Use of Scanning Vibrating Electrode Technique to Localized Corrosion Evaluation of ASTM F139 Stainless Steel Marked by Laser

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Abstract

In this study, Scanning Vibrating Electrode Technique (SVET) was used to investigate the effect of marking the surface of the ASTM F139 austenitic stainless steel with laser engraving, on its localized corrosion resistance. Laser marked samples were immersed in a phosphate buffered solution (PBS) with pH 7.4 and the development of anodic and cathodic regions at the interface between heat affected areas by laser beam and not affected regions was evaluated. The results showed that the area with anodic current density was related to the laser regions and the cathodic one was generated on the adjacencies, which was best reveled under polarized conditions.

Keywords: Corrosion, Biomaterials, Stainless Steel, SVET

Introduction

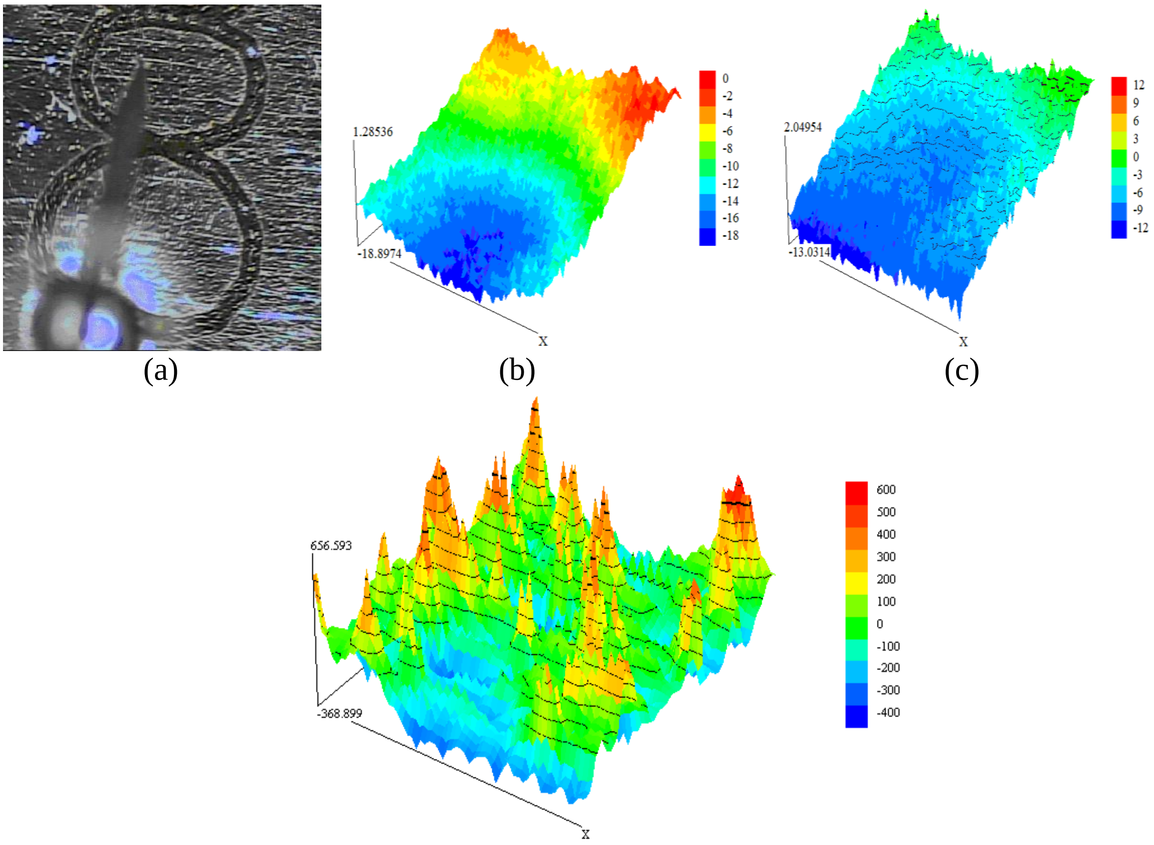
The metallic materials used in implants or prostheses are passive materials and therefore are subject to localized corrosion when in contact with body fluids. Pitting corrosion is one of the most common types of localized corrosion observed in metallic implants [1]. The susceptibility to this form of corrosion might be increased by the production processes involved in implants manufacturing, mainly those affecting surface finishing, such as, marking of the surface for identification and traceability of the manufactured implant device. The laser marking is a largely adopted technique due to its properties, such as high rate of production and reproducibility. Investigation carried out in our laboratory showed that this type of marking technique has a detrimental effect on the corrosion resistance of the laser affected area. This effect was clearly evidenced by electrochemical impedance spectroscopy. However, this technique shows the global effect of the analyzed surface, with a large contribution of the unaffected area. In order to investigate the effect of the region affected by laser beam on the localized corrosion resistance of the ASTM F139 stainless steel, the Scanning Vibrating Electrode Technique (SVET) was used in the present investigation. Many researches [2-3] have used the SVET technique as a tool to evaluate localized corrosion. However, in most published studies, the tested samples were specially prepared electrodes using dissimilar metals to form galvanic couples of well-known behaviors [4-5]. The aim of this study is to investigate the localized corrosion behavior of the laser affected zone by the Scanning Vibrating Electrode Technique.

Experimental

Samples of ASTM F139 stainless steel (SS) with the following composition (wt. %): 0.38 Si, 2.09 Mn, 0.026 P, 2.59 Mo, 18.32 Cr, 14.33 Ni, 0.023 C, 0.0003 S, and Fe balance, marked by laser, were tested by immersion in a phosphate buffer solution (PBS), with pH 7.4, at 25 °C. The conductivity of the solution was measured and found to be 15.35 mS. The electrochemical behavior of these samples was analyzed by SVET using and Applicable Inc. (USA) equipment controlled by ASET software from Science Wares (USA). This technique measures potential gradients in the electrolyte and converts the results in current densities after a calibration based on the solution conductivity [6]. The vibrating microelectrode had a 10-20 μm spherical platinum black tip and vibrated at the distance of 100 μm above the sample surface.

Results and Discussion

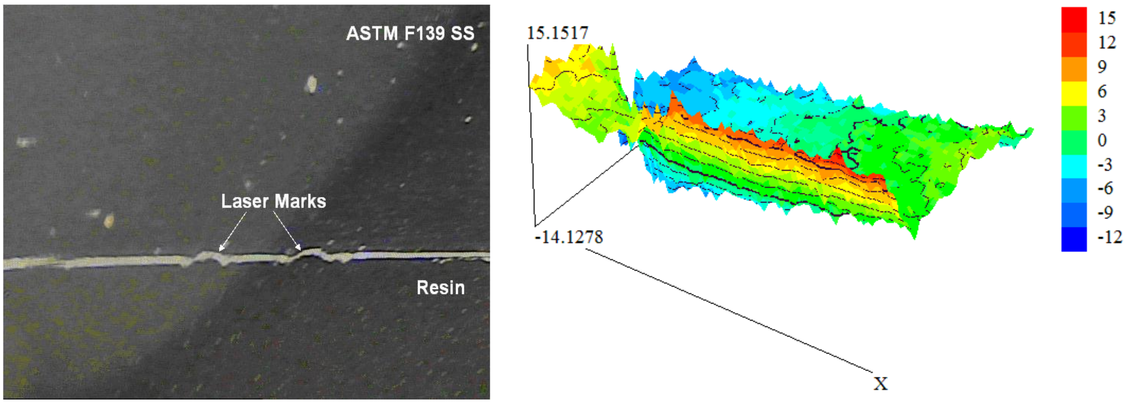
Fig. 1 shows the analyzed laser marked area (an engraving number eight) at the surface (a), and SVET maps of the local ionic currents in the solution, immediately after immersion in the PBS solution (b) and 17h after the sample has been immersed in this solution (c). The maps show that soon after immersion the anodic areas (red ones) corresponded to that where the laser beam has passed twice, whereas the cathodic areas (blue ones) were located at the heat unaffected zone. It also shows that 17h after immersion, the distinction between anodic and cathodic regions is not very clear, likely due to thickening of the passive oxide film on the SS surface. Subsequently, the sample was polarized to 0.6 V and 3D current density maps were obtained under polarized conditions (Fig. 1 d). The currents generated by the polarized sample clearly reveal the distribution of the anodic areas as spots inside the heat affected zone. This result shows that under more corrosive conditions, the anodic areas must be related to microstructural characteristics of the laser beam affected areas, leading to localized corrosion. Experiments were also carried out in the cross-section of a sample embedded into inert epoxy resin. The SVET maps revealed an area mainly anodic near the laser marked one and a cathodic one at other regions, far from the laser marks, as Fig. 2a-b presents. This result indicates that the currents are affected by the heated zone.



(a) (b) (c)

(d)

Fig. 1. Optical micro-photo of the analyzed area (a), 3D distribution of local ionic current density, immediately after immersion in PBS (b), 17h after immersion in PBS (c), under polarization conditions (d).



(a) (b)

Fig.2. Cross-section optical micro-photo (a), and corresponding 3D distribution of local ionic current density (b).

Fig. 2a is a cross-section of the region shown in Fig. 1a. The current density maps (Fig. 2b) related to the analyzed region show that the anodic current densities are associated to the laser marked areas mainly at the outer surface, and the cathodic areas are associated to the inner surface. These results show that the laser marking technique promotes galvanic cells and localized corrosion nucleation.

Conclusions

The results of the present study shows that the SVET is a very useful technique in monitoring the dynamic development of anodic and cathodic areas as a function of time in consequence of the surface modification caused by laser marking technique. The results also suggested that for investigating the correlation between microstructural characteristics and localized corrosion at the surface, more aggressive conditions such as those provided by sample polarization must be necessary.

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