The study of the corrosion resistance of steel in different environments

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Abstract

In this work, we carried out a study on the corrosion resistance of steel to different environments (tap water, distilled water and industrial water). The study was conducted by stationary electrochemical methods (monitoring of the potential in open circuit, polarization curves) and non-stationary (electrochemical impedance diagrams). The results obtained by potentiometry and in the presence of distilled water show a slight variation of the corrosion potential, a decrease of the cathodic branches and a decrease of the anodic branches inducing an important decrease of the current density corresponding to the dissolution of the steel. Nyquist diagrams are characterized by a single capacitive loop, at high frequencies, corresponding to a charge transfer phenomenon. The Bode diagrams are characterized and at high frequencies by a resistive region; the charge transfer resistance R_t increases up to 145 $\Omega.cm^2$ for distilled water and then decreases to 133 $\Omega.cm^2$ for city water with a single time constant, for the different media that confirm the previous results. The morphologies of the substrate surface are examined by optical microscope.

Keywords: Corrosion, distilled water, EIS, industrial water, steel.

Full length article   *Corresponding Author*, e-mail: *abderrahimkarima@hotmail.fr, **odeykhamaysah@yahoo.com

1. Introduction

Austenitic stainless steels are widely used in the industrialized world, due to their high corrosion resistance, electrical and thermal properties as construction materials in several industries: biomedical, food [1], steam power plants [2], piping systems, chemical plants and heat exchanger equipment [3]. This corrosion resistance is due to the formation of a passive chromium oxide film on the surface. This metal can undergo severe corrosion exposed to aggressive environments, especially those containing chloride, sulfate or nitrate ions [4]. This is a severe problem to be addressed by industries and educational sectors because it causes enormous economic losses all over the world. According to NACE 2016, the economic losses due to corrosion have become about 2.5 trillion US dollars. The objective of this work is to study the corrosion resistance of steel in different environments (distilled water, city water, industrial water) using both the potentiodynamic polarization method (Tafel) and the electrochemical impedance spectroscopy (EIS).

2. Materials and methods

2.1. Materials and solution

The chemical composition of the steel substrate employed in this study is illustrated in Table1

Table 1: Chemical composition of the steel

Eléments	C	Si	Mn	P	S	Al	Cr	Ni	V
Composition (wt. %)	0.2	1.56	0.74	0.017	0.014	0.28	26.94	11.23	0.08

We are interested in the corrosion of steel in three different environments, the first is a distilled water, the second is a city water (ANNABA) and an industrial water from the national industry ARCELOR METAL STEEL (ANNABA). The electrochemical tests were carried out on samples embedded in an epoxy resin, with a bottom surface area of 0.5 cm². . Before each test, the working electrode undergoes a pre-treatment, which consists of a mechanical polishing of the surface with abrasive papers of different grades(80 to 4000),

followed by a cleaning and a degreasing with acetone, then rinsed with distilled water and dried under a flow of air.

Table 2: The pH and conductivity of different solutions.

Solutions	pH	C(s/m)
D.W	6.86	1.50
I.W	5.53	1.00
C.W	7.42	0.03

2.2. Electrochemical measurements

The electrochemical measurements were performed using an Autolab 302N model potentiostat/galvanostat; combined with **Nova 2** software and a conventional three-electrode electrochemical cell: the platinum counter electrode, the saturated calomel electrode (SCE), as the reference electrode, and the low carbon steel as the working electrode. The test solutions were opened to air, and the experiments were performed under the static conditions. The temperatures of the solutions during the experiments were maintained at 298 K. Potentiodynamic curves are plotted in the potential range (-250 to +250) mV / ECS at a scan rate of 1mV/s after 1 hour of immersion in solution. Polarization resistance (Rp) was measured from the obtained polarization curves obtained at ± 10 mV relative to corrosion potential. Electrochemical impedance spectroscopy **(EIS)** measurements were performed in the frequency range of 100 kHz to 10 MHz, using open circuit potential with an amplitude of 10 mV amplitude.

2.3. Surface analysis

The surface morphology of the steel immersed for 48 hours in three different environments, was studied using a **NICON Eclipse LV150N optical microscope.**

3. Results and discussion

3.1. Monitoring of the free potential

It is important to follow the evolution of the free potential until its stability and in different environments. The values of this potential are fixed by the reactions that take place on the surface of the metal. This evolution is represented on figure.1.

The evolution of the potential for the tests in different environments (D.W, I.W, C.W) characterizes the corrosion of the sample with formation of corrosion products. While in the presence of distilled water we observe an ennoblement of the potential *(Ecorr)* with a good stability which is reached after 2 hours of immersion and at a value of **-140mV/ECS.**
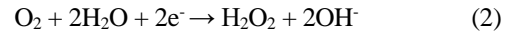
3.2. Polarization curves

Figure 2 shows the polarization curves of the steel, obtained in different environments, after 2h of immersion at a scan rate

of 1mV/s. Figure 2 represents the polarization curves of steel in different environments. We observe that the corrosion potential tends towards positive values, so the current densities decrease, especially for distilled water.
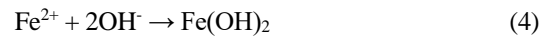
The anodic and cathodic reactions of steel corrosion are the dissolution of iron

$$Fe \rightarrow Fe^{2+} + 2e^- \qquad (1)$$

and the reduction of oxygen: :

$$O_2 + 2H_2O + 2e^- \rightarrow H_2O_2 + 2OH^- \qquad (2)$$

$$H_2O_2 + 2e^- \rightarrow 2OH^- \qquad (3)$$

Therefore, the formation of iron hydroxide near the metal surface [5]:

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2 \qquad (4)$$

From the values of electrochemical parameters, we note and in the presence of distilled water as follows:

-A shift of the corrosion potential (Ecorr) towards positive values of

-0.047mV/ECS to -0.031mV/ECS.

-A decrease of the current density (*icorr*) to a minimum value of 2.049.10-8A

-An increase in the polarization resistance **(Rp)** to a maximum value of **9.967.10^{5}Ω .cm^2.**

3.3. Electrochemical impedance spectroscopy

To understand the corrosion mechanisms taking place on the steel surface at different environments, we plotted electrochemical impedance diagrams at corrosion potential, using an **Autolab 302N** corrosion chain, associated with **NOVA 2** software. These spectra were obtained at the open circuit potential, after 2 hours of immersion, in a frequency range between 100kHz to 10 mHz, with an amplitude of 10 mV and they are represented in Nyquist **(Figure.3.a.),** on which we notice the presence of a single semicircular capacitive loop, whose size increases especially in distilled water, due to the gradual formation of a protective film on the surface of the electrode; this process of corrosion is controlled by the phenomenon of charge transfer [6-8].

We notice on the Bode diagrams:

- Figure 3.b: at high frequencies, a resistive region; with increasing charge transfer resistance Rt [9,10].

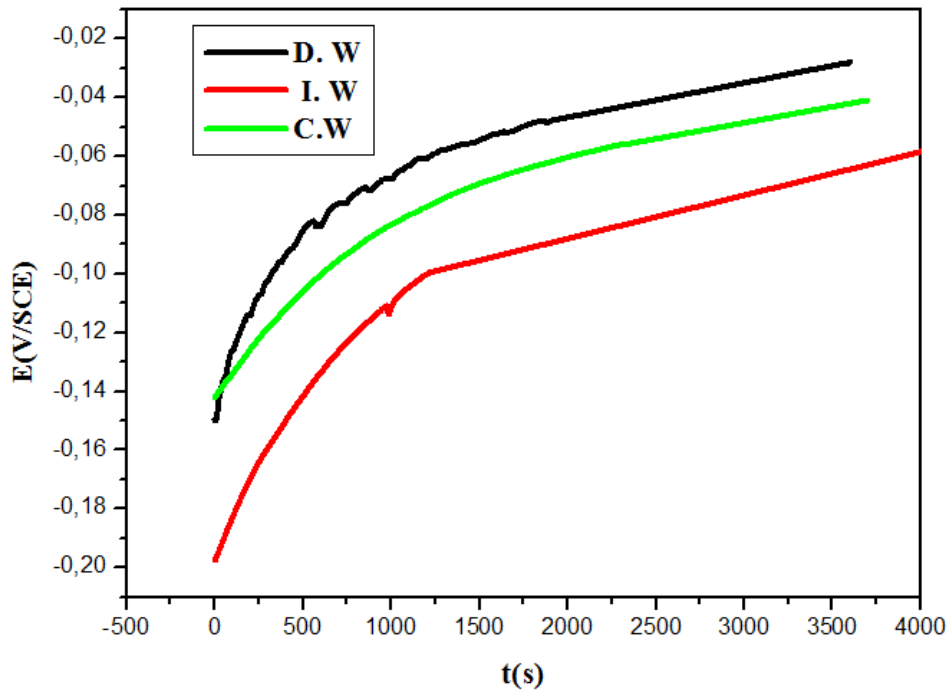- Figure 3.c: a single time constant, for the different environments [11].

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Figure .1. Monitoring of the open circuit potential of steel immersed in different Environments (D.W, I.W, C.W).
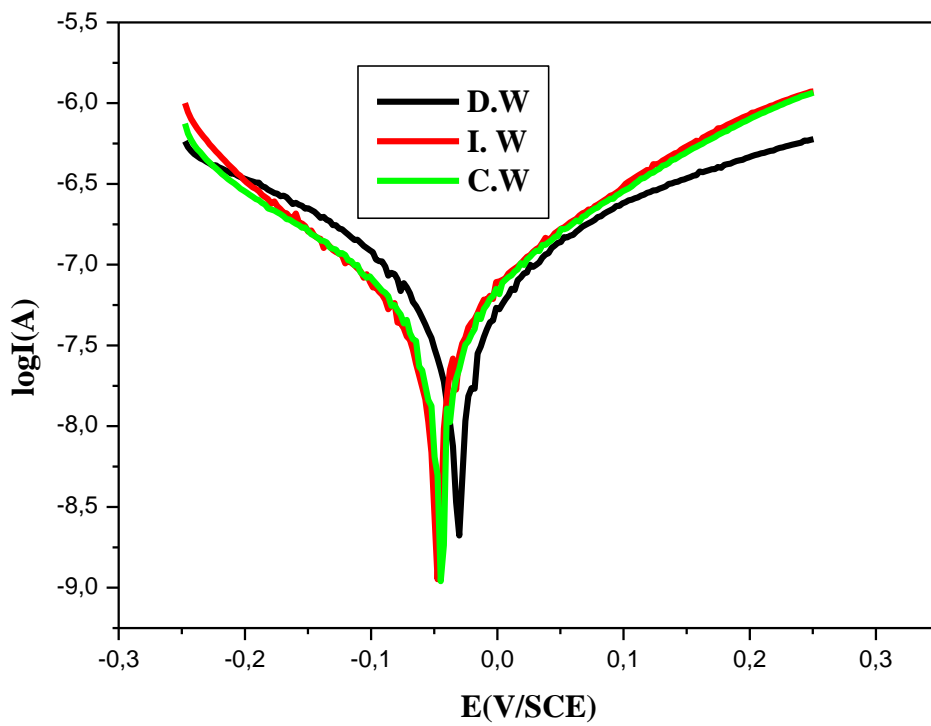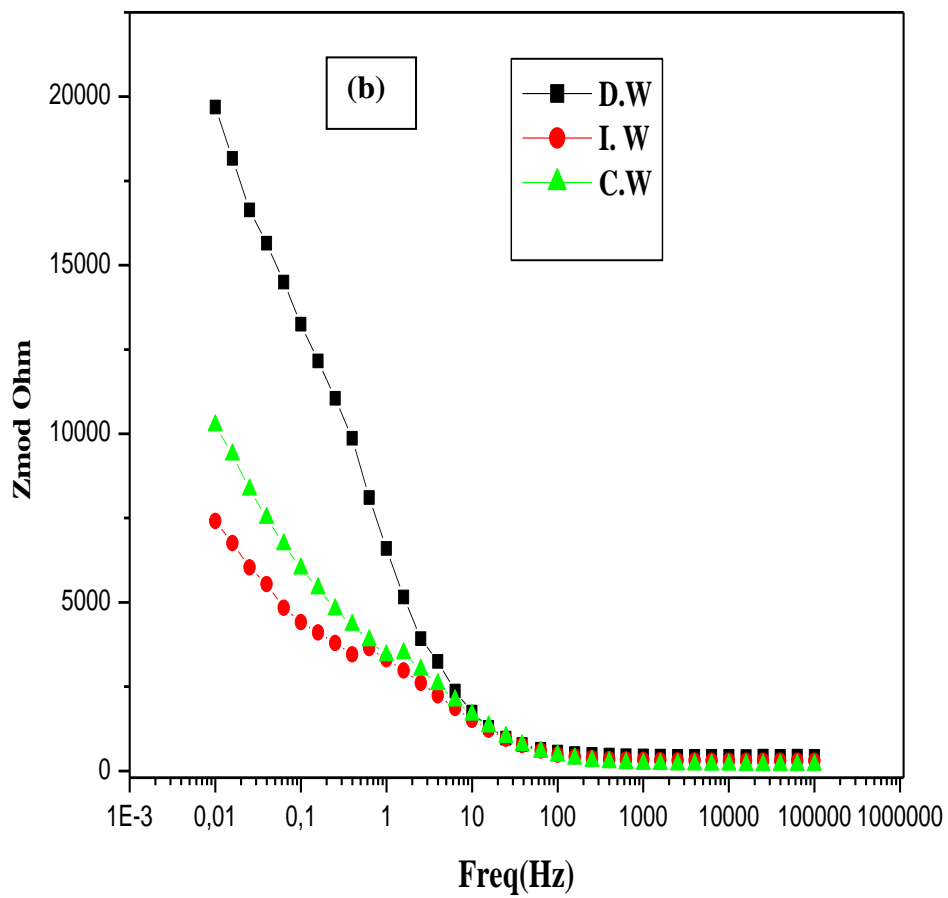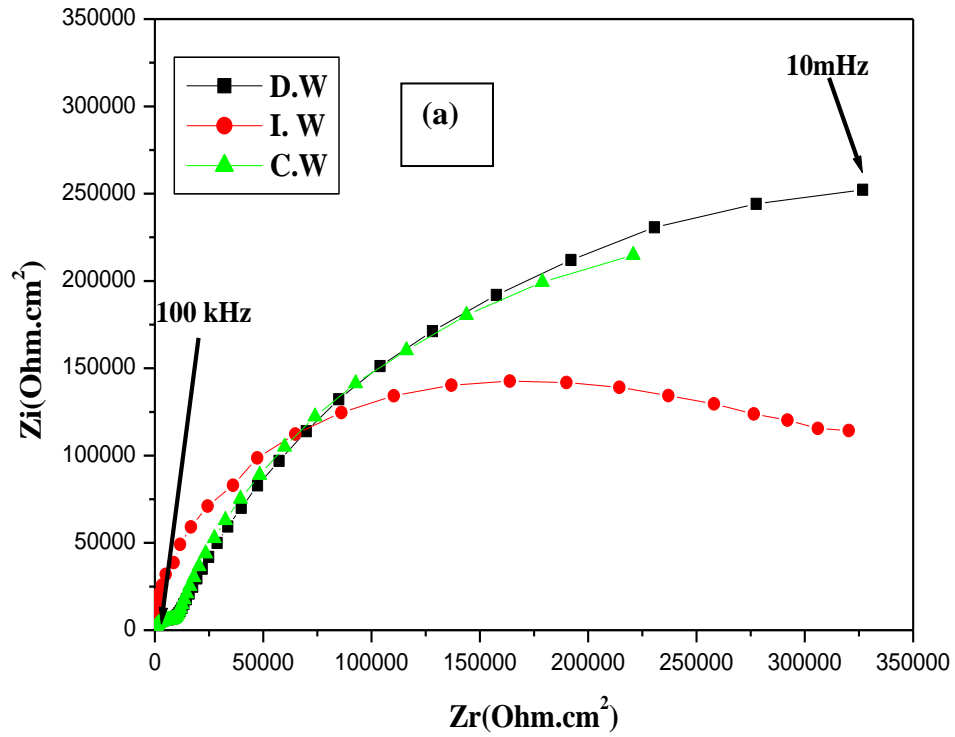

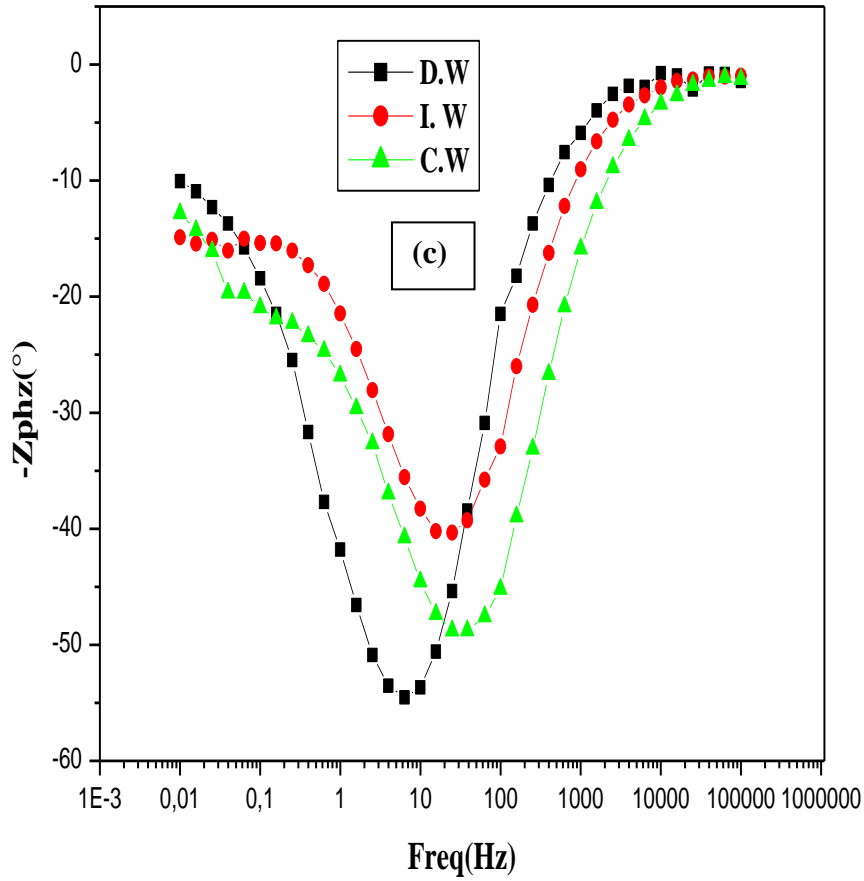Figure .2. Polarization curves of steel immersed in different environments

Figure .3. Electrochemical impedance diagrams: (a)Nyquist; (b) and (c) Bode

of steel immersed in different environments

Table .3. Electrochemical parameters deduced from the polarization curves of steel in different environments (D.W, I.W, C.W)

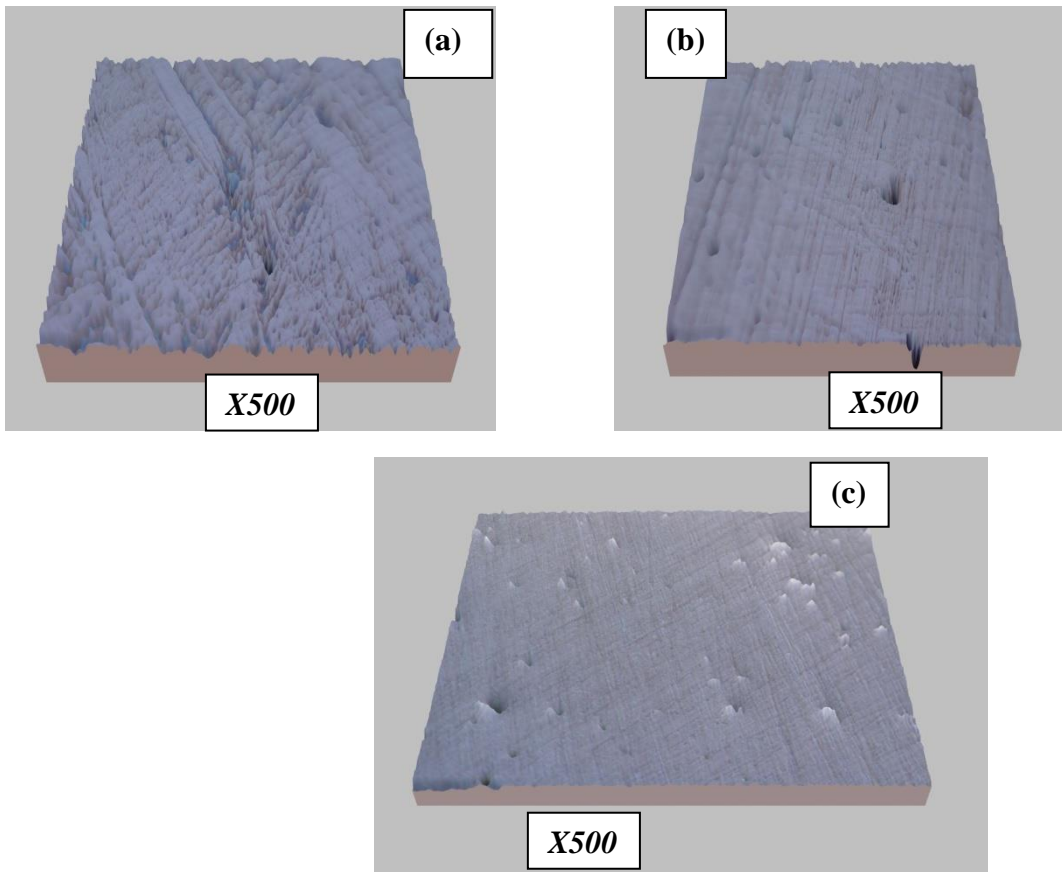| Solutions	Ba (V/dec)	Bc (V/dec)	$E_{corr,cal}$ (v)	$E_{corr,Obs}$ (v)	I_{corr} (A)	W (mm/y)	Rp ($\Omega.cm^2$)	E_i (V/SCE)	E_f (V/SCE)
D.W	0.125	0.119	-0.031	-0.031	$2.049.10^{-8}$	0.00023	$9.967.10^5$	-0.096	0.043
I.W	0.120	0.117	-0.040	-0.040	$2.594.10^{-8}$	0.00030	$8.346.10^5$	-0.086	0.025
C.W	0.089	0.080	-0.047	-0.043	$3.188.10^{-8}$	0.00037	$8.975.10^5$	-0.083	0.001

Figure 4: Micrographs corresponding to the surface of the steel after 2 hours of immersion in three different environments (D.W, I.W, C.W).

3.4. Characterization of the surface state

3.4.1. Analysis by optical microscopy

The surface morphology of the steel immersed for 2 hours in the three different environments was studied using a NICON Eclipse LV150N optical microscope

Figures 4.a, 4.b and 4.c represent the micrographs in the three different environments of the surface of the steel immersed for 3 hours, obtained by an optical microscope; NICON ECLIPSE LV150N at 25°C.

Observation with an optical microscope shows that:

In both environments (I.W, C.W). (*Figures 4. b and c*), we observe the appearance of dense areas that can be attributed to the formation of corrosion products. While

while in the presence of distilled water (*Figure 4.a*), the entire surface is relatively uniform with low roughness. This development may be associated with the formation of an oxide layer on the surface that protects the steel[12,13].

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Similar observations have been reported by other researchers [14,15].

4. Conclusions

This work is devoted to the study of the corrosion resistance of steel to different environments and the results obtained are as follows:

The evolution of the potential for the test performed in distilled water showed the formation of corrosion products. The ennobling of the potential is more marked in distilled water, and this result in the formation of a protective layer. A decrease of the anodic and cathodic branches. The electrochemical impedance diagrams showed the existence of a single capacitive loop. The MO observations showed that the roughness of the steel surface has considerably decreased due to the formation of the oxide film.

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