



The Magnetic Field Effect on the Electrochemical Oxidation Behavior of Aluminum in 3.5% NaCl solution

Surya Darma^{1*}, Sukarno Sukarno², Bambang Soegijono³, Hamdan Akbar Notonegoro⁴, Naila Mubarok⁵

¹Department of Physics, Universitas Indonesia, Depok 16424, Indonesia.

²Geophysics Study Program, Faculty of Mathematics and Natural Science, Universitas Indonesia, Depok 16424, Indonesia.

³Geology Study Program, Faculty of Mathematics and Natural Science, Universitas Indonesia, Depok 16424, Indonesia.

⁴Department of Mechanical Engineering, Universitas Sultan Ageng Tirtayasa, Cilegon 42435, Indonesia.

⁵PT. Inti Terra Prima, Jl. Kejaksaan 1 No.50, Pd. Bambu, Kota Jakarta Timur 13430, Indonesia.

*Corresponding author: suryadarma@sci.ui.ac.id

ARTICLE INFO

Received 25/04/2022
revision 18/06/2022
accepted 04/07/2022
Available online 08/07/2022

ABSTRACT

An irreversible electrochemical reaction from material interaction with the environment and causing degradation is known as corrosion. The electrolyte changes significantly affect the corrosion's reaction kinetics. Unknown factors and various notable factors influence the corrosion rate of a particular material in the environmental system. Significant interest in magnetic fields and their effects on electrochemical reactions have recently been gained. This paper studies the effect of an external magnetic field on the electrochemical oxidation of Aluminum (Al) in a 3,5% NaCl solution. The magnetic field 0; 0,8; 1,4; and 2,1 Tesla were used to expose the samples during corrosion testing. We found that the effect of a magnetic field on electrochemical oxidation shifts the oxidation potential to higher or lower than the oxidation potential without a magnetic field. Moreover, the oxidation potential's value depends on the magnetic field's intensity.

Keywords: Corrosion, Magnetic Field, Aluminum, Electrochemical Oxidation

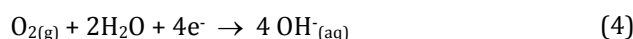
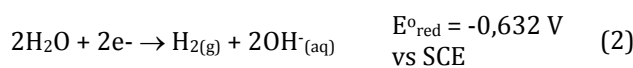
1. INTRODUCTION

An irreversible electrochemical process that causes the degradation of a material due to its interaction with the environment is known as corrosion. As the environment is like an electrolyte, the electrolyte changes significantly affect the corrosion reaction kinetics [1,2].

In the corrosion process, ions and electrons are involved between the anode and the cathode. This process occurs due to potential differences in the environment/ materials interface. During metal corrosion in a solution, anodic dissolution and reduction of oxidants are present in the solution. Anodic reaction involved in the electrochemical test is,



Five possible cathodic reduction reactions and its reduction potential versus standard calomel electrode (SCE) is,



The redox reactions equation above rate involves the movement of electrons and ions equivalent to electric currents. The biggest challenge in most industries is Corrosion control.

Unknown factors and various notable factors influence the corrosion rate of a particular material to the environmental system. The Magnetic field's effect on electrochemical reactions has recently gained interest.

Magnetic fields may affect electrochemical reactions, such as mass transport rates, for metallic materials in aqueous solutions [3–7]. Numerous reports have also been published on the effects of magnetic fields, such as the electron transfer process in solution-electrode systems [8–11].

The most probable effect of a magnetic field on an electrochemical reaction system is the introduction of additional forces on the ions in the electrolyte solution [12–15]. Lorentz force driven known as MHD (Magnetohydrodynamics) is one the most discussed generally accepted. the recent studied and most documented research in respect to the magnetic field effects of on the electrochemical behaviour of metals and their alloys are Lorentz force, paramagnetic gradient force, and forces driven convection

Therefore, the effect of a material subjected to an aggressive environment under a magnetic field can be expected compared to the corrosion rate when it is not affected by a magnetic field [16–18]. The shifting corrosion potential value may also be expected when comparing the influence of a magnetic field and a free magnetic field condition, which supports the result of the previous research [19–21].

This paper studies how an external magnetic field affects the electrochemical oxidation of Aluminium (Al) materials under 3,5 % NaCl solution. The magnetic field 0; 0,8; 1,4; and 2,1 Tesla were used to expose the samples during corrosion testing.

2. METHODOLOGY

2.1. Materials

Pure aluminum (99,9%wt) from the commercial product was used for the corrosion test. The samples have a diameter of 1 x 1 cm² and a thickness of 1 mm. The surfaces were polished before the electrochemical oxidation test in 3,5% NaCl solution. Magnetic permanent with various magnetic field intensities was used 0; 0,8; 1,4; and 2,2 Tesla. The samples were named Al-0T, Al-1T, Al-2T, and Al-3T, respectively. The permanent magnetic material was placed on one side of the sample's surface. The magnetic field is applied perpendicularly across the sample surface.

2.2. Linear Sweep Voltametry (LSV)

We used A potentiostat (DY2311, Digi-Ivy), and the LSV method was used to test the corrosion

behavior of the samples. The curve current versus potential was obtained from the experiment. The experiment was carried out at room temperature. Three-electrode systems were used to carry out the LSV measurement of the samples in a glass containing 250 mL of 3,5 % NaCl. We used a 10 mV·s⁻¹ scan rate between -2 volt and 0 volt to an exposed surface area of 1×1 cm, and the magnetic permanent was placed behind the exposed sample.

An electrode silver chloride (Ag/AgCl) was used as a reference electrode, and platinum was used as the counter electrode. The testing was obtained with and without the influence of an external field of 0; 0,8; 1,4; and 2,2 Tesla. The samples were named Al-0T, Al-1T, Al-2T, and Al-3T, respectively.

The resulted data were used to study and analyze the corrosion behavior. Comparing the result of both conditions depicts the effect of an external field on the corrosion potential and current.

3. RESULTS AND DISCUSSION

3.1. X-ray diffraction

The X-ray diffraction pattern in Figure 1 shows the relation between intensity and the diffraction angle. It describes the crystal planes of the materials. The peak position corresponds to the distance between each crystal plane.

Table 1. Crystal parameter for all samples.

Parameters	Al-0	Al-1	Al-2
Crystallite System	Cubic	Cubic	Cubic
a=b=c (Angstrom)	4,05	4,05	4,05
Volume (Angstrom)	66,41	66,38	66,38

Figure 1 shows the cubic face center of Aluminum phases detected for all samples. The crystal parameter of those crystallite structures can be seen in Table 1. The differences among the samples are the height intensity and the position of the shifting peaks. That shifting might come from the surface stress due to the aluminum atom on the surface reacting with the environment, such as dissolved oxygen or a hydroxyl ion.

As oxygen is a paramagnetic species, a magnetic field's presence might affect the kinetic reaction. The presence of reaction product on the sample might influence the surface stress or strain detected by x-ray diffraction. Figure 1 shows the x-ray diffraction pattern of the samples. The peak height and position change as the magnetic field intensity change (Figure 1 and Figure 2, respectively). It shows that the peaks shift to the

right and then back to the left as the magnetic intensity increase.

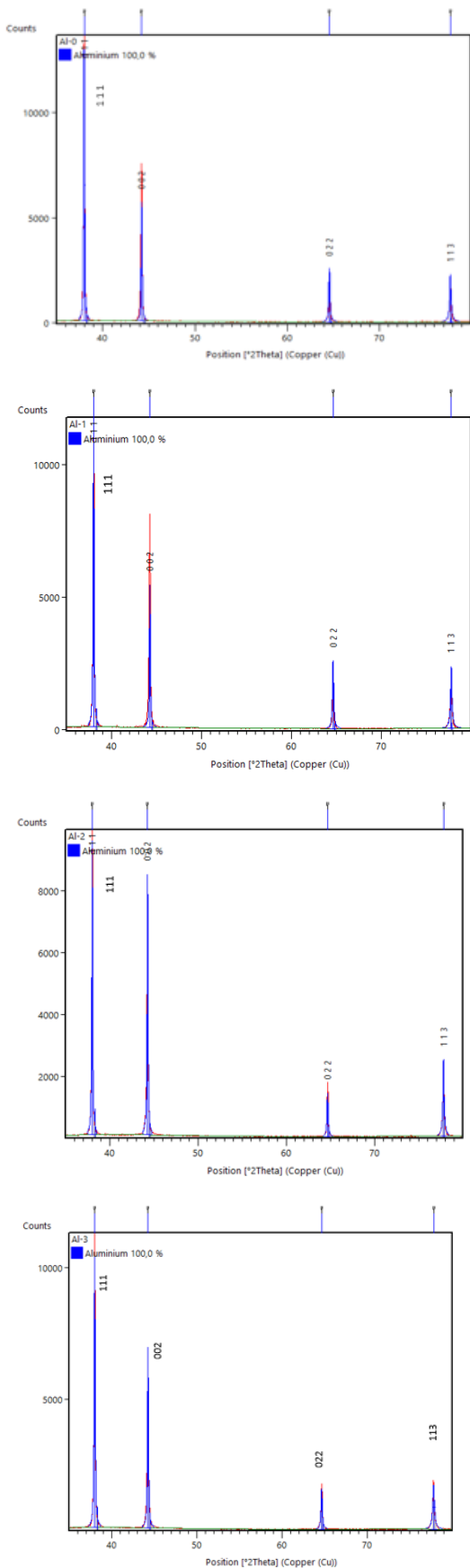


Figure 1. X-ray diffraction pattern of a) Al-0T, b) Al-1T, c) Al-2T, and d) Al-3T.

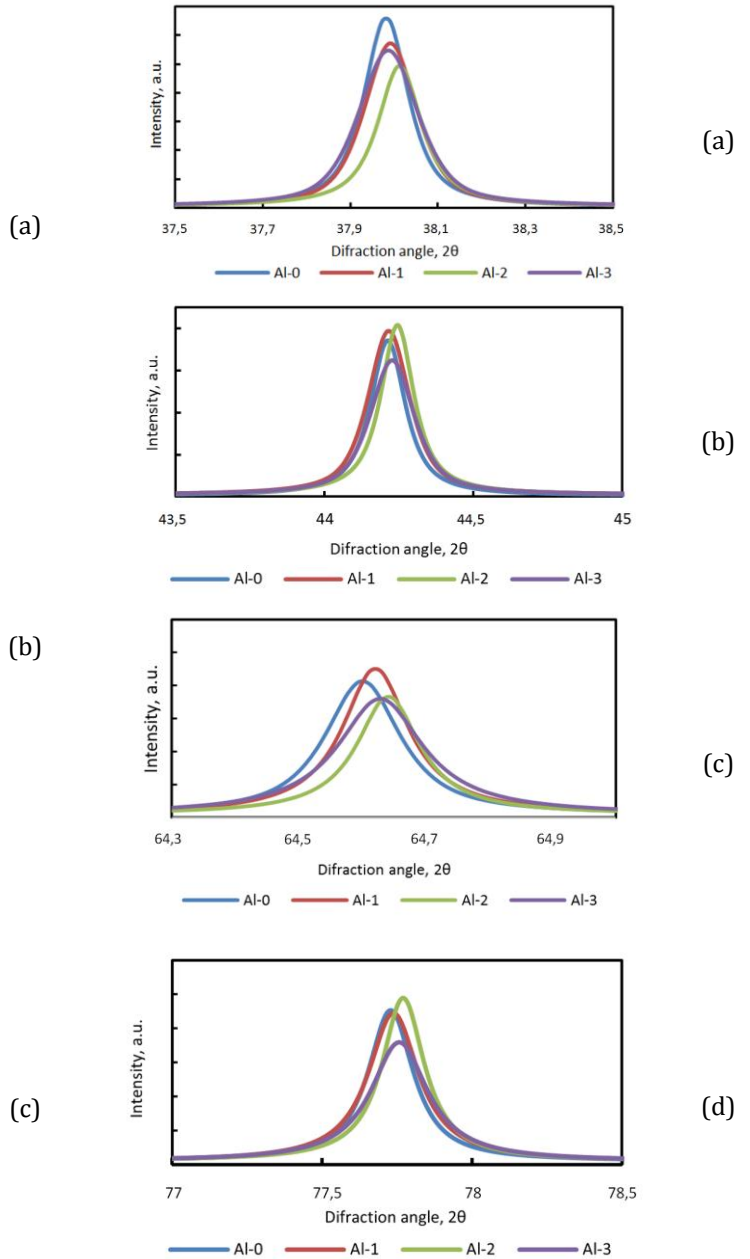


Figure 2. The height intensity and peaks position of a). peak (111), b) peak (002), c) peak (022), and d) Peak (113).

Figure 2 describes the change in peak height and shift in peak position due to magnetic field during corrosion testing. The change in peak height looks significantly different at the crystal plane (111). The height of the three rest of the peaks did not seem different. The change in peak height is usually accompanied by the change in Full width at half maximum (FWHM). Since the crystallite size depends on FWHM, the crystallite size and micro-strain were changing. This condition can be seen in the parameter shifts in the crystal planes to the micro-strain values shown in Table 2.

Table 2. Crystallite size and micro-strain of each crystal plane for all samples.

Crystal plane	Sampel	plane (111)	plane (002)	plane (022)	plane (113)
Crystallite size (nm)	Al-0	125	79	88	60
	Al-1	81,5	62	86	48
	Al-2	101	81	94	61
	Al-3	64	56	59	41
Micro-strain	Al-0	0,09	0,13	0,08	0,10
	Al-1	0,14	0,16	0,08	0,13
	Al-2	0,11	0,13	0,07	0,10
	Al-3	0,18	0,18	0,12	0,15

3.2. Linear Sweep Voltametry (LSV)

Figure 3 shows the Tafel plot of the samples. Tafel plot describes the oxidation potential and its related current. The Tafel plot was obtained from the relation of the current versus potential. In the Tafel plot, the log current versus potential.

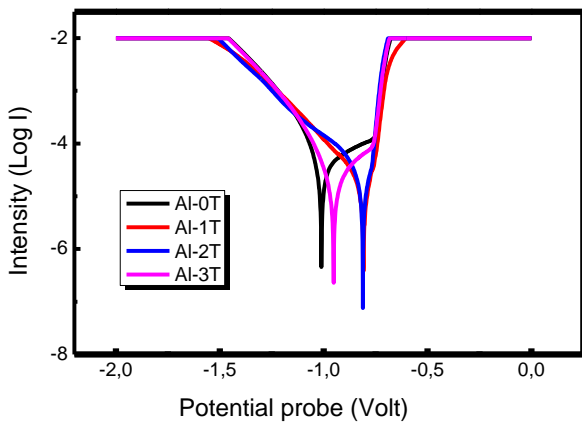


Figure 3. Tafel plot of the samples showing how the magnetic field affects the oxidation potential.

Increasing the magnetic field intensity shifts the oxidation potential to the higher potential and then back to the lower potential. The value of the oxidation potential and its current are shown in Table 3. Column 3 of Table 3 shows the resistance decrease markedly from 86,8 x 103 ohm to 1,36 x 103 ohm. Besides the oxidation potential and its current, the passivation region looks strongly influenced by the presence of the magnetic field. Table 3 also shows the change in oxidation potential, and its current strongly corresponds to the change in magnetic field intensity.

Table 3. E_{corr} , I_{corr} and Resistance of the samples.

Samples	E_{corr} (Volt)	I_{corr} ($10^{-5}A$)	R (10^3 ohm)
Al-0T	-1,011	2,98	86,3
Al-1T	-0,809	1,58	1,63
Al-2T	-0,811	1,88	1,36
Al-3T	-0,952	1,51	1,70

From the literature, the magnetic field effects of the metals corrosion behavior are still debatable. Several authors have published that magnetic fields decrease the oxidation potential of metals [6,7].

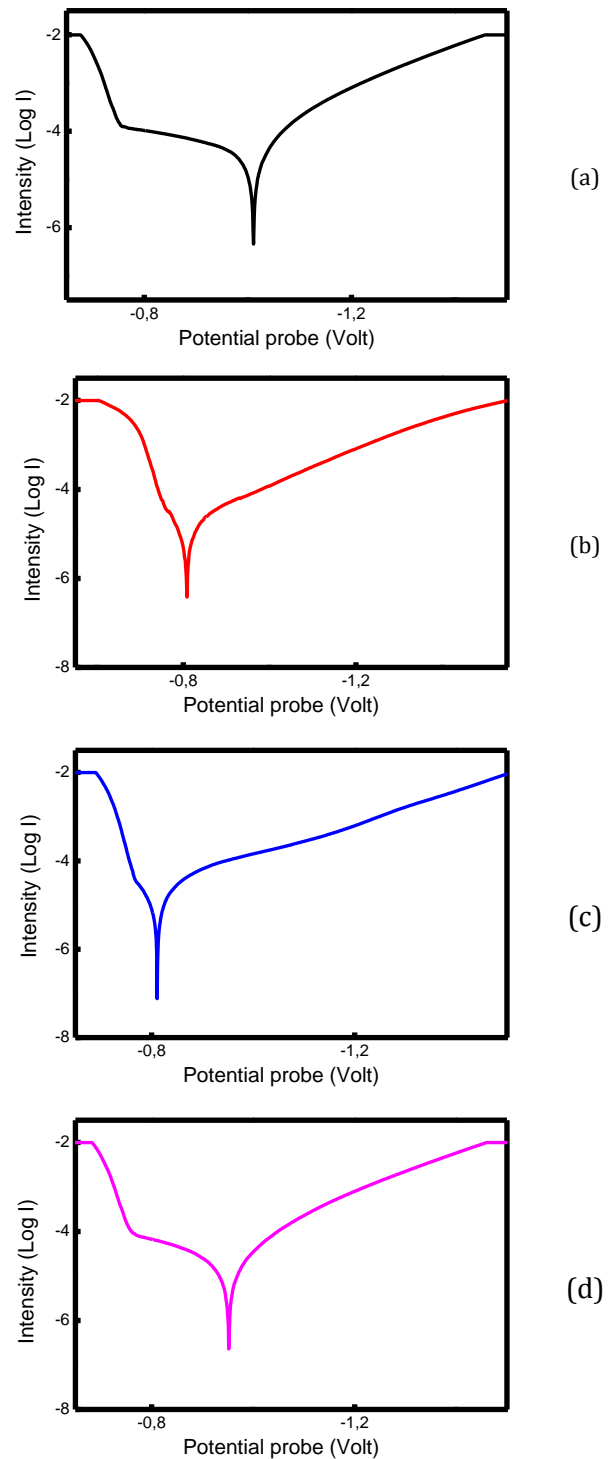


Figure 4. The Tafel plot of each samples showing the drastically change of the passivation region of a) peak (111), b) peak (002), c) peak (022), and d) Peak (113).

Figure 4 shows the magnetic field intensity changes the significant value of the passivation region; by increasing the magnetic field intensity,

the passive region change and then back again. These results agree with other research showing that the oxidation potential increases and decreases as the magnetic field intensity increases. The change in the value depends on the value of the magnetic field intensity.

4. CONCLUSION

This study shows that the magnetic field effect on electrochemical oxidation shifts the oxidation potential to higher or lower than the oxidation potential without a magnetic field. The oxidation potential's value depends on the magnetic field's intensity. The crystallite size and microstrain tend to change as the magnetic field increase. The x-ray diffraction peaks shift due to exposure to different magnetic field intensities.

ACKNOWLEDGMENTS

The authors are grateful to all who have given financial support for this research.

REFERENCES

- Jones DA. Principles and Prevention of Corrosion. 2nd ed. Singapore: Macmillan Publishing Company; 1992.
- Aaboubi O, Chopart JP, Douglade J, Olivier A. Magnetic Field Effects on Mass Transport. *J Electrochem Soc.* 1990;137(6):1796–804.
- Tacken RA, Janssen LJJ. Applications of magnetoelectrolysis. *J Appl Electrochem.* 1995;25:1–5.
- Aogaki R, Fueki K, Mukaibo T. Application of Magnetohydrodynamic Effect to the Analysis of Electrochemical Reactions—1. MHD Flow of an Electrolyte Solution in an Electrode—Cell with a short Rectangular Channel. *Denki Kagaku oyobi Kogyo Butsuri Kagaku.* 1975;43(9):504–8.
- Rucinskiene A, Bikulcius G, Gudaviciute L, Juzeliunas E. Magnetic field effect on stainless steel corrosion in FeCl₃ solution. *Electrochem commun.* 2002 Jan 1;4:86–91.
- Chiba A, Tanaka N, Ueno S, Ogawa T. Inhibition by Magnetic Fields of the Corrosion of Iron in Sodium Chloride Solution. *Zairyo-to-Kankyo.* 1992;41(5):287–92.
- Zhang X, Wang Z, Zhou Z, Yang G, Cai X. Intermetallics Impact of magnetic field on corrosion performance of Al – Mg alloy with different electrode potential phases. *Intermetallics* [Internet]. 2021;129:107037. Available from: <https://doi.org/10.1016/j.intermet.2020.107037>
- Chopart JP, Douglade J, Fricoteaux P, Olivier A. Electrodeposition And Electrodisolution Of Copper With A Magnetic Field: Dynamic And Stationary Investigations. *Electrochim Acta.* 1991;36(3-4):459–63.
- Chia-Chien L, Chou T-C. Effects of magnetic field on the reaction kinetics of electroless nickel deposition. *Electrochim Acta* [Internet]. 1995;40(8):965–70. Available from: <https://www.sciencedirect.com/science/article/pii/013468695000072>
- Shinohara K, Aogaki R. Magnetic Field Effect on Copper Corrosion in Nitric Acid. *Electrochemistry.* 1999;67:126–31.
- Hinds G, Coey JMD, Lyons MEG. Magneto-electrolysis of copper. 1998;6447:81–4.
- Costa I, Oliveira M, De MHG, Faria RN. An Investigation on the Corrosion Behaviour of Nd-Fe-B Magnets in a Chloride Solution. *Mater Sci Forum.* 2005;498-499:98–103.
- Hayashi H, Nonaka C, Tozaki K, Inabaa H, Uyeda C. Effect of the magnetic field on the ferroelectric transition of KD 2 PO 4 measured by a high resolution and super-sensitive differential scanning calorimeter. *Thermochim Acta.* 2005;431:200–4.
- Grant K, Hemmert J, White H. Magnetic focusing of redox molecules at ferromagnetic microelectrodes. *Electrochem Commun - Electrochem COMMUN.* 1999;1:319–23.
- Zhang H, Li X, Pang J, Yin L, Ma H, Li Y, et al. Non-monotonic influence of a magnetic field on the electrochemical behavior of Fe₇₈Si₉B₁₃ glassy alloy in NaOH and NaCl solutions. *Int J Miner Metall Mater.* 2014;21(10):1009–18.
- Yang Y, Luo Y, Sun M, Wang J. Effect of Magnetic Field on Corrosion Behavior of X52 Pipeline Steel in Simulated Soil Solution. *Int J Electrochem Sci.* 2021;16:211010.
- Dearnley PA, Mallia B. The chemical wear (corrosion-wear) of novel Cr based hard coated 316L austenitic stainless steels in aqueous saline solution. *Wear* [Internet]. 2013;306(1-2):263–75. Available from: <http://dx.doi.org/10.1016/j.wear.2012.09.002>
- Brondel D, Edwards R, Hayman A, Hill D, Semerad T. Corrosion in the Oil Industry. :4–69.
- Pondichery S. A Study On The Effects Of A Magnetic Field On The Corrosion Behavior Of Materials. The University Of Texas At Arlington; 2014.
- Okonkwo PC, Adel MMA. Erosion-Corrosion In Oil And Gas Industry: A Review. *Int J Metall Mater Sci Eng.* 2015;4(3):7–28.
- Fan ZD, Du JS, Zhang ZB, Ma YC, Cao SY, Niu K, et al. Internal leakage of plate heat exchangers caused by cooperation of pitting, crevice corrosion, and fretting. *Eng Fail Anal* [Internet]. 2019;96:340–7. Available from: <https://doi.org/10.1016/j.engfailanal.2018.10.007>