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Modification of AISI M2 steel tribological properties by means of plasma mixing

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Abstract

Changes in the phase and element composition, tribological properties of the Zr/AISI M2 steel system after treatment with compression plasma flows are studied in this work. It was found that the treatment resulted in the formation of a mixed layer containing atoms of a coating (Zr), a substrate (M2 steel) and a plasma-forming gas (N). The zirconium concentration in the mixed layer depends on treatment parameters. The ZrN formation in the surface layer provides microhardness increase, friction coefficient decrease and enhanced thermal stability of tribological properties.

Keywords: High-speed steel; Plasma flow; Structure-phase transformation; Tribological properties

1. Introduction

Pulse plasma beams suit well for the modification of construction and instrumental materials tribological properties. Plasma treatment of different types of steel can increase their hardness 2–4 times [1–6]. However, plasma flows with a comparatively large discharge time ~100 μs do not allow to improve strength properties of high-alloyed steels. For example, the compression plasma flows (CPF) impact on a high-speed steel surface results in partial dissolution of hardening carbides M_6C, thus leading to the decrease of microhardness [7]. At the same time CPF generated in quasi-stationary plasma accelerators can be effectively used for the "coating/substrate" system mixing just due to comparatively long discharge time, high temperature and high velocity of plasma particles [6]. These main characteristics of CPF allow to form deep layers (10–15 μm) containing atoms of coating, substrate and plasma-forming gas. Earlier it was found that the impact of CPF on the "coating/steel" system was accompanied by the following processes [8,9]: ablation of some part of coating, melting of coating and a bulk of a substrate, liquid phase mixing under plasma flow pressure, rapid cooling and crystallization of a modified layer.

This approach was used for the modification of AISI M2 high-speed steel tribological properties. The Zr deposition on the M2 steel surface before CPF treatment should diminish the effect of temperature on the structure of the high-speed steel and allow to saturate a steel matrix with an additional component, providing high hardness and high thermal stability of a treated system. The investigation of the CPF effect on the structure, phase composition and tribological properties of the Zr/AISI M2 high-speed steel system was the main aim of this work.

2. Experimental procedures

The samples used were made of AISI M2 high-speed steel which has the following element composition: 0.8% C, 6.0% W, 5.0% Mo, 4.1% Cr, 1.9% V, 0.5% Co, in wt%. The sample size was the following: thickness—2 mm and diameter—15 mm. The steel samples were subjected to thermal processing, which is typical of this class of steel.

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The phase composition of the samples contains the following main phases: α-Fe doped with the alloying elements, M_6C, MC and $M_{23}C_6$ carbides (M: Fe, W, Cr, Mo, V).

The zirconium coating was formed using cathodic arc vapour deposition with the following process parameters: the arc current of 100 A, the bias voltage of −120 V, the deposition time of 5 and 10 min. The coating thickness was ~0.98 and 1.87 μm correspondingly.

CPF were obtained using a gas-discharge magnetoplasma compressor (MPC) of compact geometry powered with the capacitive storage of 1200 mF, operating at the initial voltages from 3 to 5 kV. The discharge device and principles of CPF generation were described in detail earlier [6,7]. Nitrogen was used in the MPC as a plasma-forming gas. The pressure of the plasma-forming gas (*P*) was 400 Pa. The discharge duration in the MPC amounted to ~100 μs. The number of pulses (*n*) was 1 and 5. The energy absorbed by the surface layer was controlled by the bank capacitor initial voltage. According to the calorimetric measurements, the value of the power density absorbed by the sample surface (*Q*) was approximately 10 J/cm^2 per pulse during the CPF treatment of the samples with the coating thickness of 0.98 μm and 13 J/cm^2 for the samples with the coating thickness of 1.87 μm.

Annealing in air at the temperature of 873 K for 1 h was carried out to examine the thermal stability of the modified layer. This temperature limits the operation ability of M2 steel tools [10].

The phase composition of the samples was investigated by the X-ray diffraction analysis (XRD) at the fixed angle of incidence (3°) using a SEIFERT 3003 diffractometer with a HUBER SMC 9000 goniometer in Cu Kα radiation. Bragg–Brentano geometry with Co Kα radiation was used for the investigation of the annealed samples phase composition. The element composition was investigated by means of the Rutherford backscattering analysis (RBS) of He ions with the energy of 6 MeV. A high energy of helium ions allows to increase the yield of ions scattered on light impurities. Non-Rutherford cross-sections were used for the calculation. The microhardness of the samples was tested by means of a PMT-3 microhardmeter with a Vickers indenter under the load ranging from 0.5 to 2 N. Microhardness values at the indentation depth of 3.5 μm were chosen for comparison. The tribological test was of the "pin-on-plane" type, dry sliding dynamic friction. The linear velocity was 0.4 cm/s. The pin was made of a hard alloy (92 wt% WC, 8 wt% Co). The load on the pin was 1 N.

3. Results and discussion

The RBS spectra of two Zr/M2 systems with different coating thickness before and after CPF treatment are presented in Figs. 1 and 2. One can see that treatment with $Q = 10\,\mathrm{J/cm^2}$ and $n = 1$ results in non-uniform mixing of the surface layer. A further increase of the number of pulses leads to the formation of a mixed layer with almost constant concentration of components except for the surface. Non-uniform mixing observed in the case of $n = 1$ can occur in both lateral and transverse directions with respect to the surface. This will lead to large scattering of hardness and friction data along the surface. That is why further investigations were carried out for the Zr/M2 system (coating thickness: 1.87 μm) treated with $Q = 13\,\mathrm{J/cm^2}$.

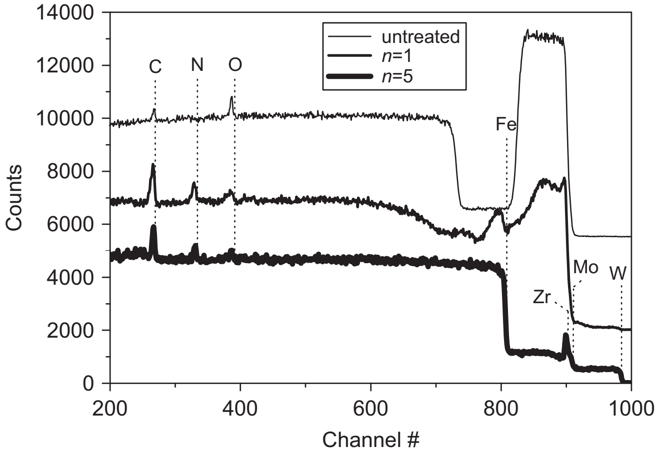

Fig. 1. The RBS spectra of Zr/M2 samples before and after the CPF treatment ($Q = 10\,\mathrm{J/cm^2}$).

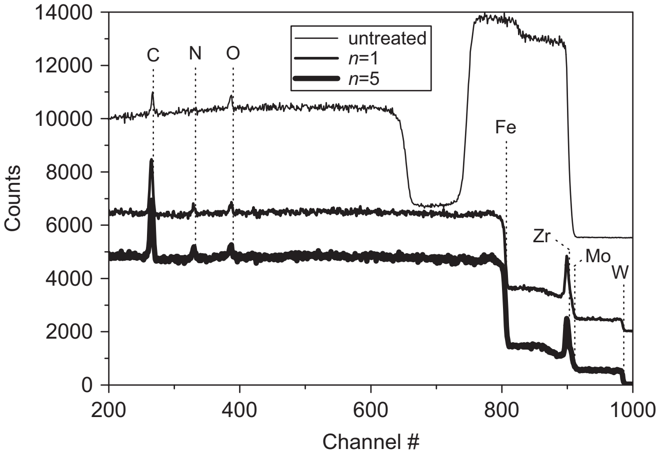

Fig. 2. The RBS spectra of Zr/M2 samples before and after the CPF treatment ($Q = 13\,\mathrm{J/cm^2}$).

The increase of energy deposited in the surface layer per pulse leads to a more uniform redistribution of components inside the modified layer except for the near surface layer (Fig. 2). One can see that the zirconium concentration decreases (Fig. 3) with the growth of *n*. This effect occurs due to the growth of the modification layer depth [7] and the diffusion of zirconium into the bulk of the sample [9]. Zirconium has a surface peak with the concentration of 20–25 at% (Fig. 3). The thickness of this layer is about 200 nm. This layer also contains the maximum nitrogen