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Anode plasma electrolytic boriding of medium carbon steel

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ABSTRACT

The influence of the regimes of the anode plasma electrolytic boriding (PEB) of medium carbon steel on its structure and properties was investigated. An X-ray diffractometer, a scanning electron microscopy (SEM) and an optical microscope were used to characterize the phase composition of the modified layer and its surface morphology. Surface roughness was studied with the use of a profilometer–profilograph. The hardness of the treated and untreated samples was measured using a microhardness tester. A pin-on-disc tribometer was occupied to evaluate friction coefficient and wear rate of the untreated and treated samples at lubricated conditions. It is established that the influence of the processing regime on the thickness of the modified layer is explained by the competition of the boron diffusion and oxidation of steel sample. The electrolyte composition (10% ammonium chloride, 5% boric acid) and processing mode (850–900 °C, 5 min) of medium carbon steels allowing one to obtain the hardened surface layer up to 0.11 mm with microhardness 1800 HV and with decrease in the roughness of 3 times are proposed. The anode PEB could decrease friction coefficient and increase wear resistance of the medium carbon steel.

1. Introduction

The plasma electrolytic saturation of metals and alloys with interstitial elements is easily combined with hardening by disconnecting voltage and cooling in the same electrolyte without reheating. In results, the processing time decreases to several minutes. A high heating rate of workpieces (up to 100°/s) because of small thickness of the vapour–gas envelope (VGE) allows avoiding the grain growth and the associated deterioration of the material properties.

Most publications associated with plasma electrolytic saturation of metals are devoted to the processes of nitriding, carburising and nitrocarburising. Moreover, there are also the promising results of studies of steel saturation with boron and other elements which provides higher hardness and other benefits. In this paper, the results of the anode PEB of medium carbon steel will be considered.

As a rule, the binary aqueous solutions serve for PEB. The first component provides a solution with a sufficiently high electrical conductivity for possible electrolyte boiling with VGE formation. The other components are the source of boron among which borax is most common. The borax based solution enables treatment of tool steel H13 [1–3], structural medium carbon [4,5] or low-carbon [5] steels, and commercial pure titanium [6]. Sodium hydroxide [1,4,5], ammonium sulfate [7], and calcium carbonate [2] are added to adjust the electrical conductivity of electrolyte. Borocarburising of low-carbon steel Q235 [8,9] or CP-Ti [10] can be implemented in the electrolyte containing borax with glycerol. Besides that, borocarburising of steel H13 is carried out in the solution of borax and carbamide [2]. The similar complex saturation of steel R6M5 is performed in the solution containing sodium thiosulfate, carbamide, borax, ammonium chloride and sodium carbonate [7]. Note also the boronitriding in the solution of borax and sodium nitrite [2]. Furthermore, potassium acetate with the addition of boron hydride [11], boric acid or ammonium borate [12] is recommended as components for electrical conductivity.

The high-speed PEB is shown to result in the formation of boride layer containing, as a rule, Fe_2B with steel 1020 hardness up to 1600 HV [5]. The high hardness of 1450 HV is obtained also at the borocarburising of steel Q235 [8] or 1800 HV at the boronitriding of the same steel [9]. The maximum hardness of 2100 HV is found after the boronitriding of steel H13 [2]. The borocarburising of steel Q235 leads to the decrease in the wear rate by a factor of 12 and boronitriding 20 times in comparison with the untreated samples.

It is established that boride layer thickness can be raised using pulse treatment at higher frequency that results in the increase in corrosion resistance of the steel H13 samples [3]. Bipolar processing allows one to obtain nanocrystals in the surface layer by means of the control of the voltage amplitude and duty cycles in the anode and cathode directions [10]. Electrochemical performance of the borided samples are improved; their corrosion potential is shifted to a positive direction compared with the untreated steel H13 [1].

The anode PEB of medium carbon steel (0.45 wt.%) in the solution of borax and sodium hydroxide results in the formation of the boride layer

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with microhardness of 450 HV while the friction coefficient and wear rate are decrease under condition of dry friction [4]. In parallel, the surface roughness is reduced due to anode dissolution. As well boric acid serves as boron source. The boron concentration in the surface layer of low-carbon steel reached 4 wt.% after saturation in the solution containing boric acid, ammonium chloride, carbamide, and sodium thiosulfate [13]. The modified layer with thickness of 35 μm and surface microhardness of 600 HV is obtained by saturation in this electrolyte at 800 °C during 5 min followed by quenching. The anode borocarburising in the solution of boric acid and carbamide provides higher hardness of 830 HV [14]. The rise of processing temperature contributes to penetration of iron oxide and decrease in microhardness.

The increase in carbamide concentration is found to promote the nitrocarburised layer growth due to the rise of the concentration of active nitrogen and carbon despite simultaneous growth of oxide layer that slows down carbon and nitrogen diffusion [15]. The boron diffusion may be accelerated by replacing carbamide by the component with lowered oxidizing ability.

The aim of this work is to investigate the anode boriding of medium carbon steel in a solution of boric acid and ammonium chloride to increase its wear resistance.

2. Materials and methods

The cylindrical samples (∅ 13 × 15 mm) of medium carbon steel (0.45% C) were PEB in a cylindrical working chamber with an axially symmetric electrolyte flow supplied through a nozzle located at the bottom of the chamber [15]. In the upper part of the chamber the

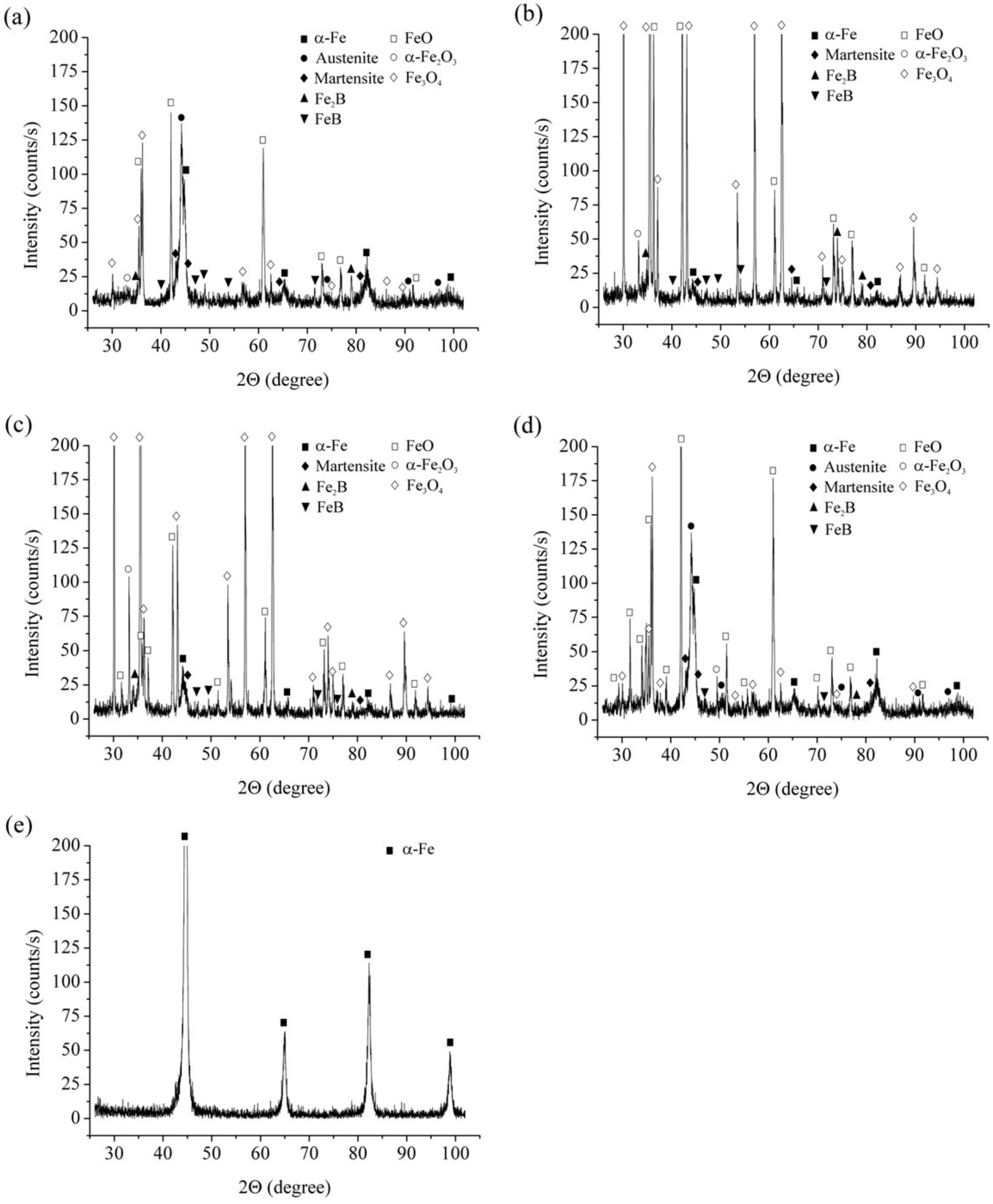

Fig. 1. X-ray diffraction patterns of surface layers after anode PEB at 800 °C (a), 850 °C (b), 900 °C (c), 950 °C (d), and before treatment (e).