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Influence of Perpendicular Magnetic Field Strength on Corrosion Resistance of 316 Stainless Steel in Nitric Acid

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Abstract: Austenitic stainless steels find extensive applications across various industries. The versatility of these steels stems from their impressive combination of properties, such as high resistance to general corrosion, exceptional mechanical characteristics, and cost-effectiveness. This study aims to analyze the impact of perpendicular magnetic field strength in an aerated solution of 68% weight nitric acid on the corrosion kinetics of AISI 316 austenitic stainless steel after one hour of immersion. Studies were conducted on open circuit potential (OCP), polarization and electrochemical impedance spectroscopy (EIS) tests. All tests were performed at a temperature of 22 °C. The results show that increased magnetic field strength decreases open circuit potential (OCP) and transfer resistance (Rt), and increases double layer capacity (Cd), polarization resistance (Rp), and corrosion potential (Ecorr) of AISI 316 stainless steel in a nitric acid solution. The magnetic field intensity influences the parameters of corrosion kinetics of 316 stainless steel in an aerated solution of 68 % weight nitric acid.

Keywords: Corrosion kinetics, Corrosion resistance, Magnetic field, Nitric acid, Double layer capacity (Cd)

Introduction

Industries, including the food, medical and construction sectors, use austenitic stainless steels extensively (González et al., 2021; Hilbert et al., 2003; Rokicki et al., 2008; Lorsbach & Schmitz, 2018; Manivasagam et al., 2010; Sumita et al., 2004; Varmaziar et al., 2022). The versatility of these steels stems from their impressive combination of properties, such as high resistance to general corrosion, exceptional mechanical characteristics, and low cost. However, despite their wide-ranging utility, austenitic steels have a low resistance to localized corrosion, particularly in highly aggressive environments (Lorsbach & Schmitz, 2018; Steinemann, 1968; Varmaziar et al., 2022). While these metals inherently possess the ability of passivation upon exposure to air and humid conditions, resulting in the formation of a protective oxide layer known as the "passive layer,"

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typically a few nanometers thick, this self-protective mechanism is challenged when these materials come into direct contact with aggressive environments (Hryniewicz, et al., 2008; Jokar et al., 2016; Lorsbach & Schmitz, 2018; Steinemann, 1968).

Numerous researchers have dedicated significant attention to enhancing the corrosion resistance of stainless steels, aiming to prolong their service life (Bond et al., 1973; Colombié et al., 1973; Condylis et al., 1970; Gwinner et al., 2010; Lorsbach & Schmitz, 2018; Noh et al., 2000; Ručinskien et al., 2002; Salvago & Fumagalli, 1994; Shalash & Nasher, 2010; Steinemann, 1968). Numerous studies have explored the influence of magnetic fields on the corrosion resistance of metals in various corrosive environments (Bech-Nielsen & Jaskuła, 2008; Costa et al., 2004; Fahidy, 2002; Rokicki, et al., 2008; Hryniewicz et al., 2008; Ručinskien et al., 2002; Shalash & Nasher, 2010; Slimani et al., 2016; Taleb et al., 2019; Zazi et al., 2018). Some investigations suggest that magnetic fields contribute to a reduction in the corrosion rates of metals (Chiba et al., 1994; Hryniewiczet al., 2008; Ručinskien et al., 2002; Sagawa, 1982). Several studies have noted the effect of the magnetic field on polarization resistance and the corrosion potential and passivation. For instance, a recent study demonstrated that applying a magnetic field during electrochemical testing significantly enhanced the polarization resistance of stainless steel, indicating improved corrosion resistance. This finding suggests that the manipulation of magnetic fields could be a viable strategy for protecting metals in environments prone to corrosion. Hryniewicz et al. demonstrated that the concurrent application of a magnetic field during surface treatment enhances the corrosion resistance of austenitic 316L stainless steels, resulting in a decreased presence of corrosive products in Ringer body fluid (Rokicki, et al., 2008; Hryniewicz et al., 2008). The magnetic field shifts the corrosion potential to higher values and increases the anodic polarization resistance of aluminum. Weight loss decreased from 5% to 38% in the presence of a magnetic field (Chiba et al., 1994). The magnetic field increases passivation potential and reduces pitting and weight loss of stainless steels (Ručinskien et al., 2002). A low magnetic field modifies the polarization curve in the anodic region of ZnO deposits and modifies corrosion potential and polarization resistance (Tacken & Janssen, 1995; Taleb et al., 2019).

The maximum benefit of HNO3 treatment was associated with obtaining optimal corrosion potential by pretreatment (Kannan et al., 2005; Noh et al., 2000; Shoji & Shibata, 1997). Kannan et al. (Kannan et al., 2005) found that all treated 316 SSL samples show an increased burst potential value compared to untreated 316 SSL, and they also found that 50% acid treatment indicated a reduction in the Ecorr value as well as the degradation potential. The impedance results showed that total impedance |Z| and polarization resistance (Rp) increased for treatments in nitric acid HNO_3. The increase in nitric acid concentration during processing increases corrosion potential (Shoji & Shibata, 1997). Noh et al. (2000) showed that the effectiveness of the passivation treatment depends on the concentration of nitric acid pretreatment and that the puncture potential of 316 SS steel varies according to the concentration of nitric acid. The pitting potential increases by up to 25% by weight of nitric acid and then decreases by increasing the concentration of nitric acid. Ben Abdesselam et al. (2024) studied the effect of preliminary nitric chemical treatment on the corrosion resistance of 316 stainless steel in 0.9% NaCl-containing glucose solution; they noticed that the chemical treatment with nitric acid changed the open circuit potential of AISI 316 SS in the chlorinated solution, and the corrosion potential increased, while the polarization resistance decreased for the treated samples.

The determination of corrosion resistance in a given solution for stainless steel can be carried out through electrochemical techniques. However, it is crucial to acknowledge that test conditions can influence the results. This study specifically aims to investigate the corrosion behavior of an austenitic 316 stainless steel, containing 2.19 % molybdenum, in a solution of 68 wt. % of nitric acid. The evaluations are conducted at a temperature of 22°C under natural aeration. The study further explores the impact of the intensity of the perpendicular magnetic field on the corrosion resistance of 316 SS steel.

Experimental Methods

Materials and Procedures

The factory-annealed AISI 316 SS alloy sheet was cut into 10 mm x 10 mm x 2 mm pieces. The detailed chemical composition of this alloy is presented in (Table 1) Prior to the commencement of the study, the samples underwent preparation following the standard metallographic procedure. A designated 1 cm² area of each sample remained active, while the remaining portion was isolated with resin. Since the electrical contact is ensured by a copper wire.

Table 1. AISI 316 SS chemical composition.

Elements (wt. %)	AISI 316	Elements (wt. %)	AISI 316	Elements (wt. %)	AISI 316
C	0.049	Cu	0.12	Bi	0.009
Si	0.63	Nb	0.016	Ca	0.0006
Mn	0.95	Ti	0.006	Ce	0.012
P	0.007	V	0.066	Sb	<0.002
S	0.004	W	<0.007	Se	<0.001
Cr	16.65	Pb	<0.002	Te	0.005
Mo	2.19	Sn	0.017	Ta	0.057
Ni	10.43	Mg	0.012	B	0.0004
Al	0.003	As	0.013	Zn	0.002
Co	0.31	Zr	0.004	La	0.001
				Fe	68.4

To induce a magnetic field, the electrochemical cell was placed within an electromagnet of the Bouhnik 13181B type, ensuring that the magnetic field was perpendicular to the surface of the samples. The applied magnetic field strengths were B=0.05T, B=0.1T and B=1T. Electrochemical studies in solutions of 68 wt. % of nitric acid. Detailed characteristics of these samples are presented in (Table 2).

Table 2. Sample types used for different electrochemical tests.

Samples	Conditions
1	Immersed in the presence of a perpendicular magnetic field with an intensity of 0.05T
2	Immersed in the presence of a perpendicular magnetic field with an intensity of 0.1T
3	Immersed in the presence of a perpendicular magnetic field with an intensity of 1T

Corrosion Behavior

Corrosion measurements were conducted using a three-electrode cell at 22°C in solutions of 68 wt. % of nitric acid aerated medium, in the presence of a perpendicular magnetic field. The test environment remained undisturbed during these assessments. This medium was chosen for its suitability in studying corrosion. The working electrode was the AISI 316 (WE) stainless steel substrate, with an Ag/AgCl (RE) reference electrode and a thick platinum wire serving as the counter electrode (CE). Open circuit potential measurements (EOCP) utilized an Ag/AgCl reference electrode. Potentiodynamic bias test measurements covered a range from -1000 mV to 1000 mV, with an acquisition rate of 1 mV/s, and current-potential curves were obtained after 1 hour of immersion. Electrochemical impedance spectroscopy (EIS) spectra were recorded after 1 hour of immersion in the corrosive medium, spanning a frequency range from 60 kHz to 10 mHz with 10 frequency points per decade and a magnitude of the potential disturbance set at 20 mV. Open-circuit potential, current-potential curves, and electrochemical impedance spectroscopy (EIS) spectra were obtained using PGZ100 VoltaLab.

Results and Discussion

Figure 1 shows the variation of open circuit potential (OCP) over immersion time for AISI 316 SS, immersed in a 68 % by weight aerated solution of nitric acid in the presence of different perpendicular magnetic field intensities. The potential of sample 1 immersed in nitric acid with 0.05T magnetic field intensity is more noble than that of samples 2 and 3 immersed in nitric acid with 0.1T and 1T magnetic field intensity respectively. The potential of 316 stainless steel is found to increase with the decrease in magnetic field intensity. The intensity of the magnetic field has a considerable influence on the potential (Chiba et al., 1994; Ručinskien≐ et al., 2002; Taleb et al., 2019). Over time, the potential increases steadily (sample1 E= 0.915 V to E= 0.967 V, sample2 E= 0.791 V to E= 0.884 V and sample 3 E= 0.758 V to E= 0.876 V), which means a passivation of stainless steel in nitric acid. These results confirm that nitric acid improves the passivation of stainless steels (Ahmadian et al., 2014; Noh et al., 2000).

The Nyquist impedance plots for samples 1, 2, and 3, after one hour of immersion in a 68 % by weight aerated solution of nitric acid in the presence of different perpendicular magnetic field intensities, are represented in (Figures 2). The solution resistance (Rs), transfer resistance (Rt), and double layer capacity (Cd) of AISI 316 SS are shown in Table 3. The transfer resistance (Rt) is 25324 Ω/cm2 for sample 1 (B = 0.05T), the transfer resistance (Rt) for sample 2 (B =0.1T) is 24213.1 Ω/cm2, and for sample 3 the transfer resistance (Rt) is about 6862.7 Ω/cm2, we found that the transfer resistance decreases with the increase of the magnetic field intensity.

The capacity of the double layer (Cd) is about 62.84 µF/cm2 for sample 1, about 65.76 µF/cm2 for sample 2 and 73.59 µF/cm2 for sample 3, we found that the double layer capacity increases with the increase of the magnetic field intensity the (Rt and Cd) are influenced by the magnetic field intensity. It is evident that the corrosion behavior of 316 stainless steel is significantly affected by the magnetic field intensity.

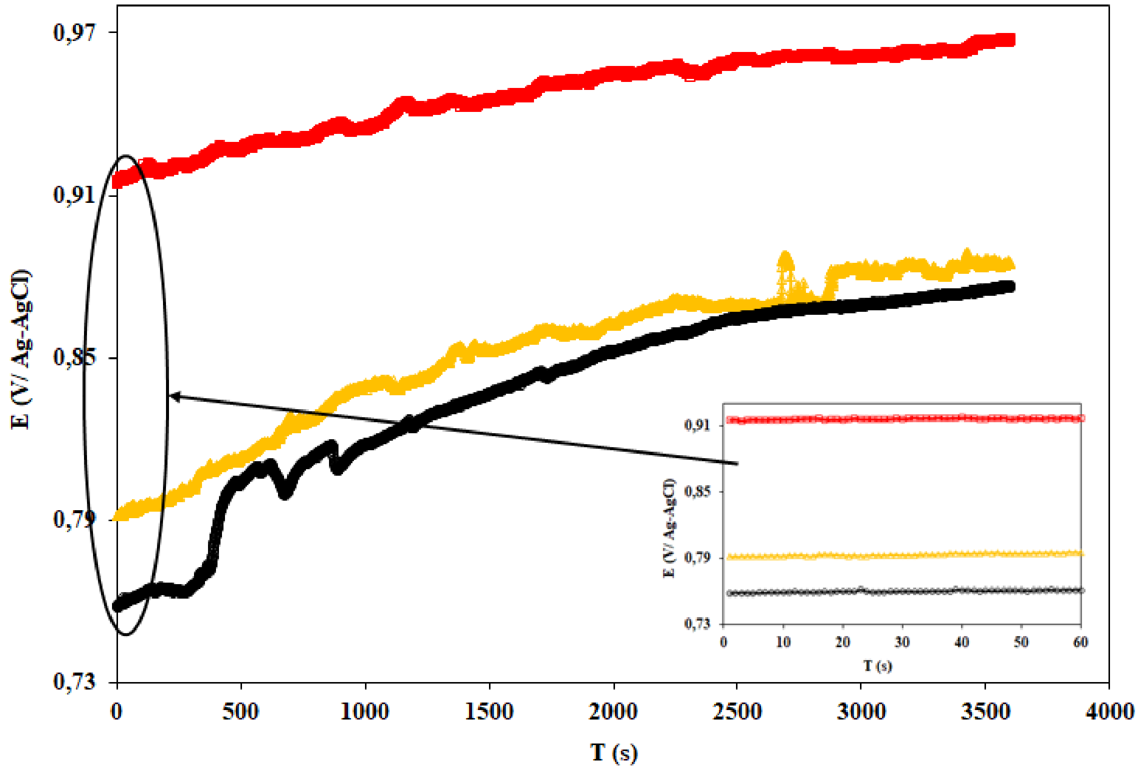

Figure 1. Variation of the open circuit potential (OCP) over the immersion time for samples 1, 2 and 3 in 68 wt.% nitric acid aerated solutions, during one hour, immersed in the presence of perpendicular magnetic field, □ B=0.05 T, △ B=0.1 T and ○ B=1 T.

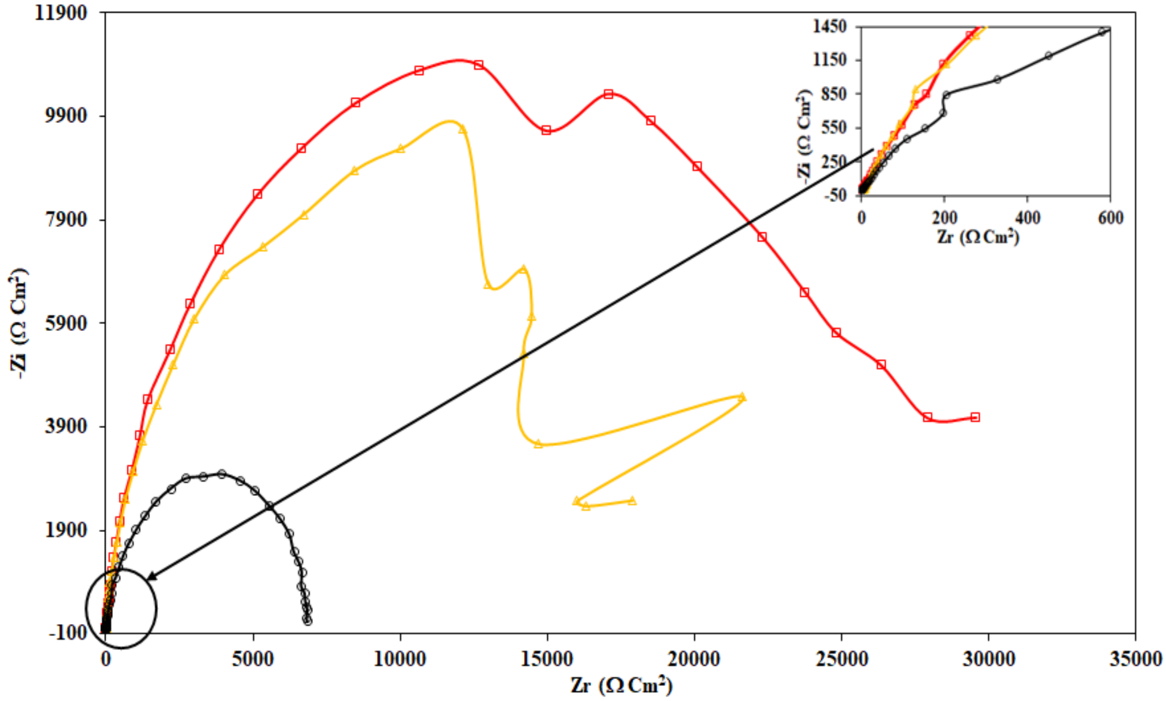

Figure 2. Nyquist plots for 316 stainless steel over the immersion time in 68 wt.% nitric acid aerated solutions, in the presence of perpendicular magnetic field, during one hour, □ B =0.05 T, △ B =0.1 T and ○ B =1 T.

Table 3. Solution resistance, transfer resistance and double layer capacity of the samples 1, 2 and 3.

Samples	Rs (Ω)	Rt (Ω/cm^2)	Cd (µF/cm^2)
1	2	25324	62.84
2	5.5	24213.1	65.76
3	1.30	6862.7	73.59

Based on the current-voltage curves (i(E)), we calculated the polarization resistance (Rp) and corrosion potential (Ecorr). These values are precisely listed in table 4. From the curves i(E) and log i(E) and table 4, we found that sample 3 in immersion in the presence of the magnetic field with a higher intensity presents a more noble corrosion potential (Ecorr = 0.701 V) and a greater polarization resistance (Rp = 234 Ω/cm2) compared to the other two samples 1 and 2. The magnetic field intensity influences the polarization resistance and corrosion potential of 316 SS (Chiba et al., 1994; Ručinskienė et al., 2002; Taleb et al., 2019). Figure 3 a and b) shows the results of the polarization tests performed on samples 1, 2 and 3, a) representing curve i(E) and a_1) magnifying effect, and b) showing log curve i(E).

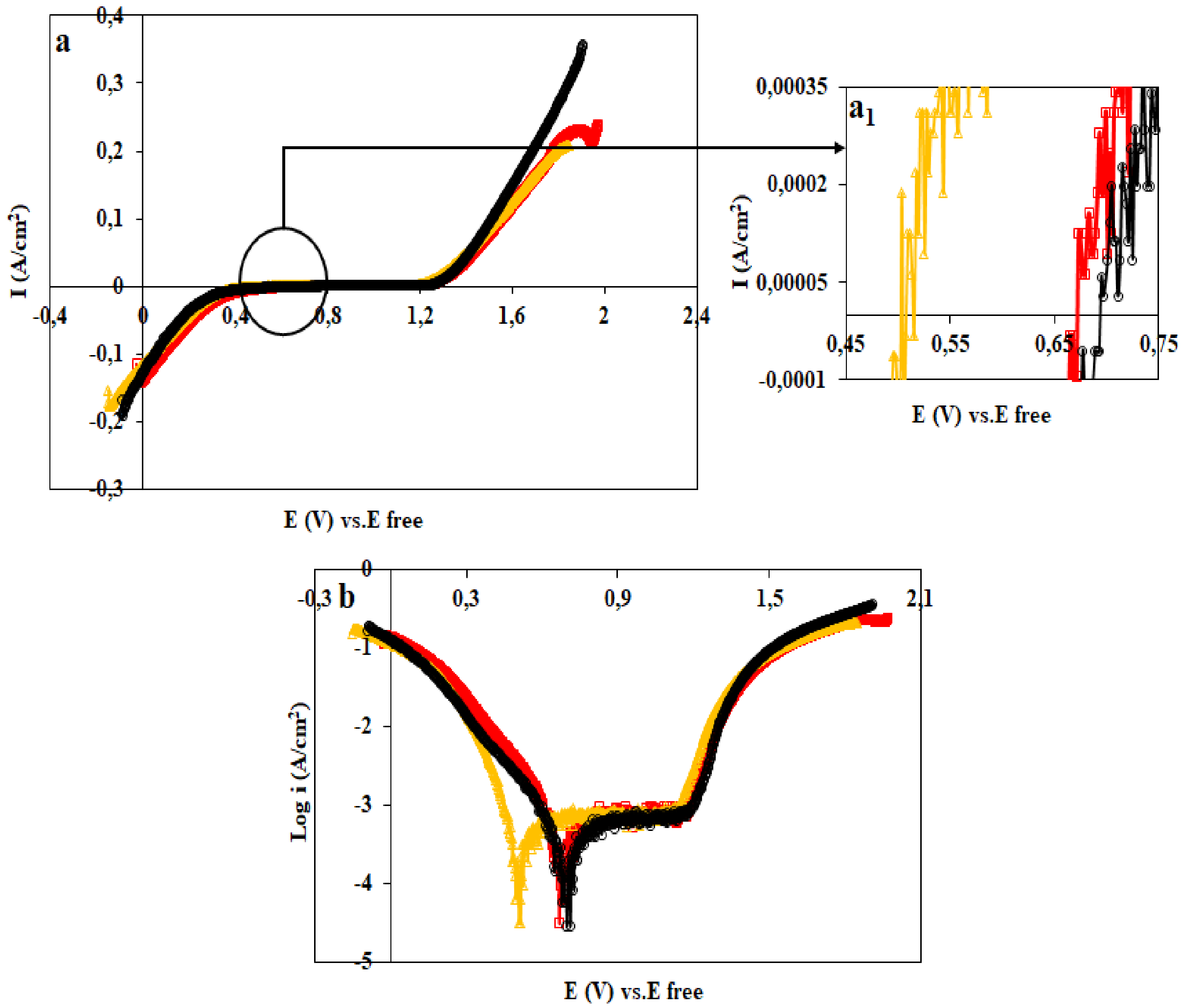

Figure 3. Illustrates the polarization curves of samples 1, 2, and 3 in a 68 wt. % nitric acid solution one hour after immersion. a) presents the i(E) curve and a1) the magnification effect, while b) showcases the log i(E) curve.

Table 4. Polarization resistance and corrosion potential of the sample 1, 2 and 3.

Samples	**E_{corr} (v)**	**R_p (Ω/cm^2)**
1	0,673	127
2	0,511	179
3	0,701	234

Conclusion

The study examines the impact of perpendicular magnetic field strength in an aerated solution of 68% weights nitric acid on the corrosion of AISI 316 SS. The analyses were carried out on open circuit potential (OCP), as well as on polarization and impedance tests. The main conclusions are as follows:

- The potential of 316 stainless steel is increase with the decrease in the magnetic field intensity;
- Stainless steel 316 is passivated in nitric acid;
- The transfer resistance (Rt) decreases with the increase of the magnetic field intensity;
- The double layer capacity increases with the increase of the magnetic field intensity;
- The (Rt and Cd) are influenced by the magnetic field intensity;
- The magnetic field intensity influences the polarization resistance and corrosion potential of 316 SS;
- the corrosion potential of 316 SS is more noble in the presence of the magnetic field with a high intensity;
- AISI 316 SS presents a better polarization resistance in the presence of magnetic field with greater intensity.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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References

Ahmadian, Z., Danaee, I., & Golozar, M. A. (2014). Effect of surface treatment on corrosion resistance of 304 stainless steel implants in tyrode solution. *Archives of Metallurgy and Materials, 59*(1), 25-30.

Bech-Nielsen, G., & Jaskuła, M. (2008). The influence of a magnetic field on the non-electrochemical dissolution of iron. *Journal of Electroanalytical Chemistry, 624*(1-2), 327-328.

Ben - Abdesselam, D., Zazi, N., Hadj - Ali, Y., Hellal, F., Chopart, J. P., Abrudeanu, M., & Negrea, D. (2024). Effect of preliminary nitric chemical treatment on corrosion behavior of 316 stainless steel in chloride solution contain glucose. *The Eurasia Proceedings of Science Technology Engineering and Mathematics, 32,* 66-79.

Bond, A. P., Dundas, H. J., Schmidt, W., & Wol, M. (1973). Etude de la résistance à la corrosion d'aciersinoxydables en vue de leur utilisationen distribution d'eau chaude. *Revue de Métallurgie, 70*(1), 33-42.

Chiba, A., Kawazu, K., Nakano, O., Tamura, T., Yoshihara, S., & Sato, E. (1994). The effects of magnetic fields on the corrosion of aluminum foil in sodium chloride solutions. *Corrosion Science, 36*(3), 539-543.

Colombié, M., Condylis, A., Desestret, A., Grand, R., & Mayoud, R. (1973). Les aciers ferritiques inoxydables ductiles à haute teneur en chrome. Nouveaux matériaux résistant à la corrosion par piqûre, par crevasse et à la corrosion sous tension. *Revue de Métallurgie, 70*(12), 949-962.

Condylis, A., Bayon, F., & Desestret, A. (1970). Aciers inoxydables austénitiques au chrome-nickel-manganèse-azote. *Revue de Métallurgie, 67*(5), 427-442.

Costa, I., Oliveira, M. C. L., de Melo, H. G., & Faria, R. N. (2004). The effect of the magnetic field on the corrosion behavior of Nd–Fe–B permanent magnets. *Journal of Magnetism and Magnetic Materials, 278*(3), 348-358.

Fahidy, T. Z. (2002). The effect of magnetic fields on electrochemical processes. In B. E. Conway, J. O. Bockris, & R. E. White (Eds.), *Modern aspects of electrochemistry* (Vol. 32, p. 333-354). Kluwer Academic Publishers.

González, A. S., Riego, A., Vega, V., García, J., Galié, S., Gutiérrez del Río, I., Martínez de Yuso, M. del V., Villar, C. J., Lombó, F., & De la Prida, V. M. (2021). Functional antimicrobial surface coatings deposited onto nanostructured 316L food-grade stainless steel. *Nanomaterials, 11*(4), 4.

Gwinner, B., Auroy, M., Bague, V., Chaachoua, S., Fieulaine, B., Tran, Q. T., & Tricoit, S. (2010). Corrosion intergranulaire dans l'acide nitrique des aciers inoxydables austénitiques non sensibilisés. *Revue de Métallurgie, 107*(10-11), 441-443.

Hilbert, L. R., Bagge-Ravn, D., Kold, J., & Gram, L. (2003). Influence of surface roughness of stainless steel on microbial adhesion and corrosion resistance. *International Biodeterioration & Biodegradation, 52*(3), 175-185.

Hryniewicz, T., Rokicki, R., & Rokosz, K. (2008). Corrosion Characteristics of Medical-Grade AISI Type 316L Stainless Steel Surface After Electropolishing in a Magnetic Field. *Corrosion, 64*(8), 660-665.

Hryniewicz, T., Rokosz, K., & Rokicki, R. (2008). Electrochemical and XPS studies of AISI 316L stainless steel after electropolishing in a magnetic field. *Corrosion Science, 50*(9), 2676-2681.

Jokar, M., Darvishi, S., Torkaman, R., Kharaziha, M., & Karbasi, M. (2016). Corrosion and bioactivity evaluation of nanocomposite PCL-forsterite coating applied on 316L stainless steel. *Surface and Coatings Technology, 307*, 324-331.

Kannan, S., Balamurugan, A., & Rajeswari, S. (2005). Electrochemical characterization of hydroxyapatite coatings on HNO3 passivated 316L SS for implant applications. *Electrochimica Acta, 50*(10), 2065-2072.

Lorsbach, B., & Schmitz, E. (2018). Influence of test parameters of potentiodynamic current density measurements on the determination of the pitting corrosion resistance of austenitic stainless steels. *Materials and Corrosion, 69*(1), 37-43.

Manivasagam, G., Dhinasekaran, D., & Rajamanickam, A. (2010). Biomedical implants: Corrosion and its prevention - a review. *Recent Patents on Corrosion Science, 2*(1), 40-54.

Noh, J. S., Laycock, N. J., Gao, W., & Wells, D. B. (2000). Effects of nitric acid passivation on the pitting resistance of 316 stainless steel. *Corrosion Science, 42*(12), 2069-2084.

Ručinskien≐, A., Bikulčius, G., Gudavičiūt, L., & Juzeliūnas, E. (2002). Magnetic field effect on stainless steel corrosion in FeCl3 solution. *Electrochemistry Communications, 4*(1), 86-91.

Sagawa, M. (1982). Effect of a local magnetic field on the dissolution of copper and iron in nitric acid solution. *Transactions of the Japan Institute of Metals, 23*(1), 38-40.

Salvago, G., & Fumagalli, G. (1994). The distribution of stainless-steel breakdown potentials: The effect of surface finishing degree and HNO3 treatment. *Corrosion Science, 36*(4), 733-742.

Shalash, L. B. T., & Nasher, L. S. H. (2010). Study the effect of magnetic field on the corrosion of steel in sodium chloride solution (NaCl). *Misan Journal of Academic Studies, 9,* 30-38.

Shoji, T., & Shibata, T. (1997). *Proceedings of the International Symposium on Plant Aging and Life Prediction of Corrodible Structures* : May 15-18, 1995, Sapporo, Japan. NACE.

Slimani, R., Zazi, N., & Chopart, J.-P. (2016). Investigation of nickel deposition onto section and central longitudinal surfaces of AA1370 aluminum electrical wire with and without a weak permanent magnetic field. *Protection of Metals and Physical Chemistry of Surfaces, 52*(1), 111-118.

Steinemann, S. (1968). Résistance à la corrosion par piqûres de l'acier inoxydable au chrome-nickel-molybdène élaboré normalement à haute fréquence et refondu sous laitier électroconducteur (ESR). *Revue de Métallurgie, 65*(10), 651-658.

Sumita, M., Hanawa, T., & Teoh, S. H. (2004). Development of nitrogen-containing nickel-free austenitic stainless steels for metallic biomaterials—review. *Materials Science and Engineering: C, 24*(6-8), 753-760.

Tacken, R. A., & Janssen, L. J. J. (1995). Applications of magnetoelectrolysis. *Journal of Applied Electrochemistry, 25*(1).

Taleb, S., Dokhan, N., Zazi, N., & Chopart, J.-P. (2019). Perpendicular weak permanent magnetic field effect on the electrodeposited nanostructured ZnO film and its kinetic corrosion behavior. *Protection of Metals and Physical Chemistry of Surfaces, 55*(4), 781-788.

Varmaziar, S., Atapour, M., & Hedberg, Y. S. (2022). Corrosion and metal release characterization of stainless steel 316L weld zones in whey protein solution. *Npj Materials Degradation, 6*(1), 1.

Zazi, N., Aouchiche, H., Benbaha, C., & Chopart, J. P. (2018). Sulfuric containing sugar bath and permanent weak magnetic field effect during anodizing AlCu6Si alloy sheet surfaces. *Russian Journal of Non-Ferrous Metals, 59*(2), 123-134.

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