а разработка новых рецептов позволит эффективно применять диспергенты в условиях пониженных температур и малой солености.

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High-temperature carbonitriding of steel in an electrostatic field

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Abstract

This scientific article is considered the physical bases and technology of the process of high-temperature carbonitriding (nitrocarburizing, nitrocarburization, nitro-cementation) of steel in an electrostatic field. It is established that an electrostatic field makes it possible to intensify the process of steel nitro-cementation by 1.5 – 2 times. According to the experimental data the diffusion layer formed in an electrostatic field shows higher efficiency of the physical, mechanical and operational properties.

Keywords: carbonitriding (nitrocarburizing, nitrocarburization, nitro-cementation), electrostatic field, physical, mechanical and operational properties, diffusion, mathematical design of experiment.

The development of science and engineering demands the creation of new materials and improvement of quality of existing materials. In this scientific problem the very important role belongs to electro-physical methods of superficial hardening in gas environment. Electro-physical methods of chemical-thermal processing allow not only possible to intensify technological process but also appreciably to raise quality of diffusion layer in a sample [1-5].

This research article considers process of carbonitriding (steel nitro-cementation) in electrostatic field with initial concentration of carbon in a sample at 0.20% (low-carbon steel). Carbonitriding (nitrocarburizing, nitro-cementation) is process of saturation of metals by carbon and nitrogen from gas environment. In our case gas environment was a mix of propane-butane and ammonia.

For the comparative analysis two processes of steel nitro-cementation were chosen: usual and under an electrostatic field at identical gas-dynamic, temperature and other technological parameters, which were chosen by us on the basis of mathematical design of experiment [6,7]. The researches have shown that at the chosen test facility (Fig.1) the

optimum technological parameters made up: use of propane-butane-0.38 l/min ($6.33 \cdot 10^{-6}$ m³/s), use of ammonia-1.88 l/min ($3.08 \cdot 10^{-5}$ m³/s), temperature-8500C, duration of process-2 hours, intensity of an electrostatic field-1.9.10⁵ V/m and negative potential on a sample.

Fig.1. Scheme of the test facility

1-gas-container with propane-butane mix; 2-gas-container with ammonia; 3- exhaust-ventilation; 4-cleaning; 5-reometers; 6-mixer; 7-manometer; 8-potentiometer; 9-gas-pipe; 10-high-tension cable; 11-high-voltage rectifier; 12-control panel; 13-furnace; 14-dead joint; 15-removal used gases; 16-top-shutter; 17-exhaust-ventilation; 18-thermocouple.

As follows from the general principles of kinetic of heterogeneous reactions the total speed at multistage processes is determined by speed of slowest of its. Such stage names as limiting stage. Limiting stage in most cases of chemical-thermal treatment is diffusion. As show our investigations process of steel nitro-cementation is limited by diffusion stage too. In this case the depth of nitro-cementation layer on a surface of steel (h) depends on time (t) under the parabolic law ($h \sim \sqrt{t}$ - Fig.2).

Fig.2. The depth of diffusion layer (mm) under duration of steel nitro-cementation:
1-in an electrostatic field (a sample is cathode); 2- usual process;
3- in an electrostatic field (a sample is anode).

Therefore, first physical part of our researches was calculation of diffusion coefficients of carbon and nitrogen in nitro-cementation layer. A meaning of these factors allows analyzing about efficiency of the chosen technology of superficial hardening.

$$\frac{\partial C_1}{\partial t} = D_{11} \frac{\partial^2 C_1}{\partial x^2} + D_{12} \frac{\partial^2 C_2}{\partial x^2},$$

In our case the task required the decision of system of the differential equations: where:

C_1, C_2 - concentration accordingly of carbon and nitrogen depending on depth of a layer (x) and time of process (t); D_{12} – coefficient of diffusion of carbon under action at a gradient of concentration of nitrogen; D_{21} - coefficient of diffusion of nitrogen under action at a gradient of concentration of carbon; D_{11} - coefficient of diffusion of carbon under action at an own gradient of concentration; D_{22} - coefficient of diffusion of nitrogen under action at an own gradient of concentration.

This system of the equations was solved by an operational method on the basis of dates of the level-by-level chemical analysis of the contents of carbon and nitrogen in a layer [4,5]. The generalized results are shown in the Table 1.

Table 1.

Diffusion coefficients of carbon and nitrogen in nitro-cementation samples

Nitro-cementation	Diffusion coefficient, $10^{-11} \text{ m}^2/\text{s}$					
	D_{11}	D_{12}	D_{21}	D_{22}	D_1	D_2
Usual process	0.40	0.06	0.002	0.46	0.44	0.42
In electrostatic field	1.00	0.03	0.007	0.75	1.05	0.74

The note: in the table D_1 and D_2 – diffusion coefficients accordingly of carbon and nitrogen without interaction of the introduced elements.

The analysis of the received data has shown that diffusion coefficients of the introduced elements at nitro-cementation in an electrostatic field (D_e) have the large values, than about usual process (D_u). So, for carbon $D_e/D_u=2,4$, and for nitrogen $D_e/D_u=1,8$.

These data show that the acceleration of diffusion process is caused not only gradient of concentration of the introduced elements, but also presence of an electrostatic field in a superficial zone of an explorer.

The following step was the comparative analysis of structure and phase structure of diffusion layer. In Fig. 3 are known the microstructures oh nitro-cementation layer by depth of 0.55 mm formed in steel by usual technology (left side) and in an electrostatic field (right side) at optical increase in 100 times.

It's possible to observe that in usual diffusion layer there are three zones: outside, under-layer and transitive. Outside zone consists from finely needle martensite, some residual austenite and inclusions of fine particles at carbonitrides. Behind an outside zone is deep enough martensite-austenite under-layer basing on fine-dispersed ferrite-cementite zone of transition to a structure of a core. The nitrocementation layer in an electrostatic field is characterized by smooth transition of structure from a surface to a core [3,5,8]. Its layer has a fine-dispersed structure.

Fig.3. Microstructure of a nitro-cementation layer by depth of 0.55 mm formed in steel by usual technology (left side) and using an electrostatic field (right side)- x 100 times

Analysis by X-ray shows multiphase structure of a superficial zone of nitro-cementation layer (Fig. 4).

Fig.4. Level-by-level diffractograms of nitro-cementation layer formed by usual technology (left side) and using an electrostatic field (right side)

In a layer formed in absence of an electrostatic field (Fig. 4 - left side), except for α - and γ -phases, carbonitrides are formed of structure saturated by nitrogen cementites $\text{Fe}_3(\text{C},\text{N})$ and, probably, carbonitrides of hematite- and magnetite-structure of the type Fe_2O_3 and Fe_3O_4 . The researches of phase structure of a nitro-cementation layer, formed in an electrostatic field (Fig. 4 - right side), also have revealed presence in its outside zone of α - and γ -phases. Carbonitrides of hematite- and magnetite structure were not reveals. Such structure of an outside zone is up to such fine-dispersed that it can be seen at optical increase not less than in 500 times. The comparative analysis of the sizes of carbonitrides, formed under usual technology and in an electrostatic field, has shown that use of an electrostatic field reduces the sizes of particles approximately by three times: from 0.3 – 3.0 up to 0.1 – 1.0 microns.

For comparative study of mechanical and operational properties of samples nitro-cementated in an electrostatic field and under usual technology the complex of tests was used: at stretching, static bend, endurance, shock viscosity, wear-resistance, hardness and microhardness. In all cases the depth of a diffusion layer was constant and laid within the limits at 0.55 – 0.60 mm.

Fig.5.

Influence of tempering on mechanical properties of nitro-cementation steel formed in electrostatic field: HV- Vickers hardness, $\sigma_{\text{бу}}$ -durability at static bend, σ_1 – limit of endurance, W-wear-resistance(optimum of tempering is 180-2000C)

Fig.6.

Wear-resistance of nitro-cementation layer formed: 1-in electrostatic field, 2-by usual technology

The results of tests have shown that the application of an external electrostatic field at its optimum parameters considerably raises mechanical and operational properties of diffusion layer: durability at static bend by 40%, limit of endurance by 47%, wear-resistance by 50% (Fig. 5,6). The appreciable increase of hardness and microhardness of diffusion layer formed in an electrostatic field is observed too.

Summary

An electrostatic field makes it possible to intensify the process of steel nitro-cementation by 1.5 – 2 times.

Solution of the general problem of diffusion allows for the non-diagonal diffusion coefficients to be estimated. Coincidence of diffusion coefficients D_1 and D_{11} as well as D_2 and D_{22} within the experimental approximation shows the insignificance of the flux interaction at carbon and nitrogen diffusion in steel.

The diffusion layer formed in an electrostatic field has a fine-dispersed structure, is characterized by smooth transition of structure from a surface to a core and by significant size of tetragonal lattice of nitric martensite phase.

According to the experimental data the diffusion layer formed in an electrostatic field shows higher efficiency of the physical, mechanical and operational properties.

The technology of steel nitro-cementation in electrostatic field can be recommended for superficial hardening of metals' details including agricultural assignment.

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