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RESEARCH ARTICLE

Role of Chloride on Corrosion of Carbon Steel Reinforcing Bar in Simulate Concrete Electrolyte

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Abstract

It is well known that chloride ion plays an important role in the destruction of various kinds of concrete structures such as bridges of buildings and reservoirs because of the corrosion of carbon steel reinforcement bar, causing huge human and material damages. In this study, the effect of saline conditions on carbon steel reinforcement was investigated artificial concrete solution in a range of sodium chloride concentrations from 0.5 to 4.5% and at temperatures of 20°C to 50°C. Three electrodes potentiostat was used to measure the corrosion rate and the probability of pitting corrosion through Tafel and cyclic polarization plots respectively. The measurements were supported using other techniques; atomic force microscopy and optical light microscopy. The results showed an increase in corrosion rates of the carbon steel reinforcing bar at all chloride ion concentrations, and increased with increasing the concentration and the temperature, all chloride concentrations showed susceptibility to pitting corrosion and highly depend on NaCl continents.

Keyword: *Reinforcing bar, Pitting, Artificial concrete solution.*

Introduction

In spite of that concrete itself has a very high alkalinity and produce a very thin passive film which limits the metal loss from the carbon steel surface, corrosion of carbon steel reinforcing bar is the major cause of destruction of concrete structures [1-3]. It is well known that chloride, carbon dioxide and other causing agents, the steel protective passive layer is locally destroyed and unprotected steel areas dissolve and will corrode faster [4-6].

The carbon steel rebar inside reinforce concrete structures is susceptible to corrosion when permeation of chloride from environments such as; deicing salts or seawater results in the chloride content at the surface of the steel exceeding a chloride threshold level[7, 8].This work is focuses on examine the effect of increasing the concentration of chloride ion on the rate of corrosion of steel rebar, its dependency on temperature, the possibility of pitting corrosion, and the effect of concentration on the size of pits volume.

Materials and Methods

The chemical composition of the carbon steel reinforcing bar(CSRB) which are used in this study is presented in Table 1, have been determined by the manufacturers.

Table 1: Chemical composition of Iraq CS and Ukraine Bars

RSB Type	C	S	Si	N	Cu	Mn	Ni	Cr
Ukraine	0.26	0.031	0.28	0.010	0.28	0.73	0.13	0.12

The first step of the corrosion measurement procedure is the preparation of CSRB, it was pickled with concentrated HCl (37%, Fluka/ Switzerland), then rinsed with running water and rinsed with ethanol and dried well, the bar was then covered with adhesive tape except for a known distance which is (16.55cm^2), Fig. (1).

Fig.1: Show reinforcement bar used in work

And put them in a the three electrode cell and serve as working electrode, the Pt-electrode serve as counter electrode, and Ag/AgCl as references electrode, as shown in Fig. (2).

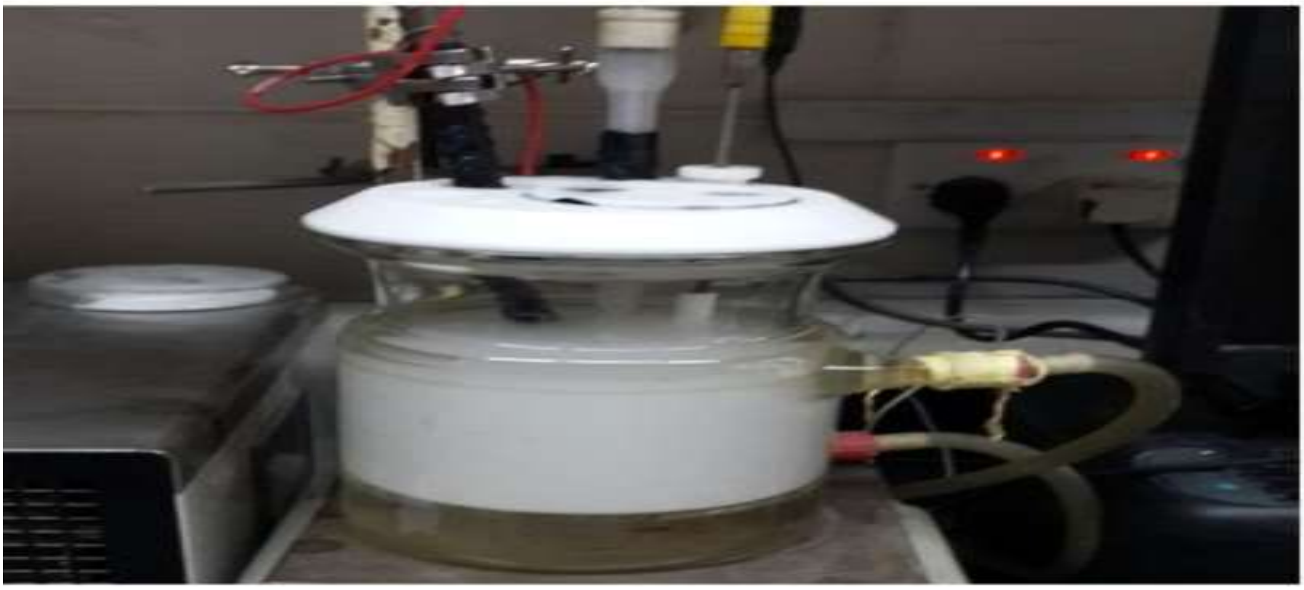

Fig. 2: The electrochemical cell for corrosion measurement of carbon steel reinforcing bar in simulates concrete solution

The open circuit potential (OCP) was measured and then the CSRB was polarized in the simulate concrete solution ($Ca(OH)_2$ (2gm), KOH (22.44mg), NaOH (8mg) in 1L of distill water) than added NaCl in different concentration (0.5%, 1.5%, 2.5%, 3.5%, 4.5%).

After that, Tafel plots were recorded for corrosion rate measurement by scanning the potentials ±200mv around the OCP with a rate of 2mv/sec. The same procedure repeated at four temperatures; 20, 30, 40, and 50^{o}C. The cyclic polarization conducted at 20^{o}C starting from few millivolts lower than OCP going up to about 1000mv.The change in the microstructure and morphology of the surface followed by optical microscope (Nikon Eclipse ME 600, Japan) and atomic force microscope (SPM AA3000, Angstrom Advanced Inc., USA) respectively.

Results and Discussion

Fig. (3) Shows Tafel plots of carbon steel reinforcing bar (CSRB) in artificial concrete solution (ACS) without and with different chloride concentrations at different temperature.

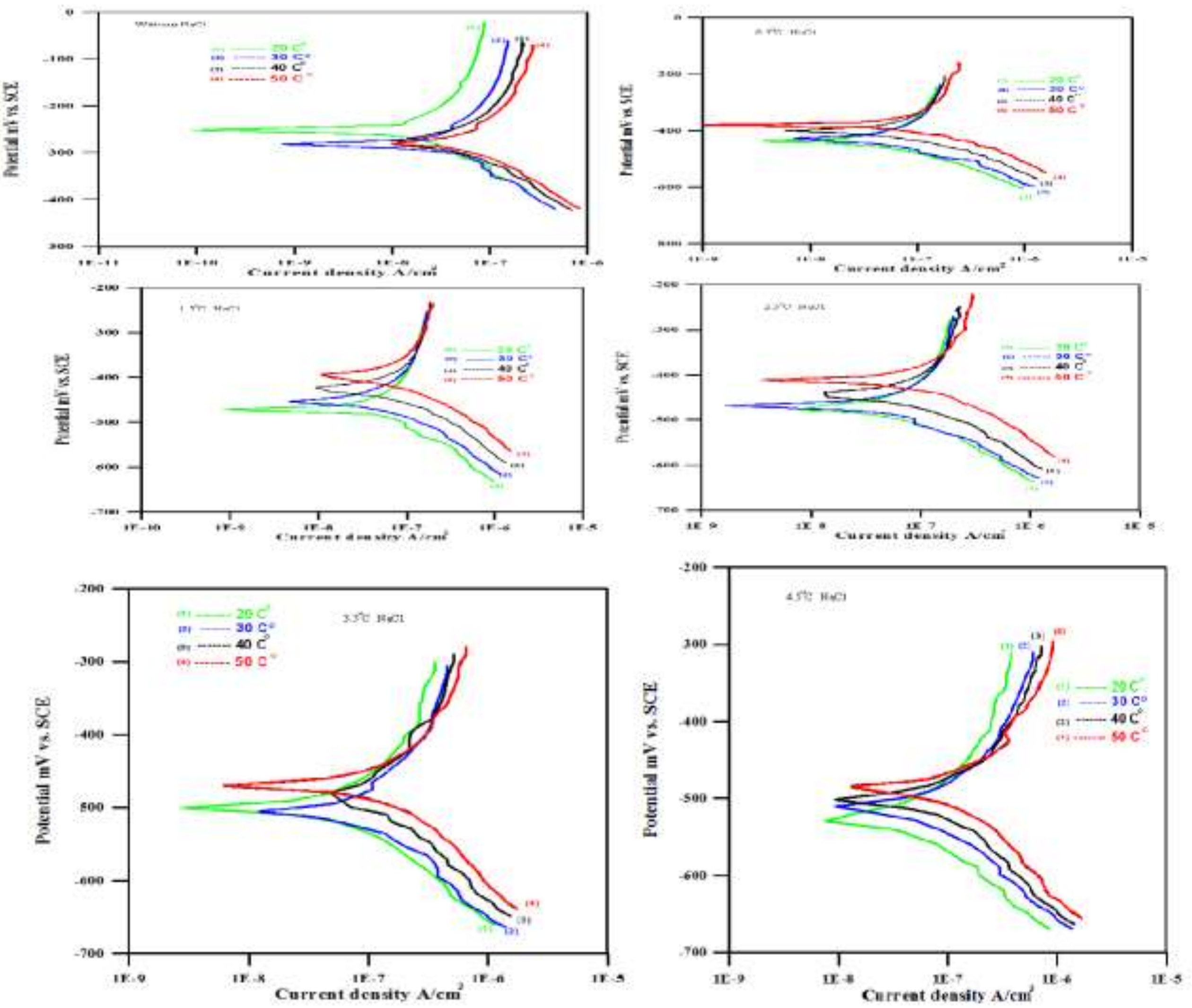

Fig. 3: Tafel plots of carbon steel reinforcing bar in artificial concrete solution containing different NaCl concentration at 20, 30, 40, and 50°C.

From these Tafel plots the corrosion current density (i_{corr}), corrosion potential (E_{corr}), anodic Tafel slopes (βa) and cathodic Tafel slopes (βc) were estimated and then used to calculate the polarization resistance (Rp) using Eq. (7) [9] the corrosion rate as which is often converted into Faradaic corrosion rate having units of (mm/y).

$$\frac{\Delta E}{\Delta i}(Rp) = \frac{\beta a \beta c}{2.303\,(icorr)\,(\beta a+\beta c)} \quad (7)$$

All corrosion parameters are tabulated in Table 2, the corrosion rates of the CSRB in ACS without NaCl reflected small values (0.28- 0.71mm/y) which attributed to the inert immunity of the concrete solution due to high pH value [10], sparingly increasing occurs when the temperature increased up to 50°C.

Table2: Corrosion rate parameters of Ukraine CSRB in chloride containing simulated concrete solution at 20, 30, 40, 50°C

NaCl %	T(K)	E_{corr} (mV)	i_{corr} (*10^{-6}/cm²)	βc (mV/Dec)	βa (mV/Dec)	Rp (Ω.cm²)	CR(WL)* $g.m^{-2}d^{-1}$	CR(PL)** mmpy
0	293	-340.3	24.20	-121.8	137.1	677.75	6.05	0.281
	303	-379.6	31.47	-129.4	176.8	1020.90	7.87	0.365
	313	-421.1	39.04	-89.8	166.6	989.12	9.76	0.453
	323	-393.2	61.45	-82.7	186.4	1528.50	15.40	0.713
0.5	293	-437.7	29.66	-80.9	149.4	675.89	7.41	0.344
	303	-430.0	37.30	-95.1	161.5	969.41	9.32	0.433
	313	-394.7	47.40	-102.3	173.7	1325.10	11.8	0.55
	323	-369.5	71.67	-113.9	217.5	2326.34	17.9	0.832
	293	-469.1	39.04	-99.3	190.5	1106.52	9.76	0.453
	303	-447.3	41.36	-98.7	174.1	1131.24	10.3	0.48

1.5	313	-416.8	64.94	-123.2	257.2	2348.87	16.2	0.754
	323	-394.4	75.79	-117.4	300.1	2777.12	18.9	0.88
2.5	293	-473.0	42.35	-94.4	172.0	1120.79	10.6	0.492
	303	-471.5	45.10	-101.7	175.9	1261.97	11.3	0.523
	313	-432.9	73.48	-135.9	228.0	2716.73	18.4	0.853
	323	-409.4	78.24	-103.7	187.9	2270.14	19.6	0.908
3.5	293	-502.9	47.02	-96.2	143.7	1176.49	11.8	0.546
	303	-503.8	54.75	-86.4	127.7	1225.12	7.13	0.635
	313	-481.4	75.69	-108.9	141.4	2021.90	9.18	0.879
	323	-471.9	86.83	-92.2	131.9	2046.02	7.21	1.01
4.5	293	-535.7	55.12	-115.1	198.1	1742.42	13.8	0.640
	303	-510.2	69.61	-131.4	139.0	2041.65	4.17	0.808
	313	-506.9	97.65	-142.0	178.0	3349.16	4.24	1.13
	323	-496.7	100.38	-113.0	157.7	2869.29	1.25	1.17

*WL: weight loss, **PL: penetration loss

The calculated Rp increased with increasing NaCl concentration which highly supported the formation of nonconductive oxide rust products[11] rather than chlorides on the CSRB surface; the mechanism of chloride attack to CSRB can be described by the primary action in chloride attack is the corrosion of CSRB and consequently damage to surrounding concrete. As long as the oxide film on steel is present, the steel remains intact Chloride ions destroy the film and in presence of water and oxygen corrosion occurs [12, 13].In this situation the surface of the steel acts as anode and the passive surface coating acts as cathode, the chemical reaction may be as follows:

$$\mathbf{Fe^{+2} + 2\,Cl^- \longrightarrow FeCl_2} \quad (8)$$

$$\mathbf{FeCl_2 + 2H_2O \longrightarrow Fe\,(OH)_2 + 2HCl} \quad (9)$$

So Cl^- is regenerated. The other reactions, especially the cathodic reaction are same as in the absence of chlorides. It should be noted that rust contains no chloride, though ferric chloride is formed at an intermediate stage [14]. Electrochemical corrosion takes place only in the presence of water and oxygen [15].

The dependency of corrosion rate on chloride concentration are represnted in Fig. 5, The microstructure of the CSRB obtained using optical microscopic examinations highly supported the estimated corrosion data as shown from the images in Fig. 6.

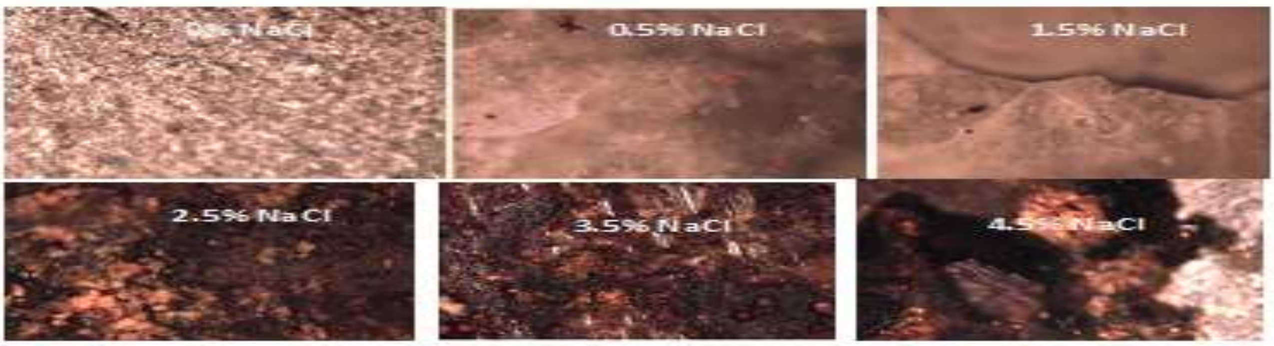

Fig. 4: Optical microscopic images of CSRB polarized in artificial concrete solution containing different NaCl concentrations

The increasing of the dark area in the above optical images with increasing the NaCl concentrations supports the measured data from polarization experiments.

The 3D view morphology deduced from AFM analysis are shown in Fig. 7, it reflects increasing attack of chloride ions with increasing the concentration.

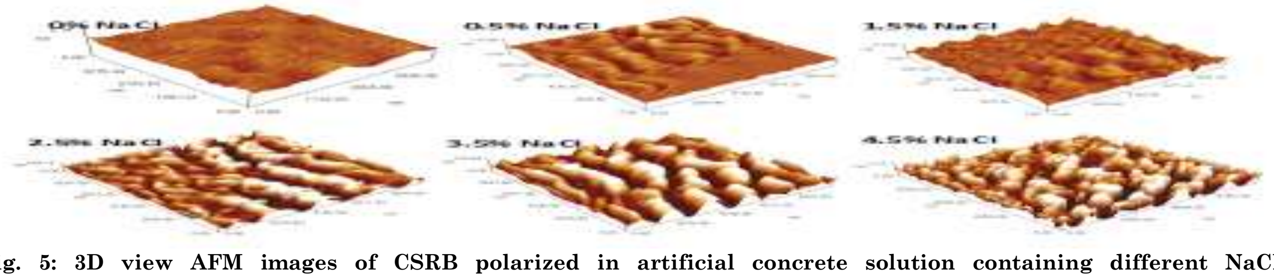

Fig. 5: 3D view AFM images of CSRB polarized in artificial concrete solution containing different NaCl concentrations

The pitting probability was estimated from the area of the hysterias loop of the cyclic polarization curve, Fig. (6), it shows propagation of pitting at all chloride concentrations, the E_{pit} and i_{pitt} at each concentration are presented in Table (2).

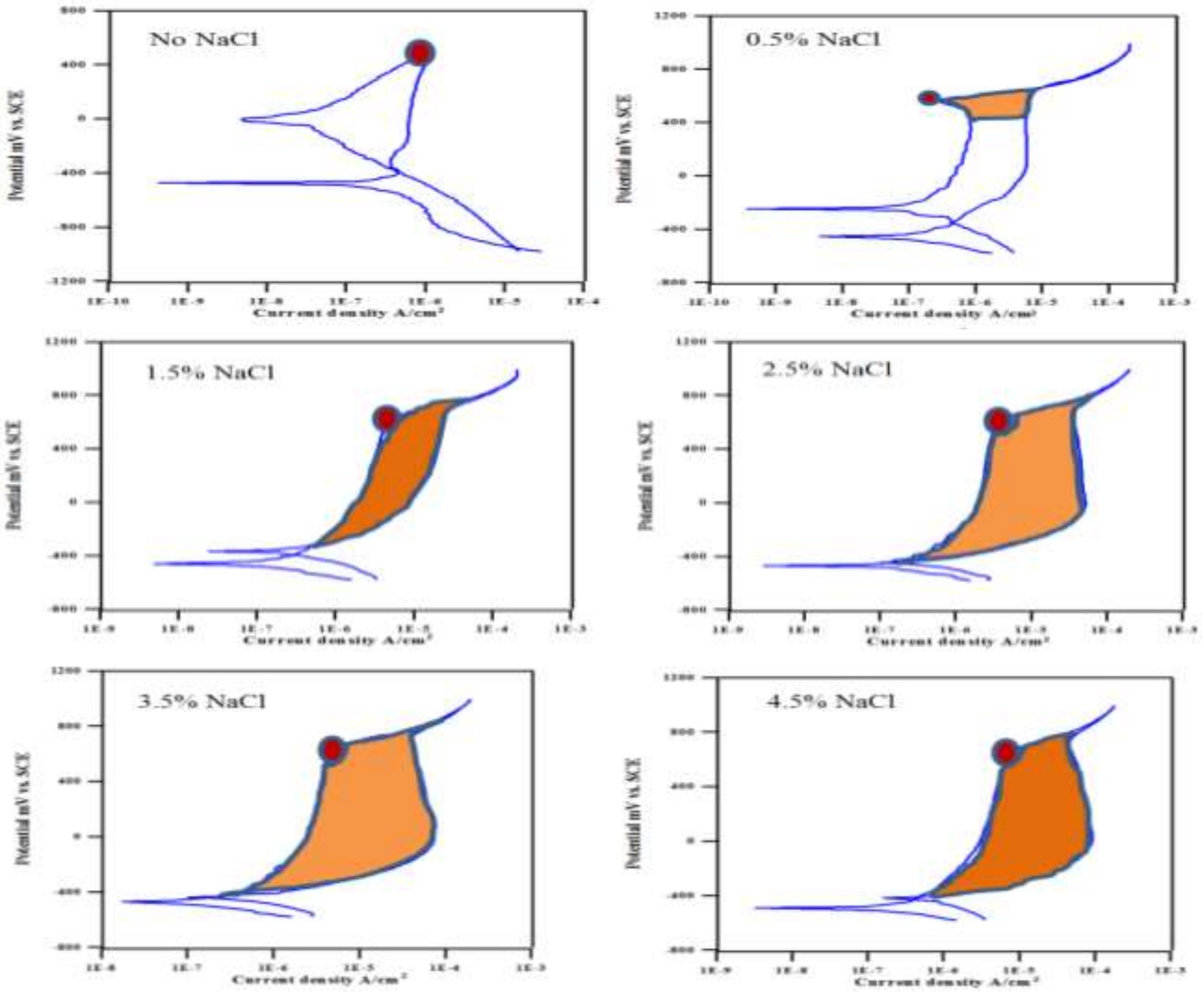

Fig. 6: Cyclic polarization curves of carbon steel reinforcing bar in simulate concrete solution containing different chloride concentration

The colored area in Fig. 6 is proportional with the metal weight loss and lead to higher volumes of pits, the order highly obeyed the increasing of the chloride ion concentration [16, 17].

Table 2: potentials and currents of pitting propagation of carbon steel reinforce concrete in artificial concrete solution

Concentration NaCl%	$E_{pitting}$ (mV)	$I_{pitting}$ ($A*10^{-6}/cm^2$)
0.5	552.2	55.3
1.5	622.6	349.4
2.5	654.8	350.4
3.5	625.7	398.3
4.5	646.3	487.5

Conclusions

Based on the scope of this investigation the following conclusions are drawn;

- The corrosion rates of CSRB was increased with increasing NaCl concentration in the range 0.5 to 4.5%, also the rising of the temperature of the simulate concrete solution increases the rates of corrosion.
- Pitting corrosion recorded at all chloride concentrations and the pits volumes increased with increasing chloride concentration, and
- The optical and Atomic force microscopes highly supported the deduced results from Tafel plots.

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