Journal of Alloys and Compounds 563 (2013) 180–185

Contents lists available at SciVerse ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jalcom

Electrochemical testing of laser treated bronze surface

B.S. Yilbas [a,*], Ihsan-ul-Haq Toor [a], Jahanzaib Malik [a], F. Patel [a], C. Karatas [b]

[a] Dept. of Mechanical Engineering, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran 31261, Saudi Arabia
[b] Engineering Faculty, Hacettepe University, Ankara, Turkey

ARTICLE INFO

Article history:
Received 11 November 2012
Received in revised form 9 February 2013
Accepted 14 February 2013
Available online 27 February 2013

Keywords:
Laser melting
Corrosion resistance
Bronze

ABSTRACT

Electrochemical testing of laser treated bronze surface is carried out and corrosion resistance of the surface is assessed. Morphological and metallurgical changes in the laser treated layer are examined using scanning electron microscope, energy dispersive spectroscopy, and X-ray diffraction. The pit sites formed at the surface are analyzed using scanning electron microscope. It is found that laser treatment improves the corrosion resistance of the treated surface. Fine grains are formed in the surface region of the laser treated layer, which are attributed to the large cooling rates from the surface.

1. Introduction

Bronze is a copper alloy and it is widely used in marine environment due to its combination of toughness and resistance to the aqueous corrosion. However, corrosion and erosion take place at the fluid–metal interface and this adverse effect accelerates for the surfaces where the non-uniform microstructures are present. In general grain refining, with uniform microstructures at the surface vicinity of the alloy, improves the corrosion and erosion resistance at the surface. One of the methods to improve the alloy microstructure in the surface vicinity is to introduce control melting incorporating the high power laser beam. In addition, laser treatment of the surfaces is involved with precision of operation, short treatment duration, shallow heat affected zone, and low cost. However, the proper selection of the laser parameters is vital in surface treatment process to avoid the surface asperities because of the excessive heating. The surface asperities such as cavities and micro-cracks act like a defect sites for accelerated corrosion at the surface. Consequently, investigation into laser treatment of bronze surface in relation to corrosion prevention in aqueous solution becomes essential.

Considerable research studies were carried out to examine laser treatment of bronze surfaces. Laser treatment of aluminum bronze was studies by Xu et al. [1]. They demonstrated that the microstructure of the treated surface was cellulated crystals and it became dendritic crystals in the midsection of the treated layer. Laser treating of sintered bronze was investigated by Gisario et al. [2]. They performed thermographic analysis on the treated samples to evaluate the thermal dispersion at the surface. Laser treatment of bronze surface and corrosion resistance was examined by Tang et al. [3]. They showed that the galvanic effect between the laser treated and as-received samples were small, which justified the use of laser surface alloying as a feasible method in the local surface treatment of bronze. The cavitation erosion resistance of laser treated bronze was studies by Kwok et al. [4]. Their findings revealed that the cavitation erosion resistance of the laser treated surface was improved by at most 7.5 times that of as-received bronze surface. In addition, laser treatment enhanced the corrosion resistance of the surface considerably. Electrochemical response of the laser treated bronze surface was examined by Klassen et al. [5]. They illustrated that the oxide formed at the surface during laser treatment behaved as the passivation film improving the corrosion resistance of the surface. The corrosion resistance of laser treated bronze surface was studied by Mazurkevich et al. [6]. They indicated that the laser treatment of the surface improved the corrosion resistance notably. The influence of laser treatment on the surface properties of copper alloys was investigated by Garbacz et al. [7]. They incorporated Raman Spectroscopy to examine the phase composition of the corroded layers at the laser treated surface. The corrosion characteristics of laser treated Ni–Al–Bronze surface were examined by Kawazoe et al. [8]. Their findings revealed that Ni–Al–Bronze had quenching characteristics closely related to that of steel and the corrosion resistance of the surface improved after the laser treatment process. Laser treatment of bronze and titanium alloy was investigated by Kac et al. [9]. They showed that the high chemical homogeneity and fine structure of the melted zone were attributed to high cooling rates due to the short interaction time with Nd:YAG pulsed laser radiation and relatively small volume of the melted

* Corresponding author.
E-mail address: bsyilbas@kfupm.edu.sa (B.S. Yilbas).

0925-8388/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jallcom.2013.02.094

Table 1
Laser heating conditions used in the experiment.

Scanning speed (cm/s)	Power (W)	Frequency (Hz)	Nozzle gap (mm)	Nozzle diameter (mm)	Focus setting (mm)	N_2 pressure (kPa)
10	80	1000	1.5	1.5	127	500

material. Yilbas et al. [10] studied laser treatment of bronze surfaces with the presence of B_4C particles. They demonstrated that the laser treated surface produced was relatively free from defects and asperities with a microhardness that was notably higher than that of the as-received bronze substrate.

Laser surface treatment of bronze was investigated previously [11,12]. The main emphasis in the previous studies was on the improvement of microhardness at the surface and corrosion resistance of the treated surface was left obscure. Consequently, in the present study, laser treatment of aluminum bronze surface is carried out and corrosion resistance of the treated surface is examined incorporating the electrochemical tests in the electrolytic solution. The morphological and microstructural changes in the laser treated layer are examined using scanning electron microscope, energy dispersive spectroscopy, and X-ray diffraction. The pits sites at the surface are also analyzed.

2. Experimental work

The CO_2 laser (LC-ALPHAIII) delivering a nominal output power of 2 kW was used to irradiate the workpiece surface. The focusing lens has focal length of 127 mm and the focused laser beam diameter was about 0.3 mm at the workpiece surface. Nitrogen emerging from the conical nozzle was used as an assisting gas. The various surface treatment tests were carried out incorporating different laser parameters and the laser parameters resulting in crack free surfaces with low surface roughness were selected. The laser treatment conditions are given in Table 1. The laser treatment experiments were repeated three times to ensure the same topology and similar microstructures forming in the treated layer.

The aluminum bronze with elemental composition (wt%) of 9% Al, 3% Fe, and balance of Cu was used in the experiments. The bronze sheet was 3 mm in thickness and the size of the samples used in the experiments was 20×20 (length $\times$ width) mm.

Corrosion tests (Potentiodynamic polarization, Tafel behavior and electrochemical impedance spectroscopy) were carried out in a three electrode cell, which composed of a specimen as a working electrode, a Pt wire as a counter electrode, and a saturated calomel reference electrode (SCE). The specimens were degreased in benzene, cleaned ultrasonically, and subsequently washed with distilled water prior to electrochemical tests. The investigations were carried out with an exposed working electrode area of 0.07 cm^2 in 0.1 M NaCl solution at room temperature in PCI4/750 Gamry potentiostat and repeated several times to ensure the reproducibility of the data. DC105 corrosion software was used to analyze the Tafel region, while Potentiodynamic polarization experiments were performed at a scan rate of 0.5 mV/s.

Electrochemical impedance spectroscopy (EIS) measurements were carried out at OCP, by applying a sinusoidal potential perturbation of 10 mV with frequency sweep from 100 kHz to 0.01 Hz. The impedance data were analyzed and fitted to appropriate equivalent electrical circuit using the GAMRY framework software.

A Jeol 6460 electron microscopy was used for the SEM examinations and a Bruker D8 Advanced with Cu Kα radiation was used for XRD analysis. A typical setting for the XRD was 40 kV and 30 mA, the scanning angle (2θ) was ranged over 20–80°. The parabolically-shaped Göbel Mirror was used in the Bruker D8 Advanced, which provided highly-parallel X-ray beams.

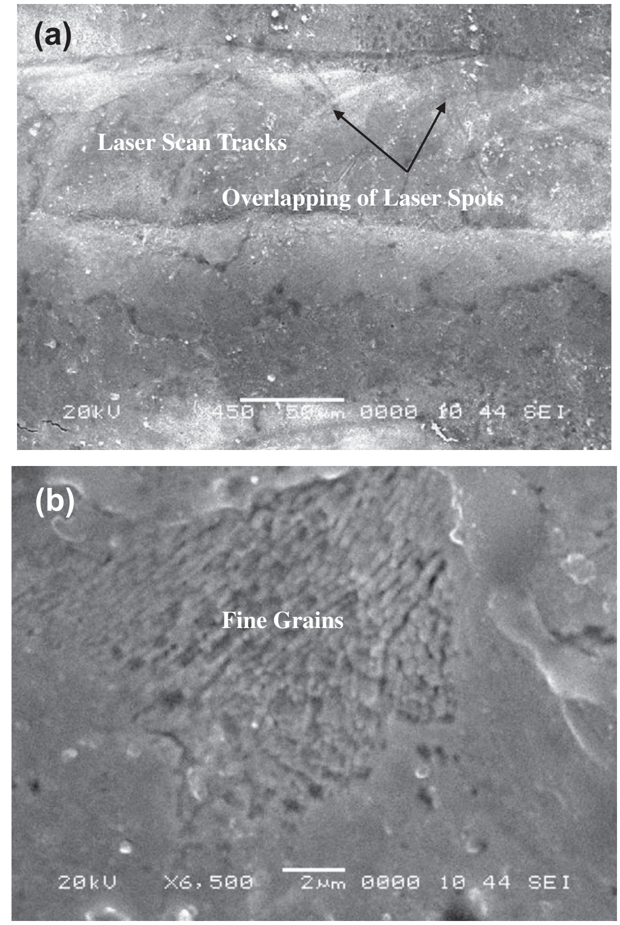

Fig. 1. SEM micrographs of laser treated surface: (a) laser scanning tracks and overlapping of irradiated spots, and (b) fine grains at the surface.

3. Results and discussion

Potentiodynamic response of laser treated bronze surface is investigated. Microstructural and morphological changes in the laser treated layer are examined prior and after the electrochemical tests.

Fig. 1 shows SEM micrographs of laser treated surface prior to the electrochemical tests. The surface comprises of regular laser scan tracks, which are equally spaced at the surface. Since the laser power intensity was adjusted to avoid evaporation at the surface, no laser induced cavity is formed at the surface. In addition, no micro-cracks or some other surface asperities are visible. It should be noted that the thermal conductivity of bronze is high; consequently, conduction heat transfer from surface region to the solid bulk is high. This, in turn, suppresses the development of high temperature gradients and high stress levels in the surface region.

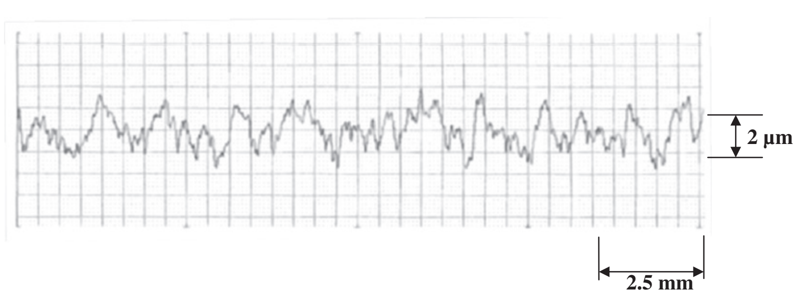

Fig. 2. Surface roughness chart for laser treated surface.