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SOLUTION OF THE DIFFUSION PROBLEM IN THERMOCYCLIC NITROCEMENTATION OF STEEL

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Abstract. It is shown that cyclic heating and cooling considerably accelerate the kinetics of chemical thermal processing of steels. The author studies the laws of formation of the strengthened layers at thermocyclic nitrocementation of steel 20 Kh. Production tests of machine parts after chemical thermal and chemical-thermocyclic processings were performed. The structure, phase composition and intensity of wear process of a blanket depending on a number of cycles are investigated.

Key words: thermocyclic nitrocementation, steel, diffusive layer, microhardness, wear resistance.

Introduction

Application of chemical heat treatment to superficial hardening of steel products material.

The majority of traditional technologies of chemical heat treatment are carried out at long endurance therefore the most important task is acceleration of diffusive saturation. It is also necessary to provide good mechanical and operational properties of steel. Chemical and thermocyclic processing will be applied for this purpose.

The research of features of formation of structure and properties of diffusive layers in the conditions of saturation is conducted became carbon and nitrogen at cyclic change of temperature. The knowledge of qualitative and quantitative regularities of formation of structural and phase states at thermocyclic influence is the cornerstone of improvement of the technologies of nitrocementation allowing to increase durability and wear resistance of products at operation.

Experiment

In this work, we investigate the influence on the wear resistance temperature and number of cycles on the distribution of carbon and nitrogen through the thickness of the diffusion layer. As well as the formation of structural sites, depending on the carbon content in thermocyclic nitrocementation of steel 20 Kh in the range of 900-600 °C [5; 6].

The chemical composition of this steel is given in Table 1.

It was implemented two modes with number of cycles 6 and 10. For comparison classic mode was carried out at a constant temperature. The carbon potential of the process atmosphere in the upper temperature boundary amounted to 1,0 ± 0,5 % in all experiments. The modes of nitrocementation are shown in Table 2.

The research was carried out on microscope "Neophot-2" at magnifications X400, X1000, X2000. The distribution of carbon and nitrogen through the thickness of the diffusion layer was determined by chemical analysis of the chips layer by layer removed from cylindrical samples with a diameter of 30 mm and length 120 mm the thickness of the release layer was 0,05 mm [1; 4].

Results and discussion

The experimental distribution curves of the carbon layer thickness for the studied modes are shown in Fig. 1.

Comparison of experimental curves of the distribution of the carbon content on the depth of the diffusion layer shows an increase of mass transfer of carbon at thermal nitrocementation, compared with the traditional process at a constant temperature. The curve on the distribution of nitrogen varies insignificantly with changes in the number of cycles.

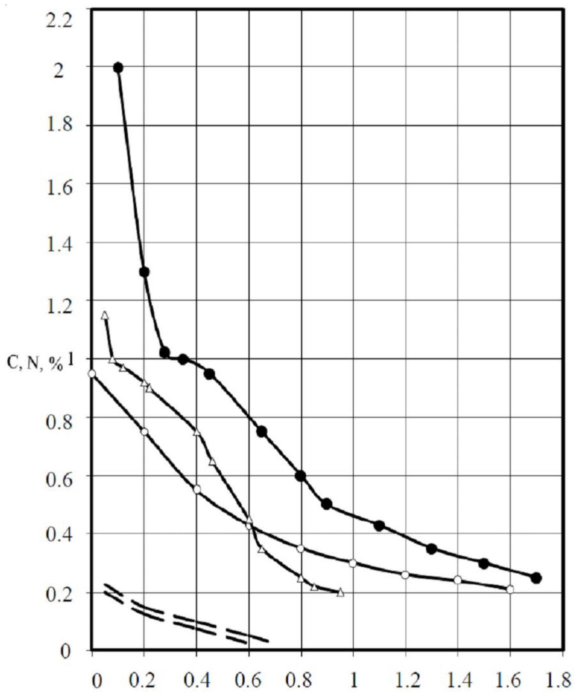


Fig 1. A curve showing the distribution of carbon in depth of the diffusion layer:

• – ten cycles; Δ – six cycles;
o – isothermal nitrocementation, the dotted lines show the interval of nitrogen content in the diffusion layer of all performed experiments

We can assume that the different content of carbon leads to different mechanisms of formation of diffusion layer in each of the plots. Each area of the experimental distribution curve of carbon in the layer depth should be described by its equation.

We also conducted a study of the distribution of microhardness across the thickness of the diffusion layer. The results of measurement of microhardness by the depth diffusion layer for the studied modes of chemical-heat treatment is shown in Fig. 2.

Table 1

Chemical composition of steel 20 Kh

Grade of steel	Chemical composition, %					
	C	Mn	Si	Cr	S	P
20 Kh	0,21	0,58	0,30	0,90	0,015	0,018

Table 2

The modes of nitrocementation of steel 20 Kh

№ experiment	Temperature, °C		The total time of the process, h	Tempering temperature, °C	Number of cycles
	heating	cooling			
1	900	–	7,5	900	–
2	900	650	4,3	900	6
3	900	650	7,5	900	10

Fig. 3 shows the influence of technological mode of nitrocementation on the wear rate.

In the case of single-component thermo-chemical treatment diffusion coefficient is determined by solving the Fick equation. For one-dimensional case, the Fick equation can be represented as:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}, \qquad (1)$$

where: C – the concentration of the introducing element; D – the diffusion coefficient of the element; x – path diffusion element; t – time of diffusion.

In the case of multicomponent diffusion, this equation takes the form:

$$\frac{\partial C_i}{\partial t} = \sum_j D_{ij}\frac{\partial^2 C_j}{\partial x^2}. \qquad (2)$$

That is, the diffusion coefficients D_{ij} are the matrix form. Study of diffusion coefficients enables to obtain additional information about the implementation of elements.

When nitrocementation (two-component diffusion) equation (2) can be converted into a system of differential equations consisting of two equations

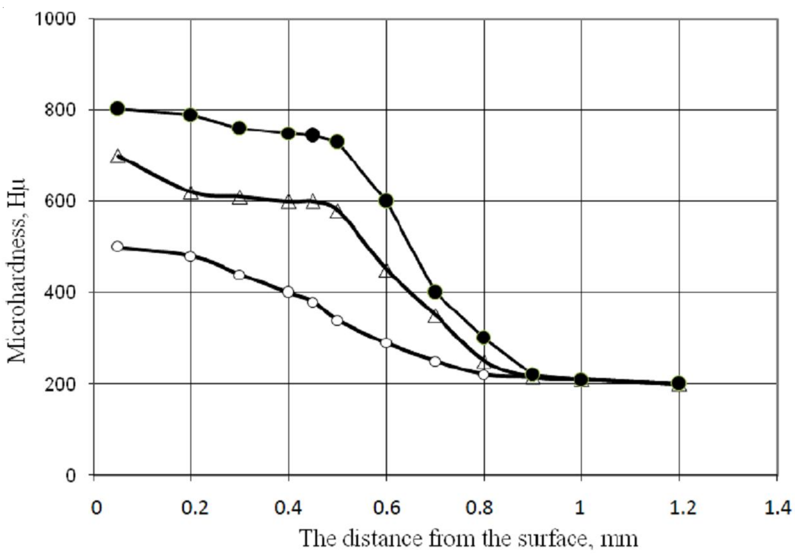


Fig. 2. The distribution of microhardness over the depth of the diffusion layer:
• – ten cycles; Δ – six cycles; o – isothermal nitrocementation

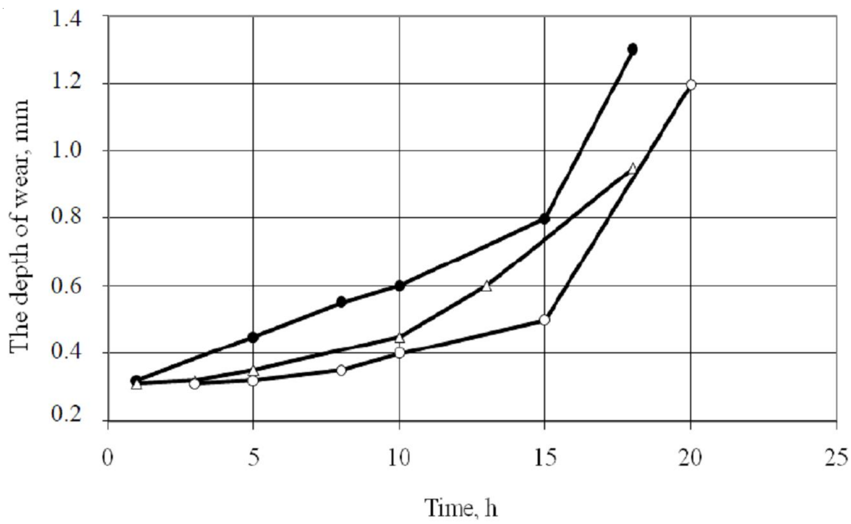


Fig. 3. The dependence of the depth of the layer worn away with time:
• – ten cycles; Δ – six cycles; o – isothermal nitrocementation

$$\frac{\partial C_1}{\partial t} = D_{11}\frac{\partial^2 C_1}{\partial x^2} + D_{12}\frac{\partial^2 C_2}{\partial x^2}$$
$$\frac{\partial C_2}{\partial t} = D_{21}\frac{\partial^2 C_1}{\partial x^2} + D_{22}\frac{\partial^2 C_2}{\partial x^2}, \quad (3)$$

where: C_1, C_2 – respectively the concentration of carbon and nitrogen in the sample as a function of x and t; D_{12} – the diffusion coefficient of carbon in the gradient of nitrogen concentration; D_{21} – the diffusion coefficient of nitrogen in the gradient of the carbon concentration; D_{11} – the diffusion coefficient of carbon under its own concentration gradient; D_{22} – the coefficient of diffusion of nitrogen under the action of its own concentration gradient.

In the literature similar solutions for the system iron-carbon-nitrogen is virtually absent. Typically, the process of nitrocementation is represented as a mathematical sum of two independent processes - carburizing and nitriding. However, the calculations showed that in the austenite (solid solution of carbon in g-iron) carbon and nitrogen displace each other and thereby increase of its thermodynamic activity [2].

The solution of equation (3) with selected boundary conditions was carried out comparatively for four plots, wherein the slope of the curve and the concentration gradient of elements across the thickness of the layer for all the studied modes. The analysis of the data shows that the effective diffusion coefficient of carbon at thermal nitrocementation have larger values than the conventional process, i. e. a cyclic change of temperature accelerates the diffusion of carbon during nitrocementation (Table 3).

As a result of thermal-cycling effects on the material diffusion mobility of atoms of saturation in the steel is increased in 2,5-3 times.

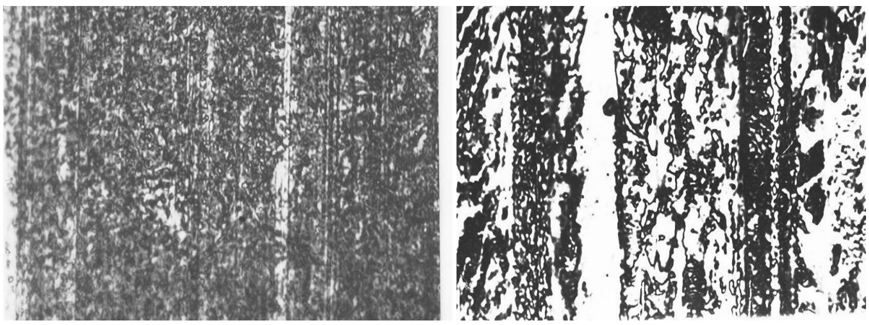
The greatest wear is observed on the samples processed according to the traditional mode at a constant temperature. The least worn specimens were observed after 10 cycles of nitrocementation. Processing steel on thermocyclic modes of nitrocementation can significantly improve the load capacity of friction surfaces. Due to the fact that wear resistance is related to the intensity of structural-phase transformations in deformed micro volumes, of great importance is the study of not only the original structure, but also complex properties emerging in the process of contact interaction. As the wear of the friction surfaces is structurally sensitive characteristic, metallographic investigation of the surface was conducted before and after friction tests [2; 3].

Metallographic investigation of the surface friction showed that after the test the surface after the carbonitriding temperature Cycling did not undergo any significant changes (Fig. 4, *a*). The surface of wear after treatment by serial technology shows traces of plastic deformation of the metal (Fig. 4, *b*).

Table 3

Data for calculation of diffusion coefficient of carbon in steel nitrozomocevina

Regime	The diffusion coefficients of carbon in steel, $D \times 10^{-11}$, m²/s			
	Part 1	Part 2	Part 3	Part 4
Ten cycles	1,09	0,74	0,69	0,54
Six cycles	0,87	0,68	0,33	–
Isothermal nitrocementation	0,49	0,42	0,39	0,34



a *б*

Fig. 4. The structure of the surface wear at magnification X1000:

(*a*) after the thermocyclic nitrocementation 10 cycles; (*b*) after the isothermal nitrocementation

Conclusion

1. The experimental results show that the increase of mass transfer of carbon during the thermocyclic nitrocementation is compared with isothermal nitrocementation.

2. The results of the study show that the thermocyclic nitrocementation provides increased durability.

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РЕШЕНИЕ ДИФФУЗИОННОЙ ЗАДАЧИ ПРИ ЦИКЛИЧЕСКОЙ НИТРОЦЕМЕНТАЦИИ СТАЛИ

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Аннотация. Показано, что циклический нагрев и охлаждение значительно ускоряют кинетику процесса химико-термической обработки стали. В работе исследуются закономерности формирования диффузионного слоя при термоциклической нитроцементации стали 20Х. Описываются сравнительные значения основных показателей механических свойств после химико-термической и химико-термоциклической обработки деталей машин. Изучаются структура, фазовый состав и интенсивность процесса изнашивания поверхностного слоя в зависимости от числа циклов обработки.

Ключевые слова: термоциклическая нироцементация, сталь, диффузионный слой, микротвердость, износостойкость.