Vacuum 136 (2017) 46–50

Contents lists available at ScienceDirect

Vacuum

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

The effect of sand blasting pretreatment on plasma nitriding

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ARTICLE INFO

Article history:
Received 24 August 2016
Received in revised form
25 October 2016
Accepted 10 November 2016
Available online 14 November 2016

Keywords:
Plasma nitriding
Sand blasting
Microstructure
Corrosion behavior
Tribological behavior

ABSTRACT

In this study, sand blasting was conducted as a pretreatment prior to plasma nitriding, and the effect of sand blasting on plasma nitriding was evaluated by means of scanning electron microscopy (SEM), optical microscopy, X-ray diffraction (XRD), electrochemical polarization and pin-on-disk tribotester etc. The results showed that sand blasting could enhance the nitriding efficiency and bring about much thicker nitrided layer than that of the nitrided-only sample under the same plasma nitriding condition, and the higher nitriding efficiency could be ascribed to the higher surface free energy (SFE). Electrochemical measurements showed that the sand-blasted sample increased the corrosion potential by approximately 100 mV and a reduced the corrosion current by an order of magnitude in comparison with the nitrided-only sample. Meanwhile, the cross-sectional hardness and wear resistance were significantly improved, which could be attributed to the thicker compound layer with higher amount of ε-$Fe_{2-3}N$ comparing with the nitrided-only sample.

1. Introduction

The surface properties of materials such as hardness, wear and corrosion resistance play an important role in the service life of most components, which brings out wide applications of surface modification, and also promotes the continuous development of novel surface modification methods [1,2]. Plasma nitriding (PN) has been proven to be one of the most effective methods to improve surface hardness and wear resistance of most metal materials [3,4]. However, conventional PN process generally takes dozens of hours or even longer duration in real applications, which results in its obvious shortcoming of energy consuming and low efficiency [5–7].

Sand blasting (SB) is a surface treatment by using sand particles continuously blasting on the surface of metal workpiece at a high speed, thus plastic deformation is produced in the surface layer [8]. Therefore, SB can be used to activate and strengthen the surface of metals [9,10]. It was reported that SB could enhance wear resistance and fatigue strength of some metals due to the compressive stress and increased dislocation density induced by plastic deformation in the surface layer [11]. However, few reports can be found about the effect of SB as a pretreatment on PN for AISI 1045 steel.

Therefore, the goal of this research is to systematically investigate the effect of SB on the efficiency of PN and the combined performance of treated AISI 1045 steel, and to discuss the related enhancement mechanism as well.

2. Experimental procedures

The material used in this research was AISI 1045 steel with the following chemical compositions (wt. %): C: 0.45, Si: 0.18, Mn: 0.52, S: 0.031, P: 0.032 and Fe: balance. The specimens were machined to the size of 10 mm × 10 mm × 5 mm, heated at 1123 K for 8 min prior to quenching in water, and then tempered at 853 K for 30 min. All the surfaces of specimens were treated by silicon carbide emery papers of different granulometries to achieve a fine finish, and ultrasonically cleaned in dehydrated ethanol for 10–15 min before SB.

SB treatment was carried out by an industrial SB equipment. The specimens were subjected blasting by Al_2O_3 particles with 0.35 mm diameter at velocity of 5 m/s, and holding time of 5, 15 or 30 min during SB process. The pressure of the compressed air was about 300 Pa.

After SB, specimens were cleaned in anhydrous ethanol for 15 min to remove surface contaminates. Then the specimens were

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http://dx.doi.org/10.1016/j.vacuum.2016.11.019
0042-207X/

placed into PN equipment (LD-8CL, 20 kW), and evacuated to 10 Pa by a rotary pump. All specimens were sputtered for 30 min by hydrogen with a flow of 500 mL/min at a pressure of 300 Pa. After sputtering process, PN was subsequently conducted at 783 K for 4 h at a hydrogen flow of 600 mL/min, nitrogen flow of 200 mL/min, and gas pressure of 400 Pa. After PN process, the nitriding furnace was pumped to 10 Pa and cooled to ambient temperature.

The cross section of specimens were metallographically polished and chemically etched in 4% nitric acid for examinations. The surface morphologies and cross sectional microstructures of samples were observed by scanning electron microscopy (SEM) and optical microscopy, respectively. The phases constituents of the samples were determined by X-ray diffraction (XRD) with Cu-Kα ($\lambda = 1.54056$ Å) radiation with scan rate of 0.2°/min, 2θ ranging from 40° to 50°. Corrosion behavior was evaluated by the potentiodynamic polarization curves in 3.5% NaCl aerated solution using ZAHNER IM6e electrochemical workstations. The scanning potential was in the scope of −1500 mV to 500 mV, and the potential scan rate was 1 mV/s after a delay period of 2000 s. At least three tests were carried out for each condition for assessing the reproducibility. A HT-1000 ball-on-disk high-temperature friction and wear tester was used to evaluate tribological properties of specimens at dry sliding with 50 N load and 200 rpm rotating rate against GCr15 ball with a diameter of 4 mm for durations of 5 min. The wear tests were performed at room temperature (~20 °C) with a relative humidity of approximately 50%.

The contact angles between the liquid drop (distilled water and formamide) and the examined surface were measured by a JC2000D1 system at ambient temperature to calculate the surface free energy (SFE) of the sand-blasted surface. Drops with a volume of 20 mm^3 were put on the specimens' surface with a micropipette. At least three times were put on each specimen and the contact angles were measured for each sample on two sides of the drops. And finally the value of SFE was calculated by Eqs. (1)–(3).

3. Results and discussions

3.1. Surface morphology and cross-sectional microstructure

The surface morphologies and the cross-sectional microstructure of samples nitrided at 783 K for 4 h with and without SB are shown in Fig. 1. It can be seen that some bigger-size particles appear un-uniformly on the surface of the specimen without SB, while numerous granular microparticles exist on the surface of the specimen with SB. Meanwhile, it also can be clearly seen that the SB has significant enhancement effect on compound layer forming. The compound layer thickness of 16.9 μm is obtained, which is much thicker than that of 10.0 μm obtained via PN only.

3.2. Contact angle

The measured contact angles between the liquid drop and the examined surface, and the calculated SFE of the examined surface are shown in Table 1. It can be seen that SB can supply the smaller contact angles between the liquid drop and the examined surface. It was reported that the contact angle measurement is used to evaluate the surface free energy (SFE) of the treated surface, and can be calculated by the following equation [12]:

$$\gamma_s = \gamma_s^p + \gamma_s^d \tag{1}$$

where γ_s, γ_s^p and γ_s^d represent the SFE, the polar and the dispersive component of SFE. γ_s^p and γ_s^d can be calculated by the Owens–Wendt method [13,14]:

$$\left(\gamma_s^d\right)^{1/2} = \frac{\gamma_w\sqrt{\gamma_f^p/\gamma_w^p}(\cos\theta w + 1)}{2\left(\sqrt{\gamma_f^p} - \sqrt{\gamma_f^p\gamma_w^d/\gamma_w^p}\right)} \tag{2}$$

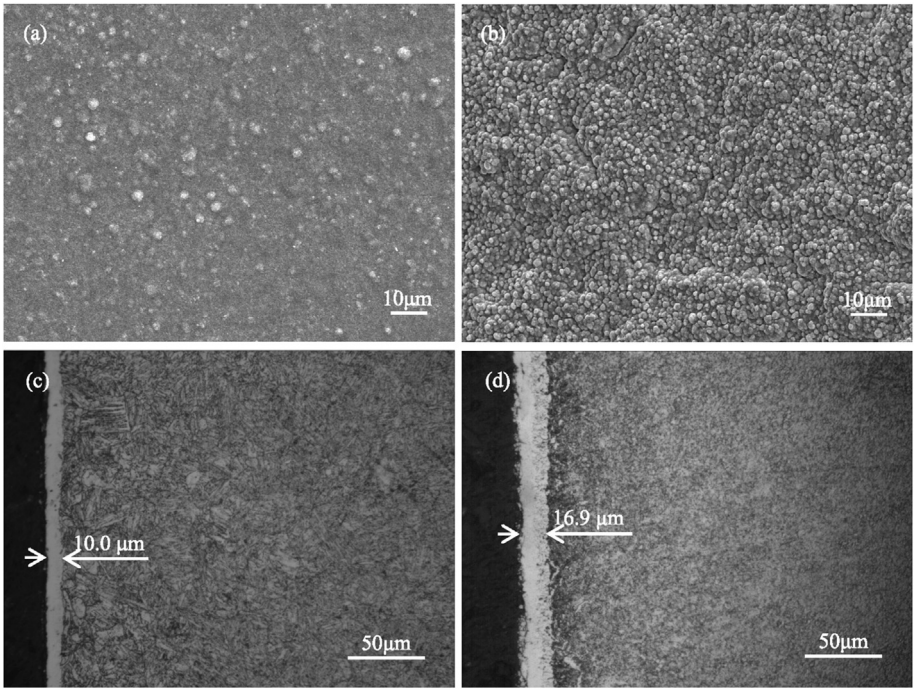

Fig. 1. Surface morphologies and cross-sectional microstructure of samples nitrided at 783 K for 4 h (a) and (c) PN only; (b) and (d) SB 15 min + PN.