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Electropolishing of Al and Al alloys in $AlCl_3$/trimethylamine hydrochloride ionic liquid

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ABSTRACT

We have investigated the electropolishing (EP) of aluminum (Al) and its alloys in an ionic liquid composed of anhydrous aluminum chloride and trimethylamine hydrochloride. The EP mechanism of Al was investigated by linear sweep voltammetry. The optimum conditions for EP of Al and Al alloys including the ionic liquid components, current density and polishing time were systematically explored. Moreover, the microstructure and chemical compositions of Al before and after EP were measured by SEM, AFM, XPS and XRD, respectively. Compared to EP in strong acid solution, EP of Al in this ionic liquid can achieve the equivalent polishing effect with less mass loss. Importantly, the polishing ability of this ionic liquid remains stable even after EP for 50 cycles. The corrosion resistance of electropolished Al is drastically enhanced due to the formation of the compact passive layer on the mirror-like bright surface.

1. Introduction

Al and Al alloys are ideal and promising materials for various applications, owing to its light weight, high corrosion resistance, good formability, high conductivity, environmental friendliness etc. [1–3]. For the past decades, Al and Al alloys with unique surface property such as super clean, homogeneous and high glossiness has the significant increased demand in precision engineering and high-tech industries [4]. Electropolishing (EP) with many advantages, including the facility, excellent controllability and the removal of productions without any damage for the surface in the whole process, has been widely used to obtain a mirror-like surface of Al and Al alloys.

EP is an electrochemical technique based on controlled anodic dissolution of a metal surface to achieve a reduction in surface roughness and hence an increase in optical reflectivity. Since the EP process was first patented in 1930, various metals have been polished in the mixtures of concentrated sulfuric and phosphoric acids on a commercial scale. However, the traditional strong acid solution used in polishing can generate pernicious gases which will cause serious damage to people's health and bring immense detriments for the environment. Meanwhile, the polishing of Al in the above-mentioned strong acid systems will result in great mass losses due to the irregular and strong corrosion of Al [5]. Thus, it is highly desirable to develop a new sort of EP electrolyte, which not only obtain the Al with enhanced surface properties such as high glossiness, but also is eco-friendliness of the whole process.

Ionic liquids, 'the green solvents of 21st century' [6], have been attracting widespread attention due to their excellent performances, such as lower vapor pressure, wide electrochemical window, high thermal and chemical stability [7]. Generally, the process of EP in ionic liquids has many advantages over the common aqueous acid solutions including the use of comparatively benign and non-corrosive liquid, high current efficiency and negligible gas evolution at the anode/solution interface. Up to now, researchers have been achieved of EP metal and alloy in ionic liquids, such as CMSX4 alloy [8], Ti [9], Cu [10,11] and stainless steels [5,12]. However, there are little reports on EP of Al in ionic liquid.

In this work, an ionic liquid composed of anhydrous aluminum chloride and trimethylamine hydrochloride was used as electrolyte for the EP of Al and Al alloy. Meanwhile, the effects of the EP parameters, such as current density, time and the composition of the electrolyte, on the morphology and optical properties of specimens are investigated. In addition, the EP behavior and surface characteristics achieved in ionic liquid are reported in comparison with the surface obtained by EP in the perchloric acid ($HClO_4$)-ethanol (Et) electrolyte.

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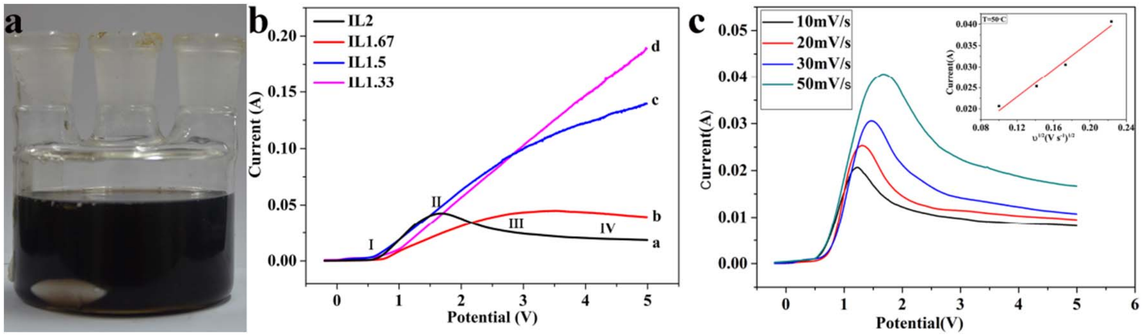

Fig. 1. (a) The picture of EP equipment (b) LSVs of Al in $AlCl_3$-TMHC ionic liquids with different molar ratios at sweep rate of 50 mV/s. a, b, c and d represent the curves of EP process in the IL2, IL1.67, IL1.5 and IL1.33, respectively. (c) LSVs of Al in IL2 with sweep rate of 10 mV/s, 20 mV/s, 30 mV/s and 50 mV/s. The inset represents the square root of scan rates vs. peak current graph conducted. All the experiments conducted at 50 °C.

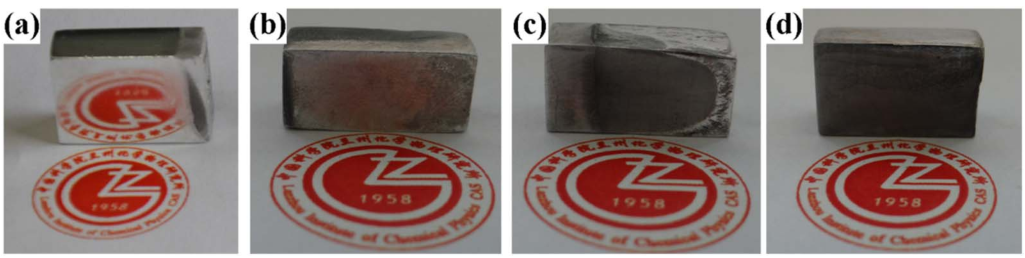

Fig. 2. Photographs of the Al samples after EP in (a) IL2, (b) IL1.67, (c) IL1.5 and (d) IL1.33.

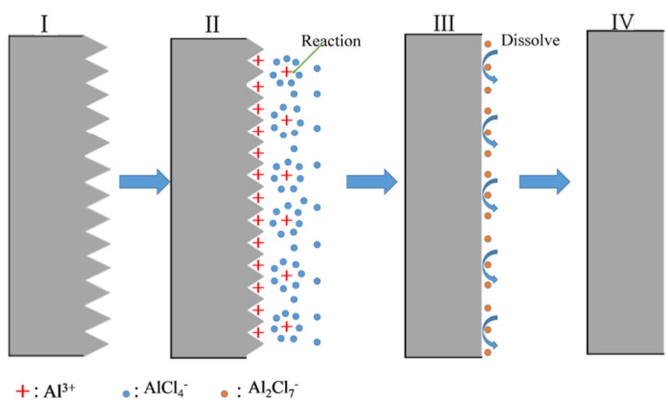

Fig. 3. Schematic diagrams of the electrochemical polishing mechanism of Al according to the anodic linear sweep voltammograms.

2. Experimental section

2.1. Materials

In this study, high-purity Al (purity 99.99%) and Al alloys (Al-5.0 wt% Si, Al-3.0 wt% Mg, Al-5.0 wt% Cu) which were all purchased from Beijing Founde Star Science and Technology Co. Ltd. (China) were used as the specimens. All the specimens were cut in the size of 20 × 14 × 8 mm. To ensure the uniformity of surface roughness at the start of experiment, all the specimens were mechanically polished prior to EP process. Directional mechanical polishing was carried out with abrasive papers whose sizes of grits gradually decreased from 400 to 1500 grit. Subsequently, the samples were degreased by using ultrasonic in ethyl alcohol solution for 10 min followed by rinsing with deionized water for 5 min. Finally, the specimens were dried with cool wind.

2.2. Preparation of electrolyte

Anhydrous aluminum chloride [$AlCl_3$, AR, ≥ 99.0% purchased from Tianjin Fengyue Chemical Co. Ltd., China], trimethylamine hydrochloride (TMHC) [$(CH_3)_3NHCl$, AR, ≥ 99.0% purchased from Sinopharm Chemical Reagent Co. Ltd.] were all used as received. The ionic liquids of $AlCl_3$-TMHC were synthesized by slowly mixing anhydrous $AlCl_3$ and TMHC together with the different molar ratio of 1.33:1, 1.5:1, 1.67:1 and 2:1, denoted as IL1.33, IL1.5, IL1.67 and IL2, respectively in the following context. All these ionic liquids were formed in 2 h under the protection of nitrogen atmosphere at 30 °C.

In the ionic liquid composed of anhydrous $AlCl_3$ and $(CH_3)_3NHCl$, $AlCl_3$ reacted with chloride ion provided by trimethylamine hydrochloride as follows:

$$(CH_3)_3NHCl + AlCl_3 \rightarrow (CH_3)_3NH^+ + AlCl_4^- \quad (1)$$

When the molar ratio of $AlCl_3$ and $(CH_3)_3NHCl$ was larger than 1:1, the following reaction taken place:

$$AlCl_4^- + AlCl_3 \rightarrow Al_2Cl_7^- \quad (2)$$

Thus, the main ions in this ionic liquid were $(CH_3)_3NH^+$ and $Al_2Cl_7^-$.

For comparison purpose, perchloric acid - alcohol system ($HClO_4$-Et) which was widely used and has good polishing effect was also used for EP of Al in this work. The $HClO_4$-Et electrolyte was synthesized with the volume ratio 1:4 at 0 °C.

2.3. Electrochemical tests

Linear sweep voltammetry (LSV) was performed using an Autolab PGSTAT 302 N potentiostat with a three-electrode system. Al sheet, a platinum plate (10 × 10 mm) and Ag wire was acted as the working electrode, counter electrode and the reference electrode, respectively. The entire electrodes were polished with 0.3 μm alumina paste, rinsed by deionized water, and dried before all measurements.

2.4. Electrochemical polishing processes

The EP process was implemented in two-electrode system in the air. The EP equipment is shown in Fig. 1a. A copper sheet (33.57 × 7.32 mm) and the Al specimen (20 × 14 × 8 mm) were acted as the cathode and anode, respectively. The distance between cathode and anode was 30 mm. In order to reduce the concentration