Progress in Natural Science: Materials International xxx (xxxx) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Progress in Natural Science: Materials International

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

Original Research

Corrosion resistance of carbon ion-implanted M50NiL aerospace bearing steel☆

Fangfang Wang, Chungen Zhou, Lijing Zheng*, Hu Zhang

School of Materials Science and Engineering, Beihang University, Beijing 100191, China

ARTICLE INFO

Keywords:
Aerospace bearing steel
Ion implantation
Electrochemical test
Corrosion resistance

ABSTRACT

The effect of carbon implantation on the corrosion behavior of M50NiL aerospace bearing steel through surface modification was investigated. X-ray photoelectron spectroscopy, Auger electron spectroscopy and X-ray diffraction were used to analyze the composition and structure of the carbon-implanted layer. The corrosion properties of the untreated and carbon ion-implanted samples were evaluated by potentiodynamic curves and electrochemical impedance spectroscopy, which were carried out in 3.5% NaCl solution. Ion implantation of carbon in the M50NiL bearing steel yielded a distinct decrease of the corrosion current densities and an obvious increase of the polarization resistance. The experimental results indicated that the content of chromium oxide in the passive film increased with carbon implantation and that the intergranular corrosion was suppressed in the carbon-implanted sample. Better corrosion protection was observed in the carbon ion implantation sample.

1. Introduction

Engine performance and reliability are crucial to the performance of jet aircraft [1], and aircraft engines represent one of the most sophisticated engineering technologies [2]. The ball bearings along the engine main shaft are critical components to tolerate high rotation speeds, vibratory stresses, elevated temperatures and a corrosive environment containing S, Cl, and other elements [3,4]. Due to the high performance requirements of aerospace bearings, ball bearing materials have been developed specifically for the main engine shaft application [1]. At present, through-hardened bearing steels, such as AISI 52100 and M50, are the simplest and most common materials used in aerospace bearing applications [5]. However, with the development of advanced gas turbine engines, bearing materials with improved life are needed. Low fracture toughness becomes a technical barrier for the application of conventional through-hardened bearing materials [6]. M50NiL is a variant of M50 alloy with much lower initial carbon concentration and a higher nickel content to promote carburization. It is an ideal material for aerospace engine bearings serving at high temperature and a high engine shaft speed (characterized by the bearing speed index (DN), where D is the bearing mean diameter in millimeters and N is the rotational shaft speed in rotations per minute) [7–9]. With the increasing thrust-to-weight ratio of aircraft engines, high temperature bearing alloys for the next generation of aircraft engines require good corrosion resistance and high surface hardness for wear resistance while maintaining a core with good fracture toughness, ductility and impact toughness [10,11]. The corrosion resistance for M50NiL aerospace bearing steel is still deficient [11,12].

Currently, surface modification methods have been proposed to prolong the service lifetime of many interesting industrial materials [13]. Ion implantation is a surface modification process by which any element can be virtually introduced into the subsurface of a solid material. The composition and structure change in the implanted area induces large variations in mechanical and chemical properties such as wear, erosion and corrosion [13–17]. It is reported that the atom implantation not only influences the crystal lattice but also may induce compressive stress close to the corrosion channels [17]. Carbon is one of the most useful ion implantation elements. There are numerous investigations on the implantation of carbon into iron or steels. Fujihana et al. [16,18] found that the high-dose implantation of C into iron reduces the anodic dissolution peak current density in an acetate buffer. In the work by Lillard, carbon implantation also increases the resistance to pitting corrosion of stainless steel in a Cl^-containing borate buffer [18]. Chigirinskaya et al. [8,19,20] found that the implantation of carbon into Fe-Cr alloys produces an amorphous phase; what is more, the anodic current density decreases in 0.1N H_2SO_4 or in 0.1 M NaCl, and the pitting potential increased. It has been found that the implantation of carbon into steels has a positive effect on their corrosion property.

☆Peer review under responsibility of Chinese Materials Research Society.

* Corresponding author.
E-mail address: zhenglijing@buaa.edu.cn (L. Zheng).

http://dx.doi.org/10.1016/j.pnsc.2017.07.003
Received 15 November 2016; Received in revised form 15 June 2017; Accepted 6 July 2017

The aim of this work is to evaluate the effect of carbon implantation on the surface topography, structure, and corrosion behavior of M50NiL steel.

2. Experimental details

The experimental M50NiL steel was prepared using a vacuum induction melting and casting furnace, followed by forging and heat treatment. The nominal composition (wt%) of the used material was 4.58 Cr, 4.34 Mo, 3.47 Ni, 1.28 V, 0.12 Mn, 0.21 Si, 0.12C and balance Fe. Annealed M50NiL steel specimens with dimensions of 10 × 10 × 5 mm^3 were used in the present study. Before ion implantation, the samples were mechanically polished with SiC emery paper up to #5000 and then ultrasonically degreased in acetone. The MEVVA (metal vapor vacuum arc) source implanter was used to conduct the carbon ion implantation. The carbon ion was implanted at a nominal dose of 5 × 10^{16} ions cm^{-2} using an acceleration potential of 30 keV. The average charge state of carbon ion is 1.0.

The elemental depth profiles of the specimens were obtained from Auger electron spectroscopy (AES) using Ar^+ sputtering at 5 kV. Survey scans and detailed scans of Fe1s, Ni1s, Cr2p, Mo1s and C1s electron emission were recorded for each sample. The chemical characterization was performed by photoelectron X-ray spectroscopy (XPS). The XPS data were collected using monochromatic AlK_α radiation at the constant analyzer pass energy of 55 eV. Fe2p, Cr2p, Mo3d, C1s and O1s photoelectron emissions were recorded.

Glancing angle X-ray diffraction (GAXRD) at 0.5° and 1° was used to discern phase changes induced by implantation, and the surface topography was measured by atomic force microscopy (AFM). The arithmetic means (Ra) and root mean square (Rq) of roughness values were used to describe the surface roughness before and after the carbon ion implantation. The corrosion behavior of the carbon-implanted samples in 3.5% NaCl solution was studied by polarization tests and electrochemical impedance spectroscopy (EIS) at 30 °C. For the polarization curve determination, a sweep rate of 0.5 mV/s was employed. The impedance spectra were acquired after 30 min of immersion and a frequency response analyzer system operating at open-circuit potential in a frequency range between 100 kHz and 10 Hz with a perturbation of 10 mV. The electrochemical experiments were conducted in a classical three-electrode cell. A saturated calomel electrode (SCE) was used as the reference electrode, and the platinum wire was the counter electrode. The surface topography after the electrochemical tests was also examined by scanning electron microscopy (SEM), and the composition of the corroded surface was detected by SEM-EDS.

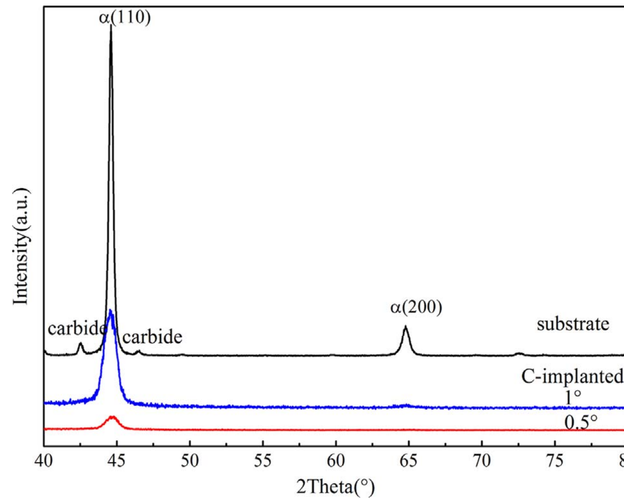

Fig. 2. GAXRD diffractograms in the 40–80° diffraction angles region acquired at 0.5°and 1° for the non-implanted and carbon implanted M50NiL.

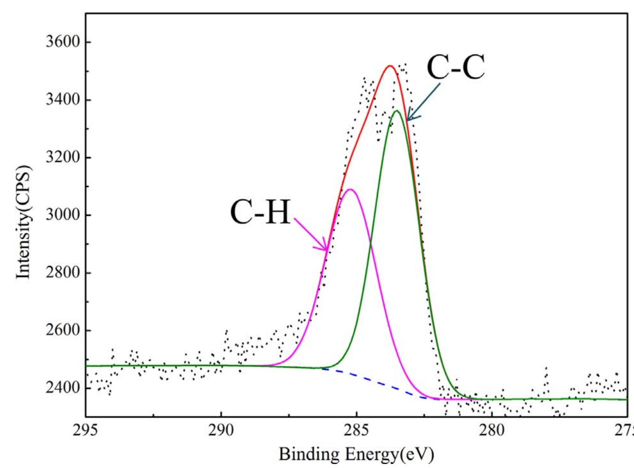

Fig. 3. C1s XPS spectra at the depth of 3 nm for carbon-implanted M50NiL steel.

3. Results and discussion

3.1. Composition depth profiles and phase constituent in the surface layer

Fig. 1 shows the AES atomic concentration depth profiles of the substrate and carbon-implanted M50NiL samples. The analyses show

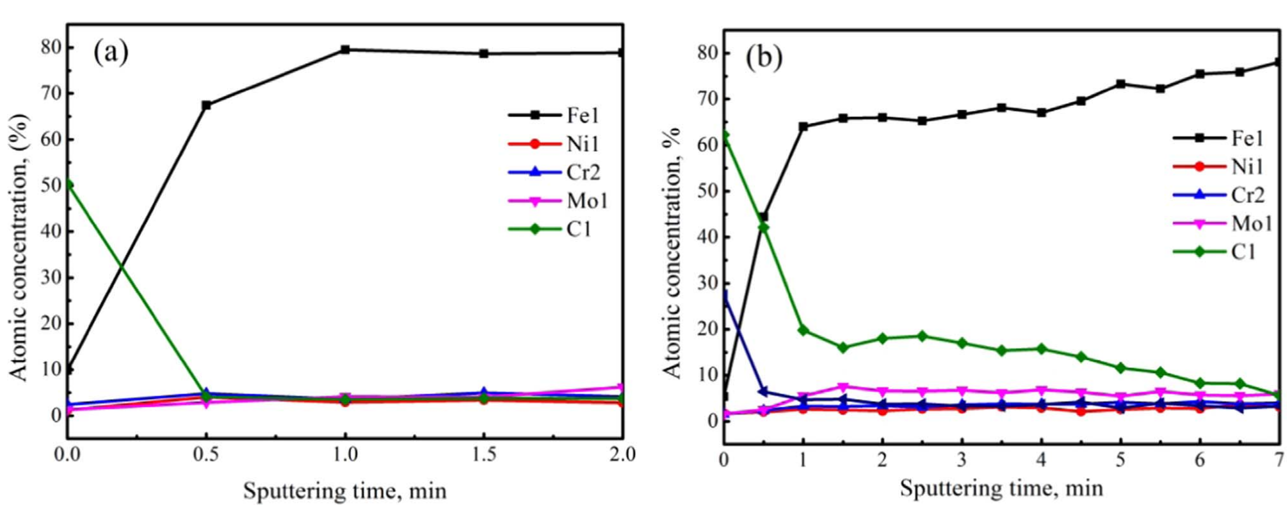

Fig. 1. Depth profile acquired from (a) substrate and (b) carbon implanted M50NiL sample, using AES.