Improving the mechanical properties of tool steel by induction chemical-thermal treatment

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Abstract. The study results of the structure and microhardness of the surface layer of high-speed tool steel after induction chemical-thermal treatment in a gaseous nitrogen-containing medium at a temperature of 900–1100 °C were presented. Due to the strengthening treatment of products a gradient diffusion nitride layer with a thickness of about 200 μm and a surface microhardness of 1950±70 HV₁₉₈ was formed.

1. Introduction
In modern industry, various types of working media are used for nitriding. The most common of them is a gas mixture of ammonia and propane (1:1). The nitriding process in this environment is performed in shaft or vacuum retort furnaces in the temperature range from 520 to 570 °C for 60–90 hrs. As a result of processing, a strengthened diffusion layer with a thickness of 150±50 μm and a microhardness of 900–1100 HV is obtained [1]. A method of ion-plasma nitriding is often currently applied, which is performed in special installations with a nitrogen-containing rarefied medium consisting of nitrogen or ammonia at temperatures from 300 to 590 °C with cycle duration of about 24 hrs. Ionic nitriding allows obtaining a nitrided layer with the thickness of 300±50 μm and a microhardness of 1000–1300 HV [2].

An alternative heating method for chemical-thermal treatment (CTT) can be induction heating, which reduces the process time [3]. Based on the mentioned above, the most promising way of heating products during the nitriding process can be induction heating [4,5]. In this paper, the mechanical properties of diffusion layers obtained on tool steel using induction chemical thermal treatment (ICTT) were studied.

2. Methodology
Cylindrical samples used in the studies had a diameter of 10 mm and a length of 5 mm and were made of high-speed tool R6M5 steel not subjected to heat treatment.

Nitriding was carried out by placing the samples in a chamber of "VCh-15A" heating device designed for ICTT (Figure 1). Sample 5 was in the active zone of inductor 3. Before the nitriding took place, air was removed from the chamber by blowing with nitrogen (at least for 1 min), which was supplied through a hole in the lower base of chamber 4. Then the outlet valve of chamber 1 was closed, as a result of which overpressure was observed.

The ICTT process was carried out at a temperature of 900–1000 °C for 10 min and a pressure of 0.2±0.05 MPa. The heating rate and temperature were controlled by varying the operating current I from 300 to 360 A, which corresponded to 1:16 of the inductor current for this device. The temperature of the induction heating was controlled according to the colors of heating of the processed
solids. When the exposure was finished, the samples were cooled to a temperature of 550–570 °C by blowing the chamber with gaseous nitrogen.

![Diagram of ICTT chamber in nitrogen](image)

**Figure 1.** Scheme showing the chamber for ICTT in nitrogen: 1 – outlet pressure reducing valve; 2 – "VCh-15A" setup; 3 – water-cooled inductor; 4 – lower base of the chamber for puffing of a working gaseous medium; 5 – sample.

The structure and depth of the nitrided layer were studied using an "Olympus BX-51" optical microscope. Cross-sections of the samples were made according to a well-known technique using a "CitoPress-1" pressing machine and a "TegraPol-15" grinding and polishing machine. The microhardness was evaluated using a "Duruscan-20" microhardness tester with a load on the Vickers indenter equal to 100 gf (0.98 N) for microsections and 200 gf (1.98 N) for the sample surface.

### 3. Results

As a result of ICTT, the samples acquired a gray-matte shade typical for nitrided products. At a maximum operating current of 360 A, the sample melted. Thus, this current value was taken as the maximum and the exposure time was within 10 min. All samples were distinguished by their uniformity of texture in the central parts and the peripheral areas had a darker shade. This was explained by their uneven heating in the course of treatment with high frequency currents. However, the microhardness over the entire surface was characterized by sufficient uniformity.

The maximum microhardness of the surface of the nitrided layers was stabilized at the level of 1928–1950 HV₁₀₀ (Table 1).
Table 1. Microhardness of the sample surfaces.

| Designation of a series of samples | Hardness, HV$_{1.98}$ |
|-----------------------------------|------------------------|
| Untreated sample                  | 256±9                  |
| Hardened sample (after quenching) | 799±34                 |
| No. 1, $I_p – 300$ A             | 1862±98                |
| No. 2, $I_p – 320$ A             | 1950±75                |
| No. 3, $I_p – 340$ A             | 1928±70                |
| No. 4, $I_p – 360$ A             | 1837±55                |

With an increase in the operating current of the inductor, an increase in the indices of the surface microhardness was observed. Changing the values of the operating current of the inductor led to a growth of the heating rate of the processed products and the emergence of a pronounced temperature gradient [6]. A significant increase in microhardness indirectly indicated the strengthening of the surface layer as a result of the formation of nitride phases in the course of ICTT.

When studying the microstructure of the nitrided samples, the uniformity of the modified layer with the thickness of 160–200 μm was noted (Figure 2).

![Figure 2](image1.png)

**Figure 2.** Layered structure of the samples after ICTT containing a strengthened layer (I), a diffusion layer (II) and a base metal (III): $a – 300$ A; $b – 320$ A; $c – 340$ A; $d – 360$ A.

The thickness of the strengthened layer for sample No. 4 was not revealed, which was due to its melting and structure homogenization. The strengthening boundary was determined by microindentation along the section to a depth of about 1 mm (Figure 3). At an operating current of 300–320 A, the layers with a smooth decrease in the microhardness over the cross section to 150 μm were formed. A microhardness gradient within 100 μm was observed in the samples treated at 340–360 A.
Figure 3. Dependences of the microhardness of nitrided samples on the indentation depth.

The constancy of microhardness was observed from a depth of 250 μm and more. The depth from 30 to 250 μm was characterized by high hardness (1694–1281 HV0.98), which was associated with the formation of finely dispersed strengthening phases in this region. In the case of sample No. 4, minimum values of microhardness in deep layers (more than 500 μm) were noted, which was associated with partial fusion of the sample.

4. Conclusion
Thus, the layers obtained on steel products were characterized by the required combination of high microhardness and a large depth of the strengthened layer, which can be effectively used under conditions of friction and dynamic loads. Using the ICTT method, a nitrided layer with a high microhardness of about 1928-1950 HV1.98 was formed on the surface of high-speed R6M5 steel.

The depth of the diffusion layer was 160–200 μm in the operating current range of 300–340 A with process duration of 10 min. Treatment in the range of 300–320 A was characterized by higher microhardness values of the strengthened layers with its uniform distribution. Intense nitriding during induction heating was achieved by increasing the localized activity of the gaseous medium, accelerating the adsorption and diffusion processes.

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