Application of hollow cathode effect for local ion nitriding of machine parts

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Abstract. Influence of hollow cathode effect (HCE) on local ion nitriding process of 16Kh3NVFMB-Sh steel was studied. Microstructures of nitrided layer, phase composition, microhardness profiles through the diffusion layer were obtained and investigated. Influence of ion nitriding duration on nitrided case depth and wear resistance was studied. Technology of ion nitriding with application to HCE for gear part was developed.

1. Introduction

It's known [1] that the most frequent cause of machine parts working in hard conditions (friction and cyclic loads) destruction is pitting and microscopic cracks formation. Methods of surface hardening, in particular ion nitriding, allow improving the reliability and durability of these parts [2].

In most cases, only local areas of machine parts surface, such as contact area of the gear teeth, are under intense wear conditions [3]. Thus, usually there is no need to treat entire surface of the part; it is enough to nitride only operating area.

In works of Tomsk scientists of ISPMS SB RAS it was experimentally proved that application of hollow cathode effect (HCE) in ion nitriding process allows significantly accelerating diffusion process compared to conventional treatment in glow discharge.

The aim of this work is to determine influence of HCE during local ion nitriding on microstructure, microhardness of diffusion layer, phase composition of 16Kh3NVFMB-Sh steel samples. In addition, technology of ion nitriding with application of HCE of gear part was developed.

2. Methods of study

Experiments were carried out on the multifunctional setup for thermal and thermochemical treatment in vacuum ELU-5M. Samples of thermal pretreated (quenching at 930°C and tempering at 600°C) steel 16Kh3NVFMB-Sh were sputtered in argon at pressure of 10 Pa during 15 min, and then ion nitrided in atmosphere of nitrogen, argon and acetylene (Ar 70%, N_2 25%, C_2H_2 5%) at pressure of 60 Pa during 12 hours. Part of the sample was covered by mesh screen (figure 1). HCE occurred in the cavity formed between the screen and surface of the sample. Process temperature was not higher than 550°C

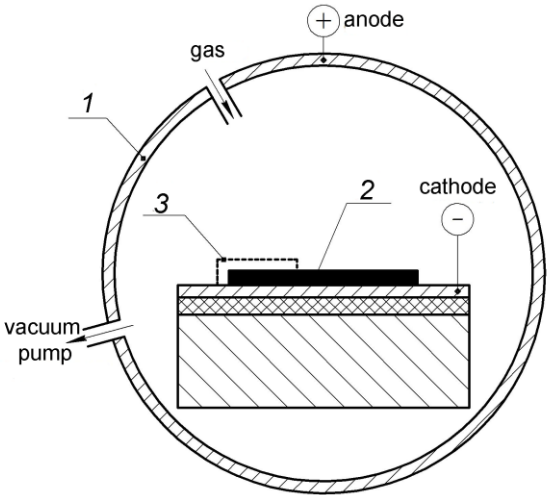

Figure 1. Scheme of experimental setup: 1 – vacuum chamber, 2 – sample, 3 – technological screen

Zeiss Axiotech 25HD microscope was used for optical microscopy investigations. Samples were etched in solution of 5% HNO3 and 95% C2H5OH. Microhardness measured on Struers Duramin michohardness tester. X-ray analysis was performed with help of DRON-4 difractometer.

3. Results and discussing

Presence of nitride elements (Cr, W, Ni, Mo, V) in 16KhNVFMB-Sh steel allows using it for improving wear resistance of machine parts, such as gears, shafts, etc.

As a result of quenching and tempering, formation of ferrite-cementite solution occurs due to diffusion redistribution of carbon atoms. Carbides of iron and other alloying elements appear as dark grain boundaries [4]. Surface microhardness before ion nitriding is 420±20 $HV_{0.1}$.

Photos of nitrided sample microstructure are presented in figure 2.

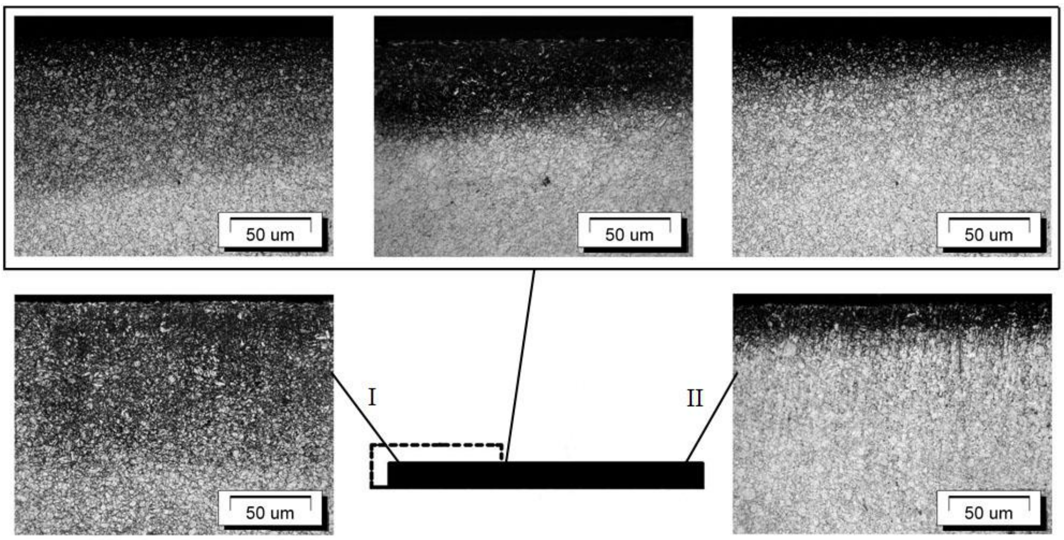

Figure 2. Microstructure of ion nitrided sample I – affected by HCE area, II – unaffected by HCE area

Investigation of microstructure of nitrided sample shows presence of two zones: zone affected by HCE (covered surface area) and unaffected zone. At covered by screen area thicker dark diffusion layer can be observed. Transition from diffusion layer to core material is smooth, that is one of major requirements to microstructure of nitrided layer [5].

Microhardness profiles allow estimating nitrided case depth.

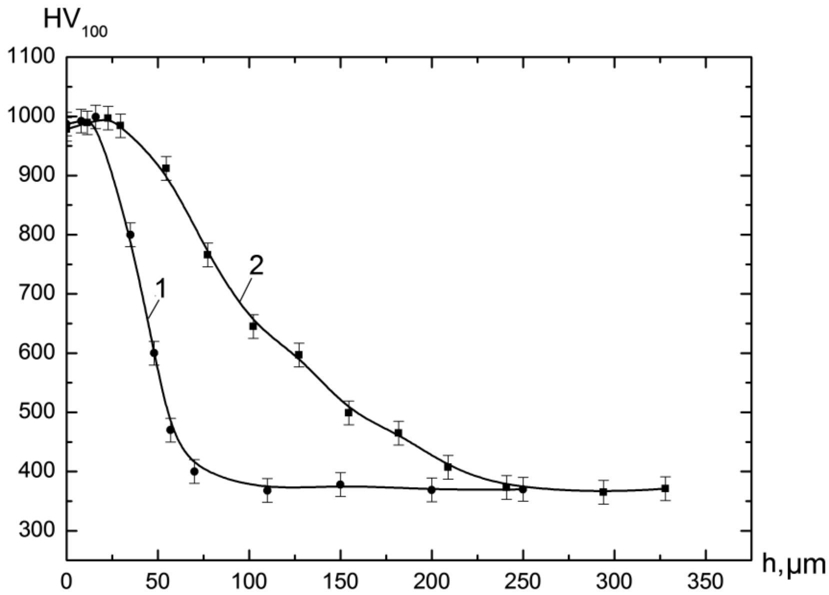

Figure 3. Microhardness profile after local ion nitriding with HCE
(1 – covered by screen area, 2 – uncovered area).

Analysis of presented in figure 3 profiles shows that covered area has up to 2 times thicker diffusion layer compared to uncovered area. Transition to core material is also smooth.

X-ray analysis was performed to investigate phase composition of steel surface after nitriding. Obtained diffraction patterns presented in figure 4.

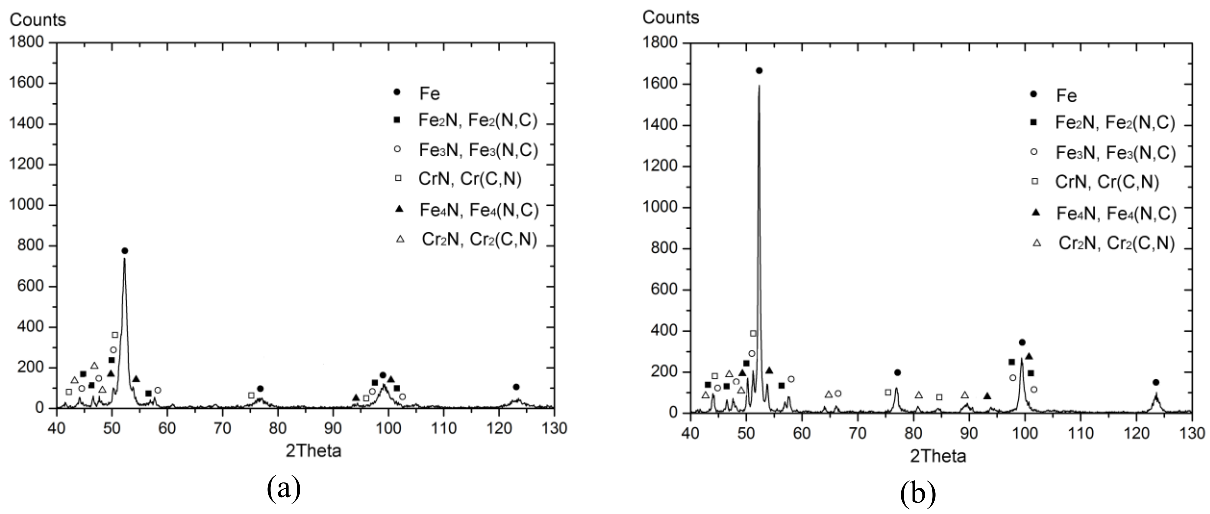

Figure 4. Difraction patterns of surface of the nitrided sample (a) – affected by HCE area, (b) – uncovered area.

The study of obtained diffraction patterns shows the presence of ε-phases Fe2-3(N), Fe2-3(N,C), γ-phases Fe_4N, $Fe_4(N,C)$, and also phases of chromium nitrides and carbonitrides CrN, Cr(C,N).

To study rate of hardened layer growing during ion nitriding with HCE, influence of process time on diffusion case depth was investigated (figure 5). It was established that saturation process during nitriding with HCE obeys the inverse parabolic law, like any diffusion process. Therefore, saturation process slows down over process time.

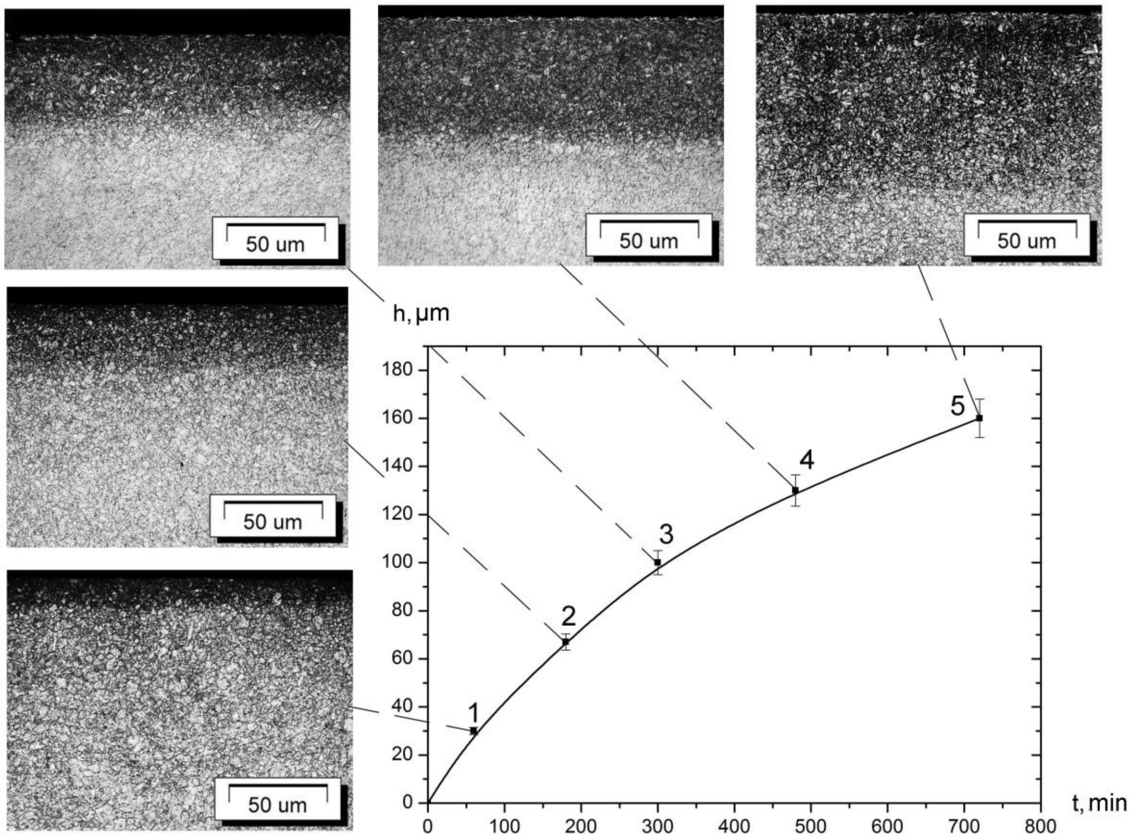

Figure 5. Kinetics of hardened layer growth thickness during ion nitriding with HCE.

Tribological properties were studied by standard method “ball on disk”. The dependences of friction coefficient on wear time for different surface areas of the sample presented in figure 6.

Study of the obtained results shows that nitrided with HCE surface bedded after 7 minutes, whereas bedding stage of nitrided without HCE surface ends after 4 minutes. Average friction coefficient of both nitrided with and without HCE areas is 0.6.

As a result of tribological tests it was established that application of HCE leads to decreasing the wear of materials up to 3 times in comparison with the case of conventional ion nitriding in glow discharge. Thus, ion nitriding with HCE is effective way for increasing of wear resistance of 16Kh3NVFMB-Sh steel.

Based on obtained results, technology of ion nitriding of gear part was developed. This process allows obtaining a uniform diffusion layer of 180 μm thickness without nitride network on sharp corners.

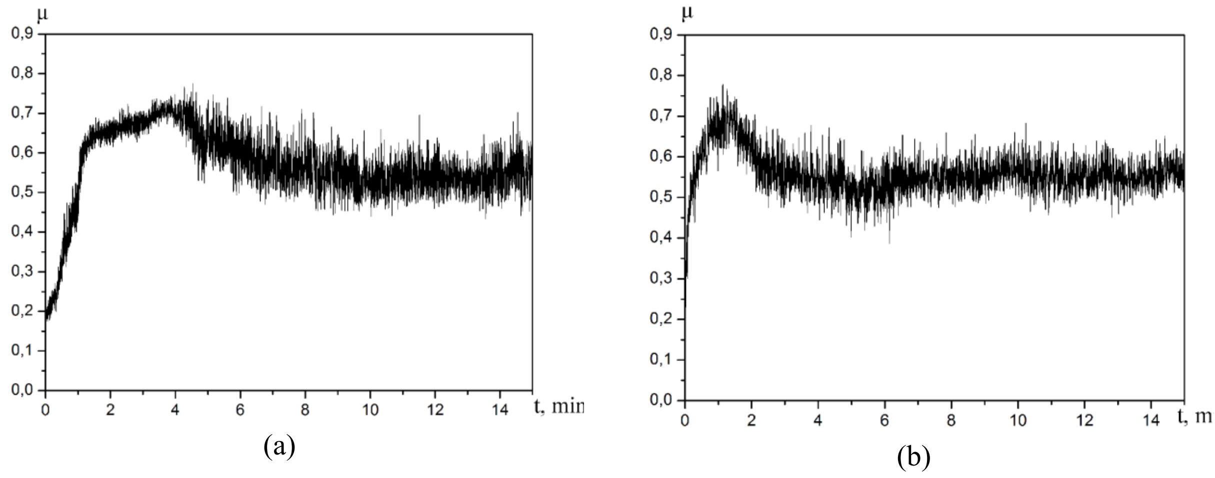

Figure 7. Dependences of friction coefficient on wear duration of the sample (a) – nitriding with HCE, (b) – nitriding without HCE.

4. Conclusions

Two zones form after ion nitriding with HCE: zone affected by HCE (covered surface area) and unaffected zone. Transition from diffusion layer to core material is smooth.

Covered by technological screen area has up to 2 times thicker diffusion layer compared to uncovered area after 12 h of ion nitriding with HCE.

ε -phases $Fe_{2-3}(N)$, $Fe_{2-3}(N,C)$, γ -phases Fe_4N, $Fe_4(N,C)$, and also phases of chromium nitrides and carbonitrides CrN, Cr(C,N) are form on surface of 16Kh3NVFMB-Sh steel after ion nitriding with HCE.

Application of HCE during ion nitriding allows significantly increasing wear resistance for 16Kh3NVFMB-Sh steel surface.

Technology of ion nitriding of gear part with HCE was developed. This process allows obtaining a uniform diffusion layer of 180 μm thickness without nitride network on sharp corners.

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