Influence of the magnetic field at ion nitriding in the glow-discharge on the microhardness of steel AISI 321

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Abstract. The influence of the magnetic field on the microhardness and thickness of the diffusion layer of AISI 321 steel is studied. The effect of preliminary mechanical treatment on the diffusion of nitrogen during ion nitriding in the glow-discharge is studied. The microhardness distribution curves by depth are obtained at various temperatures. It has been established that the use of a magnetic field during nitriding leads to an increase in the microhardness of 1.5...2 times and 1.5 times the thickness of the diffusion layer. Application of plastic deformation prior before ion nitriding in the glow-discharge increases the diffusion of nitrogen deep into the processed material, due to the formation of a deformed structure.

1. Introduction

State of new technological processes of the chemical heat treatment (CHT) of metals have to be high performance, resource-saving, low-waste, pollution-free and manageable [1]. Ion nitriding is a technological process that fully meets these criteria.

Ion nitriding is a well-known process widely used on many responsible details and tools, mainly for increasing their longevity and reliability. Whereby on processed details increasing durability, hardness, wear resistance, score-resistance, resistance to fatigue and corrosion, as also high-temperature strength at through saturation [1].

Ion nitriding has the following technological capabilities [1]: high-rate of diffusion; a possibility of receiving the nitrided layer of the given structure and phase composition; preservation of high surface finish; decrease in a brittleness of the nitrided layer; decrease of deformation of products in processing; environmental friendliness and universality of process.

The use of magnetic fields (MF) during ion nitriding in the glow-discharge (IN in the GD) increases the efficiency of ionization of the gas and increases the plasma density in comparison with non-magnetic devices [2, 3]. A characteristic property of such treatment is intensification of the process due to magnetic confinement of electrons in a processing zone, which in turn increases number of ionizing events.

Many works have been published on the effect of preliminary plastic deformation on the diffusion of a saturating element into a metal. The defects of structure caused by plastic deformation promote active diffusion of the saturating element deep into the metal [4-6].

The purpose is the research of influence of magnetic field on microhardness and thickness of the diffusion layer of steel AISI 321 after IN in the GD, depending on the premachining.
2. Methodology
For carrying out an experiment were used samples from steel AISI 321 (table 1). This steel is one of the most common and used grades of high-alloy stainless steels.

Table 1. Chemical composition 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 |

A half of the samples studied (6 pcs.) had a plastic deformed structure (PDS), and the other half (6 pcs.) – undeformed structure (UDS).

The experiment were performed on a modernized electron-beam installation ELU-5M (figure 1). For power the discharge, we used a pulsed power supply ApEl M 5PDC, from the display of which the discharge current and the potential difference were monitored. The samples were placed in a magnetic field (MF) in such a way that part of each of the samples got to a scope of a MF, and the other did not.

![Figure 1](image-url)

**Figure 1.** Scheme of the experiment on the installation of ELU-5M: 1 – power supply; 2 – cathode; 3 – neodymium magnets; 4 – anode; 5 – vacuum chamber; 6 – toroidal domain of bright glow; 7 – magnetic field lines; 8 – substrate; 9 – sample with UDS; 10 – sample with PDS.

Table 2. Conditions IN in the GD.

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

Before the IN in the GD were performed in a vacuum chamber the ion superficial cleaning of samples within 15 min. in an argon atmosphere. The ion nitriding were carried out in a gas mixture
from argon, nitrogen and hydrogen (50% Ar + 35% N2 + 15% H2). The gas flow rate was controlled by the control unit RRG BUIP 3. The pressure of the working gas was constant and was $P = 50$ Pa (table 2). Monitoring of the maintenance of the setpoint temperature was carried out by means of optical pyrometer Termiks.

Investigation of the microhardness of the surface layer of nitrided samples was carried out on oblique sections using a Struers Duramin-2 hardness gage. Optical photos of prints were obtained by means of optical microscope Olympus GX51.

3. Results and discussion

To establish the influence of the presence of a magnetic field (MF) on ion nitriding in the glow-discharge (IN in the GD) an experiment were conducted at various temperatures of nitriding (table 2), after which measurements of a microhardness of the nitrided samples on angle lap were performed, results of measurement are presented in tables 3 and 4. Optical photographs of prints are shown in figure 2 and 3.

| Table 3. The results of measuring the microhardness of samples with PDS. |
| $T$, °C | $T_h$, °C | Initial microhardness, HV100 | The maximum microhardness of the samples after nitriding, HV100 inside the magnetic field (MF) | outside the magnetic field (MF) | The thickness of the diffusion layer after nitriding, µm inside the MF | outside the MF |
|---------|-----------|-----------------------------|-------------------------------------------------|-----------------------------|-----------------------------|-----------------------------|
| 300     | 300       | 600                         | 871                                             | 689                         | 45                         | 12                         |
| 350     | 350       | 600                         | 950                                             | 732                         | 50                         | 8                          |
| 400     | 400       | 600                         | 910                                             | 774                         | 55                         | 32                         |
| 450     | 450       | 600                         | 753                                             | 637                         | 20                         | 8                          |
| 500     | 500       |                             | 1225                                            | 924                         | 45                         | 25                         |
| 550     | 550       |                             | 1445                                            | 759                         | 32                         | 12                         |

| Table 4. The results of measuring the microhardness of samples with UDS. |
| $T$, °C | $T_h$, °C | Initial microhardness, HV100 | The maximum microhardness of the samples after nitriding, HV100 inside the magnetic field (MF) | outside the magnetic field (MF) | The thickness of the diffusion layer after nitriding, µm inside the MF | outside the MF |
|---------|-----------|-----------------------------|-------------------------------------------------|-----------------------------|-----------------------------|-----------------------------|
| 300     | 300       | 600                         | 253                                             | 250                         | 16                         | 10                         |
| 350     | 350       |                             | 216                                             | 216                         | –                          | –                          |
| 400     | 400       |                             | 210                                             | 210                         | –                          | –                          |
| 450     | 450       |                             | 251                                             | 251                         | 8                          | 8                          |
| 500     | 500       |                             | 425                                             | 396                         | 16                         | 15                         |
| 550     | 550       |                             | 581                                             | 212                         | 17                         | –                          |
Figure 2. Optical photographs of microhardness measurements of samples with PDS, nitrided at (a) 300°C, (b) 350°C, (c) 400°C, (d) 450°C, (e) 500°C and (f) 550°C.

Figure 3. Optical photographs of microhardness measurements of samples with UDS, nitrided at (a) 500°C, (b) 550°C.

An analysis of the microhardness measurements of the samples with the PDS showed that a 1.5-fold increase in the thickness of the diffusion layer occurs in the zone of action of the MF. It is caused by increase in density of ion current, due to deduction by MF of electrons in a processing zone, which in turn increase number of acts of ionization. Also, the presence of a MF significantly increases the energy of the particles, thereby increasing the temperature in a processing zone.

The analysis of the microhardness measurements of the samples with the UDS showed no changes, except for those samples that were nitrided at high temperatures. Such a difference in the results obtained of the measurement of samples with PDS and UDS it is connected to their initial structure prior to nitriding. Samples with PDS were subjected to plastic deformation of the structure, this contributed to an increase in the rate of diffusion of nitrogen deep into the material.
Graphs of microhardness distribution by depth are shown in figure 4.

![Graph of microhardness distribution](image)

**Figure 4.** Distribution of microhardness by depth of samples (a) with PDS and (b) with UDS nitrided at 300 and 550°C.

Analysis of the obtained graphs showed a sharp decrease in microhardness from the surface deep into of material of samples, at high-temperature nitriding. This is explained by the fact that, at high temperatures, an excessive ion energy is generated in the MF, leading to cathodic sputtering.

4. Conclusion
- The use of a MF during IN in a GD intensifies the saturation process of steel with nitrogen, due to the increase ionization, leading to a 1.5-fold increase in the thickness of the diffusion layer of workpiece.
- At ion nitriding with a MF there is an increase in microhardness of AISI 321 samples in 1.5…2 times compared to ion nitriding without a MF.
- The use of plastic deformation before ion nitriding in the glow-discharge increases the diffusion of nitrogen into of sample.

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