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Formation of alloying layers in a carbon steel by compression plasma flows

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Abstract

The main regularities and features of steel surface alloying by means of compression plasma flows treatment of coating/substrate systems are investigated in this work. Ti, Zr, Mo and Cr were used as alloying elements. The thickness of the alloyed layer is about 8–15 μm. The mixed layer contains iron solid solutions, nitrides and possesses mechanical properties improvement. The peculiarities of alloying elements distribution are discussed.

Keywords: Compression plasma flows; Mixing; Surface alloying

1. Introduction

Nowadays, the problem of surface alloying of materials is still topical. Saturation of surface layers of low-alloyed steels with different elements in order to increase mechanical properties is of special interest. It can be successfully achieved by the impact of intensive energy fluxes (laser, ion and electron beams, plasma flows) on a coating/substrate system [1,2]. The short-term effect of high temperatures results in mixing of system components and redistribution of coating and substrate elements accompanied by the formation of various compounds in addition to quenching.

Compression plasma flows (CPF) generated in quasi-stationary plasma accelerators can also be effectively used for the "coating/substrate" system mixing due to comparatively long pulse duration, high temperature and high velocity of plasma particles [3,4]. Moreover, there is possibility of using a plasma-forming gas simultaneously both for heating near-surface layers and alloying a material by a gas element.

This work presents the results of investigations of the phase and element composition and properties of a low-carbon steel alloyed by metals under the CPF action. Ti, Zr, Mo and Cr were chosen as alloying elements that provide enhanced corrosion resistance, high-temperature stability and mechanical properties of steel.

2. Experimental

A metal layer was deposited on carbon steel (0.2 C, 0.2 Si, 0.5 Mn, in wt.%) using the PVD method (vacuum arc vapor deposition) with the following operating parameters: the arc current of 100 A, the bias voltage of −120V, the deposition temperature of 450 °C and the deposition time of 10 min. The specimens were subjected to the CPF treatment. The experiments were performed in a "residual gas" mode when the vacuum chamber was filled with nitrogen up to the preset pressure of 400 Pa. The plasma flow parameters were the following: the pulse duration of ~100 μs, the plasma velocity of (5–6) $\times 10^6$ cm/s, the electron concentration of (4–7) $\times 10^{17}$ cm^{-3}, the plasma pressure of 1.5 MPa and the temperature of 2–3 eV, respectively. The deposited energy density was 13 J/cm^2 per pulse. The treatment was carried out by one pulse

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(in case of Ti/steel system) and by a series of five pulses (in other cases) with the interval of ~40 s between pulses.

The phase composition and the crystal structure were investigated by the X-ray diffraction (XRD) method with Bragg–Brentano geometry, using the Cu Kα radiation. Surface morphology and cross-sections were analyzed by means of scanning electron microscopy (SEM), using an LEO1455VP device equipped with an energy dispersive X-ray analyzer (EDX). The element composition was determined by the Rutherford backscattering analysis (RBS) of He ions with the energy of 6 MeV. Microhardness of samples was tested with a Vickers indenter under the load of 2 N.

3. Results and discussion

The action of CPF on the coating/steel system is accompanied by the following processes [3,4]: ablation of some part of coating; melting of a coating and bulk of a substrate; liquid phase mixing under plasma flow pressure; rapid cooling and crystallization of the modified layer. One can see that the CPF treatment of the coating/steel system results in the formation of a mixed layer with the thickness of ~10 μm (Fig. 1a). The alloying element is present in the mixed layer with almost constant concentration (Fig. 1b). Moreover, the CPF treatment with five pulses shows high homogeneity of alloying metal distribution both across the layer (Fig. 1a) and along the surface (Fig. 2).

The main quantitative characteristics of the surface alloyed layers, according to RBS and EDX, are listed in Table 1. The analysis of the results obtained showed that the penetration depth of alloying elements was significantly greater than the thickness of the preliminary coated layers. As a rule, when the effect of coating ablation is insignificant, the lowest coating thickness results in the lowest concentration of an alloying element in the mixed layer. In Ref. [4] the penetration depth of Ti was calculated according to the model of impurity diffusion in terms of temperature and pressure gradients. The acceleration of diffusion transport due to the liquid phase formation during melting was taken into account in the model. It was found that the penetration depth was ~4 μm. These calculations revealed the existence of additional factors causing the acceleration of diffusion. We suppose that an

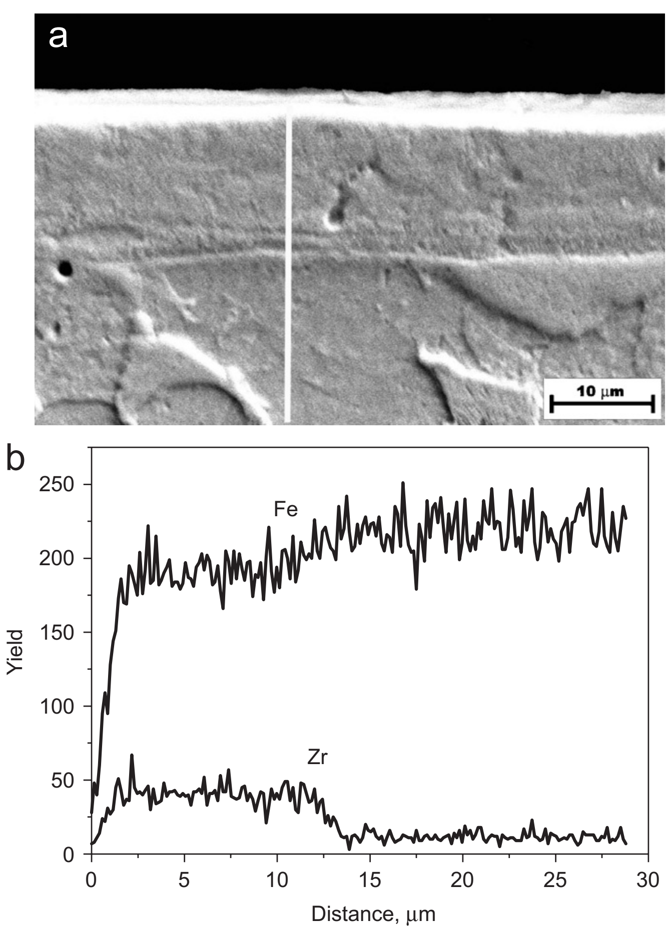

Fig. 1. Cross-section SEM morphology (a) and corresponding EDX elements profiles (b) measured along the line on the cross-section of the treated Zr/steel system.

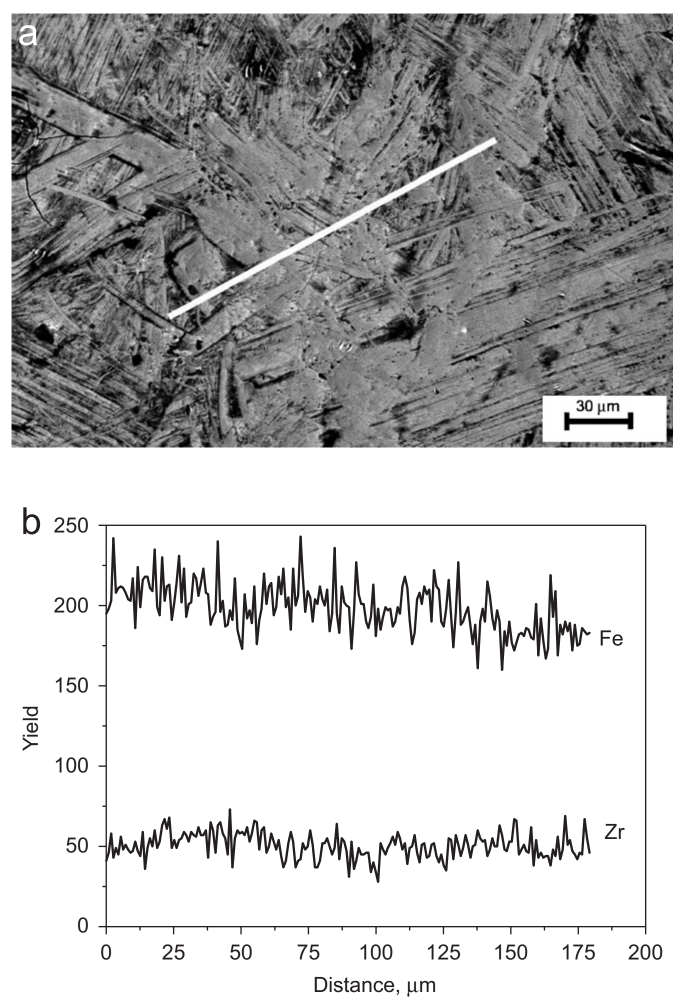

Fig. 2. Surface SEM morphology (a) and corresponding EDX elements distributions (b) measured along the line on the surface of the treated Zr/steel system.