Research of the effect of severe plastic deformation with the following ion nitriding on the thickness and microhardness of the hardened layer of tool steel R6M5

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Abstract. In this work we consider the issue of influence of initial state of tool steel P6M5 surface on thickness and microhardness of hardened layer during ion nitriding in the glow discharge. It is established that the application of intense plastic deformation torsion before ion nitriding in the glow discharge increases the rate of nitrogen diffusion deep into the tool steel R6M5, and increases the thickness of the hardened layer by 2.5 times.

1. Introduction

The present level of development of chemically heat treatment (CHT) ion nitriding allows to change operational properties of many important machine parts and tools by controlling a number of parameters: temperature, time, nitrogen content in the gas mixture (in percent) and working gas pressure [1]. However, controlling these parameters allows you to regulate the structure and properties of the nitrided layer only during the nitriding process. Meanwhile, the structure and properties of the nitriding layer are significantly influenced by the initial structural state of steel before processing [2, 3]. Therefore, an increasing number of authors devote attention to studying the influence of the initial structural state of the material on mechanical and tribological properties after ion nitriding [4–9].

The severe plastic deformation (SPD) is a type of hardening processing of details by pressure, at which plastic deformation of surface layers occurs, accompanied by size reduction of grain and formation of ultrafine grained structure. It is known that the diffusion coefficient in solids is strongly influenced by lattice defects, increasing with their number [2, 3, 10, 11], and the size of grains, increasing the diffusion rate with their reduction [12].

The purpose of this work was to study the influence of the initial state of the surface of tool steel R6M5, obtained after severe plastic deformation torsion, on the thickness and microhardness of the hardened layer during ion nitriding in the glow discharge.

2. Methods of study

In this study we used specimens of high-speed tool steel of grade R6M5 (0.9 % C, 0.5 % Si, 0.5 % Mn, 0.4 % Ni, 4.4 % Cr, 5.3 % Mo, 6.5 % W, 2.1 % V, 0.5 % Co, 0.025 % S, 0.03 % P; all in % wt). Ion nitriding in the glow discharge was carried out on the "ELU-5M" unit (figure 1) in a mixture of argon and nitrogen gases (65 % Ar, 35 % N₂) at 200 Pa pressure and 450 °C for 4 hours.
To study the influence of the initial state of the surface on the thickness and microhardness of the hardened layer of the tool steel R6M5 during ion nitriding, one of the studied specimens was subjected to severe plastic deformation torsion (SPDT). This method of processing consists in mechanical deformation of metal by two simultaneously acting forces, on compression and torsion, as a result of which a strongly size reduction of grain structure is formed - UMP (ultrafine grain) (figure 3b) [5]. In this work, a specimen of R6M5 before ion nitriding was subjected to 43 % cold precipitate and 1.5 turn torsion at 4GPa hydrostatic pressure at the "SKRUJ-200" unit, according to the scheme in figure 2.

For estimation of microhardness on specimens after ion nitriding was carried out with Struers Duramin-2 hardness tester. Microhardness was measured by the Vickers method on oblique sections (angle 7°) at a load of 980.7 mN and duration of diamond indenter exposure during 10 seconds.

To reveal microstructures, the specimens under study were subjected to chemical etching during 10 sec. with acid solution: C₂H₅OH (80 ml), HNO₃ (10 ml), HCl (10 ml) and C₆H₃N₃O₇ (1 g). The thickness of the hardened layer was estimated from the obtained optical pictures of microstructures with the Olympus GX51 microscope.

3. Results and discussion
To study the influence of initial state of surface of high-speed tool steel P6M5 on thickness and microhardness of hardened layer during ion nitriding in the glow discharge two specimens with
different initial state were processed: the first specimen – untreated, original structure (figure 3a); the second specimen – after severe plastic deformation torsion (SPDT) (figure 3b).

Figure 3. Optical pictures of microstructure: a – original R6M5, b – R6M5 after SPDT.

Figure 4 shows a graph microhardness distribution by depth of specimens from high-speed tool steel R6M5 after ion nitriding in the glow discharge at 450 °C for 4 hours.

Figure 4. Microhardness distribution by depth of specimens from R6M5 after ion nitriding at 450 °C during 4 hours.

The surface microhardness of original specimen was about 300 HV_{0.1} in average. After severe plastic deformation torsion, the surface microhardness increased up to 500 HV_{0.1} and after ion nitriding went up to about 1100 HV_{0.1} for both specimens (original and SPDT). However, for the SPDT specimen, the microhardness distribution by depth is markedly different from the original specimen. The microhardness distribution line of the SPDT specimen has a flat part about 50 µm long, while in the original specimen the microhardness distribution line was gradually decreased from surface to core. It is caused by that SPDT specimen R6M5 had highly fragmented and disoriented ultrafine grained structure, which was formed after severe plastic deformation. The formation of this structure (UFG) led to an increase in the rate of nitrogen diffusion deep into the processed specimen and as a result an increase in the thickness of the hardened layer (figure 5).
Figure 5. Optical pictures of microstructure (a) original specimen R6M5 and (b) SPDT specimen R6M5 after ion nitriding at 450 °C during 4 hours.

4. Conclusions

As a result of study the influence of the initial state of the surface of tool steel R6M5, obtained after severe plastic deformation torsion, on the thickness and microhardness of the hardened layer during ion nitriding in the glow discharge the following was established:

- The use of severe plastic deformation torsion before ion nitriding in the glow discharge increases the rate of nitrogen diffusion in the tool steel R6M5 due to the formation of a highly fragmented and disoriented ultra-fine grained structure;
- Application of severe plastic deformation torsion before ion nitriding in the glow discharge increases the thickness and microhardness of the hardened layer of tool steel R6M5 by 2 times.

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