中國機械工程學刊第四十五卷第二期第 195~200 頁(民國一百一十三年)
Journal of the Chinese Society of Mechanical Engineers, Vol.45, No.2, pp 195~200 (2024)

Investigation of Corrosion Properties of LA-91 Alloy Coated with MAO Method

Suleyman Sukuroglu*, Yasar Totik**, Ebru Emine Sukuroglu***

and Selcuk Avci****

Keywords: **Corrosion properties, LA91 magnesium alloy, Micro-arc oxidation method, Surface coating.**

ABSTRACT

LA91 magnesium alloy is a super lightweight magnesium-lithium alloy proposed for next generation materials. In addition to the advantages of these alloys such as low density, high strength-to-weight ratio, specific stiffness and brittleness, these alloys also have disadvantages such as low corrosion resistance and the oxide-carbonate film formed on the surfaces of the alloys cannot provide sufficient corrosion protection even in non-corrosive environments. In this study, micro arc oxidation, one of the coating methods, was applied to LA91 alloy. The surface morphologies of the coatings were characterized and it was aimed to increase the corrosion resistance of LA91 alloy. For this purpose, potentiodynamic polarization tests were carried out in 3.5% NaCl solution at room temperature to draw attention to the protection of the coating. As a result of the tests, it was determined that the oxide coatings raised on the surface increased the corrosion resistance of LA91 materials.

INTRODUCTION

Recently, studies carried out both in scientific research and industrial applications such as computer, aviation, space, communication, consumer electronics technologies and electronics industry, especially in the defense industry, focus on the lightness of the system in order to achieve high efficiency. For this reason, magnesium (Mg) and its alloys, which are the lightest materials among light alloy structural metallic engineering materials with its low density (1.74 g/cm³), high damping capacity, high recyclability and high specific strength, are gaining increasing popularity in industrial applications. rapidly preferred (Buldum et al., 2012; Kumar et al., 2015; Lee and Do, 2016; Kucukosman et al., 2021; Mingjin et al., 2022;).

Magnesium element can be used in industrial applications as unalloyed; It can also be used by alloying with alloying elements such as Lithium (Li), Zinc (Zn), Silicon (Si), Manganese (Mn), Aluminum (Al) in order to provide high wear and corrosion resistance, and to increase strength, castability, machinability and weldability (Baghdadabad et al., 2022). The addition of Lithium, one of these alloying elements, has been preferred more than others in recent years (Siyuan et al. 2022). When Mg-Li alloys formed by adding Lithium to Magnesium are compared with conventional magnesium alloys, Li significantly reduces the density of Mg alloys with its excellent low density (0,534 g/cm3). In addition, the addition of Li contributes to the plasticity of the Mg alloy, which is obtained by the structural transformation from hexagonal closed package to body-centered cubic and accompanies the improvement of the machining deformation ability thanks to the more shear system, thus improving the machining and formability of magnesium (Friedrich and Mordike, 2006; Feng et al., 2017).

Mg-Li alloys, also known as ultra-light alloys, are primarily used in the defense industry due to their low density as a metallic material (1.35-1.65 g/cm3), superior electromagnetic shielding capabilities, high hardness-to-weight ratio, high specific strength and extraordinary damping performances. It is recognized as one of the most promising structural metallic materials, widely

Paper Received April, 2023. Revised September, 2023. Accepted December, 2023. Author for Correspondence: Ebru Emine Sukuroglu

* *Assistant Professor, Department of Occupational Health and Safety, Gumushane University, Gumushane 29100, Türkiye*

** *Professor, Department of Mechanichal Engineering, Ataturk University, Erzurum 25240, Türkiye*

*** *Professor, Department of Mechanichal Engineering, Gumushane University, Gumushane 29100, Türkiye*

**** *Ph.D., Department of Mechanichal Engineering, Ataturk University, Erzurum 25240, Türkiye*

applied in various fields such as next generation building materials, automotive, aerospace, aerospace, biomedical materials, electronics and 3C (computer, communications, consumer electronics) industries. In particular, the use of Mg-Li alloys in the missile and spacecraft structures industry not only reduces the weight of the structural element, but also increases the carrying load and reduces the fuel cost (Esmaily et al., 2017; Yang et al., 2019; Lu et al., 2020; Ma et al., 2021; Telmenbayar et al., 2022; Jin et al., 2022).

Besides these advantages, it is well known that Li is more active than Mg (Yang et al., 2019; Ma et al., 2021; Telmenbayar et al., 2022). The addition of Li to the Mg matrix causes Mg−Li alloys to have lower corrosion resistance than conventional Mg alloys (Ma et al., 2021; Jin et al., 2022). The lattice structure of Mg-Li alloys is geometrically incompatible with the structure of the passive layer formed on its surface. This problem leads to the formation of high compressive stresses on the passive layer and crack formation on the passive layer surface. Through the cracks, corrosive substances reach the magnesium metal in time and cause the corrosion mechanism to take place. The passive layer, which is inert in humid (containing only H2O) or dry atmospheric environments, cannot provide resistance in aqueous electrolyte environments containing ionized compounds such as chlorine (Cl), nitrate (NO_3), carbonate (CO_3), sulfate (SO_4) or phosphate (PO_4). The reason for this is that the magnesium salts released as a result of the reaction between the passive layer and the ionic solution dissolve in water and form the corrosion mechanism through cracks or pores formed on the surface of the passive layer (Kurze 2006). In particular, high operating temperature and/or liquid environment often lead to deterioration of mechanical, tribological and corrosion properties of Mg-Li alloy (Jin et al., 2017; Zhang et al., 2019). Therefore, an appropriate surface treatment is required to overcome these weaknesses in order to expand the use of the Mg-Li alloy. Numerous surface treatment technologies exist, including PVD, electrophoresis deposition, anodic oxidation, plasma sputtering and micro arc oxidation (MAO). These surface treatments include micro arc oxidation (MAO); It provides important advantages such as low cost, environmental friendliness and the formation of a ceramic oxide layer, which has excellent mechanical properties on the magnesium alloy, is relatively thicker, denser and has good tight bonding stability with the base material (Zhang et al., 2019; Xia et al., 2019; Kucukosman et al., 2021; Şüküroğlu et al., 2021; Tian et al., 2022).

Recently, there has been an increasing interest in investigating the properties of MAO coatings grown on magnesium alloys (Jin et al., 2022; Tian et al., 2022). However, few studies have been conducted to determine and improve the properties of MAO coatings grown on magnesium-lithium alloys. In this study, it was aimed to grow an oxide layer in a silicate-containing solution by MAO method on a Mg-Li alloy called Mg-9Li-1Al (LA 91). The morphology, composition and structural properties of the obtained coatings were analyzed by scanning electron microscopy (SEM) and X-ray diffractometry (XRD). The corrosion behavior of the MAO coating was investigated using the potentiodynamic polarisation test in 3.5% NaCl solutions at room temperature. It was aimed to draw attention to the protection of the coating by conducting corrosion tests of the base materials with the enlarged coating.

EXPERIMENTAL SETUP

Mg-Li (LA91) alloy, whose chemical composition is shown in Table 1, with dimensions of 25x25x3 mm was used as the base material. The surfaces of each sample were polished with different grain size SiC abrasives up to a roughness value of Ra≈0.1µm. After polishing, the samples were and dried under dry air.

The coating to be grown on LA91 substrates by MAO method was carried out in bipolar mode using an AC power supply in an aqueous solution of Na_2SiO_3 (10 g/L), KOH (5 g/L), and Na_2HPO_4 (10 mL/L) as electrolytes. Other parameters used in the MAO method are frequency, current density, processing time and pulse rate, respectively, 600 Hz, 10A/dm^2, 30 min and 20%. In all coatings, the samples act as anodes, while the side walls of the stainless steel pool containing the electrolytic solution act as cathodes. During the process, the temperature of the electrolytic solution was cooled by the mains water passing through the walls of the bath so that the temperature did not rise above 30ºC. After the coating process, the coated samples were washed with alcohol and dried under dry air.

Table 1- LA 91 Chemical composition of the base material (% by weight).

Composition (% wt.)			
Alloy	**Mg**	**Li**	**Al**
%	90,108	8,829	1,063

The thickness of the MAO coating, surface and cross-section morphologies were analyzed by field scanning electron microscope (SEM, FEI brand QUANTA FEG). In addition, to characterize the phase change before and after coating, a Cu-Kα sourced Panalytical-Empyrean model XRD device with a wavelength of λ=1.5404 Aº was used. Measurement values were carried out at a scanning range of 20-90º, a scanning step of 0.1 degrees and a scanning speed of 2.5 degrees/min. Reflections were evaluated by comparing them with the standard JCPDS (Joint Committe on Powder Diffraction Standards) peak lists available in the literature.

The phases formed on the surfaces of NiTi samples coated with TiO2 and Ag-TiO2 by MAO were determined by the Rigaku-2200D/Max XRD device using Cu-Kα with a wavelength of □=1.5405 A°. The chemical compositions of the formed phases were determined by comparing the obtained results with the peak lists of JCPDS (Joint Committee on Powder Diffraction Standards).

The electrochemical polarization experiments for the corrosion behavior of the coated and uncoated LA91 were carried out using a Potentiostat in 3.5 wt% NaCl aqueous solution at the room temperature. Three-electrode cell configurations were employed for the polarization measurements. The electrochemical cell consists of coated LA91 and uncoated LA91 alloy substrates as the working electrode (WE), a standard Ag/AgCl reference electrode (RE) and a platinum counter electrode (CE).

RESULTS AND DISCUSSION

Oxide coatings were successfully grown on LA91 alloy substrates by MAO method. Figure 1 shows the surface morphology of MAO coatings grown on LA91 alloy. In the enlarged coating; The typical surface structure of the MAO method, such as micropores and microcracks caused by thermal stresses during solidification, has been determined (Jinguang et al., 2020; Linjie et al., 2021). It also shows that the pores formed on the surface after the MAO process create roughness on the surface. It can be said that the local melting and subsequent solidification trace that occurs during the coating process follows a circular path, and the micro-voids formed in the coating cause micropores similar to the volcanic peak (Darband et al., 2017). It is known that this situation is caused by micro arc discharge channels (Siyuan et al., 2022).

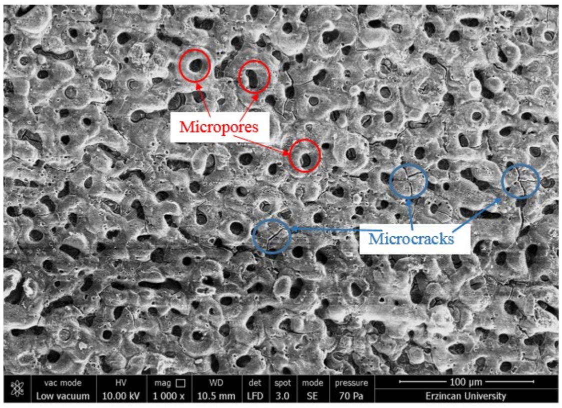

Figure 1. The surface morphologies of MAO coated LA91 alloy.

Figure 2 shows a cross-sectional view of MAO coatings. As shown in Figure 2, the coating consists of 2 regions. These regions are known as the dense inner layer and the porous outer layer (Yuqing et al., 2020; Xiaochun et al., 2022; Peng et al., 2022). In these regions, which are structurally formed in MAO coatings, it is seen that the inner layer is thinner and also denser than the porous outer layer. It can also be said that the interface between the coating and the substrate is relatively smooth, with no apparent discontinuity in the coating, indicating better cohesion and adhesion (Xiaochun et al., 2022).

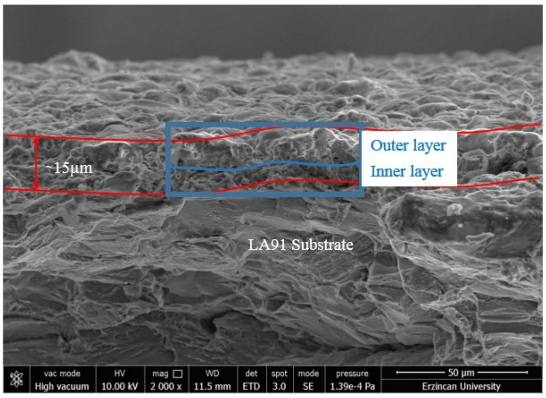

Figure 2. The cross-sectional morphologies of MAO coated LA91 alloy.

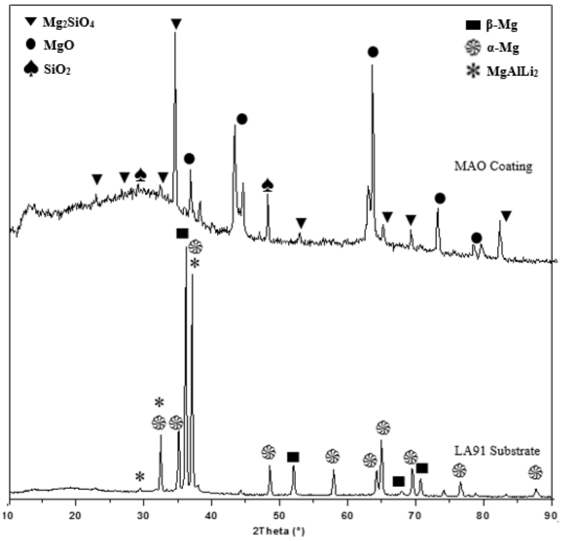

Figure 3. The XRD patterns of the LA91 alloy and MAO coating.

XRD graphs of the coating are shown in Figure 3. Accordingly, it is seen that MgO and Mg2SiO4 phases are present in the main structure of the coating. The β-Li peaks are attributed to the penetration of X-ray into the coatings and reflection from the base material (Ma et al., 2022; Jin et al., 2022; Xiaochun et al., 2022). Regardless of the composition of the Mg-Li alloys, the MgO and Mg2SiO4 phase peaks are the main phases formed in accordance with Mg alloys in MAO coatings deposited in the silicate-based electrolyte (Duan et al., 2007; Darband et al., 2017). The thickness of MAO coatings increases linearly with increasing coating formation time in relation to Faraday's Law of Electrolysis (Sundararajan and Krishna 2003;

Darband et al. 2017). It has been reported in the literature that the dense inner layer of the coating mainly contains MgO. At the same time, Mg_2SiO_4 is preferentially formed in the outer layer due to reactions between Mg^{2+} and the electrolyte (Hussein et al., 2013). As the thickness of the coating increases, the thickness of the dense inner layer also increases, resulting in X-rays not being able to penetrate through the coating to the base material, resulting in no reflection. Therefore, the coating lacks Li-containing crystalline compounds detected by XRD (Darband et al., 2017). In addition, Al_2O_3 peaks are shown very weakly in Figure 3 due to the involvement of Al in the oxidation reaction.

When Figure 4 is examined, it is seen that the potentiodynamic polarization curves of the coatings are similar to each other, and the current density in the cathodic branches of the coatings decreases slightly with the increase in potential. This is thought to be due to the accumulation of corrosion products in the microcracks and micropores formed on the surface due to the nature of the MAO coating process. The lowest corrosion current value and the highest corrosion potential values in I_{corr} and E_{corr} values determined using the Tafel graph play an important role in determining the corrosion resistance (Table 2). Figure 4 shows that coated samples have higher corrosion resistance than uncoated samples. E_{corr} and I_{corr} values of the coatings were calculated from the Tafel extrapolation method on the polarization curves. E_{corr}, I_{corr}, slope of anodic Tafel curve (βa), the slope of cathodic Tafel curve (βc) and corrosion resistance (Rp) values calculated according to Stern-Geary equation, obtained from Tafel curves determined for each sample using VersaStudio software are given in Table 2. The Rp values of coating is considerably higher compared to the LA 91 substrate. The highest I_{corr} values and the lowest Rp values were determined for LA 91 substrate.

It can be argued that the corrosion mechanism can proceed through surface defects such as pores and microcracks that are formed due to the nature of the coating process on MAO coated surfaces. As mentioned in previous studies, due to the effect of anodic polarization, Cl- ions in solution can accumulate in micropores and/or microcracks and penetrate into the substrate, resulting in high defects (Fadaee et al., 2014; Aliramezani et al., 2017; Hakimizad et al., 2017). Therefore, the migration of electrolyte to the substrate due to pores and defects on the surface can reduce corrosion resistance (Barati et al., 2017). In this study, it is emphasized that the thick, homogeneous and dense structure of the coating is much more effective than the porous structure formed by the nature of the coating on the material surface. The MgO and Mg_2SiO_4 detected from the phase analysis of the ceramic coatings grown on the LA 91 alloy contribute to the better corrosion resistance of the coated sample and the reduction of the contact area between the substrate and the corrosion medium. In addition, the thick and dense inner layer of the ceramic coating played a very active role in improving corrosion resistance (Zhang et al., 2010; Lingling et al., 2010; Cheng et al., 2013; Darband et al., 2017). The cross-sectional morphology of the coated sample with high corrosion resistance is presented in Figure 2.

Table 2- Corrosion parameters of the MAO coating and LA 91 Substrate.

Samples	**E_{corr} (V)**	**I_{corr} (µA/cm²)**	**βc (µV)**	**ßa (µV)**	**Rp (Ω.cm²)**
LA 91 Substrate	-1,538	1125,605	1105,536	625,458	0,154295730
MAO Coating	-1,715	20,952	625,22	183,425	2,942931560

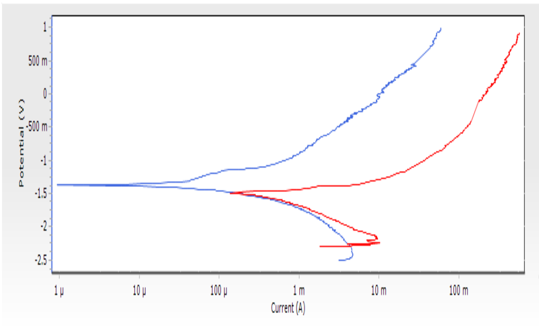

Figure 4. The potentiodynamic polarization curves (Red one is LA91 substrates and Blue one is MAO coating).

CONCLUSION

In this study, the structural properties and corrosion behaviors of ceramic-containing oxide coatings grown on LA91 Magnesium alloy were discussed and the following results were obtained;

- In the enlarged coating; The typical surface structure of the MAO method, such as micropores and microcracks caused by thermal stresses during solidification, has been determined.
- It was determined that MgO and Mg_2SiO_4 phases are in the main structure of the coating.
- It has been determined that Al in the base material is involved in the oxidation reaction. However, there are no Li-containing crystalline compounds detected in the coating.
- It was determined that the thick, homogeneous and dense structure of the coating is much more effective than the porous structure formed by the nature of the coating on the material surface. High corrosion resistance was obtained in the coated samples.

REFERENCES

Aliramezani, R., Raeissi, K., Santamaria, M., Hakimizad, A., "Characterization and properties of PEO coatings on 7075 Al alloy grown in alkaline silicate electrolyte containing KMnO4 additive," *Surface and Coatings Technology*, Vol. 329 pp. 250–261 2017.

Baghdadabad, D.M., Baghdadabad, A.R.M., Khoei, S.M.M., "Characterization of bioactive ceramic coatings synthesized by plasma electrolyte oxidation on AZ31 magnesium alloy having different $Na_2SiO_3 \cdot 9H_2O$ concentrations," *Materials Today Communications*, vol. 25 pp. 101642 2022.

Barati, N., Yerokhin, A., Golestanifard, F., Rastegari, S., Meletis, E.I., "Alumina-zirconia coatings produced by plasma electrolytic oxidation on Al alloy for corrosion resistance improvement," *J. Alloys Compd*., Vol. 724 pp. 435–442 2017.

Buldum, B., Sık, A., Özkul, İ., "Investigation of magnesium alloys machinability," *Internatıonal Journal of Electronics Mechanical and Mechatronics Engineering*, Vol. 2, No. 3, pp. 261-268 2012.

Cheng, Y.L., Wu, X.Q., Xue, Z.G., Matykina, E., Skeldon, P., Thompson, G.E., "Microstructure, corrosion and wear performance of plasma electrolytic oxidation coatings formed on Ti–6Al–4V alloy in silicate-hexametaphosphate electrolyte," *Surface and Coatings Technology*, Vol. 217, pp. 129–139 2013.

Darband, G.B., Aliofkhazraei, M., Hamghalam, P., Valizade, N., "Plasma electrolytic oxidation of magnesium and its alloys: mechanism, properties and applications," *J. Magnes. Alloy*., Vol. 5, pp. 74–132 2017.

Duan, H., Yan, C., Wang, F., "Effectofelectrolyteadditivesonperformance ofplasmaelectrolytic oxidationfilmsformedonmagnesiumalloyAZ 91D," *Electrochimica Acta*, Vol. 52, pp. 3785-3793 2007.

Esmaily, M., Svensson, J.E., Fajardo, S., Birbilis, N., Frankel, G.S., Virtanen, S., Arrabal, R., Thomas, S., Johansson, L,G., "Fundamentals and advances in magnesium alloy corrosion," *Prog. Mater. Sci.*, Vol. 89, pp. 92–193 2017.

Fadaee, H., and Javidi, M., "Investigation on the corrosion behaviour and microstructure of 2024–T3 Al alloy treated via plasma electrolytic oxidation," *J. Alloys Compd.,* Vol. 604, pp. 36–42 2014.

Feng, S., Liu, W., Zhao, J., Wu, G., Zhang, H., Ding, W., "Effect of extrusion ratio on microstructure and mechanical properties of Mg–8Li–3Al–2Zn–0.5Y alloy with duplex structure," *Materials Science and Engineering: A*, Vol. 692, pp. 9-16 2017.

Friedrich, H.E., and Mordike, B.L., Magnesium Technology, (Metallurgy, Design Data, Applications), Springer-Verlag Berlin Heidelberg. 2006.

Gao, Y., Yerokhin, A., Parfenov, E., Matthews, A., "Application of voltage pulse transient analysis during plasma electrolytic oxidation for assessment of characteristics and corrosion behaviour of Ca- and P-containing coatings on magnesium," *Electrochim. Acta* Vol. 149, pp. 218–230 2014.

Hakimizad, A., Raeissi, K., Golozar, M.A., Lu, X., Blawert, C., Zheludkevich, M.L., "The effect of pulse waveforms on surface morphology, composition and corrosion behavior of Al_2O_3 and Al_2O_3/TiO_2 nano-composite PEO coatings on 7075 aluminum alloy," *Surface and Coatings Technology*, Vol. 324, pp. 208–221 2017.

Hussein, R.O., Northwood, D.O., Nie, X., "The effect of processing parameters and substrate composition on the corrosion resistance of plasma electrolytic oxidation (PEO) coated magnesium alloys," *Surface and Coatings Technology*, Vol. 237, pp. 357-368 2013.

Jin, J., Li, H., Li, X., "Friction and wear behavior of micro arc oxidation coatings on magnesium alloy at high temperature," *Rare Metal Mater. Eng*., Vol. 46, pp. 1202–1206 2017.

Kucukosman, R., Sukuroglu, E.E., Totik, Y., Sukuroglu, S., "Investigation of wear behavior of graphite additive composite coatings deposited by micro arc oxidation-hydrothermal treatment on AZ91 Mg alloy," *Surfaces And Interfaces*, Vol. 22, pp. 100894 2021.

Kucukosman, R., Sukuroglu, E.E., Totik, Y., Sukuroglu, S., "Effects of graphene oxide addition on wear behaviour of composite coatings fabricated by plasma electrolytic oxidation (PEO) on AZ91 magnesium alloy," *Journal of Adhesion Science and Technology,* Vol. 35, No. 3, pp. 242-255 2021.

Kumar, D.S., Sasanka, C.T., Ravindra, K., Suman, K.N.S., "Magnesium and Its Alloys in Automotive Applications – A Review," *American Journal of Materials Science and Technology*, Vol. 4, No. 1, pp. 12-30 2015.

Kurze, P., "Corrosion and Surface Protections," Magnesium Technology, Ed: Mordike B.L., Friedrich H.E., Springer, Germany, pp. 431-494 2006.

Lee, S.J., and Do, L.H.T., "Effects of copper additive on micro-arc oxidation coating of LZ91 magnesium-lithium alloy," *Surface and Coatings Technology*, Vol. 307, Part A, pp. 781-789 2016.

Lingling, S., Yongjun, X., Kang, L., Zhongping, Y., Songquan, W., "Effect of additives on structure and corrosion resistance of ceramic coatings on Mg–Li alloy by micro-arc oxidation," *Current Applied Physics*, Vol. 10, No. 3, pp. 719-723 2010.

Linjie, D., Xi, L., Jiexi, L., Chuanqiang, L., Yong, D., Zhengrong, Z., "Corrosion behavior of a eutectic Mg–8Li alloy in NaCl solution," *Electrochemistry Communications*, Vol. 129, pp. 107087 2021.

Lu, F.F., Ma, K., Lia, C.X., Yasir, M., Luoa, X.T., Lia, C.J., "Enhanced corrosion resistance of cold-sprayed and shot-peened aluminum coatings on LA43M magnesium alloy," *Surface and Coatings Technology*, Vol. 394, pp. 125865 2020.

Jin, S., Ma, X., Wu, R., Wang, G., Zhang, J., Krit, B., Betsofen, S., Liu, B., "Advances in micro-arc oxidation coatings on Mg-Li alloys," *Applied Surface Science Advances*, Vol. 8, pp. 100219 2022.

Jinguang, L., Yan, Y., Hongju, D., Minmin, L., Junfei, S., Faping, H., Xiaoming, X., Xiaodong, P., "Microstructure and corrosion behavior of as-extruded Mg-6.5Li-xY-yZn alloys," *Journal of Alloys and Compounds*, Vol. 823 pp. 153839 2020.

Ma, X., Jın, S., Wu, R., Wang, J., Wang, G., Krıt, B., Betsofen, S., "Corrosion behavior of Mg−Li alloys: A review," *Transactions of Nonferrous Metals Society of China*, Vol. 31, No. 11, pp. 3228-3254 2021.

Mingjin, Wu., Feifei, Wu., Mengjun, Long., Pengcheng, Ye., Feng, Jiang., Jingyu, Jiang., "Microstructure evolution and fracture mechanism of the interfacial region between MAO ceramic film and Al-Mg-Sc alloy substrate," *Materials Today Communications*, vol. 33 pp. 104471 2022.

Peng, X., Sun, J., Lıu, H., Wu, G., Lıu, W., "Microstructure and corrosion behavior of as-homogenized and as-extruded Mg−xLi−3Al−2Zn−0.5Y alloys (x=4, 8, 12)," *Transactions of Nonferrous Metals Society of China*, Vol. 32, No. 1, pp. 134-146 2022.

Siyuan, J., Xiaochun, M., Ruizhi, W., Guixiang, W., Jinghuai, Z., Boris, K., Sergey, B., Bin, L., "Advances in micro-arc oxidation coatings on Mg-Li alloys," *Applied Surface Science Advances,* Vol. 8, 100219 2022.

Songur, F., Dikici, B., Niinomi, M., Arslan, E., "The plasma electrolytic oxidation (PEO) coatings to enhance in-vitro corrosion resistance of Ti–29Nb–13Ta–4.6Zr alloys: the combined effect of duty cycle and the deposition frequency," *Surface and Coatings Technology*, Vol. 374 pp. 345–354 2019.

Sundararajan, G., Krishna, L.R., "Mechanisms underlying the formation of thick alumina coatings through the MAO coating technology," *Surface and Coatings Technology*, Vol. 167, No. 2-3, pp. 269-277 2003.

Şüküroğlu, S., Totik, Y., Şüküroğlu, E.E., Küçükosman, R., "NiTi Alaşımının Mikro Ark Oksidasyon Sonrası İn-Vitro Özelliklerinin Araştırılması," *Politeknik Dergisi*, Vol. 24, No. 2, pp. 373-382 2021.

Telmenbayar, L., Gopal Ramu, A., Erdenebat, T.O., Choi, D., "Anticorrosive lanthanum embedded PEO/GPTMS coating on magnesium alloy by plasma electrolytic oxidation with silanization," *Materials Today Communications*, Vol. 33, pp. 104662 2022.

Tian, H., Zhang, Y., Hao, X., Zhang, H., Wu, W., Han, G., Dou, Z., Wei, Y., Zhang, Y., Chen, F., "Preparation and characterization of the low-energy plasma electrolysis oxide coatings on Mg–Li alloy," *Surface and Coatings Technology*, Vol. 440, pp. 128445 2022.

Xia, Q., Zhang, D., Li, D., Jiang, Z., Yao, Z., "Preparation of the plasma electrolytic oxidation coating on Mg-Li alloy and its thermal control performance," *Surface & Coatings Technology*, Vol. 369, pp. 252–256 2019.

Xiaochun, M., Siyuan, J., Ruizhi, W., Qing, J., Legan, H., Boris K., Sergey, B., "Influence alloying elements of Al and Y in Mg–Li alloy on the corrosion behavior and wear resistance of microarc oxidation coatings," *Surface and Coatings Technology*, Vol. 432, pp. 128042 2022.

Yang, H.P., Zhang, X., Chen, P., Fu, M.W., Wang, G.C., To, S., "Investigation on the enhanced maximum strain rate sensitivity (m) superplasticity of Mg-9Li-1Al alloy by a two-step deformation method," *Materials Science and Engineering: A* ,Vol. 764, pp. 138219 2019.

Yuqing, H., Chaoqun, P., Yan, F., Richu, W., Jianfeng, Z., "Effects of alloying elements on the microstructure and corrosion behavior of Mg–Li–Al–Y alloys," *Journal of Alloys and Compounds*, Vol. 834, pp. 154344 2020.

Zhang, X.L., Jiang, Z.H., Yao, Z.P., Wu, Z.D., "Electrochemical Study of Growth Behaviour of Plasma Electrolytic Oxidation Coating On Ti6Al4V: Effects Of The Additive," *Corrosion Science*, Vol. 52, pp. 3465–3473 2010.

Zhang, Y., Chen, F., Zhang, Y., Liu, Z., Wang, X., Du, C., "Influence of graphene oxide on the antiwear and antifriction performance of MAO coating fabricated on Mg-Li alloy," *Surface and Coatings Technology*, Vol. 364, pp. 144-156 2019.