UDC 621.314

INFLUENCE OF PLASMA NITRIDING ON SURFACE ROUGHNESS OF STEELS

M.S. AHMED, A.N. DROBOV

Physical-Technical Institute, National Academy of Sciences of Belarus
10, Kuprevich Street, 220141, Minsk, Belarus

Submitted 5 February 2016

The research results of the influence of plasma at different levels of surface roughness are presented. The objective of this work is to determine the effects of plasma after the treatment for instrument steel 40Cr and construction steel 38H2MYUA.

Keywords: roughness, sputtering, ion, hardening, process.

Introduction

Ion plasma nitriding (IPN) is hardening process used to increase surface hardness, wear resistance and fatigue of steels after treatment. The most industrialized countries uses this method of hardening for machine components and tools, which replaced the traditional variants method of thermo chemical treatment (TCT). Compared with traditional processes of gases as well as other ways of strengthening the TCT, ion nitriding has several advantages and additional process features. Nitriding is widely used in various industries to improve the durability and reliability of many critical parts and tools.

In Belarus in the field of plasma physics, including studies of nitriding process and efforts to build the equipment of IPN were carried out in the Institute of Physics, the Institute of Heat and Mass Transfer of NAS of Belarus, BSUIR, BSU, BNTU. However, real progress in the studies of ion nitriding achieved in recent years in the Physical Technical Institute of National Academy of Science of Belarus also created reliable and innovative industrial equipment of IPN [1–3]. Its features are the ability to select the processing chamber pressure, changing the concentration of nitrogen in the working gas mixture during the process, software process control and high energy efficiency.

The author [4] explained that particles are ejected by sputtering from a solid target material due to bombardment of the target by energetic particles, it only happens when the kinetic energy of the incoming particles is much higher than conventional thermal energies greater than 1 eV. Therefore, sputtering is driven by momentum exchange between the ions and atoms in the materials due to collisions with surface of the treatment device. When the energy of sputtering is greater than the surface binding energy, an atom will be ejected and can escape the surface binding energy.

In this paper established the nature of the changes in the surface morphology of the initial products of instrumental and constructional steels having different roughness using IPN. The studies were performed with the use of modern methods of complementary interaction, instruments and equipment to ensure the accuracy and evidence of results.

Experiments on instrument and construction steels

Plasma (ionized gas) – a fourth state of matter, plasma – a very active medium containing ions, high-energy neutral particles, as a result of the dissociation of the gas molecules in an electric field. IPN process is realized when the nitrogen in the chamber is converted into nitrogen ions and the metal is absorbed. Molecular nitrogen by direct plasma dissociation converted into nitrogen atoms: $N_2 + e^- \rightarrow N + N + e^-$.

Fig. 1. The nitriding of steel molds 4H5MFS and gears of steel 40Cr (own results)

Then, the nitrogen atoms are converted into nitrogen ions due to the ionization of the plasma:

$N + e^{-} \rightarrow N^{+} + 2e^{-}$.

Next, nitrogen ions are diffused into the N + surface of the metal and form fine nitrides that provide high hardness of the material near the surface, Visually process IPN looks like a purple glow surrounding the device as shown in Fig. 1.

Technological factors affecting the efficiency of the IPN are the temperature of the process, the duration of the saturation pressure, composition and flow rate of the working gas mixture, as well as the density of the discharge current. In this case, the discharge must be anomalous, i.e. the entire surface of the processed products should be covered with glow, and the density of the discharge current must be greater than normal density for a given pressure, taking into account the effect of heating the gas in the cathode region of the discharge [5–9].

Temperature range of IPN at hardening steels and cast irons is wider than for gas nitriding and in this study within 350–600 °C. By varying the gas composition, pressure, temperature and exposure time, you can receive a predetermined depth layers with the desired structure and phase composition.

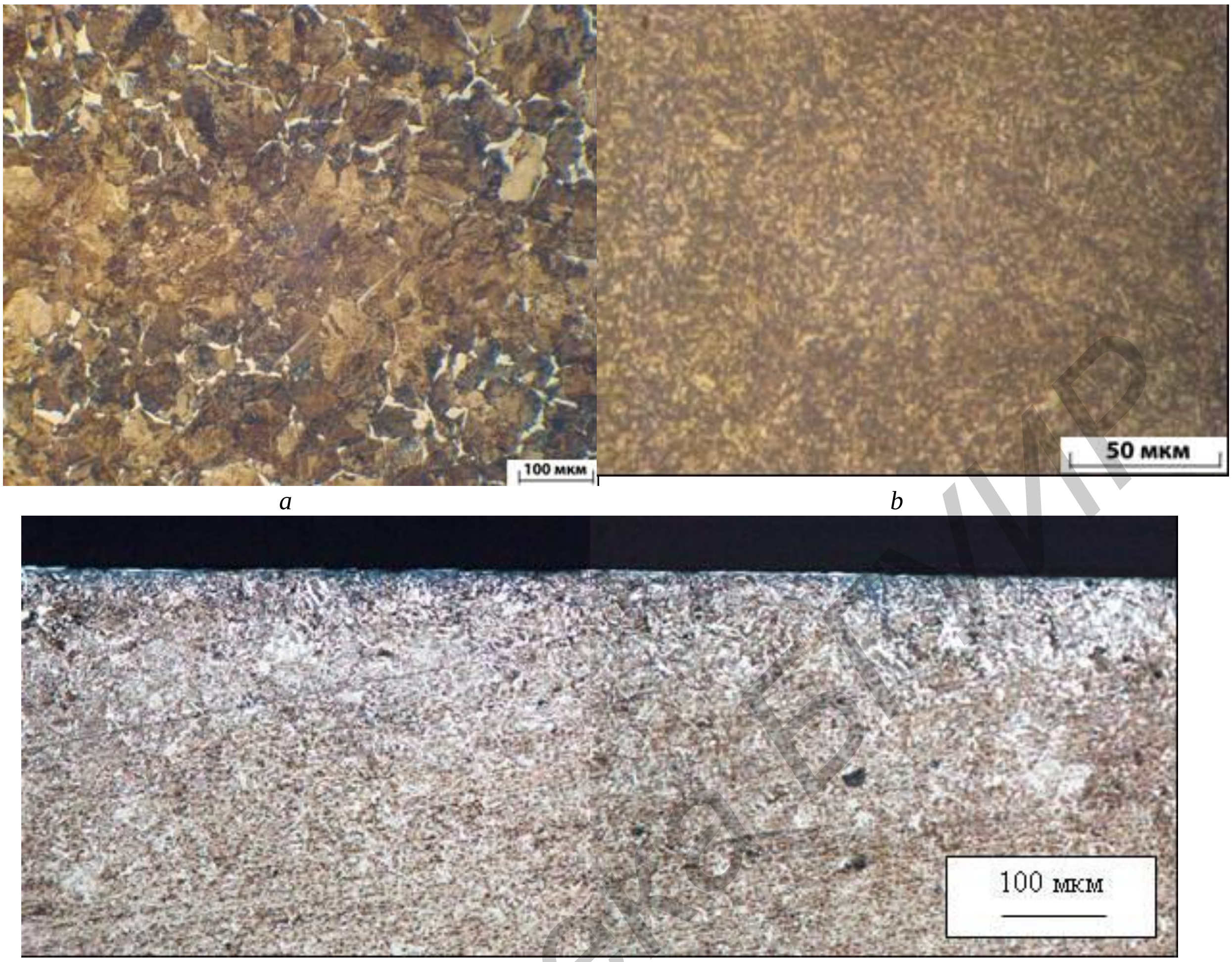
The parameter which characterizes the intensity of the ion nitriding process is the flux density of the diffusing nitrogen into the steel, which is a function of the discharge parameters (voltage and current density), and a predetermined flow of nitrogen, and may vary during the process according to any algorithm, depending on the steel grade and the requirements of the nitride layer.

Table 1. **Chemical composition (wt. %) of the investigated steels (GOST 4543–71, 5950–2000)**

Elements	40Cr	38H2MYUA
C	0.36–0.44	0.35–0.42
Si	0.17–0.37	0.2–0.45
Mn	0.5–0.8	0.3–0.6
Ni	to 0.3	to 0.3
S	to 0.035	to 0.025
P	to 0.035	to 0.025
Cr	0.8–1.1	1.35–1.65
Mo	–	0.15–0.25
Al	–	0.7–1.1
Cu	–	to 0.3
W	–	–
V	–	–
Ti	–	–
Cu	to 0.3	–

The values were obtained when materials were subjected to a series of structural studies and measurement of mechanical characteristics.

Steel 40Cr has a high performance and is widely used in industry for the manufacture of automotive parts, machine tools and other equipment, such as timing gears, axles, rollers water pump, coupling halves, rotary fists, bipod, ladders, shafts, thrust crossbars, cranks, hubs etc.



a *b*

c

Fig. 2. 40Cr steel microstructure in the initial state (*a*),
after hardening and tempering at 600°C (*b*), after quenching and tempering and IPN (*c*)

Steel 40Cr in the initial state has a banded structure consisting of lamellar pearlite with ferrite grain boundary mesh (Fig. 2, *a*) and the banded structure of steel due to the segregation of alloying elements in the smelting.

Effects of ion nitriding on surface roughness

From Table 2, with the initial state of surface roughness in the range of 0.027–0.599 microns for 40Cr, after the IPN, the surface roughness is positive. However, with the initial state of surface roughness of 0.74 microns, after the IPN, the surface roughness is negative. Also with the initial state of surface roughness in the range of 0.764–0.800 microns, the surface roughness is positive. With the initial state of surface roughness in the range of 0.889–1.650 microns, after the IPN, the surface roughness is negative.

From Table 2, with the initial state of surface roughness in the range of 0.28 - 0.92 microns for steel 38H2MYUA, after the IPN, the surface roughness is positive. With the initial state of surface roughness in the range of 1.09–1.29 microns, after the IPN, the surface roughness is negative.

On the diffusion of nitrogen into the interior of the material significantly affects the nature of the machining surface before nitriding. Such machining factor as the surface roughness, may also affect the formation and growth of the nitride layer. After grinding the diffusion of nitrogen into the metal is facilitated, since the surface tensile stresses occur during process turning, drilling, milling, magnetic abrasive, blasting and sandblasting, or plastic deformation of the surface shape different types of diagrams of residual stress in the surface, and the surface can affect the diffusion of nitrogen.

Influence of ion nitriding on the variation of surface roughness for samples of steels 40Cr and 38H2MYUA were studied, to this end, a series of samples plane cylindrical plunge quenching and tempering at 600 °C, treated with sandpaper grit for different surface roughness in the range of 0.03–1.65 microns for 40Cr and Ra 0.28–1.29 um for steel 38H2MYUA. Surface roughness was measured on a device Sustronic 25 manufactured by Taylor Hobson. Samples steel 40Cr were then simultaneously nitride at 530 °C for 13 hours. Steels 38H2MYUA carried out at 510°C for 7 hours exposure on the first treatment stage and 550 °C for 8 hours exposure in the second step. Then measure roughness, surface roughness was measured on a device Sustronic 25 manufactured by Taylor Hobson. The data reflecting the change trends of surface roughness are shown in tables 2 and 3.

Table 2. **Changes in the surface roughness of the samples of steel 40Cr in various states after the IPN**

State	Initial	After IPN	Change
The roughness Ra, um	0.027	0.235	+0.208
	0.029	0.097	+0.068
	0.033	0.103	+0.070
	0.037	0.244	+0.207
	0.038	0.257	+0.219
	0.041	+0.219	+0.241
	0.051	0.102	+0.051
	0.079	0.132	+0.053
	0.100	0.218	+0.118
	0.152	0.267	+0.115
	0.406	0.588	+0.182
	0.599	0.641	+0.042
	0.74	0.67	–0.07
	0.764	0.828	+0.064
	0.800	1.018	+0.218
	0.800	0.940	+0.140
	0.889	0.781	–0.108
	1.400	1.378	–0.022
	1.650	1.634	–0.016
	1.650	1.560	–0.090

Table 3. **Change in surface roughness of steel samples 38H2MYUA after IPN**

State	The roughness Ra, um							
initial	0.28	0.38	0.39	0.44	0.51	0.92	1.09	1.29
after IPN	0.44	0.48	0.40	0.48	0.72	0.93	0.96	1.24
change	+0.16	+0.1	+0.01	+0.04	+0.21	+0.01	–0.13	–0.05

When initial roughness in the range of 0.03–0.6 microns, after treatment roughness increases. Surfaces with an initial roughness in the range of 0.74–0.9 microns, after treatment the roughness declines. In the case of the original surface with a higher value Ra, after IPN their roughness reduced. Processes of change of surface morphology during the IPN definitely related to the nature and mechanism of high exposure to the plasma glow discharge in the surface layer of metal, subjecting the surface powerful stationary or pulsed energy fluxes (ions, plasma) leads to a series of melting and solidification processes in surface layer of macroscopic thickness in steels.

During IPN, samples with high initial surface roughness (0.9 um and more), there were smoothing of the projections and surface irregularities. In the case of surface treatment with low initial roughness was a “backwash” of the surface by bombardment with nitrogen ions. In this case, except for the serial melting and solidification of the surface layer, there is a process of “ion etching”, which consists of bombarding the surface of the reinforcing product ions with an energy of 1 keV, in the creation of an atomically clean surface of the material (steel), the defective surface layer with a large number of active sites sorption and surface temperature and the entire part both during the pre-cleaning products, and directly nitriding process. Therefore, the formation of relief etching is associated with changes in the surface topography caused by the ion-stimulated structural and chemical changes in the surface layers.

For tools, machine components and devices depending on its purpose, for example applied to a thin blade processing may require low surface roughness (less than Ra = 0.63 m). Surface roughness Ra 1–1.6 microns is acceptable for general engineering components (gears, gears, shafts, guides), and also for forming tool and equipment in industries.

Conclusion

The regularities of changes in the morphology of the surface of steel depend on the nature of the surface roughness. Nitriding initially polished samples (Ra 0.03–0.04 m) increase their roughness due to ion etching. When the value of Ra is in the range 0.8–0.9 microns, an increase in roughness was obtained for instrument steel 40Cr, this was due to sputtering. Surface roughness of construction steel 38H2MYUA was in the range of 0.28–0.92 microns after the IPN, the surface roughness was positive, and surface roughness was in the range of 1.09–1.29 microns after the IPN, the surface roughness was negative. Plasma-nitriding as surface treatment is important for achieving good corrosion and wears properties of steels.

References

1. *Bosiakov M.N., Kozlov A.A.* // Doklady BGUIR. 2013. № 3 (73). P. 76–82.
2. *Behrisch R., Eckstein W.* Sputtering by Particle bombardment: Experiments and Computer Calculations from Threshold to Mev Energies. Berlin. 2007.
3. *Arzamasov B.N.* The ionic chemical-thermal treatment Alloys. M., 1999.
4. *Bosiakov M.N.* // Coll. Reports of the 8th International Symposium "Powder metallurgy: surface engineering, new powder composite materials. Welding". Part 2. Minsk, Belarus, April 10–12, 2013. P. 34–40.
5. *Bosiakov M.N.* // New equipment ion-plasma nitriding. 2013. № 3 (91). P. 30–34.
6. Nitriding and carbonitriding // Ed. A.V. Supova. M., 1990.
7. *Mittemeijer E.J.* Fundamentals of Nitriding and Nitrocarburizing ASM Handbook, Volume 4A, Steel Heat Treating Fundamentals and Processes J. Dossett and G.E. Totten, editors, ASM International, 2013.
8. *Mittemeijer E.J., Somers M.A.J.* // Proceeding of the 10th Congress of the IFHT "Thermodynamics, Kinetics and Process Control of Nitriding". Moscow, 1996. P. 83–117.
9. *Rolinski E.* Electrical discharges in gases and principles of ion nitriding. Advanced Heat Treat Corp., 2009.