Preparation of MAO Film Layer on LY12 Aluminum Alloy Surface in Sodium Hexametaphosphate Solution

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Abstract. Aluminum alloy is widely used in power grids to solve the problem of aluminum excess and copper deficiency. The MAO film is prepared by micro-arc oxidation on LY12 aluminum alloy with phosphate electrolyte. The growth rate of film layer in different treatment time is studied and the variation trend of film in growth and outward growth was carried out. Finally, the morphology and composition of the film were tested by SEM and EDS. The results show that the initial growth of micro-arc oxidation is slow, mainly grow outwards, the medium-term rate is accelerated, the later period is slow, and the middle and late stages are mainly grow inwards. Phosphorus in the electrolyte participates in the film reaction.

1. Introduction

With the development of science and technology, grid security is the fundamental factor for the survival and development of power countries and enterprises [1]. With the continuous development of power grids, the security and reliability of power grids are of great importance. Among them, the safety of equipment caused by the corrosion of metal materials in power grid equipment is more common, and it is increasingly valued by the electric power departments in various regions of the country [2]. Surface treatment on alloys is one of the main measures for anti-corrosion. As a high-strength aluminum alloy, LY12 is widely used in aerospace and civil engineering. In addition, aluminum alloy materials have outstanding advantages in power architecture. Wire and cable "Aluminum instead steel" has strategic significance for solving the excess of electrolytic aluminum and ensuring national resource security [3, 4].

Therefore, in order to strengthen the application of aluminum alloy, the surface modification treatment of aluminum and its alloy materials by micro-arc oxidation technology has the advantages of simple process, high production efficiency and high industrial production. The electrolyte has strong anti-pollution ability and high re-use rate, low environmental pollution, and meet the needs of China's sustainable development strategy [5]. Liu Wenliang et al. [6] studied the MAO of LY12 aluminum alloy in solution systems such as silicate, aluminat e and phosphate. It was found that the coating grew faster in silicate and phosphate systems. For the LY12 aluminum alloy, the ceramic layer formed in the phosphate solution is the thickest and fastest. Therefore, in this experiment, a sodium phosphate hexametaphosphate solution was selected as the micro-arc oxidation electrolyte. it is necessary to analyze the micro-arc oxidation process.
2. Experimental

The LY12 aluminum alloy was selected as the experimental material, and its chemical composition is shown in Table 1. After grinding, the burrs and surface scales and stains generated by the wire cutting are removed, cleaned and dried. The polished sample is drilled at the center of the edge as needed, with a hole diameter of approximately φ3 mm to facilitate suspension with the clamp during the ceramic layer preparation process. The sample is connected to one end of the aluminum wire, the joint is covered with a polymer liquid sealant, and the other end of the aluminum wire is fixed on the power supply bracket, the sample is used as an anode, and the stainless steel piece is used as a cathode. The MAO200H-III micro-arc oxidation equipment developed by the School of Materials Science and Engineering of Xi'an University of Technology is used. The alkaline electrolyte was prepared by using deionized water which is 20 g/L sodium hexametaphosphate solution. The chemical reagents used in the experiments were analytically pure reagents. The whole process is controlled by constant current, manual, current density is 0.5A/dm², solution temperature is 20 ~ 40 °C, and oxidation time is 2 ~ 120 min. The thickness of the ceramic layer was measured using a TT240 cladded eddy current thickness gauge. The microstructure and chemical composition of the micro-arc oxidation ceramic layer were analyzed by JSM-6700F field emission scanning electron microscope and X-ray energy spectrometer (Oxford INCA).

| Chemical composition | Cu   | Mg   | Mn   | Ti    | Zn    | Fe    | Si    | Ni    | Impurities | Al    |
|----------------------|------|------|------|-------|-------|-------|-------|-------|------------|-------|
| Content (mass fraction)% | 3.8–4.9 | 1.2–1.8 | 0.3–0.9 | ≤0.15 | ≤0.3  | ≤0.5  | ≤0.5  | ≤0.1  | ≤0.1 margin | ≤0.1  |

3. Results and Discussion

Figure 1 is a plot of current density versus oxidation time for micro-arc oxidation of LY12 aluminum alloy in sodium hexametaphosphate solution. During the micro-arc oxidation process, the current density rises first with the oxidation time, and then slowly decreases, during which there is a moment of abrupt change. Before the start of micro-arc oxidation, due to the high voltage preset by the power supply, it is impossible to directly reach such a high voltage, and it can only rise slowly. When the voltage rises above the breakdown voltage, it enters the micro-arc oxidation stage. At this instant, the current density instantaneously increases to a maximum due to the large voltage breakdown the oxide film on the surface of the sample. Then entering the micro-arc oxidation stage, the surface spark of the sample gradually becomes larger and brighter, and the thickness of the formed ceramic film is also thicker and thicker, but the increase in thickness becomes slower and more difficult. The impedance of
the formed ceramic film is also getting larger and larger, and at this time, the current density is correspondingly reduced. In the sodium hexametaphosphate solution, when the voltage is kept constant, the film growth rate and the rate of dissolution are substantially the same, the film thickness is substantially not change again, at this time the current density is also stabilized at a certain value.

The variation of the outward and inward growth dimensions and total thickness versus time of the ceramic layer formed during the micro-arc oxidation of LY12 aluminum alloy is shown in Fig. 2(a). (b) is a schematic diagram of the size of the micro-arc oxidation film.

![Figure 2](image.jpg)

**Figure 2.** Thickness versus time curve (a) and schematic diagram of the micro-arc oxide film size (b)

It can be seen from Fig. 2(a) that the total thickness of the ceramic layer is close to linear growth. the MAO coating formed on the surface of the sample is thin and not continuous for about 1 min after the start of the micro-arc oxidation stage. As the micro-arc oxidation proceeds, the MAO coating grows inwardly and outwardly on the surface of the sample in such a manner that the density and thickness of the coating are continuously increased. As the thickness of the coating increases, more energy is required to break through the coating, so a bright orange-yellow spark begins to appear frequently on the surface of the sample. This is because of the high spark energy and the larger range of action. The coating growth at the stage was the fastest. When the micro-arc was oxidized for 60 min, the coating quickly increased to about 23 µm, but the coating surface became rougher. As the micro-arc oxidation continues, the greater the thickness of the coating, the more difficult the spark is to break down, so the thickness of the coating increases less and less, and becomes slower and slower. When the micro-arc is oxidized to about 120 minutes, the coating thickness increased to a large spark can not be broken, the growth of the coating is finished, and the thickness of the coating is substantially unchanged.

In the initial stage of micro-arc oxidation, the outward growth rate of the ceramic layer is slightly larger than the growth in the matrix, and then in the middle and late stages, the rate of ingrowth is slowly greater than the rate of outward growth, and the speed difference between the two is getting bigger and bigger. Therefore, in the whole micro-arc oxidation process, the growth of the ceramic film layer is mainly ingrowth. It can also be considered that the growth in the initial stage is mainly based on outward growth, and the growth in the middle and late stages are mainly ingrowth.

![Figure 3](image.jpg)

**Figure 3.** SEM photo of LY12 aluminum alloy micro-arc oxidation ceramic film: (a) 2000x; (b) 7500x
The ceramic layer prepared in the sodium hexametaphosphate electrolyte is fine grayish white, and the microscopic surface morphology of the ceramic coating film in the micro-arc oxidation process is shown in Fig.3. It can be seen from the figure that a large number of micron-sized pores of different sizes are distributed on the surface of the formed ceramic layer, similar to the "volcanic spray" melt, and there are obvious traces of melting and sintering around. This is because, after entering the micro-arc oxidation stage, although the spark exists for a short time, the instantaneous high temperature in the local area around the spark can still melt the anodized film on the surface of the sample and the aluminum alloy substrate under the film, and part of the melt follows many tiny discharge channels are sprayed into the electrolyte and rapidly cooled by the electrolyte, thus forming a porous structure on the surface of the sample similar to a "crater".

![Figure 4. EDS spectrum of micro-arc oxidation ceramic film of LY12 aluminum alloy](image)

**Table 2. Chemical composition of micro-arc oxidation ceramic film of LY12 aluminum alloy**

| element | Weight percentage | Atomic percentage |
|---------|------------------|------------------|
| O K     | 58.21            | 70.91            |
| Al K    | 29.93            | 21.62            |
| P K     | 11.86            | 7.46             |
| total   | 100.00           |                  |

The results of EDS analysis of the obtained ceramic layer are shown in Fig. 4 and Table 2. It can be seen from Figure 4 and Table 2 that the content of O, Al and P is higher and the content of O is the highest. In the initial stage of micro-arc oxidation, anodizing reaction occurs on the surface of the aluminum alloy to passivate the surface of the aluminum alloy, but some aluminum elements are still dissolved in the solution to form a colloid. In the subsequent spark discharge process, since the dissolution function of the electrolyte continues to act on the surface of the aluminum alloy, as the experimental time increases, the more aluminum elements enter the electrolyte, which is the main reason for the loss of aluminum in the aluminum alloy matrix.

4. **Summary**

(1) The thickness of the micro-arc oxidation ceramic film of LY12 aluminum alloy increases with the increase of oxidation time, and the film thickness is basically linear with the oxidation time. The growth rate is different in different micro-arc oxidation stages, and the initial stage is slow. When the micro-arc oxidation discharge is more intense, the film thickness has the highest growth rate. When
the micro-arc oxidation is nearing the end, its growth rate gradually decreases, and finally stops growing.

(2) The thickness of the micro-arc oxidation ceramic film is basically linear with the oxidation time. The film thicknesses of inward and outward growth at different times are different. The initial stage of micro-arc oxidation is mainly outward growth, and the growth in the middle and late stages is mainly ingrowth.

(3) The ceramic layer prepared by LY12 aluminum alloy in sodium hexametaphosphate electrolyte is off white, with fine touch feeling, and the microscopic morphology is a porous structure similar to "crater". The elements contained in the ceramic layer are O, Al, and P, and the content of the O element is the highest.

5. References

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