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Preparation of Fe_2B boride coating on low-carbon steel surfaces and its evaluation of hardness and corrosion resistance

Jibo Jiang, Yi Wang, Qingdong Zhong *, Qiongyu Zhou, Lei Zhang

Shanghai Key Laboratory of Modern Metallurgy and Material Processing, Shanghai University, Shanghai, 200072, PR China

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ABSTRACT

Fe_2B coating was prepared on low-carbon steel by surface alloying. A series of experiments were carried out to examine some surface properties of boride coating. The surface heat treatment of coated low-carbon steel was performed at 700 °C, 800 °C and 900 °C for 2 h, 4 h, 6 h and 8 h under hydrogen atmosphere. The boride coating was revealed by XRD analysis and the microstructure of the boride coating was analyzed by scanning electron microscopy (SEM). Depending on the temperature and time of the process, the hardness of the borided low-carbon steel ranged from 99 to 1100 HV. The hardness showed a maximum (about 1100 HV) at 900 °C for 8 h. The corrosion resistance of the borided samples was evaluated by the Tafel polarization and electrochemical impedance spectroscopy (EIS). Shift in the corrosion potential (E_{corr}) towards the noble direction was observed, together with decrease in the corrosion current density (I_{corr}), increase in the charge transfer resistance (R_{ct}) and decrease in the capacitance (C_c), which indicated an improvement in corrosion resistance with increasing temperature and time of the treatment.

1. Introduction

There has been extensive research on the development of surface treatment processes to improve the hardness, corrosion resistance, thermal stability and wear resistance of steel [1–4]. The use of surface coatings opens up the possibility for material design to meet the demands of specific properties where they are the most needed. Recently, many new modified surface treatment processes, such as pulse gas tungsten arc treatment [7], plasma paste boronizing treatment and electron-beam boriding treatment [8,9], have been investigated since conventional boronizing processes [10,11] such as formal salt boronizing and gas boronizing have various problems such as environmental contamination, toxicity, explosive nature, etc.

Depending on the potential of the medium and the chemical composition of the base materials, single or duplex ($FeB+Fe_2B$) boride coatings may be formed. A single-type (Fe_2B) coating is generally desirable for industrial applications, owing to the difference between the specific volume and the coefficient of thermal expansion of the boride and the substrate [5,6].

The coatings on the substrate improve the performance of the cutting equipments which are used in industry. Because of the higher hardness of boride coatings, these coatings are the appropriate choices to increase the durability of the cutting tools. The use of hard coating to improve the corrosion resistance of boride-coated steels surface properties is a method for protecting substrate from corrosive environmental effects. The corrosion resistance properties of hard coating especially boride coating are studied less frequently than mechanical properties, though there are quite a few publications on the boride coating studies [12,13]. In these papers, the corrosion resistance properties of hard coatings have been studied only by current density-potential measurements. However, nowadays, electrochemical impedance spectroscopy method is becoming a powerful method for the corrosion resistance research.

In this study, an attempt is made to develop a more economical and simple process for surface modification of low-carbon steel. We adopt high-energy ball milling to produce the nano-hybrid particles (nano-sized FeB/Fe_2O_3) and apply to the surface treatment of low-carbon steel to develop the Fe_2B coating metallurgically bonded to the base material instead of the conventional boronizing process. Short processing time, flexibility in operation, low energy and material consumption are the major advantages of preparing Fe_2B coating using nano-particles on low-carbon steel over the conventional processes. The corrosion resistance of boride coating on the low-carbon steel with variable conditions was evaluated by Tafel polarization and electrochemical impedance spectroscopy (EIS).

2. Experimental

2.1. Preparation of the nano-sized particles and samples

For the preparation of the coating, FeB was used as the boron source and Fe_2O_3 as the activator. FeB and Fe_2O_3 were placed in an

* Corresponding author at: School of Materials Science and Engineering, Shanghai University, Shanghai 200072, PR China. Tel.: +86 13391312191.
E-mail address: haojue1016@yahoo.com.cn (Q. Zhong).

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Table 1
The composition of boriding powder with size in this study.

Composite particles size	FeB	Fe_2O_3	Impurities
			Si S P Ca C
100 nm_{max}	45.5 wt.%	55.5 wt.%	<0.1 wt.%

agate jar with absolute ethanol used as the dispersing agent and ball-milled for 24 h. Molar ratio of FeB:Fe_2O_3 was 2:1 and liquid:solid ratio was 80:15. The compositions of boriding powder with size in this study are given in Table 1.

The low-carbon steel (10×10×1.2 mm) was used as substrate, which was mechanically polished using 240 to 1200 grit papers in sequence. Then the samples were rinsed in acetone, ethanol and water for 5 min respectively by an ultrasonic cleaner in order to degrease and clean the surfaces to improve the adhesion of the coating. After the treatment, the surfaces of the substrates were sprayed with the nano-sized particles (nano-sized FeB containing Fe_2O_3) prepared above. The coatings were dried at room temperature, and then the heat treatment was carried out at temperatures of 700 °C, 800 °C, 900 °C and 2 h, 4 h, 6 h, and 8 h at each temperature under hydrogen atmosphere with the heating rate of 10 °C/min.

2.2. Characterization of the boride coating

After the heat treatment, the surface morphology and microstructure of boride coating were evaluated by scanning electron microscopy (SEM) using the JEOL JSM-6700F microscope. The composition of the coating was investigated by X-ray diffraction analysis (XDR) with a diffractometer D/max-2200 V and Cu Kα radiation. The surface hardness of boride coating was measured using a microhardness tester at an applied load of 100 N with a dwelling time of 15 s.

The corrosion behavior of the coating was studied using polarization techniques (Tafel) and electrochemical impedance spectroscopy (EIS) with an electrochemistry station (CHI660C). Tafel and EIS for the substrate and the borided low-carbon steel were performed in 3.5 wt.% NaCl solution with a conventional three-electrode cell. A saturated calomel reference electrode (SCE) and a platinum wire as counter-electrode were used in the tests. The surface area of the test coupons (as the working electrode) exposed to the electrolyte was 1 cm^2. The impedance data were obtained at the open circuit potential. When the corrosion potential remained stable, a sinusoidal AC signal of 5 mV (rms) amplitude at the open circuit potential (OCP) was applied to the electrode over the frequency which ranged from 10^{-2} Hz to 10^5 Hz. Each value was obtained as the mean value of five measurements in a logarithmic sweep of frequencies. Impedance fitting was performed using Gamry Echem Analyst software.

3. Results and discussion

3.1. Microstructure

The topography of boride coating at 700 °C for 8 h was shown in Fig. 1a. In this figure, the boride coating was uniform and crack-free. However, the coating bears bigger particles and looser packing particles, which cannot cling to substrate well. With further increase in temperature, the structure of the coating begins to change as the result of the gradual fusion of the surface particles (see Fig. 1b and c). This phenomenon was probably caused by the new Fe atoms generated by the hydrogen reduction of Fe_2O_3, which promoted the boride coating fusion with the low-carbon steel surfaces, and then improved the bonding with the substrate. The microstructure of using

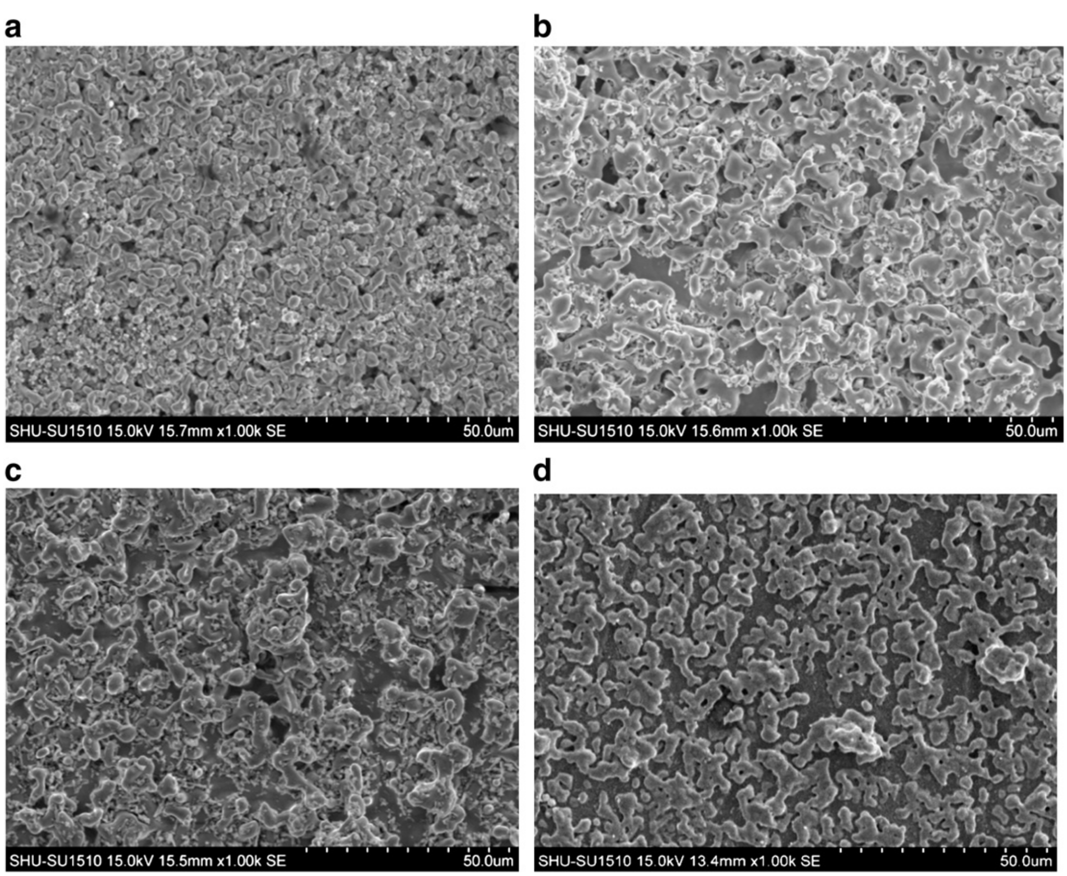

Fig. 1. SEM micrograph of the boride coatings under various temperatures: (a)700 °C, 8 h; (b) 800 °C, 8 h; (c) 900 °C, 8 h; (d) 900 °C, 8 h (FeB without Fe_2O_3).