Influence of Voltage on the Corrosion and Wear Resistance of Micro-Arc Oxidation Coating on Mg–8Li–2Ca Alloy

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Abstract

Calcium phosphate (CaP) coatings were prepared on Mg–8Li–2Ca magnesium alloy by micro-arc oxidation (MAO) in an alkaline $\text{Na}_3\text{PO}_4\text{--Ca}[\text{C}_3\text{H}_7\text{O}_6\text{P}]$ base solution at the different applied voltages. Scanning electron microscope and X-ray diffraction were employed to characterize the microstructure and phase composition of the coatings, respectively. The corrosion resistance of the coatings was assessed by potential dynamic polarization curves, electrochemical impedance spectroscopy and hydrogen evolution experiment in simulated body fluids solution. The friction and wear properties were evaluated by friction and wear testing machine. The results demonstrate that the coating surface is porous and mainly composed of MgO , $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ and $\text{CaH}_2\text{P}_2\text{O}_5$. With the increase in voltage, the corrosion resistance and wear resistance of the MAO coating are both enhanced. The corrosion current density of the MAO coating decreases about two orders of the magnitude compared to the substrate. Additionally, wear and corrosion mechanisms are discussed.

Keywords Magnesium alloy · Micro-arc oxidation · Electrochemical impedance · Wear mechanisms

1 Introduction

Mg–Li alloys have been widely used due to their ultra-low density, high specific strength, and excellent biocompatibility [1–4]. With the addition of Li, not only the density of the Mg alloys has been brought down, but also the crystal structure of magnesium has been changed. A two-phase structure ($\alpha + \beta$) can be obtained in Mg–8Li alloys [5]. However, Mg–Li alloys have a relatively low strength and corrosion resistance, which limits their wide applications [6]. The mechanical properties and corrosion resistance can be improved by

alloying and surface technologies. The physical and chemical properties of Mg–Li alloys can be improved by alloying with Al, Zn, Mn, RE, Ca, etc. [7–9]. Among them, Ca, as a vital component of human bones, can refine the microstructure, enhance the strength and flame resistance as well as biocompatibility of Mg [10, 11]. However, the Mg_2Ca phase reduces the ductility and influences the corrosion properties of Mg alloys with increasing Ca content. Therefore, Ca content should be relatively low [12]. In contrast to the limitation and toxicity of alloying, surface technology has more extensive application prospect. Many surface technologies for Mg–Li alloys, i.e., micro-arc oxidation (MAO) [13], chemical conversion coating [14], layer-by-layer assembled coating [15], electrodeposition coating [1], biomimetic deposition coating [16], were developed to obtain coatings to improve corrosion resistance. As the surface properties play important roles in the physio-chemical processes, the coating should be biocompatible and has a slower corrosion rate than that of Mg alloys. MAO, which is also called as micro plasma oxidation (MPO) or anode spark deposition (ASD), has been applied in the surface modification of magnesium and its alloys for biomedical applications [17, 18]. The corrosion behavior of MAO-coated Mg alloys in simulated body fluids (SBF) solution has been widely studied [19, 20], and the

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effect of various electrolytes on the electrochemical corrosion behavior of MAO coating has also been investigated [20, 21]. The thickness, micromorphology, tribological properties and other properties of the micro-arc oxide coating were affected by many other factors, such as energy parameters (including current density, voltage, duty cycle, and treatment time), solution properties (including solution composition, concentration, temperature, conductivity and pH) and matrix alloy elements [22–24]. Most previous researches about MAO coatings on magnesium alloy focused on the anti-corrosion property and the morphological feature. Little literature reports the effects of voltage on MAO coating formation and corrosion resistance for Mg–Li alloys.

In present work, MAO treatments at various applied voltages were carried out in Na_3PO_4 – $\text{Ca}[\text{C}_3\text{H}_7\text{O}_6\text{P}]$ electrolyte, and the microstructure, corrosion and wearing properties of MAO-treated Mg–8Li–2Ca alloy were assessed. The influences of voltage on formation of MAO coating were investigated and the corrosion and wear mechanisms of MAO coating were further taken insights.

2 Experimental

2.1 Materials

The as-cast Mg–8Li–2Ca alloy for MAO treatment was prepared with the compositions of 8.14 wt% Li, 1.78 wt% Ca, and balance Mg. The substrate surface was ground with SiC papers up to 2000 grit. The substrate surfaces were then ultrasonically cleaned in ethyl alcohol and dried with warm air. Aqueous electrolytes were prepared from solutions of 20 g/L Na_3PO_4 with 0.2 mol/L $\text{Ca}[\text{C}_3\text{H}_7\text{O}_6\text{P}]$. $(\text{NaPO}_3)_6$ (0.5 g/L) and $\text{C}_6\text{H}_9\text{O}_7\text{Na}_3$ (0.5 g/L) were selected as additives in order to improve discharge and accelerate the growth rate of the coating. The immersion test was carried out in SBF with a pH of 7.4 containing the following components: 142.0 mmol/L Na^+ , 5 mmol/L K^+ , 1.5 mmol/L Mg^{2+} , 2.5 mmol/L Ca^{2+} , 147.8 mmol/L Cl^- , 4.2 mmol/L $(\text{HCO}_3)^-$, 1.0 mmol/L $(\text{HPO}_4)^{2-}$, 0.5 mmol/L $(\text{SO}_4)^{2-}$, and 1 L distilled water at 37 ± 0.5 °C.

2.2 Equipment and Methods

The micro-arc oxidation process was conducted in a HG-2000 micro-arc oxidation power supply, with a frequency of 700 Hz and a duty cycle of 50%, and a stirring and cooling system. The Mg–8Li–2Ca alloy was used as the anode electrode and graphite as the cathode electrode. The applied voltage was in the range of 375–475 V. The MAO treatment time was 20 min.

X-ray diffraction (XRD, D/Max2500 X-ray Diffractometer) was used to characterize the phase of untreated and

MAO-treated Mg–8Li–2Ca alloy before and after the corrosion tests. The surface and cross-sectional microstructures were measured with a Camscan MX2600 FE scanning electron microscope. Friction and wear experiments were carried out on HT-1000Z ball disk friction and wear tester. The friction pairs were GCr15 quenched steel balls with a diameter of 6 mm, a load of 2 N, a rotating speed of 50 r/min and wear time of 300 s. The average weight loss of the coating was obtained from 5 values.

Electrochemical tests were performed on the IM6 electrochemical workstation in SBF solution at 37 °C. A three-electrode system was applied with samples as working electrode with an exposed area of 2.84 cm^2 , and a saturated calomel electrode (SCE, Sat'd KCl) as reference electrode and a platinum foil electrode as counter electrode. Stabilization time is 3000 s at a scan rate of 1 mV/s for OCP test. During the Tafel polarization test, the start potential was -0.3 V versus OCP and final potential was $+0.3$ V versus OCP at a rate of 0.5 mV/s. The electrochemical impedance spectroscopy (EIS) measurements were obtained after OCP test. The frequency of EIS was from 1 kHz to 10 MHz with a perturbation amplitude of 10 mV RMS. The hydrogen evolution tests were also conducted at a water bath of 37 ± 0.5 °C in SBF solution.

3 Results and Discussion

3.1 Effect of Voltage on Microstructure of MAO Coating

Figure 1 shows the surface microstructure of MAO coating on Mg–8Li–2Ca alloy with different voltage. The coating is composed of molten products formed during electrification and micron-sized pores distributed therein. With the increase in voltage, the average size of micropores increases and the amount of micropores decreases, as shown in Fig. 1a–e. The results indicate that the applied voltage has an important effect on the surface morphology of the MAO coating. During the MAO process, high temperature arises immediately with the appearance of sparking phenomenon when the voltage increases to breakdown voltage. There are some weak sites in the thin and dense layer of the samples. The as-formed layer is broken down at these weak sites, leading to the formation of new layer and micro-arc discharge channels. The melted depositions are cooled down around the micro-arc discharge channels, resulting in the increase in coating thickness. The number of weak sites in the coatings reduces with the coating thickness increasing, which makes the breakdown of layer become difficult, needing a higher applied voltage to offer the supplementary energy. Accordingly, the dielectric breakdown is easy to occur at the micro-arc discharge

Fig. 1 Surface microstructure of MAO coatings on Mg-8Li-2Ca alloy prepared at **a** 375 V, **b** 400 V, **c** 425 V, **d** 450 V, **e** 475 V

channels, which leads to the increase in micropore diameter [25–27].

Figure 2 illustrates the cross-sectional morphology of MAO coatings at 375, 400, 420, 450 and 475 V. No apparent defects between the MAO coating and the substrate are found, indicating that the interfacial bonding is relatively good and the structure of the coating is relatively compact. The thickness of MAO coating at different applied voltages is shown in Fig. 3. With the increase in the applied voltages (375–475 V), the thickness of the MAO coatings increases from 14.5 to 72.7 μm , indicating that the thickness of MAO coatings can be modified by varying the applied voltage. When the treatment voltage is 375 V (Fig. 2a), the surface of the thin MAO coating is very rough. During the MAO process, the elapsed time during the anode oxidation period decreases as the voltage increases. When the voltage is 375 V, the anodic oxidation time is relatively long before

entering the micro-arc oxidation reaction stage, and the voltage distribution is uneven after the oxidation breakdown, which leading to the uneven growth of the MAO coating. When the voltage increases to 400 V, the anodizing is shortened, and the growth rate of the MAO coating is accelerated. The thickness of the coating is uniform, and the interface is relatively straight, as shown in Fig. 2b. Up to 425 V (Fig. 2c), the growth rate and the thickness of the coating continue to increase, and the inner and outer boundaries of the coating are relatively flat. When the voltage increases to 450 V, as shown in Fig. 2d, the thickness of the coating continues to increase, the thickness of the coating is uneven, and a small number of holes appear inside the coating due to the different growth rate. It is found that the film consists of three layers in Fig. 2e: the internal layer, the tight intermediate layer, and the rough outer layer. As the voltage increases, the thickness increases. In addition, the surface

Fig. 2 Cross-sectional microstructure of MAO coatings on Mg-8Li-2Ca alloy prepared at **a** 375 V, **b** 400 V, **c** 425 V, **d** 450 V, **e** 475 V

structure of the coating develops cracks owing to the thermal stresses that are generated by rapid solidification during the process. The cracks on the surface generally grow with an increase in voltage [28]. The coating growth can be influenced by the increase in voltage through affecting the direction and speed of ions transferring. With the increase in voltage, the speed of ions exchange and inter reaction increases, the coating growth rate enhances.

Figure 4 shows the phase composition of the MAO coating prepared at different voltages. The coating is mainly composed of MgO and Ca-containing phosphate. As the voltage increases, the thickness of the coating

increases, and the intensity of the diffraction peak of Mg decreases. The peak intensity of the MgO and Ca-containing phosphate increases with the increasing voltage. The result implies that the voltage accelerates the formation of MAO coating. The content of the phase in the coating is proportional to the thickness of the coating [29]. There is no peak corresponding to Li phase in the XRD patterns. This is because that Li element is so reactive that it preferentially reacts with the electrolyte, the lithium-containing oxide dissolves and enters the electrolyte [30]. The diffraction peaks of the matrix Mg disappear and that of $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ phase are detected at 475 V, which

Fig. 3 Thickness of MAO coatings on Mg-8Li-2Ca alloy prepared at different voltages

Fig. 4 XRD pattern of MAO coatings on Mg-8Li-2Ca alloy prepared at different voltages

demonstrates that the P element is incorporated into the coating successfully.

3.2 Effect of Voltage on Immersion Corrosion of MAO Coating

Figure 5 shows the relationship between the amount of hydrogen and the immersion time of MAO coating at different voltages. It can be seen intuitively that the hydrogen evolution rate of the Mg-8Li-2Ca alloy matrix is much larger than that with MAO coating. After a certain immersion time, the hydrogen evolution rate of both the matrix and MAO samples decreases and reaches a stable state. The average hydrogen evolution rate of the matrix is 0.12 ml/(h cm²). With increasing voltage, the hydrogen evolution rate of the specimen with MAO coating decreases, and the average hydrogen evolution rates of the specimen are 0.029 ml/(h cm²), 0.026 ml/(h cm²), 0.022 ml/(h cm²), 0.018 ml/(h cm²), and 0.015 ml/(h cm²), respectively. The hydrogen evolution rate is 1/8 that of the substrate when the voltage is 475 V. As the

Fig. 5 Hydrogen content of MAO coating at different voltages in different immersion time

voltage increases, the corrosion resistance increases. The thickness, porosity and cracks are important influencing factors of coating corrosion property. With increasing voltage, the coating thickness increases while the structure is dense, and the resistance of the etching solution to the substrate is increased. However, as the voltage increases, the pore size of MAO coating increases, which causes the diffusion of the corrosive medium becoming faster, resulting in a slower decline in the average hydrogen evolution rate.

3.3 Effect of Voltage on Electrochemical Corrosion Properties of MAO Coating

Figure 6 shows the Tafel curves of the MAO coating at different voltages. The corrosion potential and corrosion current density are listed in Table 1. The corrosion potential of Mg-8Li-2Ca matrix is -1.8520 V. The corrosion potential shifts positively to -0.6471 V when the voltage is 375 V. The corrosion current density decreases from 10⁻⁴ to 10⁻⁶ A/cm², two orders of magnitude, indicating that MAO treatment can significantly improve

Fig. 6 Tafel curve of MAO coating at different voltages and matrix

corrosion resistance. The electrochemical curves are characterized as electrochemically activated polarization before and after micro-arc oxidation. Generally, the anodic polarization curves represent the dissolution of magnesium while the cathodic polarization curves are assumed to represent the hydrogen evolution reaction. It can be seen that the various voltages give rise to different cathodic polarization currents. The slope of the Tafel curve increases with increasing voltage, indicating that the cathodic reaction is kinetically easier at lower voltage.

In order to find out a mechanism of voltage effect on the corrosion property of the coatings, EIS measurements are conducted. The EIS spectra for matrix and MAO coatings prepared at different voltages are presented in Fig. 7a, and the high-frequency region is partially enlarged, as shown in Fig. 7b. Two time constants at low and high frequencies are detected in MAO coatings Nyquist plots. These plots with two time constants represent coatings with an inner dense layer and an outer porous layer. The time constant at higher frequencies presents the responses of the porous outer layer and the time constant at lower frequencies corresponds to the responses of the compact inner layer [31, 32]. It is obvious that the corrosion resistance of the compact layer is higher than that of the outer porous layer for all the MAO samples. The diameter of capacitive semicircle at higher frequencies of the substrate is less than that of the MAO sample prepared at 375 V. As the voltage increases, the capacitive loop diameter of the low-frequency zone increases, and the high-frequency zone first increases and then decreases. The EIS plot appears as a straight line with a slope of 45° in the low-frequency region which indicates the Warburg diffusion process. The appearance of Warburg diffusion impedance is related to the surface roughness of the membrane layer. Generally, the smaller the surface roughness of the film layer and the more complete the film cover is, the larger the value of Warburg diffusion impedance is.

Equivalent circuits with two time constants, which have an acceptable fitness with the Nyquist and Bode plots (Fig. 7) are shown in Fig. 8. Figure 8a shows a fitting circuit of a sample after MAO, and Fig. 8b shows a circuit of Mg–8Li–2Ca alloy. R_s is the resistance of the electrolyte, R_1 and C_1 are the resistance and capacitance of the outer layer of the micro-arc oxidation film. For Mg–8Li–2Ca matrix, R_1 is the substrate resistance and C_1 is the surface oxidation film capacitance. R_2 and C_2 denote the

resistance and capacitance of the inner layer of the MAO coating. W is diffusion impedance.

The specific values are shown in Table 2. R_s is between 20 and 30 Ω . R_1 increases as the voltage increases which is related to the compactness, micropore and thickness of the inner layer. R_2 is related to the density, pore size and thickness of the outer layer. As stated above that, with increasing voltage, the thickness of the film layer increases, while the number pore size on the surface increases. The value of R_1 increases first and then decreases slightly with the increase in the voltage due to the combined effects. The total resistance of the coating is determined by the sum of R_1 and R_2 . With the increase in voltage, the resistance values of the coating are 1709.1 Ω , 2281.8 Ω , 2854.9 Ω , 4157.8 Ω , and 5892.9 Ω , respectively. The Warburg diffusion impedance is related to the surface roughness of the coating. It can be seen from the W value in Table 2 that the corrosion resistance of the MAO coating increases with increasing voltage.

3.4 Effect of Voltage on Tribological Properties of Micro-Arc Oxide Coating

Figure 9 shows the variation of coefficient of friction (C.O.F.) with time at different voltages. When the voltage is 375 V, the C.O.F. is about 0.2 and changes gently. When the voltage is 400 V and 425 V, the C.O.F. increases slowly first then remains stable after 3 min, with the value of 0.30 and 0.35, respectively. When the voltage is 450 V and 475 V, the C.O.F. remains stable after 4 min and up to 0.45 and 0.55, respectively. The C.O.F. is relatively stable, indicating that the MAO coating is not worn. The variation of friction and wear curve with time reveals that friction and wear can be divided into two stages. The first stage is a running-in stage. The contact between the GCr15 steel ball and the coating is a little contact between the friction pair and the coating, and the C.O.F. quickly increases to a small stable value. The second stage is that, after the running-in stage, the C.O.F. curve enters a stable stage [33]. The frictional properties of the MAO coating are related to the thickness, the compactness, the hardness, and the bonding strength with the substrate. Similarly, with the increase in voltage, the thickness, tightness of the coating increase. However, the defects of cracks and pores occur in the coating, which reduces the bonding strength between the coating and the substrate. Under the combined action of

Table 1 Free-corrosion potential and free-corrosion current density of coatings prepared at different voltages and Mg–8Li–2Ca matrix

Parameters	375 V	400 V	425 V	450 V	475 V	Matrix
E_{corr} (V)	– 0.6471	– 0.6284	– 0.5634	– 0.4079	– 0.3324	– 1.8520
I_{corr} ($\mu\text{A}/\text{cm}^2$)	6.298	4.230	4.375	2.087	1.271	243.8

Fig. 7 EIS spectra of MAO coatings at different voltages in SBF solution **a**, **b** magnification of high-frequency region

Fig. 8 Equivalent electric circuits represent **a** MAO coatings, **b** Mg-8Li-2Ca matrix

Table 2 Fitting results of EIS plots of the Mg-8Li-2Ca matrix and MAO coatings at different voltages

MAO voltages	R_s (Ω)	R_1 (Ω)	C_1 (F)	R_2 (Ω)	C_2 (F)	W ($\Omega \text{ s}^{-1/2}$)
375 V	24.79	245.1	$1.333\text{E}-7$	1464	$1.009\text{E}-6$	2387
400 V	23.74	375.8	$1.154\text{E}-7$	1906	$6.415\text{E}-7$	2480
425 V	27.82	759.9	$9.751\text{E}-8$	2095	$5.968\text{E}-7$	2918
450 V	22.87	701.8	$1.091\text{E}-7$	3456	$6.001\text{E}-7$	3866
475 V	28.91	678.9	$5.803\text{E}-8$	5214	$7.448\text{E}-7$	4268
Matrix	23.56	149	$9.635\text{E}-7$			642.3

Fig. 9 Coefficient of friction of MAO coatings at different voltages

these reasons, the C.O.F. eventually increases with the increase in voltage. Figure 10 is abrasion loss of the coating at different voltages. With the increase in the

voltage, the wear weight loss of the coating is 7.3 mg, 6.5 mg, 4.8 mg, 2.9 mg, 2.2 mg, corresponding to the variation of C.O.F.

Figure 11 shows the wear morphology of the coating prepared at 425 V. The wear width is uniform, about 0.5 mm, as shown in the macroscopic morphology of the wear scar in Fig. 11a. Figure 11b shows the local wear morphology. The oxide coating flakes out, and the lamellar crack occurs in the wear scar. The relative loose nodular structure on the outer layer is subject to wear off. After several cycles of friction, crack initiation and expansion are caused to accelerate the oxidation peel off. Therefore, the crack propagates along the friction direction and parallel to the friction surface, resulting in fatigue wear. There are many flaking debris in the wear scar, as shown in Fig. 11c. During the friction process, the detached particles from the coating surface can serve as “third body” at the interface. The friction mechanism of the micro-arc oxide coating is

Fig. 10 Abrasion loss of MAO coatings at different voltages

the mixed mechanisms of fatigue wear and abrasive wear [34].

3.5 Formation Mechanism of MAO Coating

The process of MAO coating includes a series of complex reactions, such as electrochemistry, thermochemistry, plasma chemistry. The formation of the coating is also affected by the surface state, electrical parameters and electrode characteristics of the metal sample.

The initial experimental phenomenon is that a large number of bubbles are formed from the surface of the metal sample, the metallic gloss of the substrate gradually disappears, and a very thin gray-white oxide coating is formed on the surface. A large number of bubbles are also produced on the graphite cathode at the same time. No micro-arc discharge is found on the surface of the sample, and the main reaction is anodic oxidation at this stage. The main chemical reaction process is as follows.

Anode reaction:

Cathode reaction:

After a period of reaction, the current density and the surface temperature of the sample increase, and the weak site of the oxide layer is broken down to form a discharge channel. PO_4^{3-} and OH^- in the solution enter the channel and react with Mg^{2+} . The anode reactions are as follows.

Fig. 11 Wear morphology of MAO coating prepared at 425 V **a** macromorphology, **b** high magnification of A region shown in (a), **c** high magnification of B region shown in (b)

As the reaction progressing, the temperature and current density of the sample surface increase continuously, and the melt formed by the reaction in the channel is ejected to form micropores on the surface of the MAO coating. At the same time, other forms of P such as $\text{H}_2\text{P}_2\text{O}_3^{2-}$ and $\text{P}_2\text{O}_7^{4-}$ also form micellar particles with Ca^{2+} . These particles reach the arc discharge reaction interface through diffusion and electrophoretic action, and enter the coating [35].

3.6 Corrosion Mechanism of MAO Coating

Figure 12 shows the different corrosion morphology of the micro-arc oxide coating prepared at 425 V after immersion in SBF solution for 160 h. The coating still retains obvious

microporous structure, and corrosion products adhere to the coating, as shown in Fig. 12a. Figure 12b shows the crack in the corroded coating, and the width of the crack is more than 100 μm . Figure 12c shows a large corrosion pit on the coating, where the coating completely falls off. Figure 12d is a magnified morphology of Fig. 12c, which is exactly the same as the corrosion morphology of the matrix, indicating that the coating is damaged completely and loses the protectiveness.

Figure 13 shows the XRD of the MAO coating prepared at 425 V after immersion in SBF solution for 160 h. The main phases after corrosion are MgO and $\text{Ca}_3(\text{PO}_4)_2(\text{OH})$. The thickness of the coating becomes thinner, and Mg peaks appear in the XRD pattern due to the peeling of the coating during the etching process. The original phosphoric acid compounds containing calcium in the coating are converted to $\text{Ca}_3(\text{PO}_4)_2(\text{OH})$. It can be seen that the prepared MAO coating can deposit bioactive $\text{Ca}_3(\text{PO}_4)_2(\text{OH})$ in SBF solution.

Figure 14 is a simulation diagram of the immersion corrosion process of the MAO coating in the SBF solution. The etching liquid enters the coating through the holes and contacts the substrate in the initial stage of immersion as shown in Fig. 14a. The coating is substantially not destroyed but the substrate is corroded and hydrogen is

Fig. 12 Corrosion morphology of MAO coating prepared at 425 V after immersion in SBF solution for 160 h **a** intact coating, **b** cracks in the corroded coating, **c** corrosion pit, **d** high magnification of A region shown in (c)

Fig. 13 XRD of MAO coating prepared at 425 V after immersion in SBF for 160 h

produced as shown in Fig. 14b. Then the resulting corrosion products enter the coating with hydrogen gas, infiltrate and slowly deposit into the pores, as shown in Fig. 14c and d. As the immersion time continues, the dense layer at the bottom of the holes is eroded step by step. Corrosive ions gradually erode the dense layer as the corrosion product gradually accumulating in the hole begins to dissolve or the porous micro-arc oxide coating becomes loose, that is, the corrosion occurs in the vicinity between the holes and the substrate. Therefore, the corrosion spreads to the substrate step by step, and the hydrogen produced during the corrosion process expands in volume during the process. A certain amount of stress on the coating due to hydrogen evolution, lead to the relatively weak part of the coating forming cracks, as shown in Fig. 14e. The coating falls off finally, as shown in Fig. 14f, and the corrosive

Fig. 14 Schematic representation of the corrosion process of MAO coating immersed in SBF

medium starts to enter the surface layer of the substrate, causing severe corrosion and the coating loses protection when the small cracks are connected to each other.

4 Conclusions

- (1) MAO coating was prepared on the surface of Mg–8Li–2Ca alloy in Na_3PO_4 – $\text{Ca}[\text{C}_3\text{H}_7\text{O}_6\text{P}]$ system. The main phases of MAO coating are MgO, $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ and $\text{CaH}_2\text{P}_2\text{O}_5$. The formation of MAO coating can be divided into two stages: the first stage is anodic oxidation. The second stage is the breakdown of the oxide layer and coating growing with micro-arc reaction.
- (2) The voltage has a significant effect on the surface morphology of the coating. As the voltage increases, the number of micropore decreases, and the pore size and the thickness of the coating increase. The defects such as the cracks and the holes formed in the coating increase.
- (3) The corrosion resistance and wear resistance of Mg–8Li–2Ca alloy can be significantly improved by micro-arc oxidation. With the increase in voltage, the corrosion resistance and wear resistance of the MAO coating are both enhanced.
- (4) The wear mechanism of the MAO coating and the GCr15 steel ball is the mixed mechanism of fatigue wear and abrasive wear. The corrosion mechanism of the MAO coating in SBF solution is mainly characterized by pit corrosion, and the corrosion phases are mainly MgO and $\text{Ca}_3(\text{PO}_4)_2(\text{OH})$ which are harmless to the human body.

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