Surface & Coatings Technology 276 (2015) 529–533

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Electrochemical and physical characteristics of the steel treated by plasma-electrolysis boronizing

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ARTICLE INFO

Article history:
Received 13 February 2014
Revised 1 June 2015
Accepted in revised form 11 June 2015
Available online 14 June 2015

Keywords:
Plasma-electrolysis
Boronizing
Corrosion resistance
Fe_2B
Borax

ABSTRACT

Boride layers have potential industrial applications as abrasive and corrosion-resistant materials due to their high hardness values and chemical characteristics. In this study, boride layers are formed on the surface of St 14 steel samples using the plasma electrolyte method. The process was performed for a holding time of 10 min at the preset temperature of around 900 °C. The microstructure, hardness, and corrosion resistance characteristics of the boride layer are investigated by X-ray diffraction, hardness indentations and Tafel polarization. XRD results showed that boride layers are detectable on the surface of steel when the borax content of the solution is above 20 wt.%. Moreover, there are no peaks of the boride phase in X-ray patterns when the borax content is below 20 wt.%. Corrosion resistance characterization showed that layer created in 25% borax provides the best corrosion resistance. Maximum hardness values of samples processed with 10, 15, 20 and 25 wt.% borax were 750, 915, 1100 and 1250 HV, respectively.

1. Introduction

Coating processes based on the plasma technique have been increasingly developed in recent decades [1]. Recently, a new technique known as plasma electrolysis has been added to these methods. In the plasma electrolysis method, the overall rate of the process, compared to the conventional processes, is extensively increased [2]. This increase is due to the presence of the particles and elements, that react with the surface, in the vicinity of the surface and because of the application of the high electrical field, in the level of 10^6 to 10^8 V/m [3], that accelerates them toward the surface. Hence, in plasma electrolysis, the rate of processes is higher than conventional processes. Deposition by plasma electrolysis processes was divided into two main categories by Yerokhin et al. [3] in their review paper: (a) Plasma electrolytic saturation (PES) and (b) plasma electrolytic oxidation (PEO). The diffusion of interstitial elements into the steel surface can be performed by plasma electrolytic saturation.

Boron atoms have relatively small size and high mobility; therefore, they can easily diffuse into ferrous alloys, forming FeB and Fe_2B intermetallics [4]. According to the boron–iron phase diagram, maximum amount of boron that can form a single-phase Fe_2B is 33.5 at.% [5]. Boron is one of the elements that can generate unique properties in the steel surface. The use of hard layer (such as boride) to improve surface properties is a method for protecting substrate from environmental effects. The boride layers have high hardness, low porosity, high corrosion resistance, and adhesive wear resistance [6].

The thermo-chemical boriding process of steel allows FeB and Fe_2B phases to be obtained. Generation of these layers can improve the surface hardness and wear resistance of equipments and components for tribological applications. By controlling the boron potential in the steel surface, both single-layer (only the Fe_2B phase) or multilayers (FeB–Fe_2B phases) can be produced [7]. The presence of the FeB phase in the layers leads to the brittleness of layers and high stress intensity at FeB–Fe_2B interface [8].

In plasma electrolysis saturation studies, the diffusion of nitrogen and carbon has been more attentively addressed [2,9–13]. Lower temperature is required for the diffusion of nitrogen compared to the diffusion of boron. Standard boriding temperature slightly differs from the carburizing temperature. The latter is 950–1050 °C using powders, 600–950 °C during electrolysis, 850–1000 °C in liquids, and 750–950 °C in gases. Therefore, temperature control of the plasma electrolysis for nitrocarburizing is easier. However, boron diffusion is performed at a temperature of about 900 °C; therefore, the adjustment of temperature is more complex. Due to complex circumstances of boronizing, very limited studies on boron diffusion using this technique has been reported [3,14,15]. Hence, various aspects of the plasma electrolysis process of the boronizing are unknown. The aim of this study was to investigate the feasibility of boron diffusion into the steel surface using an aqueous solution of borax. Moreover, the effects of plasma-process parameters on the physical and electrochemical characteristics of boride layer are explained.

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http://dx.doi.org/10.1016/j.surfcoat.2015.06.020

Table 1
Chemical composition of treated steel (wt.%).

C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	Fe
0.075	0.06	0.34	0.015	0.026	0.03	0.007	<0.005	0.002	<0.006	0.02	Balance

Table 2
Chemical composition of used tap water (mg/L).

Sodium	Potassium	Calcium	Magnesium	Iron	Chloride	Bicarbonate	Sulfate
191	9.3	332	10.4	0.17	199	120	NIL

2. Experimental procedures

2.1. Materials

The chemical composition of the St 14 steel used in this study is given in Table 1. As can be seen in this table, the selected steel contained low alloying elements so that the plasma electrolysis process could be examined without induced disturbance from alloying elements. The samples were cut from the above-mentioned steel in cylindrical shape with 10 mm (Ø) × 20 mm (h) dimensions. These samples were polished using 1200-grid emery paper to obtain a smooth surface. They were, then, cleaned in acetone using ultrasonic bath and dried. Corrosion tests were carried out at constant temperature, 30 °C, with tap water as the electrolyte and in equilibrium with the atmosphere. The chemical composition of the tap water used in this study is given in Table 2.

2.2. Plasma electrolysis procedure

In this research, the auxiliary electrode of stainless steel 316 had a cylindrical shape and the workpiece was placed in the center of the auxiliary electrode. Plasma electrolysis processes were carried out while the specimen was in the cathodic polarity. The schematic layout of the system cell used in this study is shown in Fig. 1.

The ratio of workpiece surface area to auxiliary electrode surface area was, approximately, one to sixty. Power source used in the investigation consisted of two transformers which were connected to a control system. This control system had the capability of producing the DC regime. Voltage and current monitoring was performed by a TNM-DS2006 oscilloscope that was connected to a laptop. Electrolyte composition, conductivity of electrolyte and applied voltage used in this study are listed in Table 3. Setting the temperature at 900 °C was conducted by changing the voltage. Due to higher electrical conductivity of concentrated borax solution (samples 3, 4), a lower voltage is required to reach 900 °C at the steel surface.

For temperature measurement, two K type temperature sensors were used. Temperature measurements in this study were performed according to the method proposed by Tyurin [16]. Plasma electrolysis processes were performed in 600 s and DC regime.

2.3. Characterization of the layers

The layers were analyzed by the TESCAN VEGA II Scanning Electron Microscope (SEM) and Philips 1480 X-ray diffraction. Corrosion resistance measurements were carried out at electrolyte tap water, using a 273A potentiostat PAR EG&G. Corrosion current densities were obtained from the polarization curves by linear extrapolation of the Tafel curves at 50 mV more positive and 50 mV more negative than Eoc to the open circuit value. The micro-hardness measurement of samples was carried out with a Shimadzu micro-hardness tester. 50 g load was applied for measuring the micro-hardness and the duration was 10 s.

3. Result and discussion

3.1. Composition of the boride layer

In the plasma electrolysis method, initially, vapor is formed near the electrode surface. This vapor contains ingredients of electrolytes. If the electrolyte contains borax, the vapor contains boron compounds. After each discharge, in the vapor envelope, boron-containing compounds can decompose to form active boron atoms. These atoms, in a strong electrical field, are concentrated in the gaseous envelope [17] and are accelerated toward the steel surface. Moreover, other boron compounds which have not been decomposed (under electrical discharge) reach the hot surface of the steel and can be decomposed to boron atoms.

If the condition of the steel surface temperature is appropriate for boron diffusion, boron can diffuse into the steel surface. Given that electrical discharge occurs randomly in different parts of the steel surface,

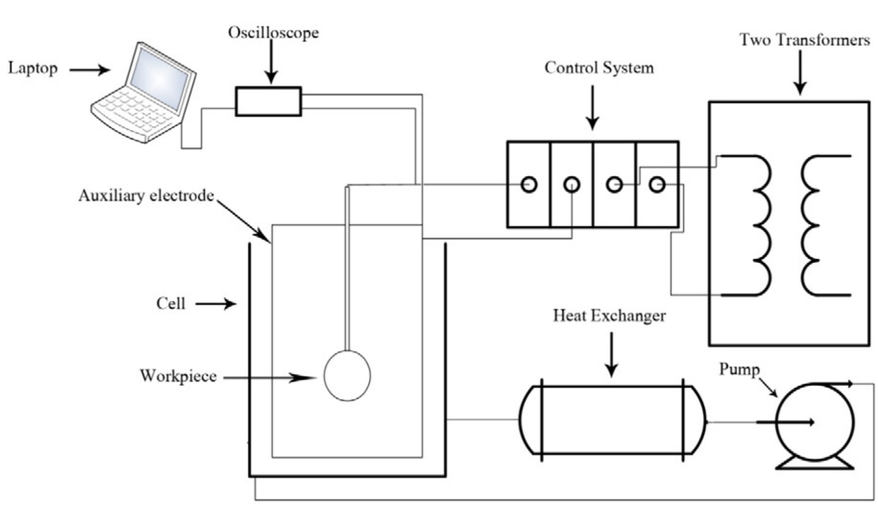

Fig. 1. The schematic layout of the cell used in this investigation.