Wear behaviour of 38NCD4 N-ion implanted steel

S. TOSTO*
Istituto per la Ricerca Scientifica e Tecnologica, 38050 Povo (Trento), Italy

A wear test at increasing load has been performed on 38NCD4 steel ion implanted with a dose of 2×10^{17} ions cm^{-2} and a beam current of $100\,\mu A$. A considerable reduction of the cumulative damage occurring during the test was found. This has been correlated with the surface precipitation hardening caused by the implantation.

1. Introduction

Ion implantation has been successfully used as a surface treatment to improve the wear [1], fatigue [2] and corrosion resistance [3] of materials. In particular, wear tests performed in our laboratories [4] on 38NCD4 steel showed that, after N-ion implantation, the steady-state part of the wear curve (weight loss against time) can be significantly prolonged (by a factor of about 3) thus showing that the mechanism responsible for the onset of severe wear can be delayed. In this respect, the effectiveness of the ion-implantation treatment can be seen as a more prolonged service life (under constant conditions) before the onset of rapid surface deterioration hinders further usage. However, the wear behaviour of implanted samples can also be seen from another point of view. It is well known that the length of the steady-state part of the wear curve depends on the load acting upon the surface as well as on the coupled materials. Different mechanisms of surface damage are, in fact, induced when the load is increased, with microwelding phenomena becoming more and more important at higher loads. The question arises whether the beneficial action of ion implantation is also effective in this respect. The purpose of the present work was to examine this aspect of the problem and to obtain evidence concerning the mechanism responsible for the improved wear resistance after N-ion implantation.

2. Experimental details

The wear test was performed on four of the samples prepared previously [4], using a reciprocal motion machine; two samples were unimplanted, two were implanted with a dose of 2×10^{17} ions cm^{-2}. The nitrogen beam had an energy of 30 keV and a current of $100\,\mu A$. Both N^+ and N_2^+ ions were implanted because no mass analysis was performed (to allow a high beam current). No lubricant was used, only alcohol as a refrigerant. The runner, a parallelepiped of 3 mm × 5 mm × 5 mm, was made of 19CN5 steel, (composition, wt%, C 0.19, Mn 0.9, Cr 1.0, Ni 0.8, Si traces) carburized to a thickness of 0.7 mm to increase surface hardness (about 700 HV). The bar of 38NCD4 steel (5 mm × 5 mm × 50 mm) was implanted in the central region over a length of 30 mm.

The chemical composition of the steel (wt%) was C 0.35, Ni 0.82, Cr 0.72, Mo 0.20, Mn 0.73 and Si 0.20. The microhardness of the bar was measured before and after implantation; the values (about 360 and 600 HV, respectively) were obtained using a load of 15 g. Further details on measurements and equipment are described elsewhere [4]. The procedure during the wear experiment was as follows: a time was selected (10 min) during which the test was performed with an initial load acting upon the surface of the steel bar (5 kg). Then, after 10 min under these conditions, the load was increased (to 6 kg) and the wear test was continued for a further 10 min under the new conditions. Further increases in load were made every 10 min until microwelding phenomena stopped the experimment. After 80 min the load steps were 2 kg to accelerate the test. The results obtained for unimplanted and implanted

*Present address: Centro Ricerche Fiat, Strada Torino 50, Orbassano 10043, Italy.

0022–2461/83/030899–04$02.98/0

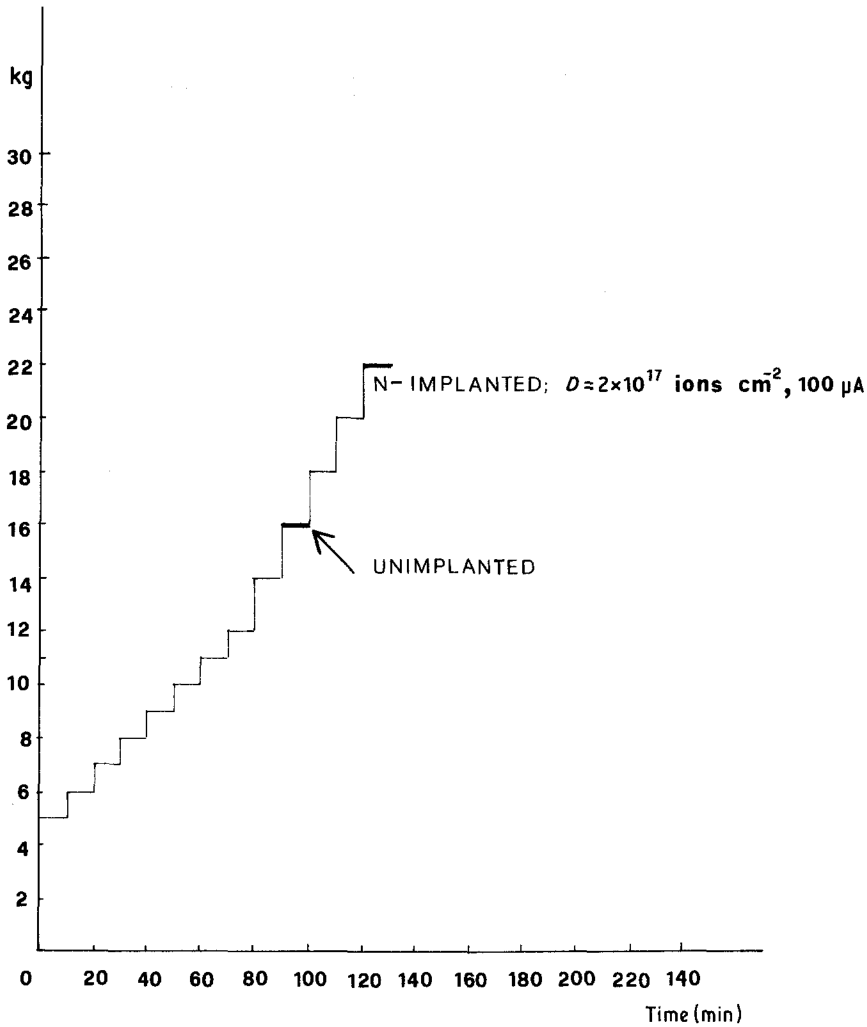


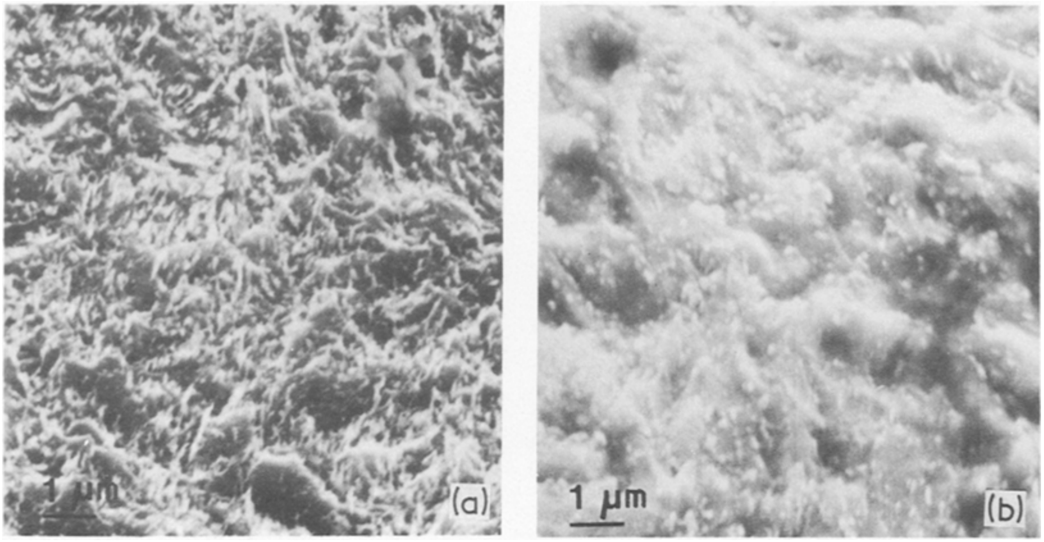
Figure 1 Wear test at increasing load of unimplanted and implanted specimens; the limit loads for the occurrence of critical microwelding phenomena are indicated. All the treated and untreated samples gave the results shown in the figure.

samples are shown in Fig. 1. It appears that the critical load for the two implanted specimens (indicated in the figure) was about 40% higher than for the two unimplanted ones.

Scanning electron microscopy was performed to obtain microstructural information about the unimplanted and implanted steel. The samples for observation, having a geometry identical to that used for the wear test, were polished before implantation following standard metallographic procedures and etched in 1% Nital. The etching time (1 min) was carefully controlled to avoid complete dissolution of the implanted layer. Fig. 2a shows the virgin material; the structure was bainitic, the light particles being cementite embedded in a ferritic matrix. Fig. 2b and c shows the surface layers after implantation. A very fine precipitation is evident in Fig. 2b and, in more detail, in Fig. 2c. The mean dimension of the particles is of the order of 100 nm.

3. Discussion

The results show that the cumulative damage which occurred during the wear test was considerably reduced by the implantation treatment. The reason for this must, therefore, be sought in the structure of the surface layers affected by the ion bombardment. It must be remembered that the thickness of the implanted zone for the beam energy used is a few hundred namometres [7], much less than the diamond indentation depth in a microhardness test. This fact suggests that



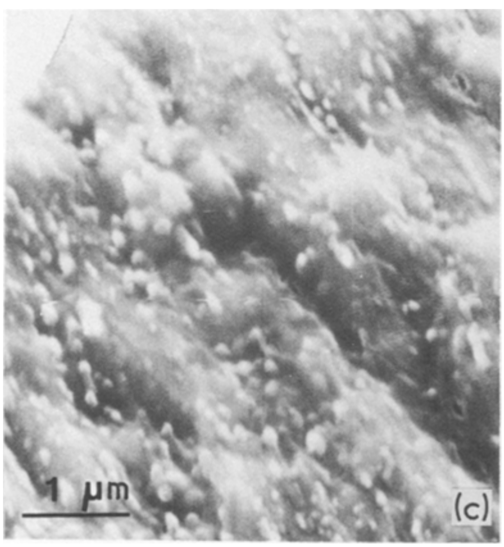


Figure 2 (a) The microstructure of 38NCD4 steel. The (b) microstructure of N-ion implanted 38NCD4 steel; beam current: 100 μA; beam energy: 30 keV; dose 2×10^{17} ions cm^{-2}. (c) Detail of (b).

the local hardness should be considerably higher and also that the inner thermally affected layers contribute to the measured value. The hardness values can be explained on observing the fine dispersion of precipitate present after implantation. The particles have been identified [5] by means of surface Mössbauer spectroscopy, as iron nitrides with chemical composition ranging from Fe_2N to Fe_4N, depending on their distance from the surface. It seems quite reasonable to hypothesize some precipitation strengthening model (such as Orowan's [6] mechanism) to account for both hardness and improvements of mechanical properties. These arguments suggest an hypothesis to correlate surface hardening with the results of the present work. It is well known that the coupling most likely to cause microwelding during wear tests occurs when the two partners form a solid solution. In this situation, an oxide layer, formed in the wear zone as a consequence of the rising temperature, acts as a protective interface, by preventing metal-to-metal contact. From the above arguments, it seems reasonable to suppose that the oxide layer at the surface of the 38NCD4 bar is a more effective interface when formed on a hard substrate; in effect, a pronounced plastic deformation of the steel, caused by the sliding contact with the very hard runner, is not conducive to the maintenance of a protective oxide barrer. Thus, the strengthening mechanism responsible for the delay in the onset of severe wear at constant load, appears to be effective also in delaying the onset of microwelding at increasing load. Electron microscopy observations and Auger profiles on the wear surfaces are in progress to clarify these conclusions.

References

1. N. E. HARTLEY, "Application of Ion Beams to Materials", Conference Series No. 28 (Institute of Physics, London, 1976).
2. S. LO RUSSO, P. MAZZOLDI, I. SCOTONI, C. TOSELLO and S. TOSTO, *Appl. Phys. Lett.* **36** (1980) 822.
3. P. L. BONORA, G. CERISOLA, C. TOSELLO and S. TOSTO, in "Proceedings on modification of the surface properties of metals by ion implantation", Edited by V. Ashworth, W. A. Grant and R. P. M. Procter (Pergamon Press, Oxford, 1982).

4. S. LO RUSSO, P. MAZZOLDI, I. SCOTONI, C. TOSELLO and S. TOSTO, *Appl. Phys. Lett.* **34** (1979) 627.
5. M. CARBUCICCHIO, L. BARDANI and S. TOSTO, *J. Appl. Phys.* **52** (1981) 4589.
6. A. G. GUY and J. J. HIREN, "Elements of Physical Metallurgy" (Addison Wesley, London, 1974).
7. I. SCOTONI, C. TOSELLO, S. STURLESE and S. TOSTO, *La Metallurgia Italiana* **718** (1979) 313.

Received 22 February
and accepted 16 July 1982