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Material surface modification by pulsed ion beam

Z. G. SHEN, C. H. LEE
Institute of Fluid Mechanics, Beijing University of Aeronautics and Astronautics, Beijing, People's Republic of China

C. WU, D. Y. JIANG, S. Z. YANG
Institute of Physics, Academia Sinica, Beijing, People's Republic of China

A new technique utilizing a high-power-density pulsed ion beam for modification of material surfaces is presented. The power density of the pulsed ion beam ranges between 10^4 and 10^7 w cm^{-2}, the kinetic energy is 1 to 5 KeV, the deposition energy is of the order of 1 to 10 J cm^{-2} and the pulsed duration is about 60 μsec. The post-treatment samples were analysed using Auger electron spectroscopy, scanning electron microscopy, X-ray diffractometry, and Vicker's microhardness tester. It is found that the concentration of the injected particles has a Gaussian distribution. The thermal zone induced by the fast heating–cooling process forms a white-bright layer, indicating that there are new carbides and nitrides produced in the surface layer, which increases the microhardness of the surface.

1. Introduction

Various techniques have been developed for surface modification utilizing ion, electron and laser beams [1–3]. A new technique based on the interaction between a high-power-density pulsed ion beam and the material surface is proposed to serve similar purposes. There are two mechanisms involved in the modification process for this technique: the implantation of the needed elements into the surface layer; and the fast heating and cooling process induced by the high-power-density pulses. These mechanisms may cause phase changes, melting or evaporating in the surface layer, and changes in the chemical composition and the microstructures of the material surface. The physical as well as mechanical properties of the material surface may be modified to some extent.

2. Experimental procedures

The set-up for generating the pulsed ion beam is depicted in Fig. 1. Its working principle can be described as follows: the gas is puffed by a fast electromagnetic valve, [4] and then ionized in a coaxial plasma gun [5]. Under the axial force $\vec{j} \times \vec{B}$, the plasma is ejected from the gun into the quartz tube where, due to the interaction between the biased electric field and the confined magnetic field, a pulsed ion beam forms and bombards the sample at a very high speed. The measured-power-density of the pulsed ion beam ranges from 10^4 to 10^7 w cm^{-2}, the kinetic energy of the ion is about 1 to 5 KeV, the deposition energy ranges from O(1) to O(10) J cm^{-2}, and the interaction time between the beam and the sample per pulse is about 60 μsec. A detailed description of the set-up is given in [6].

The post-bombardment samples of fast-speed steel and stainless steel (S.S. 45) using a pulsed N^+ beam were analysed by Auger electron energy spectroscopy, scanning electron microscopy, and X-ray diffractometer. We also used the Vicker's microhardness tester to measure the surface microhardness of the samples.

3. Results and discussion

The distribution of nitrogen concentration along the penetration depth measured by Auger electron spectroscopy is shown in Fig. 2. It is seen that the nitrogen concentration forms approximately a Gaussian distribution, a similar feature to that obtained by the ion implantation technique [7]. The penetration depth for the pulsed ion beam, however, is found to be shallower than those produced by conventional ion implantation techniques.

The cross-sectional structures of the post-treated samples were investigated using the scanning electron microscope. The metallographical microstructures of the samples are illustrated in Fig. 3. As shown in the micrograph, there is a white-bright layer with thickness ranging from a few micrometres to 20 μm, depending on the parameters in the sample materials, the power supplies, and the ion beams. In fact this structure may also be found in any carbon steel treated by certain fast-quenching processes using laser beam, electron beam or high frequency pulsed quench [8]. However, the structure inside this layer could not be observed in detail by the electron microscope even with the magnification up to 5000. Thus it is possible that, due to a fast melting and solidification process, the fine martensite and residual austenite structures may be produced in the layer. But it is also possible that the layer is composed of fine, dispersed precipitates of nitrides and carbides.

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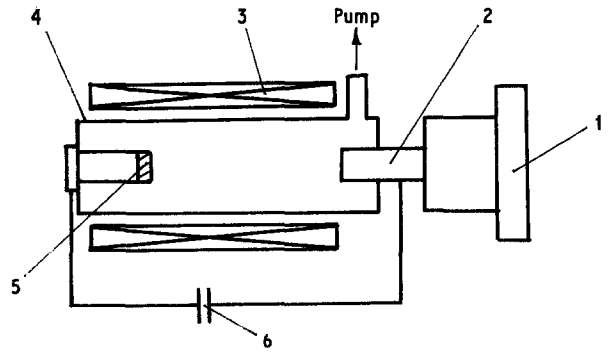

Figure 1 The pulsed ion beam generator. (1) Fast electromagnetic valve; (2) coaxial plasma gun; (3) confined magnetic field; (4) quartz glass tube; (5) sample; (6) biased electric field.

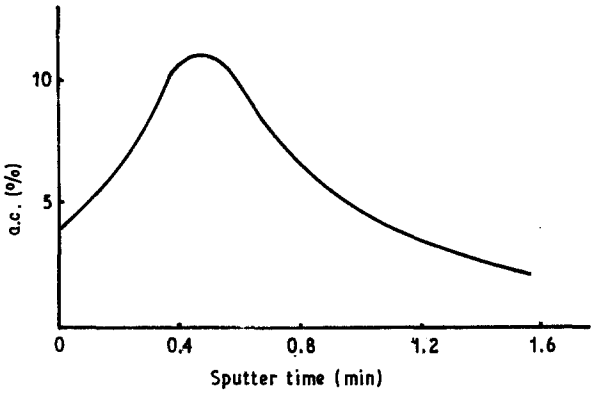

Figure 2 Nitrogen concentration distribution along the penetration depth.

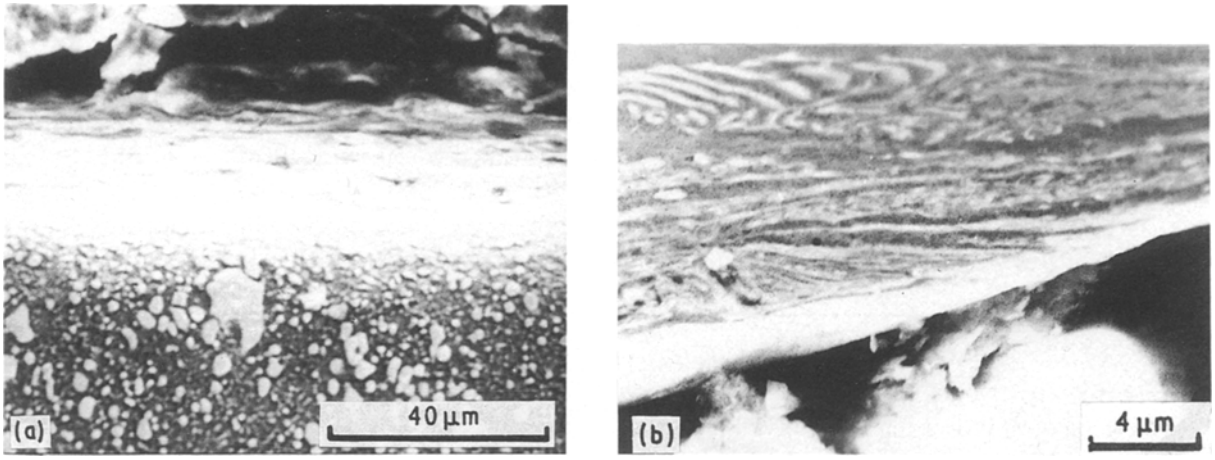

Figure 3 The microstructures in the surface layer taken by SEM. (a) Matrix of the fast speed steel; power density = 1.6×10^6 w cm^{-2}, ion kinetic energy = 3 keV, deposition energy = 95 J cm^{-2}. (b) Matrix of the stainless steel (S.S.45); power density = 9×10^5 w cm^{-2}, ion kinetic energy = 2 keV, deposition energy = 53.7 J cm^{-2}.

The post-treated samples were also examined using an X-ray diffractometer with incident angle 2θ ranging from 20 to 90°. Some new nitride and carbide phases, such as Fe_3N, $(Cr, Fe)_7C_3$, and $Cr_{23}C_6$ are produced in the surface layer.

These phenomena suggest that the surface microhardness of the post-bombarded samples can be modified as expected. The Vicker's microhardness of the post-bombarded samples for steel is shown in Fig. 4. It is believed that the strengthening of the surface hardness by the presently developed technique stems from the following mechanisms:

1. The interstitial carbonitride strengthening [9]. The carbonitrides possess very high melting points and hardnesses. These carbonitrides are finely dispersed in the vicinity of the surface to restrict the motion of dislocations, and thus enhance the hardness and wear-resistance of the material.

2. Thermal stress strengthening. The fast heating and cooling process may induce compressive stresses in the surface layer.

3. Grain-size strengthening. The crystals in the vicinity of the surface become finer after treatment. These fine structures may increase the potential to prevent movement of the dislocation.

4. Dislocation strengthening. The pulsed bombardment may cause the surface layer to produce a high density of tangled dislocations. This formation can also restrict the motion of the dislocation.

5. Interstitial solid solution strengthening. After

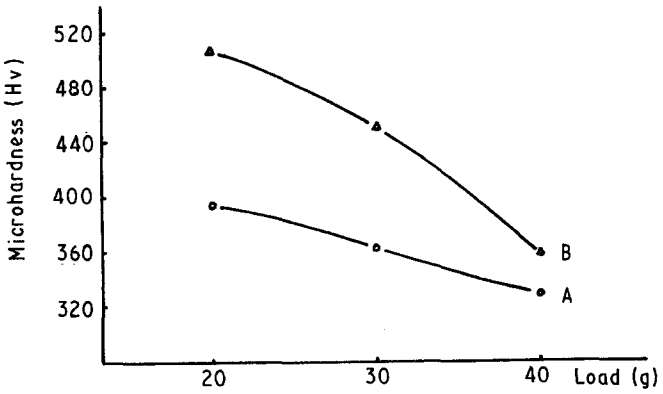

Figure 4 Change in microhardness against load for steel. (A) Initial hardness; (B) after treatment.

bombardment, the carbon and nitrogen particles dissolve into the surface layer to form the interstitial solid solution. This solution can cause the crystal lattice in the surface layer to deform. It is clear that the more severe the deformation is, the greater the resistance to the motion of the dislocation could be.

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