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Influence of laser surface treated on the characterization and corrosion behavior of Al–Fe aerospace alloys

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ABSTRACT

In this research laser surface remelting without protective coating with a 2 kW Yb-fiber laser (IPG YLR-2000S) was applied in the Al–1.5 wt.%Fe alloy in order to investigate the layer treated with different techniques of superficial characterization, thereby, the technique of optical microscopy, atomic force microscopy and low-angle X-ray diffraction were used. The present work mainly focuses on the corrosion study by diverse techniques in aggressive environment of the laser-treated area and the substrate material was carried out, thereby, at open circuit potential testing, the results have shown a displacement to more anodic values in the corrosion potential for the laser-treated specimen when compared to the untreated specimen; in potentiodynamic polarization tests have shown that as a result of the laser treatment, the corrosion current can be reduced by as much as ten times, and a passive region was obtained, which served as an effective barrier for reducing anodic dissolution and finally, the result in cyclic polarization curves of the untreated sample there was a greater area of the hysteresis loop, implying that it is more susceptible to corrosion. This study was complemented by other techniques mentioned above in order to elucidate this study. Laser surface remelting process has definitely modified the surface film, which results in higher corrosion resistance, a large range of passivation and a lower area of the hysteresis loop.

1. Introduction

One of the non-traditional surface engineering techniques, namely laser surface melting (LSM) has attracted growing interest in recent years for its ability to improve the corrosion performance of aluminum alloys. LSM is a versatile and promising technique that can be used to modify the surface properties of a material without affecting its bulk properties.

An interesting study was conducted by authors Viejo and co-workers [1], where they argue that in recent years, the aluminum industry have been developing alloys with increased damage tolerance in order to meet the demands of the latest and upcoming generations of commercial aircraft. Particular attention was focused on Al–Cu–Li alloys (i.e. AA2050 or AA2198 alloys) that have been used in the recent past in the military and space sectors. Their favorable density, strength, toughness, fatigue behavior and thermal stability make them attractive candidates in applications requiring both high specific strength and excellent damage tolerance. Additionally, unlike most conventional aerospace alloys, Al–Cu–Li alloys are fusion weldable, which opens up new opportunities in fuselage construction. Nevertheless, as with other AA2xxx aluminum alloys, Al–Cu–Li alloys can be susceptible to localized and exfoliation corrosion, particularly in chloride-containing environments. Accordingly, great efforts have been made to produce surface layers that are free of intermetallic precipitates in order to eliminate, or at least reduce, their detrimental effects. For example, it is generally accepted that laser surface melting (LSM) is a useful tool to improve the corrosion resistance of aluminum alloys, as a result of the formation of thin melted layers with refined microstructures that are virtually free of intermetallic precipitates and inclusions. Thus, LSM, using CO_2 or Nd:YAG laser irradiation, can improve the localized corrosion resistance by modifying the near-surface region through rapid melting and solidification processes.

The authors Yue et al. [2] investigated the laser-treated surface using a KrF excimer laser, according to them it was found that the laser-treated layer consists of polycrystalline α-Al_2O_3 together with some undetermined precipitates. They show that the size of α-Al_2O_3 crystalline is approximately 5–6 nm. In addition, they verified by selected-area electron diffraction patterns (SAED) of the laser-melted zone, that the structure was of crystalline form. These same authors examined by TEM the laser-treated specimen

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and they concluded that it did not reveal any coarse second-phase particles, as found in the untreated specimen. However, a stable corrosion film had not been formed at the surface of the untreated specimen due to the presence of numerous second-phase particles, which readily initiated pitting corrosion and destroyed the integrity of the film. Being that the base result of this study, the laser-treated layers mainly consisted of nanocrystalline structures α-Al_2O_3, which is a chemically stable phase, serves as an effective barrier to protect the matrix against corrosion attacks.

According to the study of Ryan and Pragnell [3] by the technique of pulsed laser surface melting (PLSM), they showed that the increase in the corrosion performance of pulsed laser-treated alloys has been widely attributed to the formation of a surface layer that is much more chemically homogenous than the bulk material. It has generally been assumed that the laser treatment removes second phase particles and partitionless re-solidification of the layer occurs. To prevent the formation of a cellular structure throughout the layer on re-solidification and ensure a reasonable chance of obtaining a chemically homogeneous layer, the melt depth is thus restricted to less than 10 μm thickness. The success of laser-treatment relies on the aluminum matrix and second phase particles being taken into the liquid phase and mixed with a combination of stirring and diffusion to form a uniform liquid. Ideally, the liquid film should then re-solidify sufficiently quickly to prevent interface instability, trapping the solute in solid-solution. However, due to the short time spent in the liquid phase, it is extremely difficult to achieve a uniform solute distribution. The study of pulsed laser surface melting of aluminum has concluded that the improvements in corrosive properties are a result of homogenization of the surface region.

Pariona et al. [4] reported a study of the laser treatment irradiated Al–1.5 wt.%Fe alloy with Yb-fiber laser beam. This laser treatment without an assisting gas jet was applied to augment the production of metal oxides on the laser-treated surface. The laser-treated samples were covered with several weld filets during the remelting process. The results reveal the formation of weld filet structures with metastable phases and finely dispersed precipitates. The creation of a finely porous layer of protective coating produced during the rapid remelting process contributed to increase the corrosion resistance and homogeneous properties of laser-treated samples when compared with untreated samples. The Yb-fiber laser beam technology applied to the surface treatment of aluminum alloys proved efficient in augmenting their corrosion resistance, thus deserving further investigation for aerospace and automotive applications.

Recently, Pariona et al. [5] investigated AFM study of the effects of laser surface remelting on the morphology of Al–Fe aerospace alloys. This work focused on the characterization of the surface roughness by AFM technique and cyclic voltammetry of Al–1.5 wt.%Fe alloy samples subjected to laser surface remelting (LSR). The AFM technique is a highly efficient tool for studying surface topographies, providing details of the surface on a nanometric scale. This technique enables the quantification of the peaks and valleys that characterize surface roughness. The analyses were performed on both laser-treated and untreated sanded surfaces, revealing significant differences. The region between weld filets in the laser-treated samples showed by AFM technique the presence of lamella-like morphology. The low-angle X-ray diffraction analysis revealed the presence of alumina, simple metals and metastable intermetallic phases, which considerably improved the microhardness of laser-remelted surfaces. The treated surfaces showed passivity and stability characteristics by cyclic voltammetry in the electrolytic medium employed in this study. The morphology produced by laser surface remelting enhanced the microstructure of the Al–Fe alloys by reducing their roughness and increasing their hardness.

Table 1
Chemical composition of the Al–1.5 wt.%Fe alloy (wt.%).

Al	Fe	Cu	Ni
98.347	1.545	0.068	0.04

In this paper the laser surface remelting (LSR) was applied in the Al–1.5 wt.%Fe alloy in order to investigate the treated layer with different corrosion characterization techniques and complemented with other techniques to elucidate the behavior of corrosion. For this purpose, multiple laser weld filets were generated on an entire surface of the samples by LSR technical. Thus, the morphological characteristic of cross-section of the LSR-treated surface was examined and the existence of different phases in the treated sample was verified. In addition, corrosion testing was carried out, using different techniques to understand the performance of the samples and their stability in the aggressive environment of laser-treated surface in relation to the substrate material. The application possibilities of this technique may be in aeronautic, automotive, energy, electronic, biomedical implant applications, etc.

2. Experimental setup

2.1. Specimen preparation of Al–1.5 wt.%Fe

A cylindrical ingot of Al–1.5 wt.%Fe alloy was prepared with pure raw materials. Chemical composition of the Al–1.5 wt.%Fe alloy measured through the technique of florescence (Shimadzu, EDX-700) is shown in Table 1. The casting assembly used in solidification experiments consists of water-cooled mold with heat being extracted only from the bottom, promoting vertical upward directional solidification. This apparatus was used to obtain an Al–1.5 wt.%Fe alloy cylindrical casting, with dimensions of 6 cm diameter and 10 cm length. Longitudinal samples, coincident with the columnar growth direction were extracted approximately 4 cm near the water-cooled mold to be used in the laser remelting experiments.

2.2. Laser surface remelting of the Al–1.5 wt.%Fe alloy

The samples were cut, polished and sand-blasted to reduce their surface reflectance for the subsequent laser treatment, which was performed with a 2 kW Yb-fiber laser (IPG YLR-2000S) operating at wavelength of 1.06 μm, with an effective focal distance of 160 μm. The laser beam presents a near Gaussian intensity profile with a spot size of 50 μm and the sample surface was positioned 3 mm out of beam focus and the laser beam diameter was estimated at 560 μm on the sample surface. The laser scanning speed was kept at 40 mm s^{-1}. The average power of the laser beam was fixed at 600 W and the power density on the surface of the sample was estimated as 4.8×10^5 W cm^{-2}. This laser treatment without an assisting gas jet was applied to augment the production of metal oxides on the laser-treated surface. The laser-treated samples were covered with several weld filets during the remelting process [4].

2.3. Phase, microstructure, and elements characterization

For the metallography characterization of the cross section, small specimens were cut and sanded with 600, 800, 1200 grit SiC sand paper, and polished with colloidal silica in a semi-automatic polishing machine (AROTEC Ind. and Com., Brazil). The micrographs were obtained by optical microscopy (OM, Olympus-BX51).

The low-angle X-ray diffraction (LA-XRD) technique was employed to identify the phases on the laser-treated surface. The