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Effects of oxygen ion implantation on wear behavior of NiTi shape memory alloy

L. Tan [a,*], G. Shaw [b], K. Sridharan [a], W.C. Crone [a]

[a] *Department of Engineering Physics, University of Wisconsin-Madison, 1500 Engineering Drive, Madison, WI 53706, USA*

[b] *Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706, USA*

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Abstract

The plasma source ion implantation (PSII) technique was employed to modify the near-surface region of NiTi shape memory alloy by ion implantation with oxygen at 45 kV bias and 5×10^{16} ions/cm^2 dose. Wear resistance of control and oxygen-implanted NiTi samples was evaluated using fretting wear tests followed by the measurement of wear scar volume. Oxygen ion implantation improved the wear resistance of the NiTi alloy. The wear of NiTi has been described by a modified Archard's equation which incorporates the effect of elasticity and pseudoelasticity on wear resistance in addition to hardness. The relative contribution to wear resistance by elasticity and pseudoelasticity versus hardness is discussed.

Keywords: Fretting wear; Pseudoelasticity; Hardness; Nanoindentation; Archard's equation

1. Introduction

A unique combination of shape memory effect and pseudoelasticity, as well as good wear and corrosion resistance have led to the wide-spread use of NiTi shape memory alloy in both non-medical and medical applications (Duerig et al., 1999; Humbeeck, 1999). For specific applications, a variety of surface treatment approaches have been employed to reduce surface roughness, sterilize and passivate the surface of this alloy (Trépanier et al., 1999; Thierry et al., 2000a,b). In addition, coating and surface modification approaches such as ion implantation have been investigated (Rechavia et al., 1998; Schafer, 2002; Green et al., 1993; Wu et al., 1997; Tan and Crone, 2005). In the present research, plasma source ion implantation (PSII) with oxygen as incident ion species has been investigated with the goal of studying its effect on wear resistance of this alloy. The surface characteristics, hardness and corrosion resistance of the surface modified NiTi using oxygen PSII

* Corresponding author. Tel.: + 1 608 262 3437; fax: +1 608 263 7451.
E-mail address: lizhentan@wisc.edu (L. Tan).

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were reported in our previous work (Tan et al., 2002; Tan and Crone, 2002; Tan et al., 2003).

Wear testing was performed using a fretting wear tester, which involves high frequency, low amplitude displacement between two contacting surfaces. This type of wear usually occurs between two surfaces that are not intended to slide against each other, but over time will experience some minor sliding movement. An example of this is press-fit components used in modular orthopedic devices. In this application, such a wear process may not only disrupt the protective oxide film, but can also result in the generation of wear debris, further increasing the risks for immunologic response.

In this study the wear behavior of control and oxygen-implanted NiTi samples was studied using a fretting wear tester. The wear process has been described by a modified Archard's equation, which is developed based on the results of the composition of near surface region, volume of the fretting wear scar, and applied stress.

2. Sample preparation and experiments

2.1. Sample preparation

A commercial Ti–50.7 at% Ni alloy in sheet form was procured from Nitinol Devices & Components (NDC), Inc. in the flat annealed condition and cut into 5 mm × 10 mm flat samples by electro-discharge machining (EDM). To obtain the shape memory effect with a desirable phase transformation temperature, an aging treatment was performed on the as-received alloys at 550 °C for 20 min followed by quenching in water at room temperature. The austenite finish temperature (A_f) of the alloy was determined by differential scanning calorimetry (DSC) to be −3 °C, and therefore the alloy was austenitic at room temperature. All samples were mechanically polished using progressively finer grade of silicon-carbide paper ranging from 240 to 1200 grit size.

In preparation for oxygen ion implantation, the samples were ultra-sonically cleaned in acetone. Once in the PSII chamber, the samples were sputter-cleaned using energetic argon ions at 5 kV to remove any residual surface contaminants. Oxygen ion implantation was carried out at 45 kV target pulsed-bias and at an incident ion dose of 5×10^{16} ions/cm^2.

2.2. Auger Electron Spectroscopy (AES)

Control and oxygen-implanted samples were analyzed with a Perkin-Elmer PHI 670 Auger Electron Spectroscopy (AES) system, using an argon ion sputtering at 3 kV and an emission current of 25 mA. The argon sputtering rates for control and oxygen-implanted samples were determined to be 16 and 43 nm/min, respectively, by separately measuring the depth of the sputter crater by profilometry.

2.3. Fretting wear test

Fretting wear tests of control and oxygen-implanted samples were conducted using specially designed fretting wear tester (Sandstrom et al., 1993). The present study was conducted using a 3 mm diameter stainless steel (AISI grade 316) stylus and an applied force of 196 mN. The tests were carried out for 2000, 10,000, and 50,000 cycles separately, with the stylus oscillating at a frequency of 20 Hz over a linear displacement of 100 μm. Six fretting wear tests were conducted for each condition in order to obtain statistically valid results. Based on stereoscopic images taken from a LEO 1530 field emission scanning electron microscope, the volume of each wear scar was calculated using the Alicona-MeX (Alicona) software package. To eliminate the influence of wear debris on wear volume measurements, the samples were ultrasonically cleaned and flushed with pressurized air before introducing them into the SEM chamber. In order to create a stereoscopic SEM image, a stereo image pair was captured by slightly tilting (15°) the specimen eucentrically to the right or left about the vertical axis of the specimen surface.

2.4. Nanoindentation testing

Nanoindentation testing was performed using a Hysitron TriboScope connected to a Digital Instruments Multimode Scanning Probe Microscope equipped with a Berkovich indenter. To