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Improved two-step Brytal process for electropolishing of aluminum alloys

M. Sepúlveda*, D. Quintero, J.G Castaño, F. Echeverría

Centro de Investigación, Innovación y Desarrollo de Materiales CIDEMAT, Facultad de Ingeniería, Universidad de Antioquia UdeA, Calle 70 No. 52-21, Medellín, Colombia

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ABSTRACT

Three aluminum alloys (5N, 1100 and 8005) were electropolished with an environmentally friendly Brytal process in order to evaluate the influence of the substrate and the operating parameters in the roughness and reflectivity of the specimens. Electropolishing was implemented in two-step, allowing lower roughness than those reported in the one-step process. Morphology and second-phase particles on electropolished samples were analyzed by SEM, roughness was measured by means of AFM and reflectivity was measured with a UV–vis spectrophotometer getting a high reflectivity for high purity aluminum and for two aluminum alloys in which reflectivity decreased due to second phase particles.

1. Introduction

Aluminum alloys are used in a wide range of applications due to their unique properties such as low density (2.70 g cm^{-3}), high corrosion resistance, good electric and thermal conductivity, a good reflectivity of heat and light, easy machinability and a relatively low cost [1]. In practical applications of the aluminum and its alloys, a good surface finishing is often required. The surface finishing highly affects properties such as reflectivity, which is important in applications like solar collectors and mirrors. Furthermore, for coating formation on aluminum, it is well known that the surface roughness of the metallic substrate influences the final properties of the coating obtained. For example, in the formation of anodic porous alumina, the surface roughness plays an important role in order to obtain an organized nanostructure, improving the coating properties [2]. Several surface modification techniques can be used to obtain a smooth surface on aluminum alloys like mechanical polishing, chemical polishing, thermal polishing and electropolishing [3,4]. The electropolishing process is an efficient method that allows reducing the surface roughness of aluminum alloys. The main advantages of the process are as follows: Complex geometric shapes can be polished, the process is inexpensive and the equipment required is simple and easy to operate [5].

Electropolishing is an electrochemical process carried out in an adequate aqueous solution, which dissolves the metal in a controlled way, allowing reducing the surface roughness up to a mirror finish. A number of operational conditions of electropolishing have been widely used for aluminum and its alloys in order to obtain a specular reflectivity. Within the electropolishing solutions that are more frequently reported can be mentioned: Perchloric acid mixed with an alcohol solution [6], nitric acid [7], mixture of H_3PO_4/CrO_3, mixture of H_3PO_4/H_2SO_4, among others [8–11], which allows obtaining of a surface with low roughness and high specular reflectivity of aluminum alloys. Most of these solutions contain hazardous chemicals to the environment or to people, and special conditions are required to store them in order to avoid accidents [12]. Currently, most researchers seek to develop environmentally friendly processes avoiding using toxic and hazardous chemicals. The Brytal process [5] is an electropolishing process developed for aluminum and it has been widely employed in the industry given that allows obtaining mirror finishes. The Brytal solution is an alkaline solution that consists of an aqueous of Na_2CO_3 and Na_2PO_4 [2,13–16] and it is a well-accepted electrolyte for electropolishing due to its environmentally friendly composition. Mahmood et al. [13] obtained organized nanostructure on aluminum alloys electropolished using two solutions, Perchloric acid, and the Brytal solution. These authors report that the Brytal solution leads to the formation of a more organized nanostructure due to the formation of a better surface finishing.

Usually, the electropolishing process is carried out in one-step allowing to obtain surfaces with low roughness [17]. Nevertheless, a two-step electropolishing process carried out on titanium alloys has been shown the formation of smoother surfaces than surfaces obtained with one-step electropolishing. The two-step electropolishing consists in applying first a high voltage is used in order to decrease the coarse roughness in the substrate, and in the second step, a low potential is applied with the purpose of giving a final smoother finish to the surface [18,19]. For better results during electropolishing process, some researchers recommend doing an annealing to the samples before electropolishing, looking to promote a good crystalline structure,

* Corresponding author.
E-mail address: lina.sepulveda@udea.edu.co (M. Sepúlveda).

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Table 1
Chemical composition of the materials used assessed by optical emission spectrometer and annealing parameters of the three aluminum alloys.

Sample	Wt. %								
	Al	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
8005	98.58	0.262	0.499	0.037	0.139	0.016	0.0055	0.0042	0.018
1100	99.25	0.150	0.355	0.072	0.031	0.0081	0.0075	0.0042	0.069
5 N	99.9997	–	0.000028	0.000023	–	0.000016	0.00001	0.000024	–

Annealing treatment of Aluminum Alloys

Samples	Time (h)	Temperature (ºC)
8005	6	500
1100	12	500
5N	12	500

homogenize second-phases and release material residuals stress [20]. However, information of two-step electropolishing process on aluminum alloys using Brytal solution is scarce. In the present work, a two-step electropolishing process was carried out in three different aluminum alloys using the Brytal solution. Results show that the two-step electropolishing allows obtaining smoother surfaces than the one-step electropolishing, improving reflectance of the surfaces obtained, especially for high purity aluminum (5N Al). Ra surface roughness values obtained after the two-step electropolishing treatment was around 150 nm for the sample with higher content of alloying elements (Al 8005) and 3 nm for the high purity aluminum (5N Al) according to AFM analysis. The second electropolishing step generated surfaces with a reduction of the roughness greater than 50% respect to roughness generated with the one-step electropolishing treatment.

2. Experimental details

Three different aluminum alloys were used in this study; the chemical composition of the aluminum alloys is shown in Table 1. Samples were cut from a sheet of each material with dimensions of 20 × 10 mm and 2 mm of thickness. Sample was coated with dielectric tape (Nitto tape P-422) and the working area was 1 cm^2. The samples were annealed at 500 °C at different annealing times for each material as observed in Table 1. An abrading procedure was carried on the samples with SiC paper using a progressive series of sandpapers up to 1500 grit. After this, the samples were degreased in acetone for 15 min using an ultrasonic bath, washed with deionized water and dried in a cool air stream. The two-step electropolishing process was carried out using a DC power supply with a capacity of 500 V and 0.4 A, reference Kepco Power Supply BHK 500–0.4MG. The electropolishing solution used was the Brytal solution (15 wt. % Na_2CO_3 (Panreac, 99.5%) and 5 wt. % Na_3PO_4 (Panreac, 98%)) with a pH of 13. The chemicals were of analytical grade. The electrochemical cell, composed of two electrodes, was immersed in a hot oil bath to keep the temperature at 75 °C. The volume of the Brytal solution used for the electropolishing process was 250 ml. The electrolyte was strongly stirred with a magnetic stirrer during electropolishing. A stainless steel plate was used as counter electrode to electropolish the three aluminum alloys. The two-step electropolishing was carried out as follows: In the first stage of the process, a constant potential of 5 V was applied during 30 min, then the sample was removed from the electrolyte, washed with distilled water and dried in a cool air stream. In the second electropolishing step, a constant potential of 0.5 V was applied during 30 min. After this, the sample was taken out from the electrolyte, washed with deionized water in an ultrasonic bath for 15 min to clean the surfaces and then dried in a cool air stream. In both process stages, the current was recorded throughout the process. Weight loss measurements were carried for the electropolishing process, using a Mettler Toledo UMX5 microbalance with an accuracy of ± 0.1 μg.

The surface of the samples was observed using a scanning electron microscope JEOL JSM 6490 LV, equipped with energy dispersive X-ray spectroscopy (EDS). An atomic force microscope (Park systems NX10 in tapping mode) was used to study the surface roughness of the electropolished surface. The composition of the samples was assessed in an optical emission spectrometer (BRUKER Q8 MAGELLAN). The surface reflectivity was measured by a spectrophotometer UV–vis (Varian spectrophotometer Cary 100). Anodic polarization curves were performed at 75 °C and the applied potential was anodically swept from the open circuit potential at a scan rate of 80 mV s^{-1}, and then swept cathodically from 0 to 10 V.

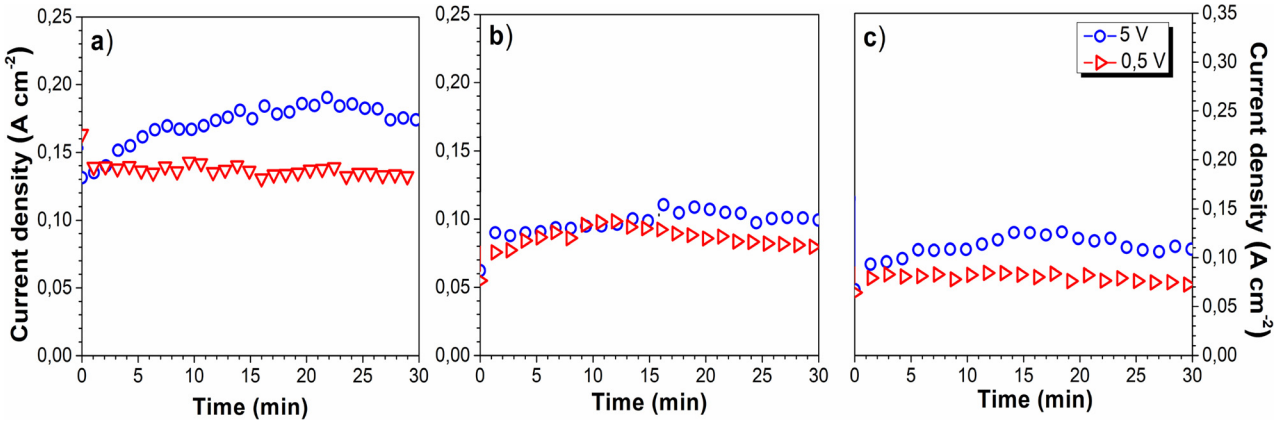

Fig. 1. The current density-time response of the two steps of the electrochemical polishing for the following materials: (a) 5N, (b) Al 1100 and (c) Al 8005.