Influence of the magnetic field at ion nitriding in glow discharge on probe characteristics, microhardness and structure of 08H18N10T (AISI 321) steel

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Abstract. The study is devoted to the influence of the magnetic field on ion nitriding of stainless steel of austenite class – 08H18N10T (AISI 321). The experimental volt-ampere characteristics (VAC) of the glow discharge were obtained under the influence of crossed electric and magnetic fields (CEMF), plasma parameters were calculated. The microhardness measurements made it possible to establish that the surface hardness increases 1.5 times when nitriding with CEMF in comparison with that without CEMF, while the hardened layer thickness increases 1.5 times.

1. Introduction

Ion nitriding is efficient and widely used technology that improves mechanical and performance properties of various structural materials [1, 2]. In recent years, many scientists have studied low temperature nitriding of austenitic stainless steel, and hence, this technology was quickly adopted by the industry. This is due to the fact that low temperature nitriding of austenitic steel leads to the formation of the S-phase. Austenitic steel with such structure is not only characterized by high surface hardness and wear resistance but also by considerable corrosion resistance [3, 4].

However, low temperature ion nitriding is a long process, which reduces its overall efficiency. Therefore, the intensification of ion nitriding seems a relevant task. One of such methods is the use of the system of crossed electric and magnetic fields that considerably increases the energy of particles affecting the working surface. This considerably increases the diffusion coating of a steel surface with nitrogen [5, 6]. The magnetic field keeps electrons in the cathode region thus causing additional ionization acts and hence, increases the generation of charged particles thereby increasing the ion current density. Probe measurements make it possible to assess the changes of plasma characteristics when applying the magnetic field. Probe measurements also result in the calculation of volt-ampere characteristics and the necessary parameters of the discharge [7–9].

The study is devoted to the influence of the magnetic field at ion nitriding in glow discharge on probe characteristics, microhardness and structure of 08H18N10T steel.

2. Methodology

The 08H18N10T (AISI 321) steel samples (table 1) were used in the experiment, which were pre-treated through surface plastic deformation via diamond smoothing (SPDDS).
Table 1. Chemical composition of AISI 321 (wt. %).

|   | C    | Si   | Mn   | Ni  | Cr  | Cu   | Fe  | S   | P   |
|---|------|------|------|-----|-----|------|-----|-----|-----|
| max | 0.08 | max 0.8 | max 0.2 | 9–11 | 17–19 | max 0.3 | ~ 65 | max 0.02 | max 0.035 |

An electron-beam facility modernized for conducting chemical-thermal treatment in a glow discharge plasma (figure 1) was used for the experiment. Glow discharge combustion was supported by the ApEl M 5PDC power source.

![Figure 1](image.png)

Figure 1. Scheme of the experiment: 1 – power supply ApEl M 5PDC; 2 – cathode; 3 – neodymium magnets; 4 – anode; 5 – vacuum chamber; 6 – toroidal domain of bright glow; 7 – magnetic field; 8 – substrate; 9, 10 – samples.

Table 2. Conditions IN (ion nitriding) in the GD (glow discharge).

| №  | T (°C) | U (V) | P (Pa) | t (h) |
|----|--------|-------|--------|-------|
| 1  | 300    | 310   | 50     | 6     |
| 2  | 350    | 385   | 50     | 6     |
| 3  | 400    | 310   | 50     | 6     |
| 4  | 450    | 440   | 50     | 6     |
| 5  | 500    | 500   | 50     | 6     |
| 6  | 550    | 590   | 50     | 6     |

Before starting IN in GD in the vacuum chamber, ionic cleaning of the sample surface was performed for 15 min. in argon medium. Ion nitriding was carried out in a gas mixture of argon, nitrogen and hydrogen (50% Ar + 35% N₂ + 15% H₂). The gas flow rate was controlled by the RRG BU1P 3 control unit. The working gas pressure was constant and was \( P = 50 \) Pa (table 2). Monitoring the maintenance of a given temperature was carried out using an optical thermometer Thermix. The microhardness of the surface layer of nitrated samples was studied on slanting thin sections using a Struers Duramin-2 hardness meter. Optical images of the microstructure were obtained using an Olympus GX51 optical microscope.

3. Results and discussion

Micrographical investigation was conducted by optical metallography of 08H18N10T steel samples to study the influence of the magnetic field at ion nitriding in glow discharge on the structure of stainless steel (figures 2–8).
Figure 2. Microstructure of 08X18H10T steel samples after ion nitriding in the magnetic field at 500°C in 50% Ar+35% N₂+15% H₂ at 50 Pa during 6 hours: a – sample with initial structure; b – sample with structure after SPD DS.

The sample with initial structure (figure 2a) mainly consists of austenite, while the structure of a sample shown in figure 2b has three zones: upper –zone with ultra-fine grain structure formed after SPD DS; transition – dark diffusive zone consisting of the S-phase (nitrogen supersaturated austenite); bottom –base material (figure 7b).

The formation of a transition dark diffusive zone is caused by grain refinement and deformation of steel surface structure after pre-treated SPD DS, which increases the diffusion of the saturating element [14] along grain boundaries thus allowing nitrogen to impregnate and distribute deep into the treated sample.

Figure 3. Microstructure of 08X18H10T steel samples after ion nitriding in the magnetic field at 300°C in 50% Ar+35% N₂+15% H₂ at 50 Pa during 6 hours: a – without magnetic field; b – with magnetic field.
Figure 4. Microstructure of 08X18H10T steel samples after ion nitriding in the magnetic field at 350°C in 50% Ar+35% N₂+15% H₂ at 50 Pa during 6 hours: a – without magnetic field; b – with magnetic field.

Figure 5. Microstructure of 08X18H10T steel samples after ion nitriding in the magnetic field at 400°C in 50% Ar+35% N₂+15% H₂ at 50 Pa during 6 hours: a – without magnetic field; b – with magnetic field.

Figure 6. Microstructure of 08X18H10T steel samples after ion nitriding in the magnetic field at 450°C in 50% Ar+35% N₂+15% H₂ at 50 Pa during 6 hours: a – without magnetic field; b – with magnetic field.
Figure 7. Microstructure of 08X18H10T steel samples after ion nitriding in the magnetic field at 500°C in 50% Ar+35% N₂+15% H₂ at 50 Pa during 6 hours: a – without magnetic field; b – with magnetic field.

Figure 8. Microstructure of 08X18H10T steel samples after ion nitriding in the magnetic field at 550°C in 50% Ar+35% N₂+15% H₂ at 50 Pa during 6 hours: a – without magnetic field; b – with magnetic field.

Figure 9. Dependence of hardened layer thickness on ion nitriding temperature of 08X18H10T steel samples in glow discharge at 50 Pa in 50% Ar+35% N₂+15% H₂ during 6 hours: a – with magnetic field; b – without magnetic field.
Besides, it is established that the use of the magnetic field at ion nitriding twice increases the hardened layer thickness in comparison with standard nitriding (figures 3–8). This is caused by the fact that by localizing high-density nitrogen plasma the magnetic field increases the concentration of the diffusing element of processed samples as such.

Consequently, high gradient of nitrogen concentration is formed, which allows nitrogen to diffuse more deeply in a material thus increasing its surface hardness by 1.5 times (figure 9). Moreover, the figures show that the transition from the dark diffusive zone to the base material zone is similar in both cases, i.e. at ion nitriding without magnetic field (figures 3a–8a) and at ion nitriding with magnetic field (figures 3b–8b).

4. Conclusions

- The study showed that the use of the magnetic field at ion nitriding intensifies the process in comparison with standard ion nitriding due to increased concentration of the diffusing element in the cathode region, which forms high gradient of nitrogen concentration and as a result increases the surface hardness by 1.5 times and the hardened layer thickness by up to 2 times;
- It is found that the use of surface plastic deformation via diamond smoothing before ion nitriding in glow discharge with magnetic field increases the diffusion of the saturating element on grain boundaries thus allowing nitrogen to impregnate and distribute deep into the treated 08H18N10T steel sample.

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