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Microstructure of nitrogen implanted stainless steel after wear experiment

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Abstract

Outstanding wear resistance of austenitic stainless steel after nitrogen insertion and formation of expanded austenite in the temperature range below 420 °C is a well established phenomena. However, detailed information on the wear mechanism for the modified surfaces is still missing. This paper presents the results of wear experiments performed in a dry oscillating geometry against a WC ball (diameter 3 mm, load 3 N), together with metallographic investigations of the resulting cross-sections, both with and without nitriding. Comparisons with calculated stress distributions indicate that those nitrided samples showing a specific wear reduction by a factor of about 100 were subjected to a combination of stress maxima within the surface layer and below the layer in the bulk material.

Keywords: PIII; Expanded austenite; Wear; SEM

1. Introduction

Nitrogen insertion into austenitic stainless steel in the temperature range from 350 to 380 °C is a well established process leading to outstanding wear resistance of the modified stainless steel surface together with a hardness increase up to 1200 HV. The wear resistance is between 2 and 3 orders of magnitude higher than that of the base material. At the same time the excellent corrosion resistance of the stainless steel is retained [1–4]. These properties result from formation of a so-called expanded austenite phase, which is metastable and has a supersaturated unit cell with more than 20% nitrogen, with corresponding lattice expansion by up to 12% [5]. Layers of the order of 10–50 μm thick are formed within 1–5 h, thus suggesting a huge potential for technological application of these layers [6].

Nevertheless, the exact formation mechanism, the nitrogen diffusion, and the origin of the wear reduction, are not understood in detail, and they necessitate further investigation, especially since similar effects are found in martensitic and ferritic stainless steel [7–9]. In this paper, the results of metallographic investigation of the cross-sections of untreated and nitrogen implanted samples before and after nitriding are presented. Additionally, calculations of the three-dimensional distribution of the von Mises stress are performed, to allow a detailed insight into the origin of the material wear.

2. Experiment

Nitrogen plasma immersion ion implantation (PIII) was performed using polished flat samples of austenitic stainless steel AISI 304 (X5CrNi18.10–DIN 1.4301). In the vacuum chamber equipped with a helix plasma source, the working pressure was 0.2 Pa, while the base pressure was kept below 5×10^{-3} Pa. High voltage pulses of 10 kV and pulse length of 15 μs were applied to the samples immersed in a plasma with a density of 6×10^{9} cm^{-3} and an electron temperature of 1 eV. The total implantation time was set to 2 h, with an incident fluence at 1.5×10^{18} atoms/cm^{2}. The process temperature was 350 °C, maintained by adjusting the pulse repetition rate.

The elemental depth profiles were obtained from glow discharge optical emission spectroscopy (GDOS) allowing an accuracy of better than 0.1 at.% and a reproducibility of 0.1–0.2 at.%. Nanoindentations were carried out with a Vickers tip at an applied load of up to 1 N to obtain dynamic hardness values, which were not corrected for elastic recovery, so real values should be 15 to 20% higher.

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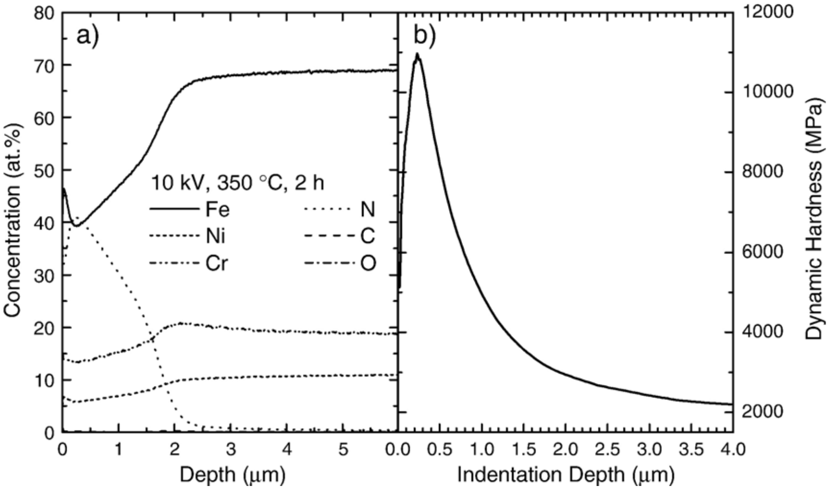

Fig. 1. (a) Elemental depth profiles of 6 selected elements by GDOS after nitrogen implantation by PIII at 350 °C with 10 kV for 2 h; (b) dynamic hardness data for the same sample.

Wear data for implanted and non-implanted samples were derived from an oscillating dry ball-on-disc test against a WC ball with 3 mm diameter. The applied load was 3 N, resulting in a Hertzian contact pressure of 1.0 GPa. The measurements were performed at an average velocity of 15 mm/s using a track length of 20 mm and wear paths up to 400 m. Profiles of the wear tracks, either one-dimensional line scans or two-dimensional images, were obtained using an optical profilometer.

Metallographic cross-sections of implanted and non-implanted samples after the wear tests at different wear paths were prepared using aqua regia as etchant, and subsequently analyzed by scanning electron microscopy (SEM). Additional images were obtained from optical microscopy. Furthermore, three-dimensional distributions of the von Mises stress below the contact area [10] were calculated for treated as well as untreated samples, both with and without lateral forces, in the latter case simulating a friction coefficient of 0.25.

3. Results and discussion

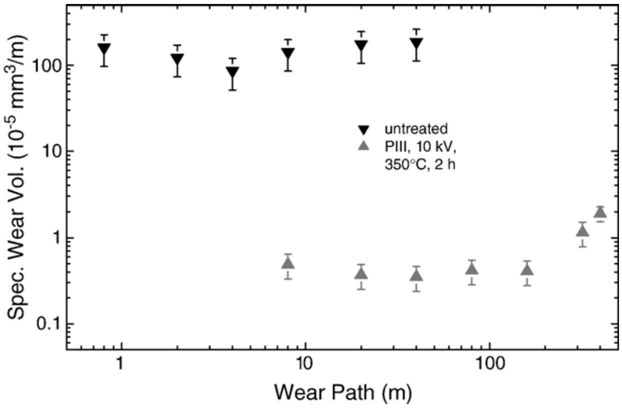

Fig. 2. Specific wear volume as a function of the wear path for untreated and implanted (10 kV, 350 °C, 2 h) using a WC ball.

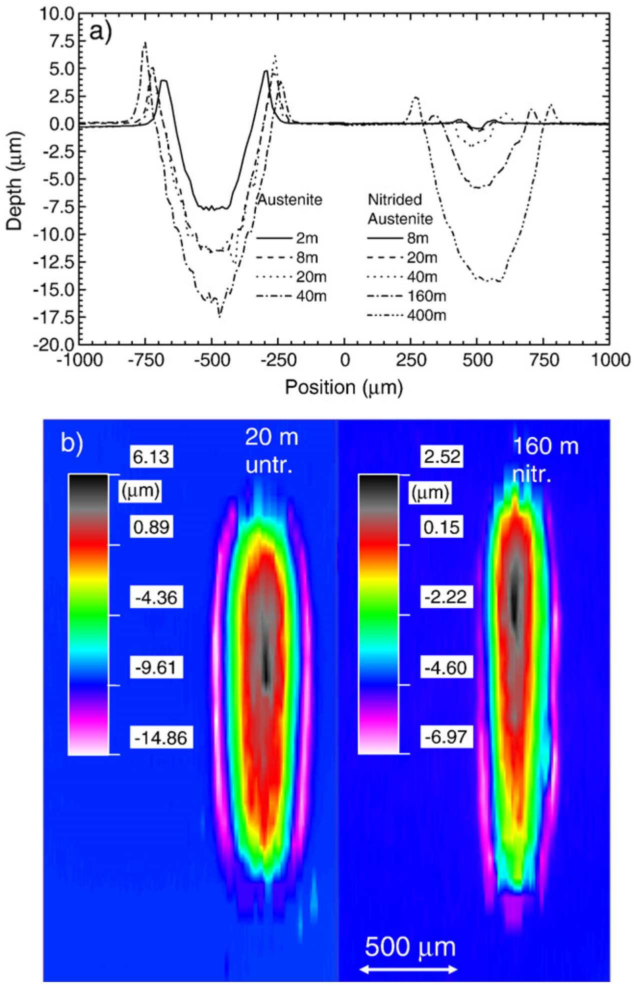

Fig. 3. (a) One-dimensional wear track profiles after different wear paths (different time for wear test) for untreated and nitrogen implanted (10 kV, 350 °C, 2 h) samples; (b) two-dimensional color coded scans of wear tracks on a non-implanted sample and an implanted sample at different wear paths but similar track depth.

Even though in this paper we will focus mainly on the wear behavior of austenitic stainless steel at one representative