1 PPC mortar



carried out at the initial and final exposure points. From this table it can be understood that bacterial counts have increased by the end of the exposure period. This type of bacteria utilize sodium citrates as a nutrient source, thereby affecting the both strength and corrosion performance of both OPC and PPC.

4. Discussion

4.1 Compressive strength measurements

It can be observed from data presented in Tables I and II that for plain OPC and PPC the compressive strength of the samples had increased after 90 days of curing. However, the addition of up to 1 percent of sodium citrate did not affect compressive strength values. With additions of greater than 1.0 percent of sodium citrate, the compressive strength values were decreased in both mix ratios (1 : 1 and 1 : 3) in OPC and PPC. This may be to the fact that bacteria may consume sodium citrate in the mortar and thereby the permeability may be increased.

4.2 Potential-time behavior studies

Potential-time behavior studies indicated that with less than 1.0 percent sodium citrate additions, the steel rebars were in passive condition, and corrosion potentials of less than − 275 mV were observed up to 90 days of exposure. However, with sodium citrate additions of greater than 1.0 percent, the steel rebars were actively corroding. The results indicated that sodium citrate levels of less than 1.0 percent were suitable for concrete wherever it can be exposed to the heterotropic

Figure 4 Potential-time behavior of CTD rebars embedded in 1 : 3 PPC mortar

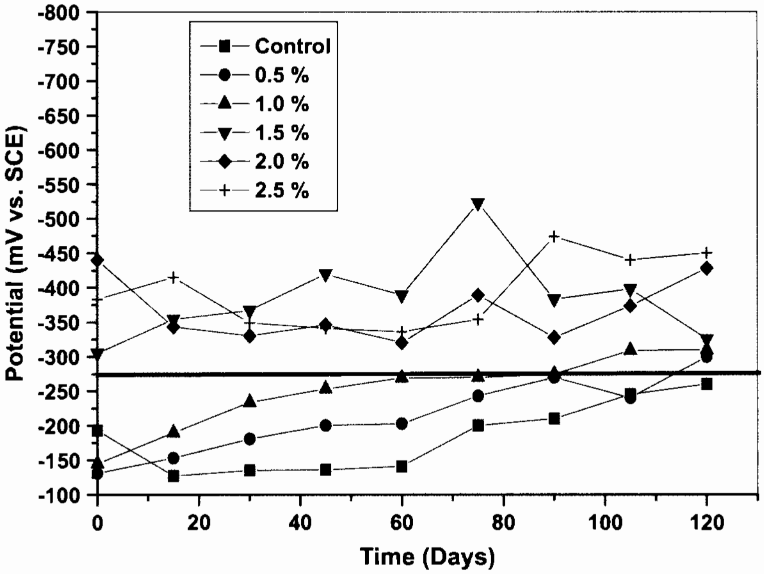


Table III Corrosion rate data for steel embedded in 1 : 3 OPC and PPC mortar specimens inoculation with heterotrophic bacteria

Sl. No	System (percent)	Corrosion rate (mmpy) OPC	 PPC
1	0	0.0014	0.0012
2	0.5	0.0012	0.0011
3	1.0	0.0012	0.0011
4	1.5	0.0017	0.0014
5	2.0	0.0024	0.0020
6	2.5	0.0030	0.0028

Table IV Microbiological counts for OPC and PPC mortar specimens

Enumeration of bacteria in OPC system (CFU/ml)				
System	10^{-2}	10^{-4}	10^{-6}	10^{-8}
OPC (Initial)	TNTC	TNTC	170	100
OPC (Final)	TNTC	TNTC	200	130
Enumeration of bacteria in PPC system (CFU/ml)				
PPC (Initial)	TNTC	TNTC	200	150
PPC (Final)	TNTC	TNTC	231	180
TNTC	Too numerous to count			

bacteria because where sodium citrate concentrations exceeded 1 percent the bacteria were able to utilize the citrate as a nutrient source. In addition, at higher citrate levels the permeability of the mortar also increased. As the permeability of a mortar increases, the diffusion of more chloride ions will allow the rebars to enter the more active region and the passivity of the film is lost.

4.3 Weight loss measurements

Gravimetric weight loss measurements showed that comparable corrosion rate with OPC and PPC were observed with less than 1.0 percent sodium citrate additions. Additions of citrate of less than 1.0 percent gave corrosion rates that were lower than were obtained for untreated OPC and PPC. At concentrations of greater than 1.0 percent, an increase in corrosion rate was observed compared to both plain systems. This interesting observation was due to the fact that, in the case of 1.5, 2 and 2.5 percent additions, the permeability of concrete increased. The same behavior was evident in potential-time behavior studies.

4.4 Microbiological examinations

Enumeration of the citrate bacteria in the OPC and PPC samples showed that there was an increase in the bacterial count at the end of the exposure period. This may be due to the fact that, this type of bacteria can use sodium citrates as a nutrient source, thereby affecting the both strength and the corrosion performance of both OPC and PPC.

5. Conclusions

The following conclusions were drawn from the present investigation:

1. Additions of sodium citrate of greater than 1 percent by weight of cement severely affected both the mechanical and the corrosion resistance properties of OPC and PPC. This was due to the fact that the bacteria consume citrates in the mortar and thereby the permeability of the mortar can be increased.
2. Potential-time behavior studies indicated that with additions of less than 1 percent sodium citrate, the steel rebar was in a passive condition, but for concentrations of greater than 1 percent sodium citrate, the steel rebar was in an active condition.
3. Weight loss measurements showed that comparable corrosion rates with OPC and PPC (plain) were observed only for citrate additions of less than 1 percent sodium citrate.
4. Microbiological data showed an increase in the counts of heterotrophic bacteria at the end of the exposure period.
5. In the past, citrates were considered to be good corrosion inhibitors for steel in concrete. However, the present

results indicated that additions of less than 1 percent of sodium citrate by weight of OPC and PPC are suitable for those concretes exposed to heterotrophic bacterial environments.

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