



Performance of a Zinc-Based Sacrificial Anode for Cathodic Steel Protection Against Corrosion in a Salty Medium

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Abstract

The cathodic protection by means of sacrificial anodes is often used for the corrosion protection of immersed metallic components. The electrochemical behavior of Zinc sacrificial anodes was investigated in this study employing electrochemical impedance spectroscopy (EIS) and polarization curves, as well as Scanning electron microscopy (SEM). The impedance diagrams are generated by two capacitive loops at high and intermediate frequencies, with the first linked to the charge transfer resistance parallel to the double-layer capacity, and second to zinc ions concentration. At low frequencies, a broadcast line from Warburg is obtained, indicating that Zn corrosion is controlled by diffusion.

Keywords: *Cathodic protection, Sacrificial anodes, Zinc, Corrosion.*

1. Introduction

Today carbon steel has taken a prominent place in our lives. Due to its good mechanical and thermal properties, its low weight, and its low purchase and manufacturing cost, this material is available in different shapes and sizes, for many and varied applications: automotive industry, buildings, electrical appliances, petroleum installations, and materials in contact with sea water ... etc [1-5]. However, steel is subject to corrosion problems which limit its use in industry. Every second, some five tons of steel are transformed into iron oxides. The implications are considerable in many areas, particularly industry: production suspends, replacement of corroded equipment, accidents, and pollution concerns are all common occurrences with often severe economic effects [6-8].

To prevent the development of corrosion in steel, some inhibitors used for these purpose naturals ones as an example, *Artemisia Herba Alba* extract were deployed to prevent carbon steel corrosion in acidic medium, where the active sites are blocked by inhibitor molecules [9]. Modified Nano-Lignin also act as a good inhibitor forming a protective layer leading to corrosion inhibition efficiency 95.3% for carbon steel [10]. *Rosmarinus officinalis* Methanolic extract also applied as natural carbon steel inhibitor in acidic medium with an efficiency of 89% [11].

In other side, there are two types of systems could be also used: either passive systems where protection is provided by creating a more or less tight barrier between the steel and the ambient environment, or active systems where protection is ensured by making the steel cathode

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to stop the oxidation reaction by lowering its electrochemical potential to the so-called immunity level [12,13]. This is the case of the cathodic protection which works either by circulation of a current between the steel to be protected and an anode, or by sacrificial effect of a metal based on zinc, aluminum or magnesium, more electronegative (less noble), when it is coupled with steel. This mode protection can only be used in a submerged or buried environment [14-16].

Zinc and its alloys are an important class of materials because of their strong technological value and extensive range of applications, particularly in the maritime, automotive, and household industries [17-18]. Zinc anodes are frequently used for the protection of structures in contact with seawater, due to their economic advantages (low cost) and its abundance in nature. Several zinc alloys and coating types (Zn-Al, Zn-Fe, Zn-Ni, Zn-Co, Zn-composite) are implemented for this. Also, could provide corrosion performance [19-21], Magnesium and Aluminum also could be used as a sacrificial anode in aggressive solutions [22,23].

This study aims to examine the electrochemical corrosion behavior of a commercial zinc electrode that serves to be sacrificial anode in the cathodic protection of steel in NaCl, the studies explored three electrochemical tests, potentiodynamic-potentiostatic polarization, and electrochemical impedance spectroscopy (EIS). SEM and EDX approaches were also used for characterization of Zn anode.

2. Experimental methods

The material adopted was a typical zinc sacrificial anode. Before use, the samples are rubbed with sandpaper to reduce particle size to 1000, cleaned with distilled water, rinsed with acetone, and dried in hot air. The potentiodynamic and potentiostatic polarization curves were plotted using an EGG M.173 chain coupled to an M.175 driver. The PGZ 301 potentiostat/Galvanostat with the "Volta Master 4" software is implemented to perform electrochemical impedance measurements.

With a scanning rate of 30mV/min, the potentiodynamic polarization curves are generated. This speed enabled it to operate in a quasi-stationary state and achieve better reproducibility of findings. Graphing polarization curves in the potentiostatic domain aims to analyze anode attitudes in areas characterized by characteristic

potential values: $E_{\text{corrosion}}$ and $E_{\text{passivation}}$, the amplitude of the sinusoidal voltage supplied to the dropout potential at 25°C following every polarization in a chloride medium is 10 mV peak-to-peak with frequencies that range from 50 kHz to 10 MHz, including five points each decade.

With all experiments, a three-electrode cell is employed. Platinum serves to construct the auxiliary electrode, and the reference electrode was made of KCl saturated silver chloride. A disk with a surface area of 1 cm² serves as the working electrode.

3. Results and discussion

3.1. Zinc anode composition

SEM matched to EDX was employed to confirm the composition and purity of the commercial sacrificial zinc anode surface. Fig. 1 depicts the micrograph and the resultant composition.

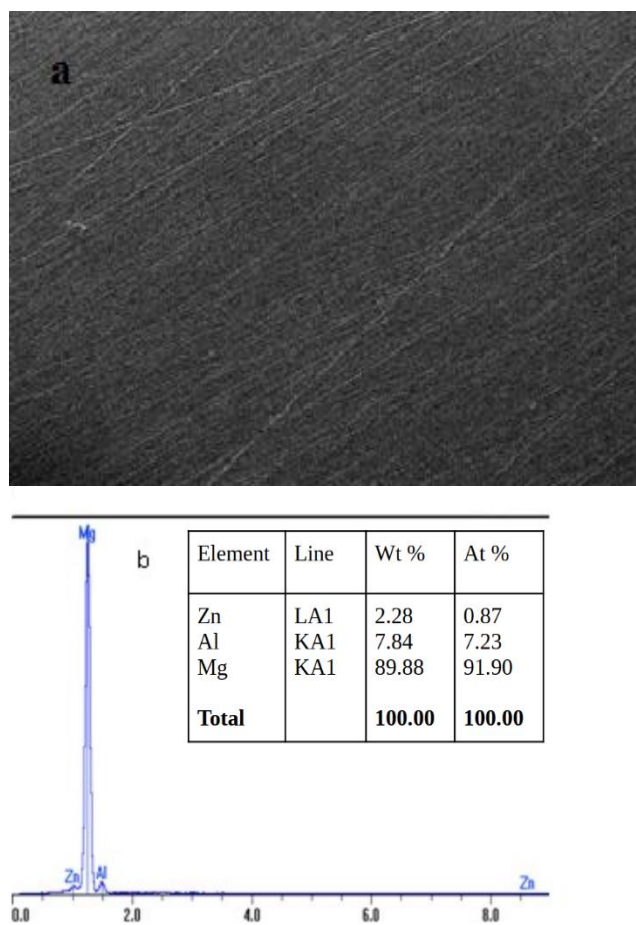


Figure 1. (a) SEM examination, (b) assessment of the zinc anode surface prior to soaking in the corrosive solution.

3.2. Evolution of open circuit potential

The electrochemical investigations were conducted in a corrosive media containing 32 g/L NaCl, to gather information on the material surface alteration. Figure 2 depicts the open circuit potential development of a zinc anode in room temperature.

It can be seen from the abandonment potential evolution curve a displacement of the potential towards more electronegative values. A quasistatinary state is obtained from 45 minutes of immersion.

3.3. Potentiostatic polarization curves

The potentiostatic polarization curves Fig. 3 and Fig. 4 have been plotted at potential values recorded in the

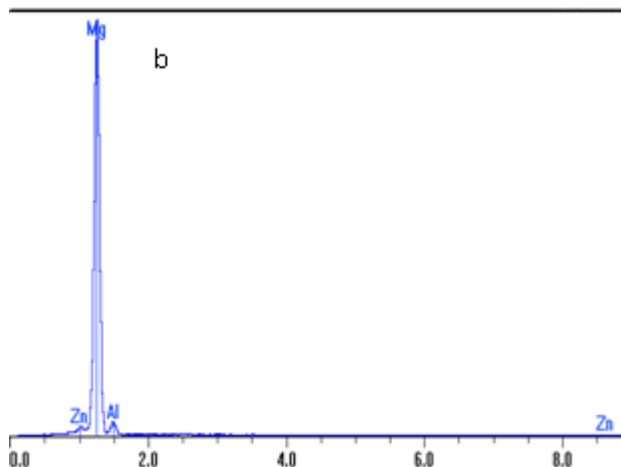
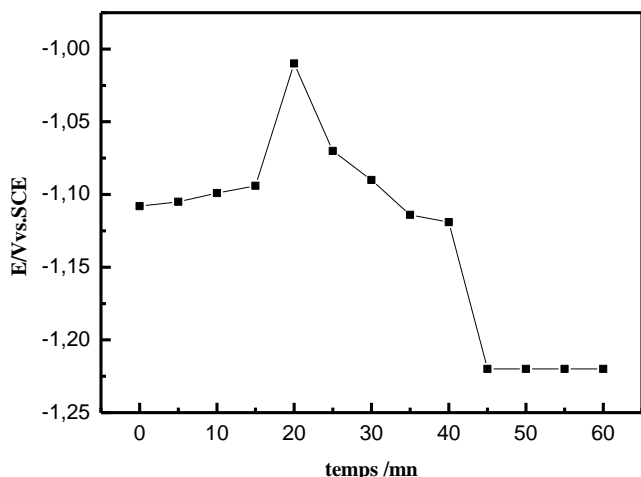


Figure 2. Open circuit potential of a zinc sacrificial anode for the experiment's medium (3% NaCl).

different characteristic domains. In the case of zinc, the potential fluctuations would be linked to the formation of an unstable deposit likely to partially or completely cover the electrode surface. When the deposit is formed, the anode becomes less reactive and, the mixed potential becomes more noble. Conversely, when the deposit comes off, the anode reactivates and the potential evolves towards more electronegative values.

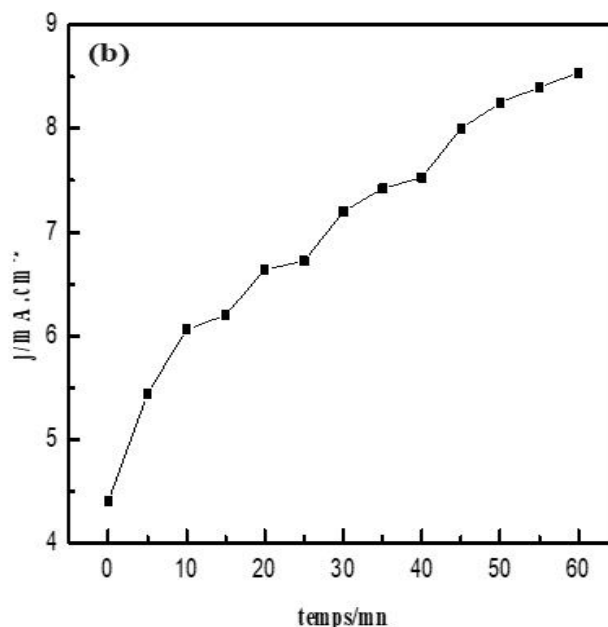
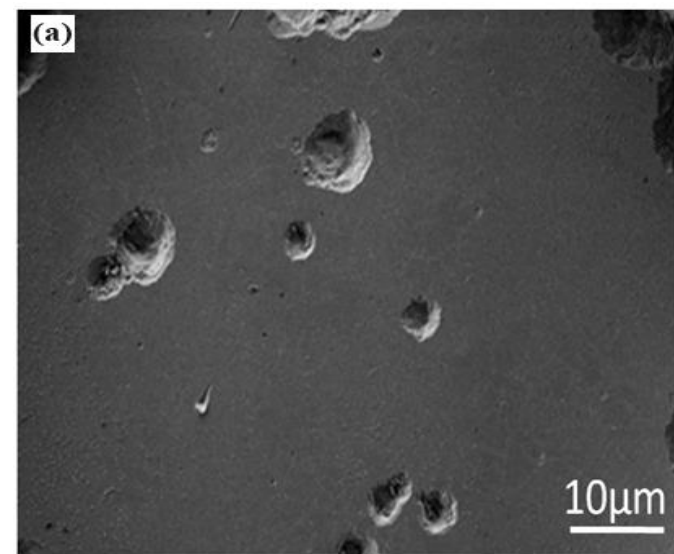


Figure 3. Characterization of zinc anode surface in the active state by (a) SEM image, and (b) evaluation of the potentiostatic polarization result at -850mV/ECS at Eimp > ER in 3% NaCl.

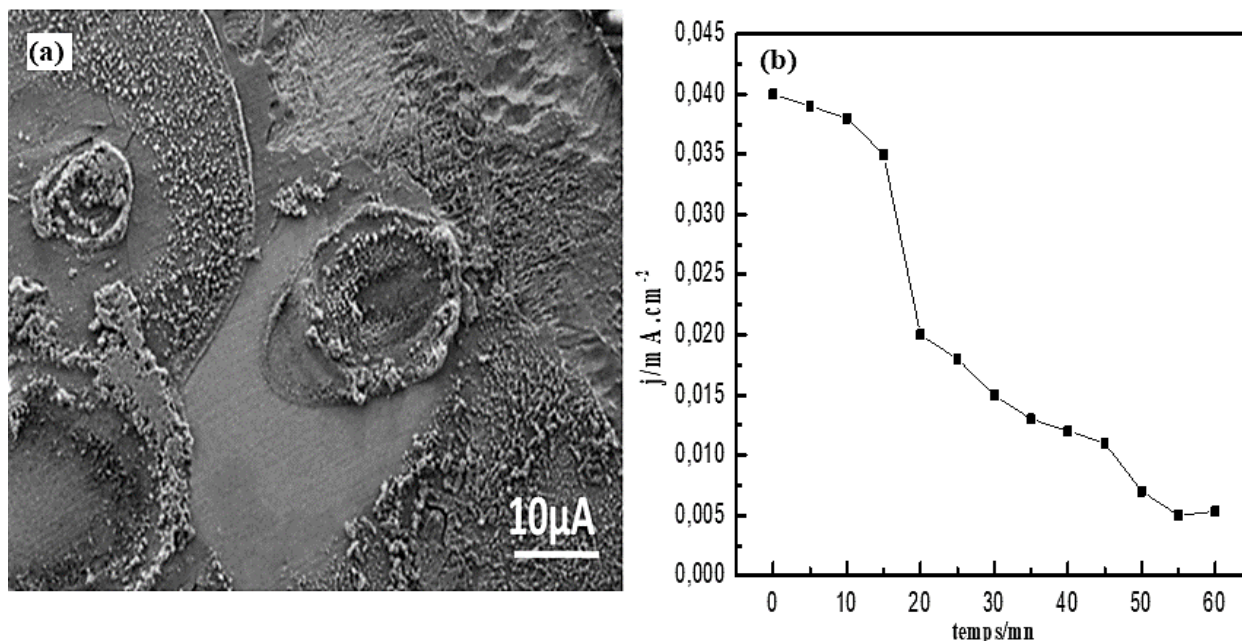


Figure 4. Characterization of zinc anode surface in the passive state by (a) SEM image, and (b) evaluation of the potentiostatic polarization result at -1050 mV/ECS ($E_{corr} < E_{imp} < E_R$)

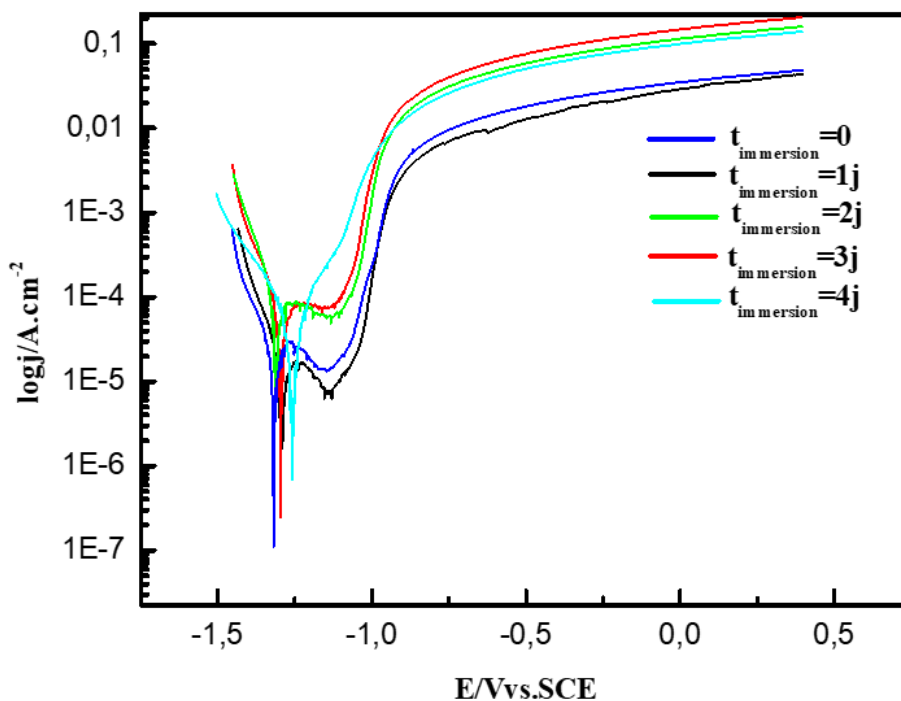


Figure 5. Potentiodynamic polarization curves of Zinc anode in 3% NaCl at various immersion times.

3.4. Potentiodynamic polarization curves

Potentiodynamic polarization measurements provide more information regarding the kinetics and behavior of cathodic and anodic reactions. As shown in Fig. 5,

Polarization curves had been generated using different time immersions in NaCl solution.

The anodic component of polarization curves has a complicated appearance that could be attributable to metastable passive states associated with pitting on the one hand and the production of more or less adherent deposits on the other, as illustrated in the SEM observations in Fig. 6.

Table 1 summarizes the electrochemical parameters. It is clear that the corrosion current rose with time, which appears to be consistent with a lower in corrosion potential and polarization resistance

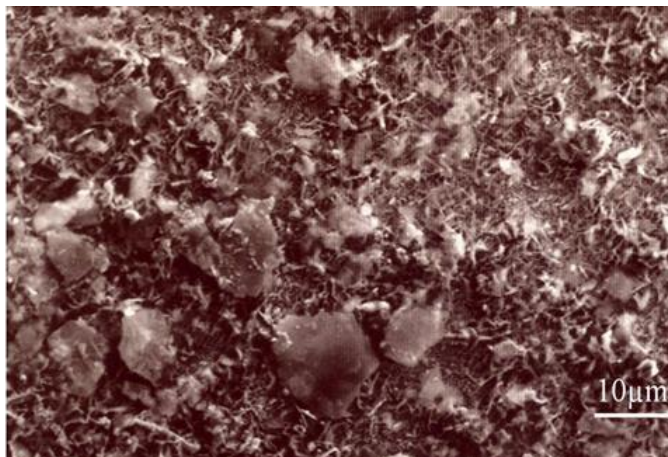


Figure 6. SEM view of a Zn anode in NaCl at corrosion potential.

Table 1. Electrochemical parameters obtained from potentiodynamic polarization curves.

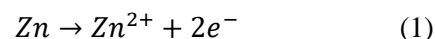
Immersion time (Days)	$R_p(\text{Ohm.cm}^2)$	$E_{corr}(\text{V})$	$i_{corr} (\text{A/cm}^2)$
0	942,72	-1.2161	1.7897E-5
1 Day	327,97	-1.2937	3.211E-6
2 Days	219,04	-1.3082	1.3615E-6
3 Days	890,83	-1.3162	2.9284E-5
4 Days	196,35	-1.2579	7.2704E-5

3.5. Electrochemical impedance measurements

Electrochemical impedance spectroscopy (EIS) was employed to examine the corrosion actions of a Zn anode in the same solution and under the same circumstances for the experiment. As seen in Fig.7, Electrochemical impedance spectroscopy data were presented as Nyquist diagrams (complex versus real impedance components).

The impedance diagram has two capacitive loops at the beginning of immersion (high and medium frequencies). The first loop is usually associated with the electrochemical double-layer capacity, whereas the second loop is associated with the growth of a layer of corrosion product on the surface. An inductive loop was

observed after a day of immersion linked to the presence of pitting and following the presence of intermediate adsorbed species during the zinc dissolution reaction:



A charge transfer loop is very well defined for immersion times two up to four days. Its diameter decreases over time due to the thinning of the passive layer. After five days of immersion in the low frequency range, a broadcast line from Warburg is obtained. The Warburg scattering angle points to the theoretical value of 45° . The presence of this straight suggests that Zn corrosion is controlled by diffusion [24].

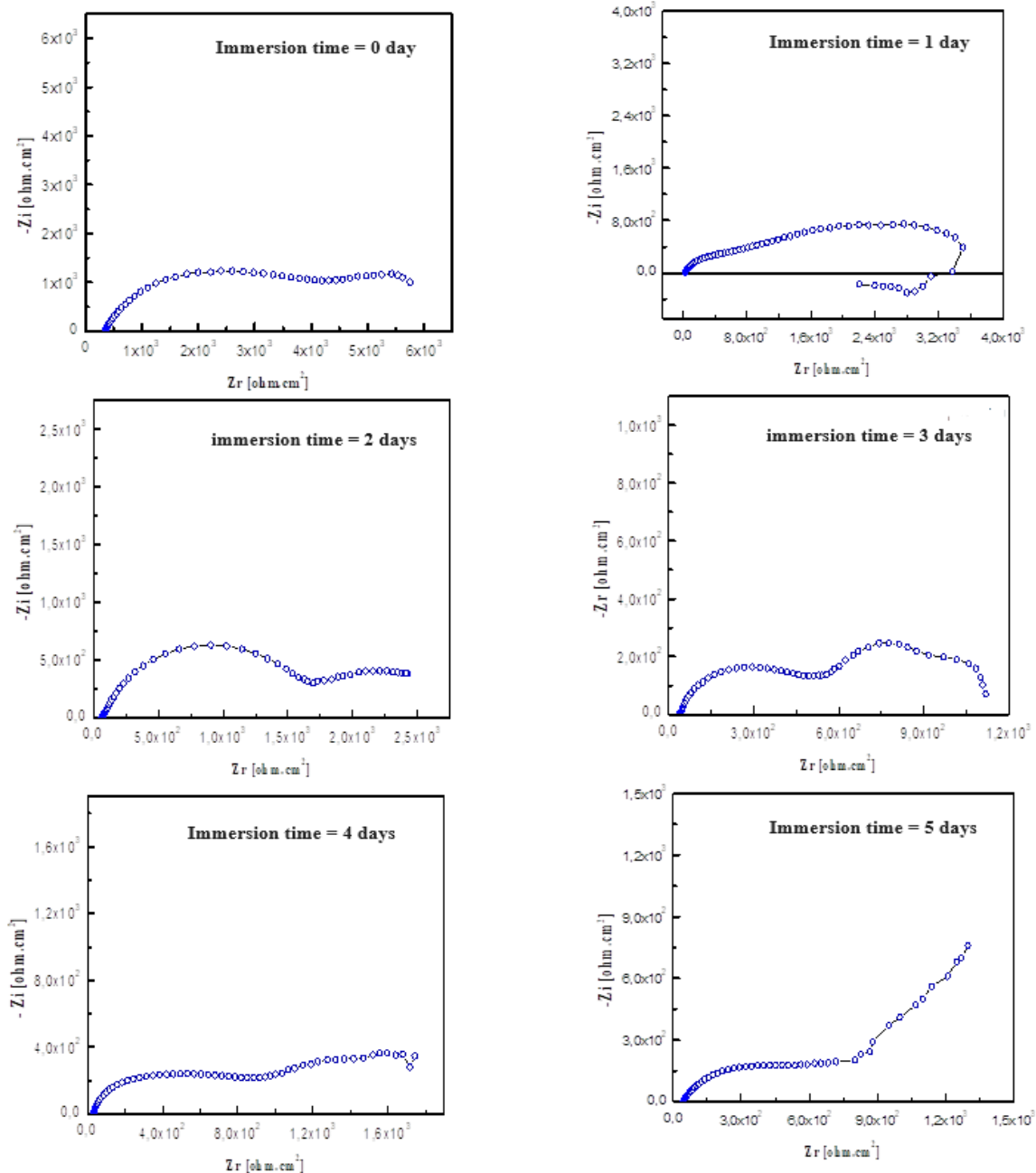


Figure 7. Nyquist diagrams of Zn metal immersed in 3% NaCl measured at various immersion times.

4. Conclusion

This work assesses the electrochemical behavior of a Zn sacrificial anode and its structure in a chloride-containing aqueous solution via EIS, Potentiodynamic polarization and open circuit potential methods, and SEM-EDX approaches. The findings indicate that when a zinc anode is exposed to a corrosive environment, it suffers from macroscopical corrosion damage. Indeed, the electrochemical data indicate that the corrosion

current increased with time, which appears to be commensurate with the decrease in corrosion potential and polarization resistance.

SEM analyses of zinc anode reveal homogeneity in anode surface attack and the production of adhering deposits.

With high and medium frequencies, the EIS of the Zn anode identified two capacitive arcs. A broadcast line from Warburg is obtained after five days of immersion in the low-frequency band, indicating that Zn corrosion is regulated by diffusion.

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