Vacuum 109 (2014) 144–147

Contents lists available at ScienceDirect

Vacuum

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

Rapid communication

A novel rapid D.C. salt bath nitrocarburizing technology

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ARTICLE INFO

Article history:
Received 19 May 2014
Received in revised form
24 June 2014
Accepted 5 July 2014
Available online 17 July 2014

Keywords:
Salt bath nitrocarburizing
D. C. electric field
Mechanism
Microstructure
Surface

ABSTRACT

A novel rapid salt bath nitrocarburizing technology was primarily developed by additionally applying direct current (D. C.) electric field on the basis of traditional technique (NM). The results showed that D. C. electric field could significantly enhance the nitrocarburizing efficiency, shorten the holding time and decrease the treating temperature comparing with the NM. To get a composite layer thickness of 18 μm at treating temperature of 575 °C, the holding time was shortened from 100 min in NM to less than a half by additionally applying 7.5 V D.C., and the thickness was increased from 18.0 μm up to 29 μm at the same holding duration of 100 min. And it was found that the enhancement effect was closely related to the voltage of D. C. electric field, voltage higher than 3 V was necessary to get obvious enhancement effect. The main enhancement mechanism was analyzed as well.

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QPQ is a kind of valuable surface modification technology widely used for steels to improve their surface combined properties; its essence is low temperature salt bath nitrocarburizing + short time salt bath oxidation [1–5]. A protective coating can be formed on the surface of components in QPQ process, which can improve its wear resistance, and especially the corrosion resistance [6–8]. Therefore, it is gradually used to replace plasma nitriding, soft nitriding and hard chromium plating in many applications.

In order to obtain the required depth of composite layer, several hours is normally taken for salt bath nitrocarburizing, which is the crucial and time consuming step in the QPQ process [9]. Therefore, it is of significant value to improve its efficiency and thus shorten the treating time [10]. Base on the enhancement effect of D. C. electric field on powder-pack thermo-chemical treatment [11], the aim of this research is to develop a novel rapid salt bath nitrocarburizing technology enhanced by D. C. electric field. The results showed that D. C. electric field could significantly enhance salt bath nitrocarburizing process, and the enhancement mechanism was analyzed as well.

Samples from the same batch of 35 steel source (0.36C, 0.3Si, 0.72Mn, 0.23Cr, 0.21Ni, 0.24Cu, 0.022S, 0.023P, balance Fe (wt.%)) were used in this research. The specimens were machined into a size of 10 mm × 10 mm × 10 mm, followed by quenching at 840 °C and tempering at 580 °C to get a substrate with uniform microstructure. Then the mechanically polished specimens were treated with emery papers of different granulometry to achieve a fine finish. Finally, the specimens were ultrasonically cleaned in anhydrous ethanol and dried before salt bath nitrocarburizing treatment.

Schematic diagram of the experimental apparatus is shown in Fig. 1a. In this process, two electrodes with a distance of 10 mm were put into the salt bath in a crucible placing in a vertical pit furnace, and the specimen was cathode. And then, D. C. electric field was applied between the two electrodes and held for a designed duration time when the pit furnace was heated to the determined temperature (575 °C here) to conduct the D.C. salt bath nitrocarburizing test. The process parameters are shown in Table 1.

AXUG-05 optical microscopy was employed for observing the cross sectional microstructure and the phases constituents were determined by X-ray diffraction (XRD) with Cu-Kα ($\lambda = 1.54$ Å) radiation.

The typical cross sectional microstructures of 35 steel after salt bath nitrocarburizing are shown in Fig. 2, and the statistic data of the thickness of composite layer, also called white layer under different treating conditions are indicated in Table 1. We can see that D. C. electric field has a significant enhancement effect on salt bath nitrocarburizing process. By additionally applying D. C. electric field, even a little thicker white layer is obtained at only half time of

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http://dx.doi.org/10.1016/j.vacuum.2014.07.016
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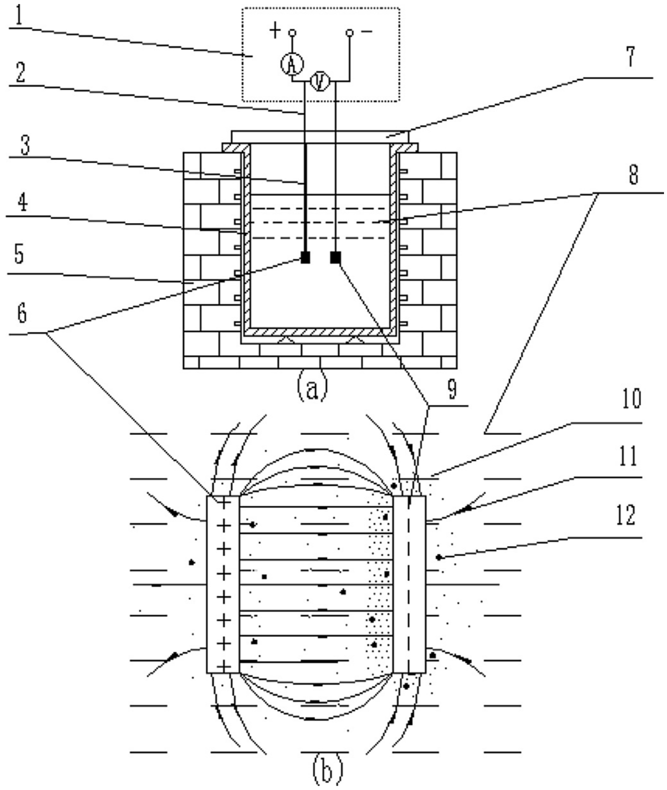

Fig. 1. Schematic of the experimental apparatus and enhancement mechanism assisted by D. C. electric field in salt bath nitrocarburizing technology. 1 – voltage-controller, 2 – conducting line, 3 – ceramic pipes, 4 – crucible, 5 – pit furnace, 6 – anode, 7 – lid, 8 – salt bath, 9 – specimen as cathode, 10 – active nitrogen atoms, 11 – electric field lines, 12 – active carbon atoms. (a) Experimental apparatus; (b) Enhancement mechanism.

that in NM process at the same heating temperature as shown in Table 1 (D.C.1 and NM2), Fig. 2(a) and (b), and the thickness of white layer is increased more than 60%, from 18.0 μm in NM process up to 29 μm assisted by D. C. electric field at the same treating temperature of 575 °C and holding duration of 100 min as shown in Fig. 2(b) and (c). The white layer thickness of 31.1 μm can be achieved at 575 °C for 120 min as shown in Fig. 2(d). Therefore, it can be concluded that D. C. electric field can significantly enhance the efficiency of salt bath nitrocarburizing, and thus effectively shorten the holding duration or decrease the heating temperature to get the required thickness of white layer.

Fig. 3 shows the relationship between the depth of white layer and the voltage of D. C. electric field at 575 °C for 120 min. It clearly presents that the depth of white layer increases with the increasing voltage of D. C. electric field and it increases very slowly when the voltage is lower than 3 V, while increasing significantly when the voltage exceeds 3 V, which indicates that the enhancement effect is closely related to the voltage of D. C. electric field. Therefore, in order to get a significant enhancement effect on the efficiency of salt bath nitrocarburizing, applying appropriate voltage of D. C. electric field is necessary.

Fig. 4 presents XRD patterns of 35 steel samples treated at the same temperature of 575 °C and the same duration of 50 min with and without additional D. C. electric field. It clearly shows that the typical characteristic peaks formed during nitrocarburizing process are the same for both samples treated with and without additional D. C. electric field, which are mainly composed of ε-Fe_3 (N, C) and a little γ'-Fe_4N, while their diffraction intensities of the D. C. assisted sample are getting stronger and the characteristic peaks of α-Fe disappeared due to the thicker white layer [12], as shown in Fig. 4(b). The result can also confirm that the depth of white layer formed in D. C. assisted process is much thicker than that in NM, which is in good agreement with the data shown in Table 1 and Fig. 2.

The thickness of white layer with additional D. C. electric field is much thicker than that formed in NM process when the other conditions are the same as shown in Table 1 and Fig. 2, which clearly illustrates that D. C. electric field has a significant enhancement effect on the efficiency of salt bath nitrocarburizing. The schematic D. C. enhancement mechanism in salt bath nitrocarburizing is shown in Fig. 1b, firstly, D. C. electric field can promote the following chemical reactions and thus increase the concentration of active nitrogen and carbon atoms in the salt bath,

$$4CNO^- \rightarrow CO_3^{2-} + 2CN^- + CO + 2[N] \tag{1}$$

$$4CNO^- + 3O_2 \rightarrow 2CO_2 + 2CO_3^{2-} + 4[N] \tag{2}$$

$$2CO \rightarrow CO_2 + [C] \tag{3}$$

More importantly, the active nitrogen and carbon atoms can be positively charged by D. C. electric field, thus they are forced to diffuse directionally toward the surface of the specimen at cathode. The directional diffusion rate is obviously faster than that in random and it can also reduce the absorption of the inner wall of the crucible and the non-working surface of component. Therefore, the concentrations of the active atoms around the surface of the specimen (cathode) can be much higher than that at any other positions, and the efficiency of the active atoms in the salt bath is significantly improved, hence promoting the formation of white layer and resulting in thicker depth. The schematic enhancement mechanism assisted by D. C. electric field shown in Fig. 1b clearly indicates the nonuniform distribution of the active atoms in the salt bath, especially of much higher concentrations around the facing anode surface of the specimen due to the promoted chemical reactions and directional diffusion to cathode assisted by D. C. electric field.

In conclusion, a novel rapid salt bath nitrocarburizing technology assisted by additional D. C. electric field was developed primarily. It was found that D. C. electric field could effectively shorten the holding time or decrease the treating temperature to obtain the same thickness of white layer comparing with NM process; and the enhancement effect was closely related to the D. C. voltage, which could significantly accelerate the process when

Table 1
Process parameters and corresponding thickness of white layer.

Process	D.C.1	D.C.2	D.C.3	D.C.4	D.C.5	D.C.6	D.C.7	NM1	NM2	NM3
Nitrocarburizing Time/min	50	100	120	120	120	120	120	50	100	120
D.C. Voltage Intensity/V	7.5	7.5	7.5	6	4.5	3	1.5	–	–	–
Thickness of white layer/μm	18.4	29	31.1	29.7	25.7	22.9	22	9.8	18	21.7

D.C. represents processes with additional D. C. electric field; NM represents traditional processes.

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