

Performance of Galvanized Steel Reinforcement in Concrete in Sea and Dead Sea Water

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Abstract

Steel reinforcements of 8 mm diameter and 24 cm length were cut from steel and after pickling treatment of all specimens. Steel reinforcements then were galvanized by hot dipping method. The measured coating thickness by thickness gage meter of zinc coat was in the range 8 - 11 μm . Bare steel samples were also used for comparison reasons. Each steel bar was inserted in a middle of a plastic tube with 4.5 cm diameter into which concrete was cast. After proper curing, specimens were immersed into 3.5% NaCl and Dead Sea water separately. Electrochemical impedance spectroscopy measurements were performed at different time intervals. Results showed that galvanized steel was corrosion resistant in sea water, and Dead Sea water over the test period.

Keywords

Electrochemical Impedance, Concrete, Galvanized Steel, Dead Sea Water

1. Introduction

Corrosion of the reinforcement causes significant damage to the concrete. The corrosion products formed are expansive (2 - 3 times larger) and precipitate at the bar-concrete interface [1]-[9]. This causes a swelling pressure of sufficient magnitude (3 - 4 MPa) to crack the concrete in tension, the cracks usually running from the bar to the nearest outer surface. Once cracking has occurred, rust staining of the surface usually follows with subsequent delamination of the mass or spalling of pieces of concrete from the surface [7]-[13]. By this stage, the structure would be seriously distressed, and repair would be necessary to extend its life [14]-[18].

Corrosion of steel reinforcement in concrete subjected to chlorides has led an impulse for researching and finding proper solutions to reduce this type of concrete problems [16]-[21]. Many approaches were made to

control corrosion of steel in concrete, including cathodic protection, use of inhibitors, steel reinforcement coatings. Galvanizing is among the possible coatings to be applied on steel reinforcement. Zinc has well-known protection capability on steel in many environments and is widely used because of its effectiveness and low price. The use of galvanized steel in concrete is still uncertain [22]-[26].

In this work, the performance of hot dipped galvanized steel reinforcement in 3.5% NaCl solution representing sea water, and in Dead Sea water was studied.

2. Experimental

Steel reinforcements of 8 mm diameter and 24 cm length were cut from steel and after pickling treatment of all specimens. Steel reinforcements then were galvanized by hot dipping method. The measured coating thickness by thickness gage meter of zinc coat was in the range 8 - 11 μm . Bare steel samples were also used for comparison reasons. All steel reinforcements were inserted into the middle of plastic molds with 4.5 cm diameter. A concrete mix (**Table 1**) was prepared and then cast into plastic mold with the help of a vibrator, after the hydration process took place (after 2 days) reinforced concrete samples were removed from plastic mold and cured for 28 days (**Figure 1** and **Figure 2**).

Part of samples the immersed in 3.5% NaCl solution, another part immersed into Dead Sea water, and the third part was immersed in tap water, the use of tap water is of comparison reasons.

2.1. Electrochemical Impedance Tests

Electrochemical impedance spectroscopy (EIS) tests were applied to specimens by using Princeton A273 potentiostat instrument equipped with Frequency Response Detector.

EIS tests were applied just after immersion, then, frequent tests were performed to all samples every 25 days. Electrochemical Impedance spectroscopy tests were run from 100 KHz to 1 MHz frequency range and with 20 mV amplitude. The experimental setup is shown in **Figure 3**.

2.2. Potential Measurement Tests

Frequent potential of steel in all samples were measured by a copper-copper sulfate electrode according to ASTM C876.

3. Results and Discussion

3.1. Tap Water

The behavior of galvanized steel rods tested in various environments is shown in **Figure 4**. In fact after 150 days

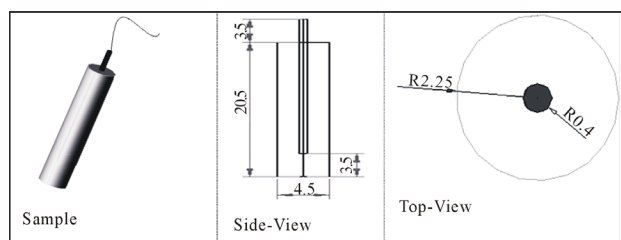


Figure 1. Specimen design and dimensions.

Table 1. Concrete mix design.

	Concrete Content	%	Total Quantity
1	Cement	14.2	2288
2	Sand	33.1	5333
3	Aggregate	39.5	6378
4	Tap Water	13.2	2128
	Total	100	16,127



Figure 2. Hot dipped steel reinforcements used in this study.



Figure 3. The experimental setup.

of exposure, only slight change in impedance value was found. In Nyquist plots straight lines were observed at frequencies greater than 1 Hz instead of a semicircle. This confirms that no corrosion process was started throughout of test period of exposure.

Figure 4(b) shows the impedance of bare steel tested in tap water, comparing with impedance of galvanized steel tested in tap water (4-d), in (4-b) a semicircle behavior was observed with $R_p + R_\Omega$ (polarization resistance and solution resistance) around 125 ohms, also showing influence of diffusion on charge transfer semi-circle. Bode plots (**Figure 4(a)** and **Figure 4(c)**) showed impedance values of bare steel much lower equals 170 Ω , where values obtained for galvanized steel were in the range 180 - 300 Ω at frequencies above 10 Hz. According to these values, the behavior of galvanized steel in tap water did not show any indication of corrosion of steel reinforcement. This can be clear from the one-time constant curves of Bode plot.

3.2. 3.5% NaCl Solution

The impedance characteristics of the samples measured in 3.5% NaCl solution are shown in **Figure 5**. The points in the plots indicate the experimental data along exposure period. The results revealed that the interface response contains only one time constant and that a characteristic frequency, where the phase shift shows a minimum, shifted in the low frequency side as the corrosion progressed. This shift indicates an increase in the capacitance value.

Due to frequency dispersion of impedance data, the constant phase element approach was used to fit the data and the equivalent circuit is shown in **Figure 7**. It consists of a solution resistance, R_s in series with a parallel

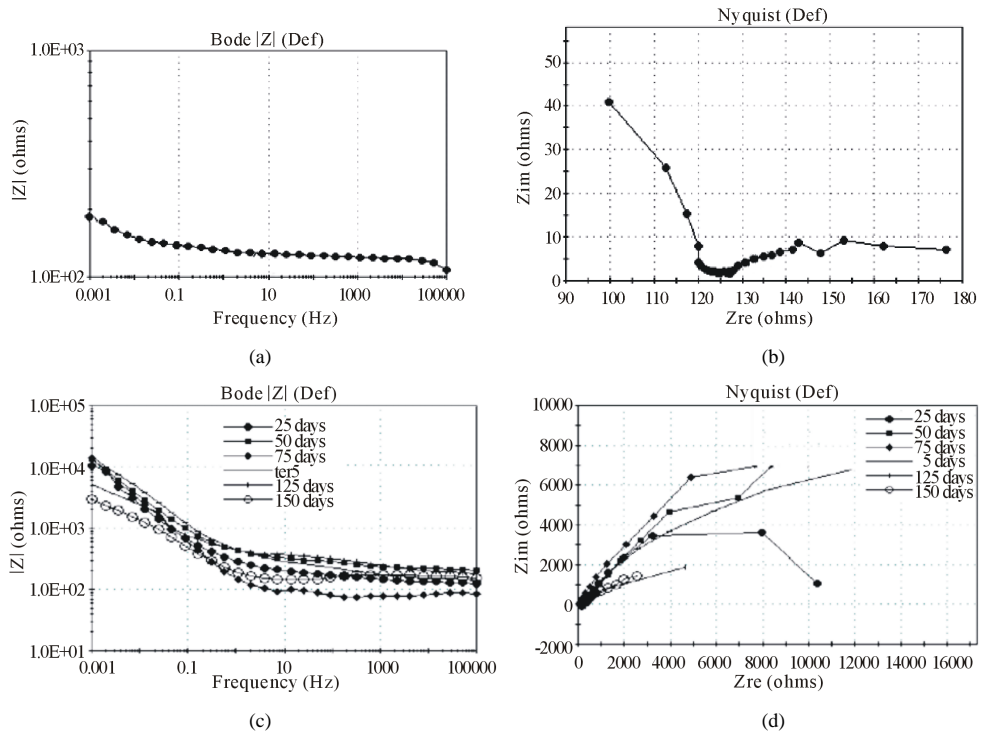


Figure 4. Nyquist and bode plots of bare steel in concrete tested in tap water: (a) bode plot of bare steel; (b) Nyquist plot of bare steel; (c) bode plot of galvanized steel; (d) Nyquist plot of galvanized steel.

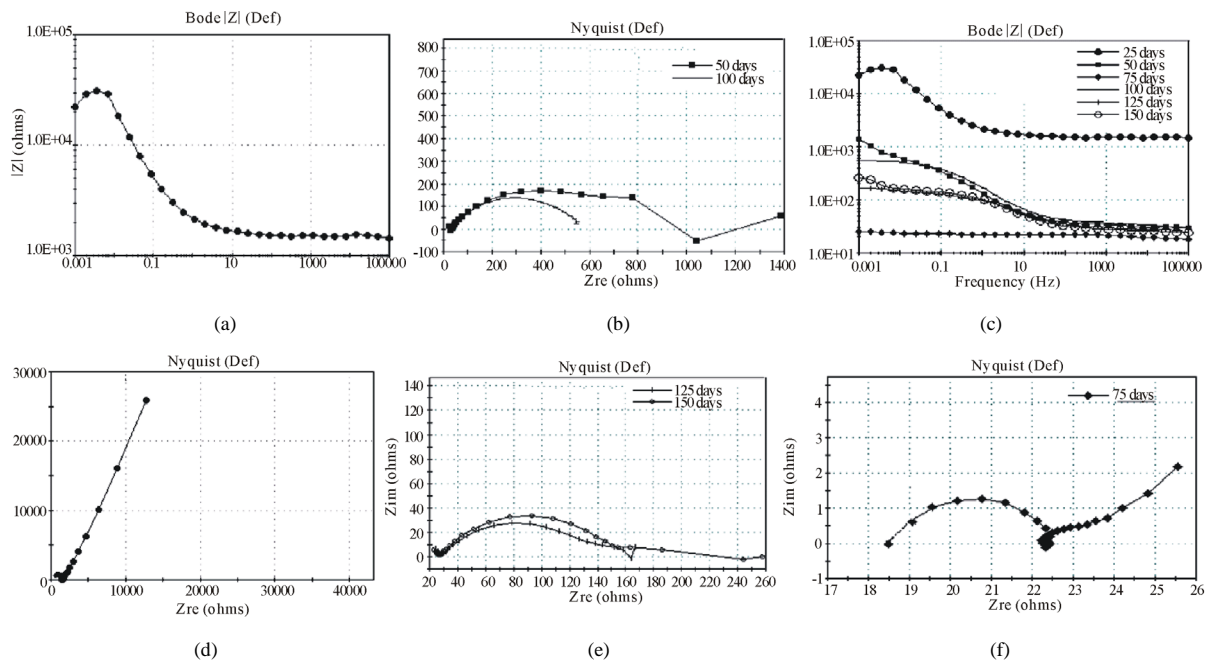


Figure 5. (a)-(c): Nyquist and bode plots of bare steel in concrete tested in 3.5% NaCl solution; (d)-(f): Nyquist and bode plots of galvanized steel in concrete tested in 3.5% NaCl solution.

circuit of a charge transfer resistance, R_{ct} and a constant phase element, CPE. Though the experimental data and the results of curve fitting are in fairly good agreement, it needs to evaluate the physical significance of parameters used for fitting.

Polarization resistance (R_p), may be calculated by subtracting the solution resistance, R_s , measured at high frequency, from the sum of ($R_p + R$) measured at a low frequency. Polarization resistance, R_p , is also inversely proportional to the corrosion current [27]-[29].

3.3. Dead Sea Water

The tests carried out of galvanized steel in Dead Sea water are shown in **Figure 6**.

The test performed for galvanized steel just after immersion has the same explanation of all samples. **Figure 6** shows that, after an immersion of 25 days, the corrosion indication was given, but after an immersion of more than 50 days, an indication of corrosion was noticed. This corrosion can be explained as the corrosion of zinc which is more active than steel in seawater according to galvanic series. The protection indication was explained to be of the bare steel reinforcement after the localized removal of Zn layer due to corrosion. The removal of Zn layer was explained due to the indication of protection in Nyquist plots.

3.4. Potential Measurements

The potential difference of steel reinforcement galvanized and without galvanizing and immersed in tap water, seawater and Dead Sea water are shown in (**Figures 7-9**). Figures show the potential change vs. copper sulfate electrode of the two steel reinforcements. It is seen that galvanized steel in all solutions (*i.e.* tap water, seawater, Dead Sea water) had the highest negative potential, where steel with no galvanization had less negative potential. The highest negative potential of galvanized steel could be due to the potential of corroding Zn layer rather than of steel reinforcement itself.

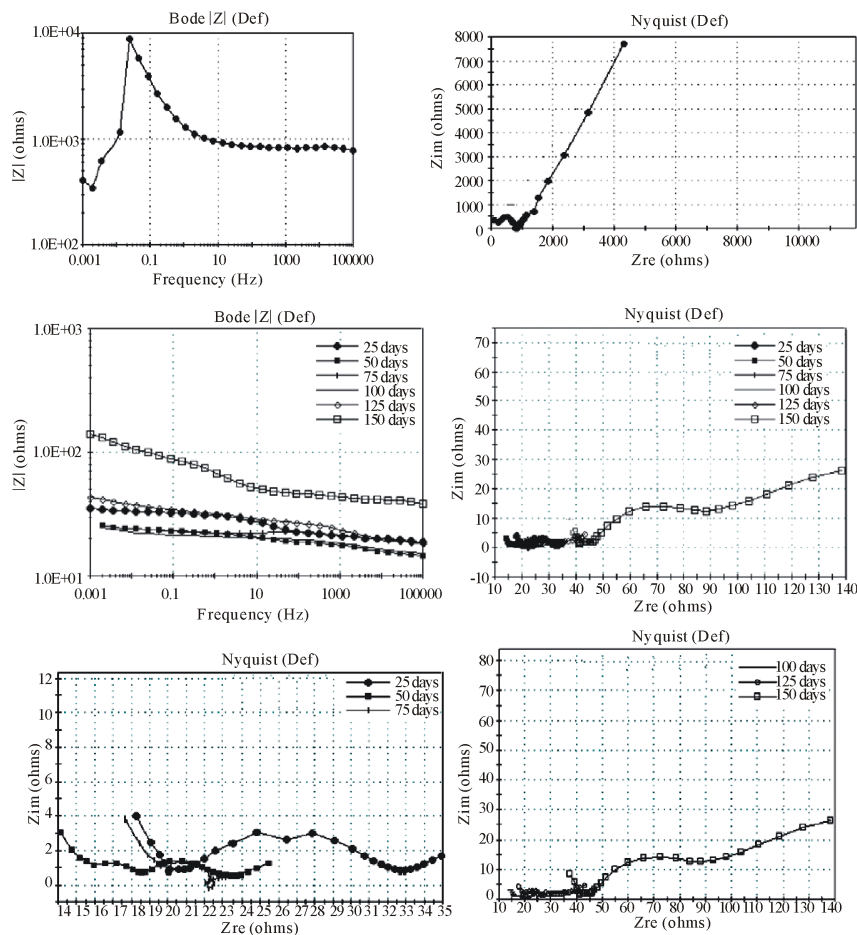


Figure 6. The behavior of galvanized steel rods tested in Dead Sea water.

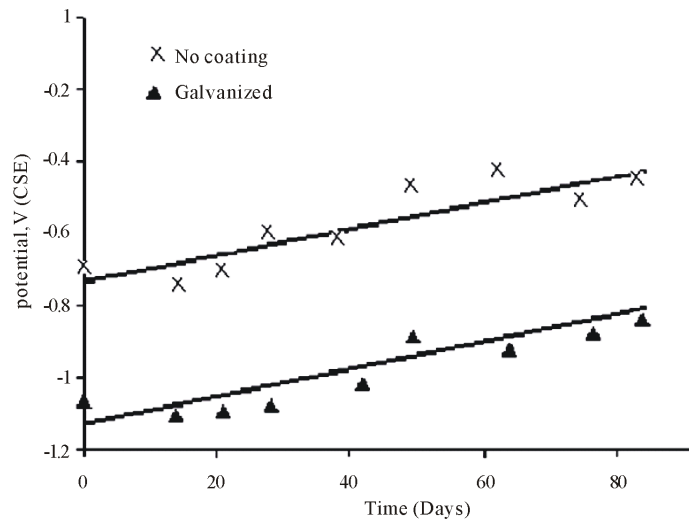


Figure 7. Potential measurements of galvanized steel tested in tap water.

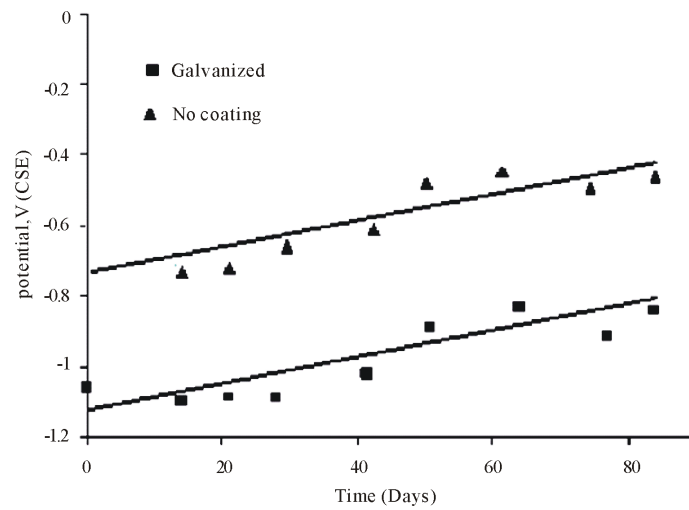


Figure 8. Potential measurements of galvanized steel tested in sea water.

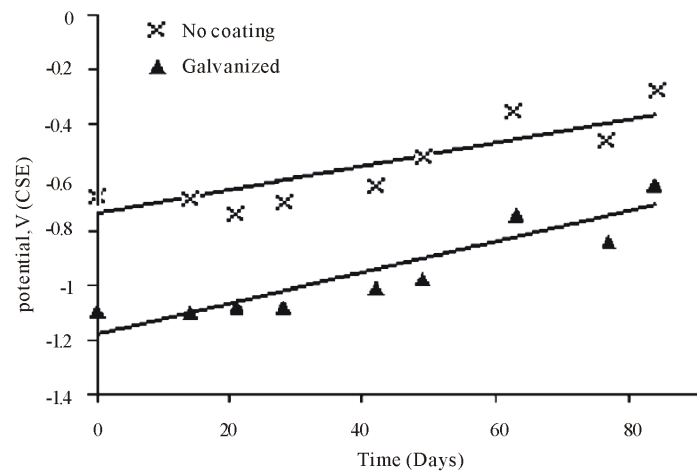


Figure 9. Potential measurements of galvanized steel tested in Dead Sea water.

4. Conclusion

- 1) Galvanized steel reinforcements showed very good corrosion resistance in sea water and Dead Sea water.
- 2) EIS techniques were very useful in studying corrosion behavior of galvanized steel in concrete.
- 3) Potential measurements did not give accurate measurements due to high potential values of Zn coat on steel.
- 4) Galvanized steel was resistant to corrosion in very high corrosive environments (Dead Sea water) over the test period.

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