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Study of the Interaction Between Magnetic Field and Imposed Potential on the Corrosion of AA6060 Aluminum Wire

Rabeh Slimani[a]***, Rabah Boubaaya***[b,c]****, Mokhtar Djendel***[b,c]***, Abdelkader Becheikh***[a]

[a]*University of Mustapha Stambouli, Department of Mechanical Engineering, Laboratory of Mechanics, Structure & Energy (LMSE), Mascara, Algeria.*
[b]*University Mohamed El Bachir El Ibrahimi of Bordj Bou Arreridj, Science and Technics Department, Bordj Bou Arreridj, Algeria.*
[c]*University of Amar Telidji, Laboratory of Process Engineering, Laghouat, Algeria.*

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AA6060 aluminum is an alloy widely used in the electrical and marine industries. However, its corrosion resistance can be compromised in certain aggressive environments. This study examines the combined effect of magnetic field and imposed potential on the corrosion of AA6060 aluminum wire in seawater. Electrochemical tests and surface analyses were carried out in free immersion, in the presence of a magnetic field, under an imposed potential, and in the simultaneous presence of a magnetic field and an imposed potential. The corrosion kinetics and the mechanisms involved were analyzed by mass loss measurements and microscopic observations.

Keywords: *Corrosion, aluminum AA6060, magnetic field, imposed potential, oxide film, metal ions, electrochemical reactions, synergistic effect.*

1. Introduction

AA6060 aluminum is an aluminum alloy widely used in the aerospace, automotive, construction, and marine industries due to its strength, formability, and corrosion resistance. However, like all aluminum alloys, it is susceptible to corrosion in certain environments[1-9]. The corrosion of AA6060 aluminum is influenced by several factors, including: Alloy composition: The composition of the alloy can affect its corrosion resistance. For example, aluminum alloys containing copper or magnesium are more susceptible to corrosion than those that do not. Environment: The environment in which the aluminum is used is a major factor in corrosion. Aluminum is more likely to corrode in acidic, salty, or humid environments. Surface treatment: The surface treatment of aluminum can affect its corrosion resistance. For example, anodizing is a surface treatment that can improve the corrosion resistance of aluminum[10-17]. The influence of magnetic fields on the corrosion of metals has been an active area of research for several decades[18,19]. Studies have shown that magnetic fields can affect corrosion in various ways, including: Disruption of the protective oxide film: The magnetic field can disrupt the structure and growth of the natural oxide film on the metal surface, making it more permeable to aggressive ions and promoting corrosion[20,21]. Increased concentration of metal ions: The magnetic field can influence the migration of metal ions in the solution, increasing the concentration of ions at the metal surface and promoting anodic dissolution[22,23]. Acceleration of electrochemical reactions: The magnetic field can influence the electrochemical reactions at the metal surface, increasing the rate of dissolution and the formation of corrosion products[24,25]. Imposed potential is an electrochemical technique widely used to study the corrosion of metals. By applying an external potential to the metal surface, it is possible to accelerate the electrochemical reactions of corrosion and to evaluate the corrosion kinetics as a function of the applied potential[26-28]. The combined effect of magnetic field and imposed potential on the corrosion of metals has been studied by several researchers[29-40]. It has been observed that, in some cases, the magnetic field and the imposed potential can have a synergistic effect, increasing the corrosion rate more significantly than the simple addition of their individual effects[41-49].

*e-mail: rabah.boubaaya@univ-bba.dz

2. Experimental Procedure

The substrate is the circular surface and the central longitudinal surface of the AA6060 aluminum wire with a diameter of 1.2 mm. It was exposed to a seawater solution (pH = 8.018) at a temperature of 26±2°C. Different electrochemical tests were performed to evaluate the corrosion kinetics in the presence and absence of a weak magnetic field (45 mT) and an imposed potential (1.5 V). The working electrode consisted of a copper electrical conductor assembled with the AA6060 aluminum wire sample with a section of 1.13 mm2 and a roughness Ra = 0.33 µm. The reference electrode used is the Ag/AgCl electrode with a standard potential E° = 0.223 V. The observation and image analysis of the samples are carried out by an optical microscope (OM) before and after corrosion. These optical microscopy analysis techniques are essential for exploring the combined effects of the magnetic field and the imposed potential on the corrosion processes. Through meticulous sample preparation, observation of morphological changes in corrosion, and examination of the influence of the magnetic field, their understanding of the complex interaction between these factors in corroded materials can be deepened. The chemical composition of this wire is given by Table 1.

3. Results and Discussion

3.1. Porosity (%)

The microstructure of the polished and unetched samples in Figure 1a and Figure 2a, illustrates the section and the central longitudinal surface, respectively, of the AA6060 aluminum wire. These samples reveal the presence of fine black spots, which become more visible after immersion in Keller's reagent and represent intermetallic particles that have undergone corrosion on their contours as depicted in Figure 1b and Figure 2b, respectively, for the section and the central longitudinal surface of the AA6060 aluminum wire.

3.2. Microhardness (HV)

Table 2 shows the Vickers microhardness measurements on the longitudinal surface of the aluminum wire at different

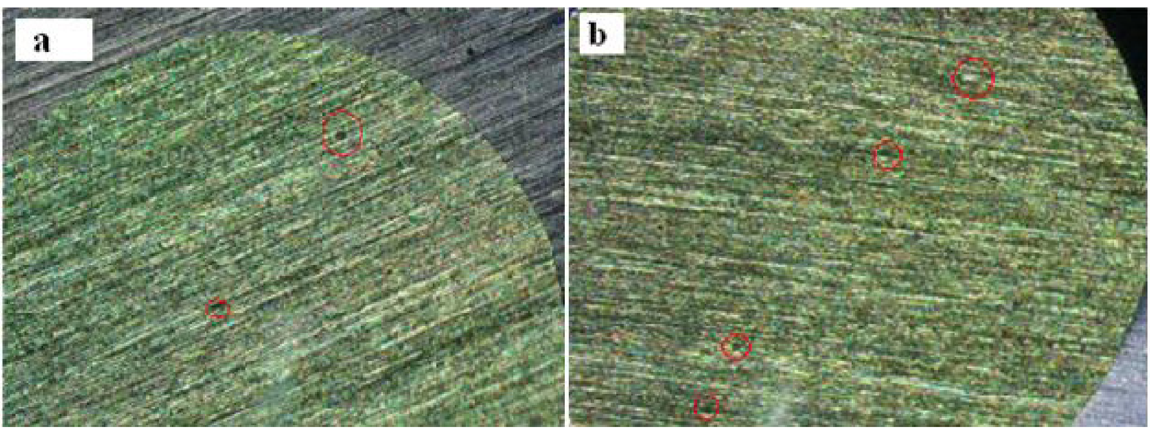

Figure 1. The section of the AA6060 aluminum wire, a) before corrosion for a polished sample, b) after immersion of a polished and unetched sample in Keller's reagent.

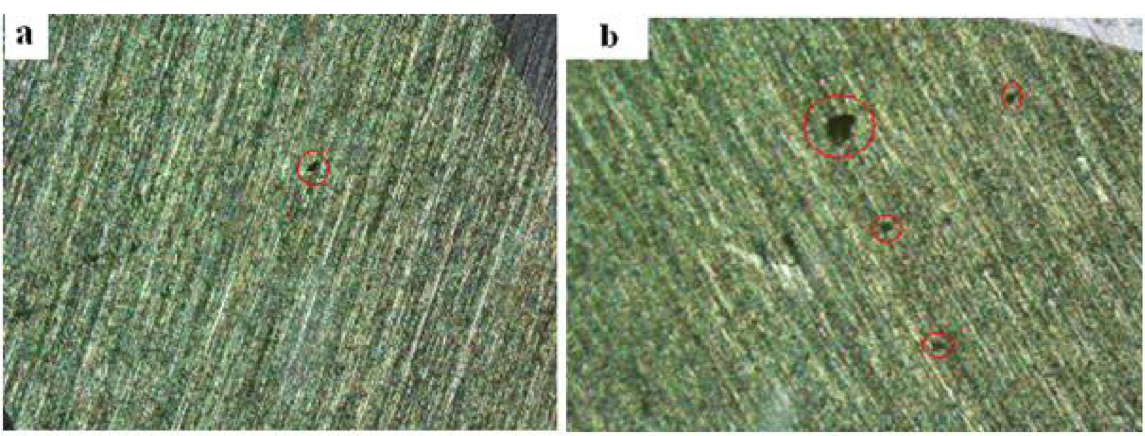

Figure 2. The central longitudinal surface of the AA6060 aluminum wire, a)before corrosion for a polished sample, b)after immersion of a polished and unetched sample in Keller's reagent.

Table 1. Chemical composition of the studied aluminum.

Wt %	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA6060	0.40	0.20	0.11	0.11	0.42	0.05	0.15	0.10	balance

Table 2. Microhardness of the studied longitudinal aluminum surface.

Distances from the surface of the aluminum wire (µm)	45	55	65	76	80	1000
Microhardness (HV)	18,92	12,71	12,13	24,18	33,91	31,65

distances show that the hardness of the material varies depending on the direction.

The results of Figure 3 show that the immersion of the section of the studied aluminum wire in seawater for 24 hours causes its corrosion. In (a) free immersion, a few small corrosion pits are observed on the surface of the wire. In the presence of a magnetic field (b), the microstructure of the aluminum wire is more corroded than in (a), with larger and deeper corrosion pits. In (c) “imposed E = 1.5V”, the microstructure of the aluminum wire is even more corroded than in image (b), and the corrosion is uniform over the entire surface of the wire. The application of a potential of 1.5V in the presence of a magnetic field (d) is the most corrosive condition for the aluminum wire, with large cracks and areas of deep corrosion being more pronounced at the edges of the wire.

The immersion of the central longitudinal surface of the AA6060 aluminum wire (Figure 4) causes its corrosion, which is more pronounced in the presence of a magnetic field (b) and/or an imposed potential. The application of a potential of 1.5V in the presence of a magnetic field (d) is the most corrosive condition for the aluminum wire. Therefore, the magnetic field can influence the corrosion of the aluminum wire by modifying the structure of the protective oxide film, increasing the concentration of metal ions, and promoting the formation of stray electrical currents. The imposed potential can also influence the corrosion of the aluminum wire by increasing the rate of electrochemical reactions.

Figure 5 shows the corrosion kinetics of the section of the studied aluminum wire after 24 hours of immersion in seawater. The four curves correspond to the different test conditions:

- (♦) Free immersion: The corrosion rate is relatively low and constant over time.
- (●) In the presence of a magnetic field: The corrosion rate is higher than in free immersion and increases slightly over time.
- (╬) “imposed E = 1.5V”: The corrosion rate is even higher than in the test in the presence of a magnetic field and increases rapidly over time.
- (▲) imposed E = 1.5V in the presence of a magnetic field: The corrosion rate is the highest of the four test conditions and increases rapidly over time.

The image in Figure 6 shows the corrosion kinetics of the section of the studied aluminum wire after 1 minute of immersion. Significant differences are observed between the curves, confirming the influence of the magnetic field and the imposed potential from the first moments of immersion. The exponential increase in curve (▲) shows an exponential increase in the corrosion rate, indicating a synergistic effect of

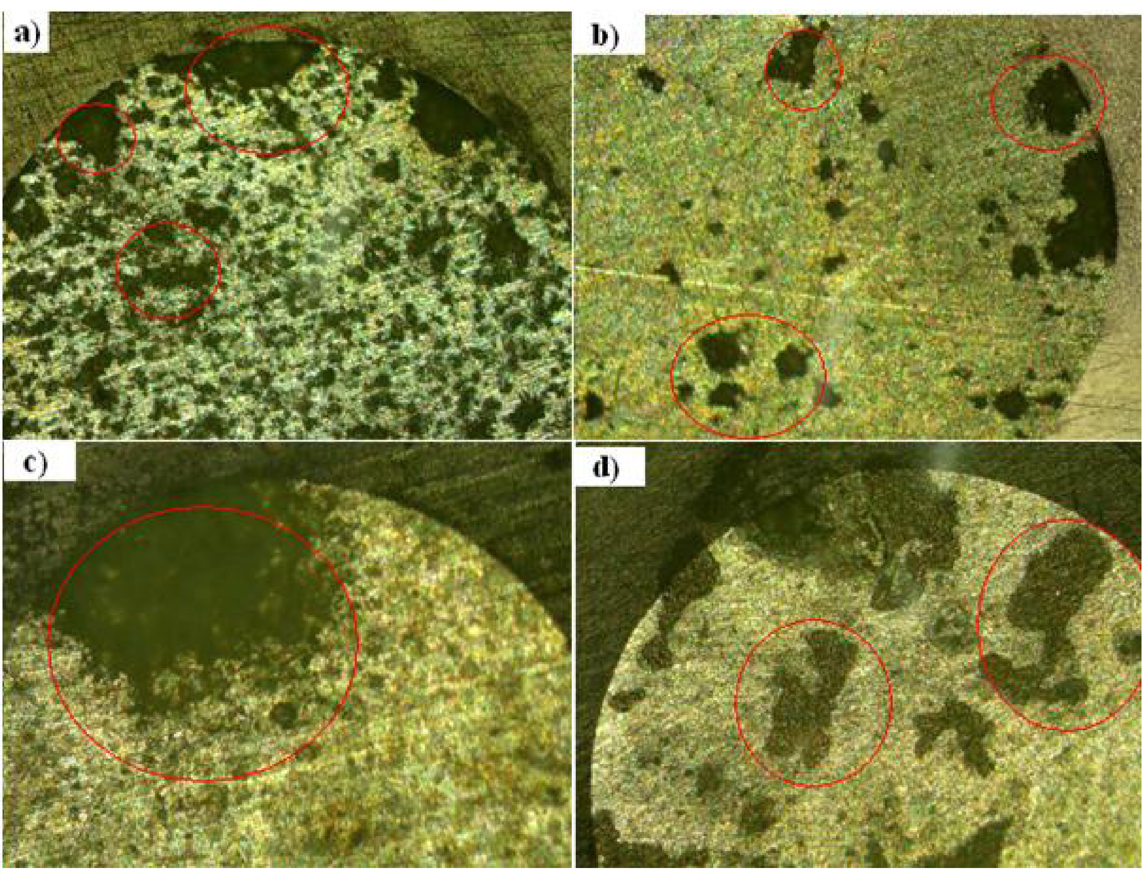

Figure 3. Microstructure of the section of the studied aluminum wire after 24 hours of immersion in seawater: a) free immersion, b) potentiostatic test in the presence of a magnetic field, c) potentiostatic test “imposed E = 1.5V”, d) imposed E = 1.5V in the presence of a magnetic field.

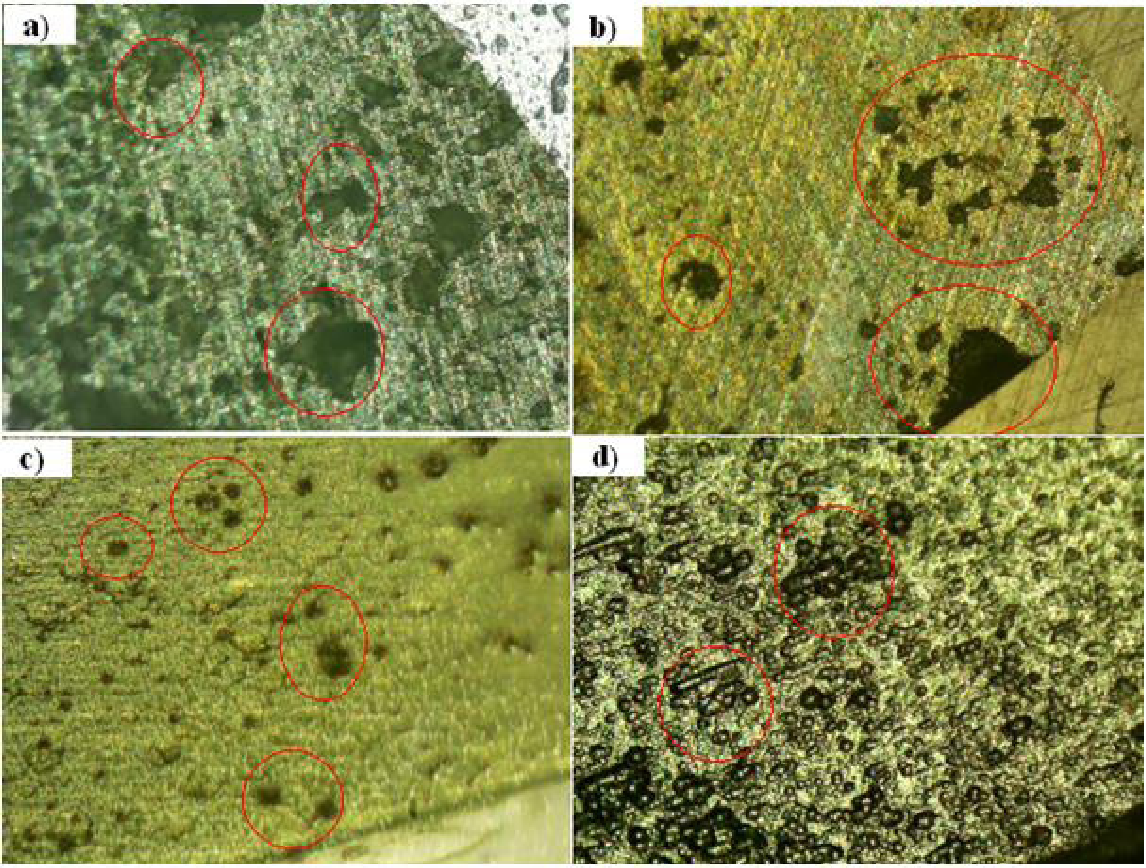

Figure 4. Microstructure of the longitudinal surface of the studied aluminum after 24 hours of immersion in seawater: a) free immersion, b) potentiostatic test in the presence of a magnetic field, c) potentiostatic test "imposed E = 1.5V", d) imposed E = 1.5V in the presence of a magnetic field.

the magnetic field and the imposed potential. The corrosion rate is particularly high in conditions (▲) and (╬), indicating a significant risk of degradation of the aluminum wire.

Figure 7 shows the corrosion kinetics of the longitudinal surface of the studied aluminum wire after 24 hours of immersion in seawater.

The free immersion curve (♦) shows a gradual increase in the corrosion rate over the 24 hours. The corrosion rate is relatively low and constant, indicating a uniform attack on the surface of the aluminum wire.

The magnetic field (●) shows a faster increase in the corrosion rate than free immersion. The corrosion rate is higher, suggesting an influence of the magnetic field on the structure of the oxide film and the concentration of metal ions.

The application of an imposed potential of 1.5 mV (╬) shows an exponential increase in the corrosion rate from the beginning of immersion. The corrosion rate is significantly higher than the previous two cases, indicating a significant effect of the imposed potential on the electrochemical reactions.

The magnetic field + imposed potential curve (▲) shows the highest corrosion rate. The exponential increase is even more pronounced than for the imposed potential alone, confirming a synergistic effect between the magnetic field and the imposed potential.

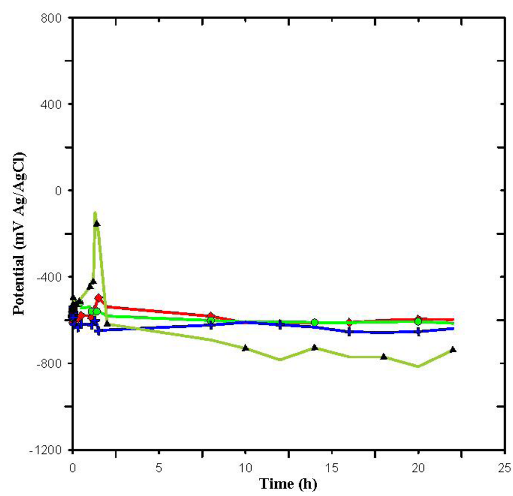

Figure 5. Corrosion kinetics of the longitudinal surface of the studied aluminum wire after 24 hours of immersion in seawater: ♦) free immersion, ●) in the presence of a magnetic field, ╬) "imposed E = 1.5V", ▲) imposed E = 1.5V in the presence of a magnetic field.

The corrosion kinetics of the longitudinal surface (Figure 8) of the studied aluminum wire after 1 minute of immersion

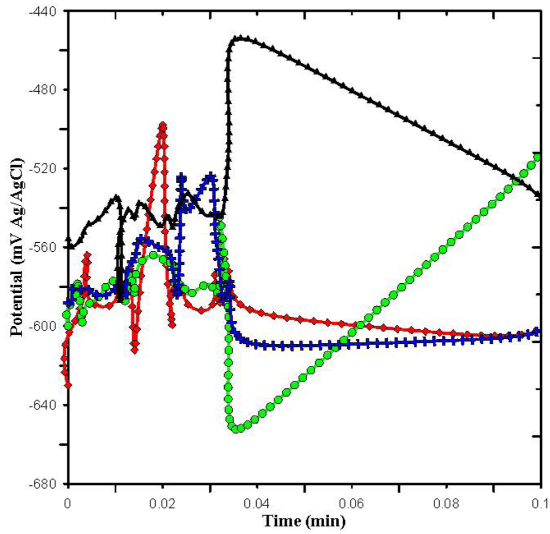

Figure 6. Corrosion kinetics of the section of the studied aluminum wire after 1 min of immersion in seawater: ♦) free immersion, ●) in the presence of a magnetic field, ╬) "imposed E = 1.5V", ▲) imposed E = 1.5V in the presence of a magnetic field.

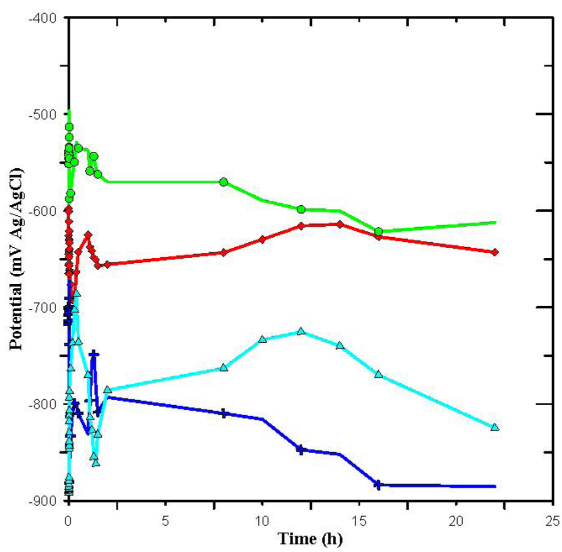

Figure 7. Corrosion kinetics of the longitudinal surface of the studied aluminum wire after 24 hours of immersion in seawater: ♦) free immersion, ●) in the presence of a magnetic field, ╬) "imposed E = 1.5V", ▲) imposed E = 1.5V in the presence of a magnetic field.

show that the differences between the curves confirm the influence of the magnetic field and the imposed potential from the first moments of immersion.

The exponential increase in the corrosion rate is shown by curve (▲), indicating a synergistic effect of the magnetic field and the imposed potential.

The corrosion rate is particularly high in conditions (▲) and (╬), indicating a significant risk of degradation of the aluminum wire.

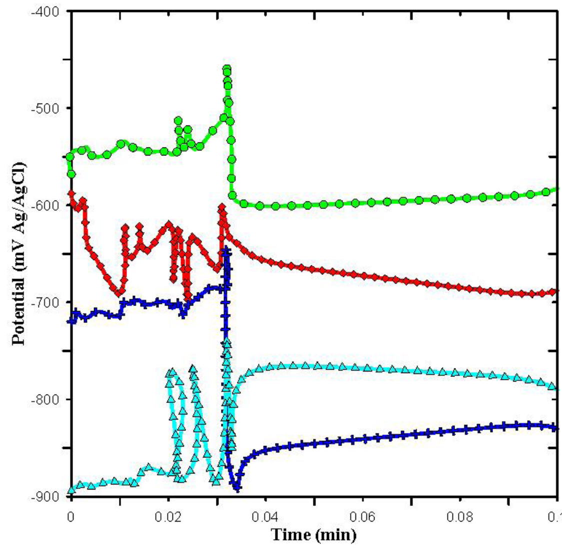

Figure 8. Corrosion kinetics of the longitudinal surface of the studied aluminum wire after 1 minute of immersion in seawater: ♦) free immersion, ●) in the presence of a magnetic field, ╬) "imposed E = 1.5V", ▲) imposed E = 1.5V in the presence of a magnetic field.

4. Conclusion

- The surface morphology can influence the corrosion rate of AA6060 aluminum.
- The corrosion morphology of the outer surface of the aluminum wire is different from that of the center of the wire. This is more visible after potentiostatic tests under an imposed voltage of 1.5V, and the hardness of the outer surface is greater than the hardness of the center.
- The magnetic field and the imposed potential have a synergistic effect on the corrosion of the aluminum wire. The combination of these two factors can lead to more severe corrosion than the sum of their individual effects.
- The magnetic field and the imposed potential have a significant effect on the corrosion of the aluminum wire from the first minute of immersion in seawater.
- The synergistic effect of the magnetic field and the imposed potential is particularly marked, leading to an exponential increase in the corrosion rate and can lead to rapid degradation of the aluminum wire.

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