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SHORT COMMUNICATION

Influence of DLC Film Deposition on the Corrosion and Micro-abrasive Wear Tests of the 2524-T3 Al Alloy

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Abstract:

The 2524-T3 aluminium (Al) alloy produced by ALCOA may be used as skin material by the aircraft industry. Some studies are available in the literature about fatigue and fatigue - corrosion behaviour of 2524-T3 Al alloy. However, the corrosion mechanisms are not yet fully understood since the material has a very complex microstructure due to impurities and the addition of alloying elements which lead to an increase in the localized corrosion process. It is known that the corrosion process in Al alloys, most of the time, is due to the galvanic coupling of the intermetallic particles (IMs) and the Al matrix. Thus, the use of protective coatings appears as a possible alternative against the advancement of the corrosion process of the 2524-T3 alloy. In this way, a set of DLC films was obtained by using physical vapor deposition (PVD) method and characterized by various techniques including scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), Atomic force microscopy (AFM) and Raman spectroscopy. The deposited films on the surface of the 2524-T3 Al alloy were characterized electrochemically by using potentiodynamic polarization curves (PPc), electrochemical impedance spectroscopy (EIS) and mechanically by using micro-abrasive wear tests (MAWTs). The results show an advantage in using the PVD method to produce thin films on the 2525-T3 Al alloy surfaces, as the wear resistance of the Al alloy coated by DLC film is higher than for the bare material and the corrosion resistance of the material is not compromised.

Keywords: Al alloy; corrosion; micro-abrasive wear; protective film

1. Introduction

The AA2524-T3 (heat-treated and cold treated) aluminium alloy produced by ALCOA may be used as a skin material in aircrafts and appears as a potential substitute for the AA2024-T3 alloy widely used by the aeronautical industry [1]. AA2524-T3 aluminium alloy presents better mechanical properties when compared to the 2024-T3 alloy; however, it is susceptible to the localised corrosion process. The effect of intermetallics (IMs) on pitting corrosion of 2524-T3 aluminium alloy is not yet fully understood and some studies suggest that the electrochemical characteristics of IMs vary significantly in terms of corrosion potential (E_{corr}), disintegration, oxygen reduction and dissolution reactions [2,3]. Other authors [4-11] describe the

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*Corresponding author. E-mail: jeferson.moreto.uftm@gmail.com galvanic coupling between the IMs particles and the aluminium matrix. In this way, the use of protective coatings appears as a possible alternative against the advancement of the corrosion process of the AA2524-T3 alloy used for the aircraft fabrication. The use of protective coatings produced by the deposition of diamond like-carbon (DLC) films has attracted interest of researchers as well as in the industrial and technological environment due to its important properties that include high hardness, low coefficient of friction, compatibility with biological systems and superior resistance to wear and corrosion [12, 13]. There are no studies published in the national and international literature on the use of the physical vapor deposition (PVD) method for the production of thin films on the 2524-T3 aluminium alloy surfaces. In the present work, a preliminary study was done and its results are now presented in order to contribute to the research in aeronautical engineering area. The results show a significant improvement in the mechanical properties of the AA2524-T3 alloy, whereas the corrosion resistance in medium containing chloride ions is not affected.

2. Results and Discussion

Figure 1 presents the potentiodynamic polarization curves for coated and uncoated 2524-T3 aluminium alloy in 0.6 mol L^{-1} NaCl solution for scan rate dE/dt = 1 mV s^{-1}. As can be seen for the uncoated 2524-T3 aluminum alloy, the pitting potential, $E_{pitting}$, and corrosion potential, E_{corr}, are nearly the same and a small increase of the potential E above E_{corr} will lead to the initiation or acceleration of pitting with a large increase of the anodic current density j [12, 13]. The results show that $E_{pitting}$ is not much affected by the carbon film.

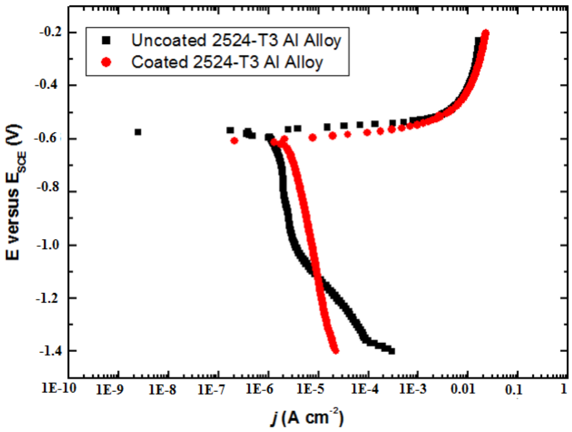

Figure 1. PPc curves obtained on aluminium in 0.6 mol L^{-1} NaCl solution for AA2524-T3 alloy (black) uncoated AA2524-T3 Al alloy and (red) coated AA2524-T3 Al alloy.

Figure 2 shows the Bode plots of electrochemical impedance spectroscopy spectra of AA2524-T3 exposed to 0.6 mol L^{-1} NaCl solution after 3 h of immersion. A general analysis of the impedance spectra indicates two time constants: one at high frequencies and the other at low frequencies. The time constant at high frequencies indicates the presence of an oxide film on the metal matrix and the second probably is due to localized corrosion processes [4].

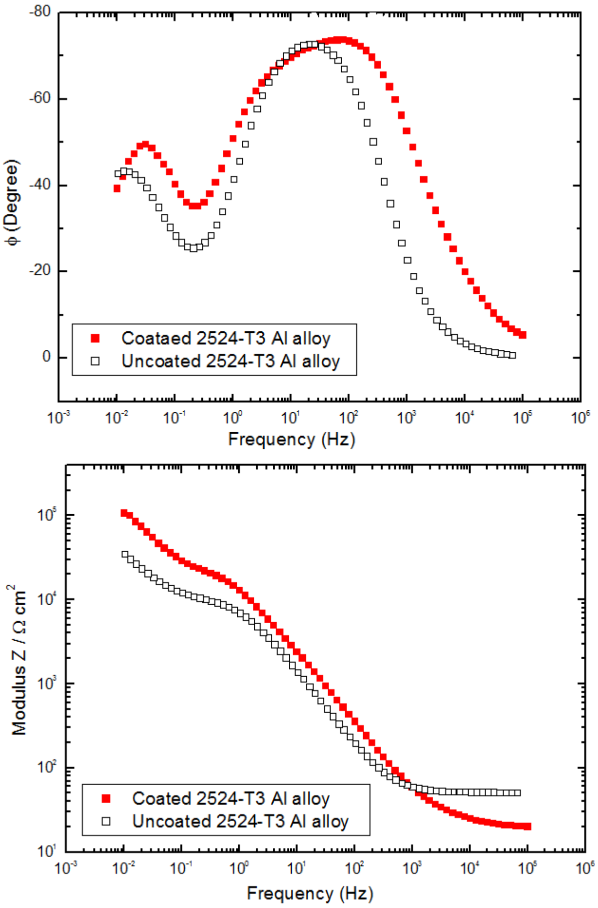

Figure 2. Bode plots of Electrochemical Impedance Spectroscopy spectra of AA2524-T3 exposed to 0.6 mol L^{-1} NaCl solution, (black) uncoated AA2524-T3 Al alloy and (red) coated AA2524-T3 Al alloy.

Thus, in the EIS spectra the higher impedance moduli corresponding both to the intermediate plateau (indicative of the coating resistance) and to the low frequency limit (indicative of the overall resistance) indicate that the coating is expected to increase the corrosion resistance of the aluminium alloy, reducing the severity of the pitting attack. Studies involving larger immersion times and the use of localized techniques such as Scanning Vibrating Electrode Technique (SVET) and Scanning Kelvin Probe (SKP), together with microstructural analysis, will provide more information about the corrosion resistance of the film formed on the surface of the 2524-T3 alloy. Figure 3 (a) presents the wear volume obtained from the micro-abrasive wear tests for the bare material and coated 2524-T3 aluminium alloy. The aluminium samples containing the DLC film presented greater wear resistance than bare material, with reduction in the wear volume, with a mix wear mode by rolling and scratching. An oxide layer was observed in the print of the cap (see Figures 3 (b), (c), (d) and (e)).

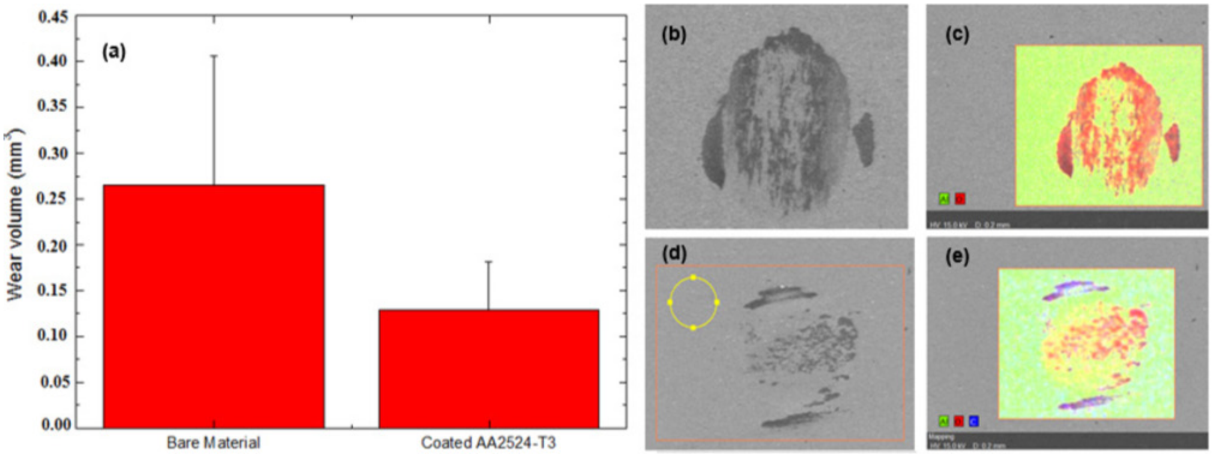

Figure 3. (a) Wear volume for the coated and uncoated 2524-T3 aluminium alloy. (b) and (c) Images of the caps produced in the micro-abrasive wear tests for the uncoated and (d) and (e) for the coated material.

3. Material and Methods

The carbon films were deposited using a custom design magnetron sputtering system as described in [14], installed at Federal University of Triângulo Mineiro (UFTM) at Uberaba, Minas Gerais, Brazil. The deposition time was 40 min, using 120 mA and 560 V applied to the 2-inch target. The target consists of natural graphite, mechanically compacted in order to result in a 5 mm thick and 2-inch diameter pellet. The residual pressure was 1×10^{-3} mTorr and the deposition pressure was reached using 99.9999% Argon at 5 mTorr. The carbon film deposited on the surface of AA2524-T3 was characterized electrochemically by potentiodynamic polarization curves (PPc) and electrochemical impedance spectroscopy (EIS) in 0.6 mol L^{-1} NaCl solution (open to air). Measurements were carried out with a PAR-VersaSTAT potentiostat-galvanostat. An electrochemical cell containing a single compartment of three electrodes was used: 2524-T3 aluminium alloy as working electrode (WE) of exposed area of 1 cm^2, a Pt foil as counter electrode (CE) and reference electrode (RE) of saturated calomel Hg/ Hg_2Cl_2, KCl_{sat}. The spectra were obtained at 20 mV negative to E_{corr} using an applied a.c. signal of 10 mV (rms) as described by Mansfeld and Fernandes [15]. All surfaces were degreased and polished up to 2400 grit prior to immersion. The micro-abrasive wear tests were performed according to the Pereira Neto et al [16] using a fixed ball device.

4. Conclusions

The EIS spectra indicate that the coating is expected to increase the corrosion resistance of the AA2524-T3 aluminium alloy, reducing the severity of the pitting attack. With regarding to the wear tests, the predominant wear mechanism for AA2524-T3 with DLC films was an equivalence between the scratching and rolling mechanisms. Based on these findings, we may prospect to explore new proof-of-concept approaches based on DLC films for protective coatings in aircraft materials.

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