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ION NITRIDING OF CONSTRUCTION STEELS

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Abstract: The present paper studies the influence of the parameters of ion nitriding (ammonia pressure in the chamber, the temperature of nitriding and the time for treatment) on the hardness of the nitride layer and the thickness of the nitride zone for construction steels 20MnCr5G and 100Cr6. To achieve the aim of this work a planned experiment has been used. A mathematical model has been derived for the two studied steels, reflecting the relationship between the parameters of control over the process of ion nitriding and the hardness of the formed layer, as well as the thickness of the combined zone.

Keywords: ion nitriding, construction steels

1. INTRODUCTION

Ensuring high quality of the products of mechanical engineering is directly related to increasing their reliability and durability, which, in turn, are defined by the wear-resistance of the materials. Ion nitriding and carbonitriding are used nowadays in machine building to improve the exploitation properties of the construction details.

The requirements toward the construction steels are quite diverse. They need to have sufficiently high resistive ability. Together with tensile strength, ductility, impact strength, fatigue resistance, wear-resistance etc., they need to have a complex of satisfactory technological properties: machinability with cutting tools, weldability, ductility at high temperature, good hardness penetration, etc. At the same time they must be cheap and must not contain scarce alloying elements. The improvable steels contain from 0.3 to 0.5 % carbon. After improvement the steels obtain the most favorable combination of strength and plastic properties: mechanical strength, fatigue resistance, impact strength etc. The mechanical properties can be changed in a broad range by varying with the chemical composition of the steels and the temperature of tempering.

Except for the steels, especially adjusted for nitriding, such as 38CrAiMoV etc. other types of construction steels are also subject to ion nitriding. These are the low and medium alloy steels 41Cr4, 42CrMo4, as well as the appropriate for cementation steels 20MnCr5G and 38 CrMo6 [3, 4, 5].

Ion nitriding is a method, which is especially appropriate for treating standard mass produced identical details as gears, axles, shafts, spindles, etc. These details very well illustrate the advantages of the nitriding in glow discharge, due to which the high precision of making wheels is retained and minimum inequality in the distribution of the contact loads across the width of the teeth is guaranteed. Distortions and deviations from the profile of the teeth are avoided or minimized, what is unavoidable at cementation and current of high frequency hardening, as well as the availability of the brittle diffusion nitride ($\gamma'+\epsilon$)-zone, characteristic of the classical gas nitriding in furnaces [1, 4].

Ion nitriding finds application also in production of screws with high precision by ballscrew mechanisms on machines with CNC. Good results can only be obtained by appropriate combination of the mechanical and thermal operations. The ion nitrided surfaces are easily and qualitatively polished, since the mono-phase and non-porous γ' -combined zone is much more suitable for polishing than the two-phase ($\gamma'+\epsilon$)-combined zone in the case of gas nitriding. The good polishing ability of the working surfaces of the details is of exceptional importance for the appearance and the properties of the produced details [2, 5].

The aim of the present work is to study the influence of the nitriding in glow discharge on the surface hardness and total thickness of the nitrided layer for constructional steels 20MnCr5G and 100Cr6.

2. METHODOLOGY OF STUDIES

2.1. Studied materials, modes of heat treatment and ion nitriding

Two types of construction steels, finding application in making gears, bearings etc. – 20MnCr5G and 100Cr6 – were chosen to be studied. They differ considerably by the type and the amount of alloying elements contained in them. The chemical composition of

the above mentioned steels (given in Table 1) was checked by the equipment for automatic analysis "SPEKTROTEST". Samples with dimensions 15 x 15 x 10 mm were made of both steels, mentioned above.

Table 1. Chemical composition of the studied materials

Type of steel	Chemical elements, percentage							
	C	Cr	Si	Mn	Ni	Ti	S	P
20MnCr5G	0.2	1.1	0.29	1.10	0.40	0.14	0.04	0.04
100Cr6	1.02	1.43	0.23	0.3	0.3	–	0.02	0.027

The samples were heat treated in a chamber furnace in an oxidative medium under the modes, given in Table 2.

Table 2. Modes of preliminary heat treatment

Steel	$T_{\text{hard.}}$ °C	Hardening HRC	Cooling medium	$T_{\text{temp.}}$ °C	Tempering HRC	Cooling medium
20MnCr5G	880	36	Oil	560	23	Oil
100Cr6	850	62	Oil	560	35	Oil

After being heat treated, the samples were grinded to surface roughness $R_a = 0.63 \mu\text{m}$. Then they were subject to ion nitriding in the installation "Ion – 20". A complete factor experiment of the type 2^3 was conducted at the following input (controlling) factors: temperature of nitriding (X_1), ammonia pressure (X_2), duration of the process (X_3); and at this target factor – maximum surface hardness ($HV_{0,1}$) and total thickness of the layer (δ_{tot}). Based on the above mentioned input factors and target parameter the following intervals of varying were used: upper, lower and zero levels – Table 3. The modes of ion nitriding of the studied steels are given in Table 4.

Table 3. Interval of varying

Factors	$t_{\text{nitrid.}}$, °C	P , Pa	τ , h
Levels	X_1	X_2	X_3
Zero level	520	300	10,5
Interval of varying (1)	20	100	3,5
Upper level (+1)	540	400	14
Lower level (– 1)	500	200	7

Table 4. Modes of nitriding

№ of the mode	Technical data		
	X_1	X_2	X_3
1	–1	–1	–1
2	+1	–1	–1
3	–1	+1	–1
4	+1	+1	–1
5	–1	–1	+1
6	+1	–1	+1
7	–1	+1	+1
8	+1	+1	+1
9	0	0	0

2.2. Metallographic and X–ray studies

Metallographic analysis was carried out in order to clear out the morphological peculiarities of the nitrided and carbonitrided layers. Microscope (Axioskop) was used for defining the structure and the thickness of the obtained layers, and the metallographic pictures were made by means of it.

The thickness of the nitrided and carbonitrided layers was defined by the depth at which micro–hardness, equal to the core plus 50, was achieved. Measuring the micro–hardness of the obtained layers was accomplished by means of a micro hardness–meter "Leitz" at a load of 0.98 N(100g), following the Vickers' method. The samples were developed with 3% nitric acid solution in ethyl alcohol.

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1. Preliminary thermal treatment

The obtained results from measuring the hardness of the thermally treated steels are given in Table 2. It can be seen from Table 2 that the steel 100Cr6 has higher hardness after hardening and tempering. This is due to the higher content of carbon and alloying elements in the hard solution, which take part in forming the carbides.

3.2. Ion nitrided steels

By means of the measured micro–hardness of the ion nitrided steels in depth, the maximum surface hardness $HV_{0,1}$ and the total thickness of the nitrided layer δ_{tot} was defined.

The thickness of the combined zone δ_z was defined by means of a metallographic microscope (Figure 1). It can be seen from Figure 1 that from the two types of steel the one with the higher micro–hardness is 20MnCr5G steel. This is due to the alloying elements (especially titanium), contained in the hard solution and taking part in forming the nitrides during the process of nitriding.

The structure of the diffusion zone after nitriding of steel 100Cr6 is heterophase. The availability of carbide phases in the steel decreases the total thickness of the diffusion zone. The carbide particles hinder the diffusion of the nitrogen atoms and slow down their penetration in–depth the steel. Therefore the thickness of the nitrided layer for steel 20MnCr5G is higher than the thickness of the nitrided layer for steel 100Cr6.

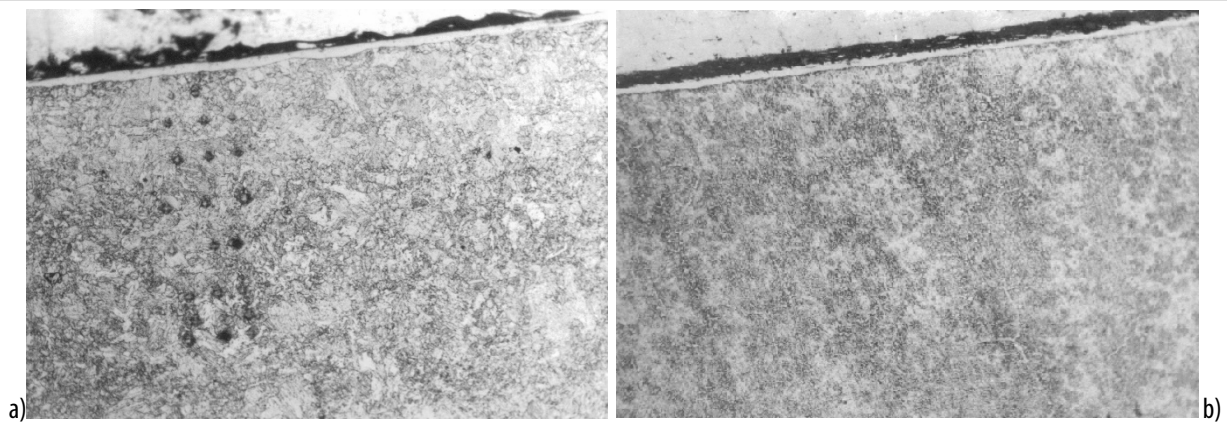


Figure 1. Microstructure of steel 20MnCr5G (a) and steel 100Cr6 (b) after nitriding at: $t_{nir} = 540^{\circ}\text{C}$, $P = 200\text{ Pa}$, $\tau = 7\text{ h}$

The alloying elements increase the hardness but decrease the thickness of the nitrided layer. The same influence have the carbide particles, especially the disperse particles, released in tempering.

The obtained results for the surface micro-hardness were entered into a personal computer and by means of an appropriate software programme the coefficients of the regression equations were defined, as well as their significance and adequacy. The results from the dispersion analysis are given in Table 5.

Table 5. Results from the dispersion analysis

Steel	Coefficient of multiple correlation R	F calc.	F table. ($\alpha = 0.05$)	Assessment of R
20MnCr5G for HV	0.789	5.66	2.9	significant
100Cr6 for HV	0.7444	13.25	2.9	significant
20MnCr5G for δ_{tot}	0.895	7.85	2.9	significant
100Cr6 for δ_{tot}	0.923	15.32	2.9	significant

$$HV_{0,1} = 888,67 + 15,25X_1 - 5,3X_2 - 3,50X_3, \text{ for steel 20MnCr5G} \quad (1)$$

$$HV_{0,1} = 798,72 + 33,5X_1 - 6,1X_2 - 1,5X_3, \text{ for steel 100Cr6} \quad (2)$$

$$\delta_{tot} = 302,5 + 25,8X_1 - 6,3X_2 - 38,2X_3, \text{ for steel 20MnCr5G} \quad (3)$$

$$\delta_{tot} = 285,2 + 30,2X_1 + 10,3X_2 - 20,5X_3, \text{ for steel 100Cr6} \quad (4)$$

From the regression equations the direction and the level of influence of the individual technical parameters on the corresponding characteristic of the layer can be defined. Equations (1) and (2) show a tendency for changing the maximum micro-hardness of the nitrided layer for steels 20MnCr5G and 100Cr6. The values of the coefficients X_1 , X_2 and X_3 show that the biggest influence on the micro-hardness have the temperature of nitriding and the ammonia pressure. Obtaining maximum hardness by the steels is accompanied by decrease in ammonia pressure, increase in the temperature of nitriding and decrease in the time of nitriding. The decrease in the temperature of nitriding is explained by the fact that the steels contain a small amount of carbon, and the bigger amount hinders the diffusion of nitrogen. The low pressure of ammonia causes activation of the process of pulverization, since the voltage of the glow discharge increases. The more active pulverization does not allow the formed nitrides to grow and coagulate. When analyzing equations (3) and (4) it can be noted that when the temperature of nitriding, the pressure and the time of treating increase, the thickness of the nitrided layer increases. The reason behind the character of this dependence is in the fact that the diffusion goes faster at higher temperatures and therefore the α -hard solution saturates with nitrogen for shorter time. The higher pressure does not activate the process of pulverization due to the low voltage of the glow discharge, and in result a bigger amount of nitrogen is delivered to the surface.

After ion nitriding in ammonia most often layers are formed, composed of two iron nitrides with different crystallographic lattices (cubic and hexagonal), which differ to some extent by the content of nitrogen. On the surface ϵ -phase is formed (Fe_{2-3}N). Below it the γ' -phase lies, which is formed independently during the nitriding, not in the process of cooling, since the two-phase layer is observed in layers, cooled in air, i.e., at comparatively high speed of cooling. Under the layer of nitrides the α -phase is formed (nitrous ferrite). The little difference in the concentration of nitrogen in both phases probably contributes to forming the two-phase nitride zone (mixture of γ' and ϵ -nitrides).

The lower content of nitrogen in the ϵ -nitride in case of ion nitrided layers is probably one of the reasons for the lack of pores in the combined zones. This is particularly favorable for the resilience of the ion nitrided layers and, respectively, for the complex exploitation properties of the layers.

4. CONCLUSIONS

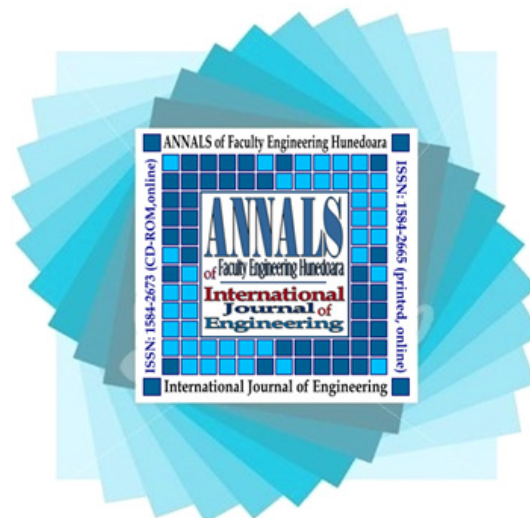
It has been established that after ion nitriding of steels 100Cr6 and 20MnCr5G the surface hardness, which depends on the chemical composition of the investigated steel and on the mode of treatment, increases.

Regression equations for steels 20MnCr5G and 100Cr6 have been derived, describing the dependence between the technological factors and the target parameter, the surface micro-hardness and the total thickness of the nitrided layer.

It has been established that for both steels the maximum thickness of the combined zone is obtained under the following mode of nitriding: $t = 540^{\circ}\text{C}$, $P = 400 \text{ Pa}$, $\tau = 14 \text{ h}$.

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