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Research Article

GALVANIC CORROSION OF ZINC ANODE AND COPPER CATHODE CELL

Nurettin Çek *[1]

[1] Fırat University, Faculty of Engineering, Department of Metallurgical and Materials Engineering, Elazığ, Turkey
ORCID ID 0000-0001-6120-9228
nurettincek001@gmail.com

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* Corresponding Author
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ABSTRACT
Detection and control of galvanic corrosion is a critical aspect of engineering for the chemical processes used in the fabrication of metals, alloys and materials industry. Galvanic corrosion can occur when two metals having different status in the electrochemical ambient are configured in mutual interaction within the galvanic cell structure and are exposed to the ion conducting electrolyte. In this study, ion-containing water was used as an electrolyte, the zinc as the anode electrode, copper as the cathode was used as an electrode, and a galvanic cell was fabricated. The formation of corrosion products with time on zinc anode reduced the voltage and current in galvanic cell considerable and anode film layer of considerable increase. Time-dependent experiments have provided good sources of information about the performance of the zinc anode electrode and the copper cathode electrode in the galvanic cell.

Keywords: *Zinc, Copper, Electrode, Galvanic Cell, Corrosion*

1. INTRODUCTION

Corrosion is the chemical and physical properties of metal and metal-like materials event change. The extensive use of metal in the process of daily life and the resulting metal corrosion has caused challenging problems. Corrosion of metals are a terrible waste both of economic and natural resources. Metals are suffering corrosion because they want to return to their natural oxide form (Ammal *et al.*, 2017). There are many factors that affect corrosion. For example; with biofilm formation, corrosion is occurring (Cordas *et al.*, 2008).

Various methods have been applied to prevent inhibit corrosion. These methods typically include: Use of alloys in place of pure metal, improvement of metal plating (organic or inorganic), improvement of metal design (avoiding excessive stress, minimizing indentation), electrochemical protection (anodic protection, reduced temperature, reduced speed liquid, removing oxygen from the environment, reduced the concentration of the solution, use of corrosion inhibitors) etc. applications (Çek, 2014, Cicek, 2017). Corrosion applications are galvanic cell of one example. The type of corrosion that occurs in the galvanic cell is called as galvanic corrosion. The galvanic cell basically consists of the anode electrode, cathode electrode and an electrolyte (water, moisture, ionic liquid etc.). Galvanic corrosion is perceptible in heat exchangers, pipelines, cooling towers, and in each status in which two different metals materials come in contact in the presence of water or moisture (Shi *et al.*, 2012; Hasan, 2014, Cicek, 2017). Example; in the study conducted by Çek (2014), corrosion of copper in the aqueous medium was prevented by using vaseline. Therefore, galvanic corrosion in copper is inhibited. Vaseline is an organic material obtained from petroleum and is often used to heal wound (Çek, 2014; Bhupinder and Manju, 2015).

In the galvanic cell, voltage and current generated values by anode and cathode electrodes are an important parameter affecting corrosion. The use of materials with minimum potential (voltage) differences would minimize corrosion in a galvanic cell. In addition, low current (ampere) production in the galvanic cell reduces usually corrosion (Taher and Al Jabab, 2003). Galvanic corrosion is one of the major problems to the use of zinc materials in the industry. During the galvanic corrosion process of zinc's, the zinc ions react and precipitate in the form of oxides or hydroxides (Song *et al.*, 2004). Therefore, detailed information about the time-dependent galvanic corrosion of the zinc materials should be obtained. In this study for this purpose, the zinc as anode electrode the copper as the cathode electrode and ionic conductive water as the electrolyte was used. The corrosion effect of the anode and cathode electrodes was studied based on time dependent voltage and current measurements on the galvanic cell.

2. MATERIALS AND METHOD

2.1. Materials

Materials and apparatus properties were as follows. Zinc (Zn) plate electrodes; 99.9% purity, 3.060 grams, each electrode has 4 cm length and 4.5 cm wide. Copper cylinder rod electrodes; 99.9% purity, 3 grams, 8 cm length, 0.75 cm diameter. Digital multimeter (UNI-T: UT61C) was used to make for direct current and voltage measurements. Resistance, 980 ohm (Ω). Digital pH meter (616.0.001, ISOLAB). Sensitive Scale (PKS 360-3, KERN). Plastic box shaped like a truncated cone (4 cm bottom diameter, 7 cm ceiling diameter, 8 cm diameter) and the empty volume of the plastic box chamber was 191.68 cm^3 (191.68 milliliter (mL)). Water is pH value about at 7.65 and it content includes sodium (Na), potassium (K), magnesium (Mg), calcium (Ca) cations and fluorine (F), chlorine (Cl), sulphate (SO_4) anion.

2.2. Method

Weight (gram (g)) measurements are made with the precision weighing instrument (Sensitive Scale). Weight measurements were made before and after use of the electrodes of the galvanic cell. The total surface area (191.68 cm^3) of the plastic box has about at 191.68 mL water intake capacity. After, zinc as anode electrode and copper as cathode electrode was used in the plastic box. Therefore, galvanic cell was designed.

The galvanic cell was subjected to daily electrical measurements according to resistance-dependent and non-resistance-related conditions. In addition, oxide layer in manufactured galvanic cell, the time-dependent states of the anode and cathode electrodes, corrosion etc. factors have been detected. Discussions were held in regard to the formation, development and effects of these factors on the system. In this study, galvanic cell model is shown in Fig. 1.

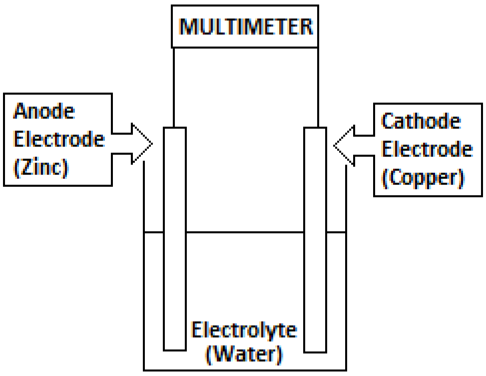

Fig. 1. Galvanic cell model of in this study

3. RESULTS AND DISCUSSION

As the zinc plate (-) load electrode and as the copper cylinder rod (+) load electrode the worked. This situation was detected by the multimeter. Without external load (resistance) on galvanic cells are open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) values measured by the multimeter. Volt (V_R) and current (I_R) values were measured by multimeter while the galvanic cells were connected to the external load (resistance). Resistance is not constantly connected to the galvanic cell; it is only connected during measurements. Time-dependent electrical generation values of galvanic cells are in shown in Table 1.

Table 1. Electrical measurements of first type galvanic cell

Time (Day)	V_{OC} (mV)	I_{SC} (μA)	V_R (mV)	I_R (μA)
1	360	33	2	3
2	180	14	1	1
3	181	1	0.5	0.5
4	152	0.5	0.2	0.3
5	67	0.3	0.2	0.2
6	60	0.2	0.1	0.1

According to Table 1, the zinc anode initially experienced a very rapid galvanic corrosion process. The rate of galvanic corrosion decreased with time in the zinc anode. Therefore, electrical (V_{OC}, I_{SC}, V_R and I_R) values decreased. The change in electrical values is evidence of galvanic corrosion. According to Table 1, the current values increase as the voltage values increased. In addition, the corrosion of the anode zinc electrode occurs whether or not it is resistance. But, the corrosion state is different when there is resistance and when there is no resistance. After 6 days, the colorless water was red colored and a red precipitate was observed under the plastic box (Fig. 4.). Due to galvanic corrosion of zinc anode, white rust first film layer formed and then red rust film layer formed. The zinc anode electrode image in the first 6 days is shown in Fig. 2.

Fig. 2. The zinc anode state in the first 6 days

Upon this, the water in the plastic box was drained, the plastic container was cleaned with clean water, and the plastic container was re-filled with clean water. Electrical measurements were made again and the results similar to the results (±10 mV of V_{OC}, ±10 μA of I_{SC}, ±0.05 mV of V_R, ±0.05 μA of I_R) in Table 1 were obtained. Observations made the additional 6 days more the first 6 days showed that the area covered by the oxide film layer increased and that red precipitate accumulated at the plastic box.

At the end of all these 12 days, the zinc anode electrode was removed from the galvanic cell, it was washed with clean water and dried in the environment (1 hour) and weigh measurement was made. At the end of 12 days, zinc anode electrode weight (W_{finish}) was measured as 3.030 gr.

Fig. 3. The zinc anode status in the second 6 days (total 12 days)

The electrodes on the galvanic cell and the appearance of red colored water (electrolyte) are shown in Fig 4.

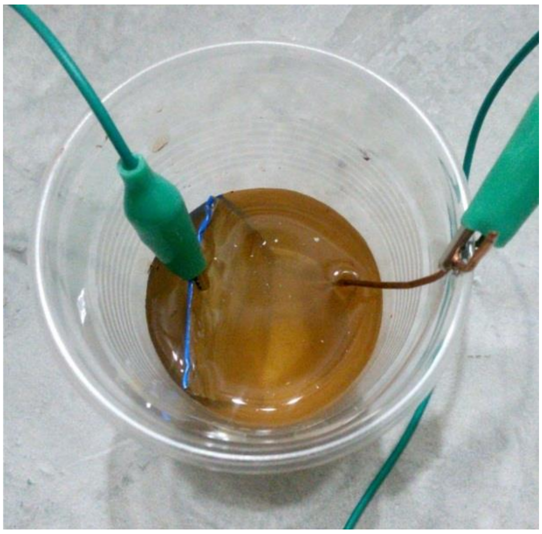

Fig. 4. The electrodes and electrolyte on the galvanic cell

The oxide layer dominates more area in Fig. 3 than Fig. 2.

Weight loss is the proof of corrosion and corrosion rate (CR) is measuring to the formula in Equation (1) (Ammal *et al.*, 2017; Tribak *et al.*,2017)

$$CR=\frac{W}{A.t} \tag{1}$$

Where, W is the difference between starting weight (W_{start}) and end weight (W_{finish}), A is the surface area of immersed anode metal and t is time (hours) of application. In this study; W_{start} is 3.060 grams, W_{finish} is 3.030 grams, W_{change} is 0.030 g (30 mg), A is 18 cm^2, t is 288 hours (12 days). The corrosion rate (CR) in this study is calculated in Equation (2).

$$CR=\frac{\mathbf{30}}{\mathbf{18.288}}=0.005\ \text{mg/cm}^2\text{h} \qquad (2)$$

Another issue to be taken into account in corrosion rate calculations is current density. Current density is shown in Equation (3).

$$\text{Current density}=\frac{\textbf{Ampere (A)}}{\textbf{Anode surface area (cm}^{\mathbf{2}}\textbf{)}} \qquad (3)$$

In this study, current density is shown in Table 2.

Table 2. In this study current density

Time (Day)	Current density (not resistance)	Current density (Resistance connect)
1	18.33x10^{-7}	1.66x10^{-7}
2	7.77x10^{-7}	0.55x10^{-7}
3	0.55x10^{-7}	0.27x10^{-7}
4	0.27x10^{-7}	0.16x10^{-7}
5	0.16x10^{-7}	0.11x10^{-7}
6	0.11x10^{-7}	0.05x10^{-7}

According to literature as the current density increases, the corrosion rate (CR) increases (Bardal, 2007). The corrosion rate due to current density is calculated as in Equation (4).

$$CR=\frac{\mathbf{I.M}}{\mathbf{z.F.p}}\ \text{cm/s} \quad \text{(Bardal, 2007)} \qquad (4)$$

Where, I is current density (µA/cm^2), M is mol mass of the anode (65.38 g/mol atom of Zn), z is number of electrons in the reaction equation for the anodic reaction (dissolution reaction) (per atom of the dissolving metal) (2e$^-$ of Zn), F is Faraday constant (96485 C/mol e$^-$), p is density of anode (7.14 g/cm^3 of Zn), Using the equation (4), the data in Table 3 was obtained.

Table 3. Corrosion rate (CR) due to current density

Time (Day)	CR (cm/s) (not resistance)	CR (cm/s) (resistance connect)
1	8.69x10^{-11}	7.88x10^{-11}
2	3.68x10^{-11}	2.63x10^{-11}
3	2.63x10^{-11}	1.28x10^{-11}
4	1.28x10^{-11}	0.75x10^{-11}
5	0.75x10^{-11}	0.52x10^{-11}
6	0.52x10^{-11}	0.27x10^{-11}

A constant corrosion rate is desirable for the calculations to be the healthy and long term. However, as shown in Table 3, the corrosion rate in this work is not constant.

The annual corrosion rate is calculated using Equation (5).

$$CR=3268\frac{\mathbf{I.M}}{\mathbf{z.p}}\ \text{mm/year} \quad \text{(Bardal, 2007)} \qquad (5)$$

Since the corrosion current and the current density are not constant, an annual corrosion rate (CR) scenario is established for each current and current density obtained. The annual corrosion rates of the different electrical values according to different days are given in Table 4.

Table 4. In this study corrosion rate (CR) scenario of year

Time (Day)	CR (mm/year) (not resistance)	CR (mm/year) (Resistance connect)
1	0.02742	0.00248
2	0.01162	0.00082
3	0.00082	0.00040
4	0.00040	0.00023
5	0.00023	0.00016
6	0.00016	0.00007

According to the table 4, the corrosion rate is reducing daily. If the galvanic cell was regularly maintained at the initial current intensities, the annual corrosion rate (CR) obtained would be 0.02742 mm/year without resistance and 0.00248 mm/year with resistance. The lowest corrosion rate was achieved on the 6th day. If the galvanic cell was regularly maintained at the 6th day current intensities, the annual corrosion rate (CR) obtained would be 0.00248 mm/year without resistance and 0.00007 mm/year with resistance.

5. CONCLUSION

The zinc anode electrode is not a material that can withstand long-term corrosion. The cathode electrode is protected until the anode electrode is depleted. During this time the copper cathode electrode is not affected corrosion by values measurable.

The formation of the oxide film (rust) on the surface of the zinc anode electrode has been increased with the decrease of voltage and current values at the galvanic cell. After 6 days the electrolyte (water) of the galvanic cell was renewed. The materials precipitate under the plastic box and the rust in the face of the anode were cleaned away with clean water. However, current and voltage values approaching to their first state. But, the current and voltage values are reducing again due to rust formation on the zinc anode electrode surface. This shows that the oxide film (rust) layer reduces the corrosion rate.

One of the important findings obtained in this study is that the current increases as the voltage increases and the current decreases as the voltage decreases. The corrosion rate increases as the current and current density increase (Bardal, 2007). In addition to this, in this study, it has been determined that the voltage values and the corrosion rate (CR) are directly proportional.

Adding on the galvanic cell of electrical resistance has also reduced and slowed down the corrosion as it reduces voltage and current. This is a positive finding. Use of electrical resistance to reduce the negative effects of corrosion on places such as galvanic cells will be a useful application.

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