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## Technological Methods of Boriding Products from Stainless Alloys Operating in Aggressive Conditions

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***Introduction.*** The durability and other performance characteristics of machine parts are largely determined by physical and chemical state of thin surface layers. The localization of hardening processes in these layers serves as a significant reserve for increasing the service life of parts while reducing the cost of manufacturing materials. One of the most progressive directions of strengthening technology is the application of protective coatings on the working surfaces of machine parts.

The article investigates the process of sintering compacts from steel PKh23N18 in boron carbide powder in containers with a fusible seal. It has been established that sintering in such containers provides high mechanical characteristics of sintered steel with good reproducibility of the sintering process.

***Problem Statement.*** To improve corrosion resistance, as well as to improve wear resistance of friction surfaces of products and machine parts operating in aggressive environments, it is necessary to choose a rational technology of chemical-thermal treatment that allows increasing the mechanical and technological properties of products.

***Theoretical Part.*** As a theoretical description, the use of various methods of stainless steel boriding is analyzed, and the dependences of changes in the mechanical and technological properties of samples on various boriding schemes and methods for obtaining samples are considered.

***Conclusions.*** It was established in the work that the increase in strength of samples subjected to boriding sintering in an autonomous gaseous medium occurred due to the absence of oxidation and deep saturation with boron (volumetric strengthening) through the vapor-gas phase. The use of container technology makes it possible not only to simplify the technology, but also to ensure the preservation of material properties, regardless of the presence of a protective gaseous medium in the thermal shop.

***Keywords:*** stainless steel, boriding, oxidation, sintering, mechanical properties.

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**Introduction**. It is known that chemical-thermal treatment is an effective way to increase physical and mechanical properties of sintered materials, as well as to give them a complex of required performance characteristics [1–4]. Boriding of sintered materials makes it possible to increase their hardness, wear resistance, as well as acid and heat resistance [3–5]. Earlier [6], the process of boriding sintering of stainless steel powders in a mixture of boron carbide with borax in a protective environment of drained hydrogen was investigated. This made it possible to create a corrosion- and wear-resistant borated friction pair designed to work in aggressive liquid media. However, for the introduction of a particular type of chemical-thermal treatment into production, it is important to preserve the reliability (stability) and simplicity of the technology during the transition from laboratory to production conditions.

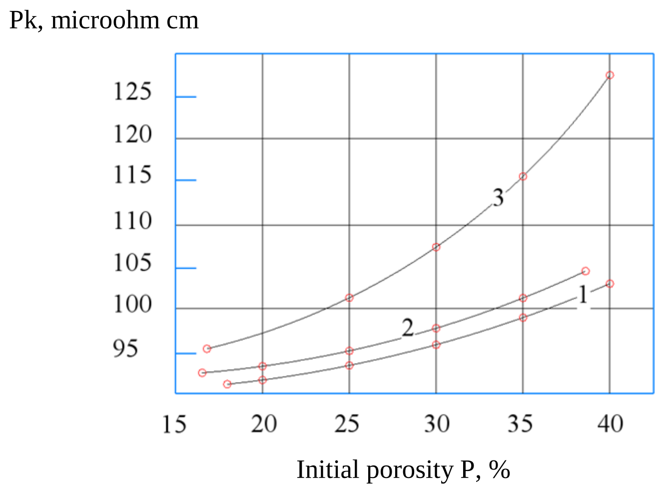
The **Aim** of the work is to study the boriding process at various temperatures, to conduct a microstructural analysis of the surface layer, as well as to study the sintering process of porous workpieces of steel PKh23N18 together with boron carbide powder in containers with a fusible seal. It is necessary to establish the dependences of the change in resistivity, mechanical properties on the density of the resulting pressings and the method of borating sintering.

**Problem Statement.** To create wear-resistant parts with high technological and mechanical properties, it is necessary to provide reliable chemical and thermal technology that will be introduced into production. To do this, it is necessary to conduct a series of experimental work to determine the dependencies of mechanical and technological properties on the boriding method, porosity of samples.

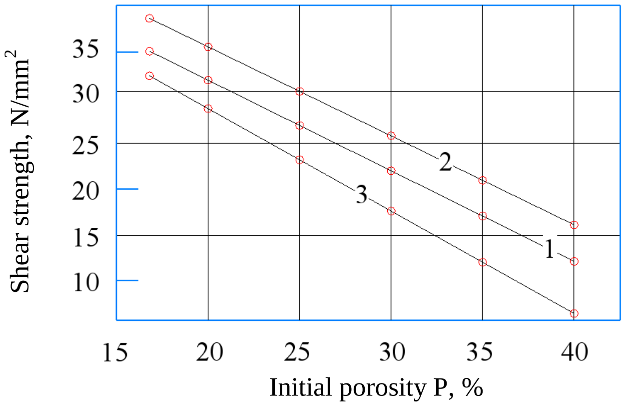
**Theoretical Part.** The technology of boriding sintering of porous blanks in a backfill from a mixture of boron carbide with borax is difficult for production conditions, since the extraction of parts from the sintered backfill (due to melting and crystallization of borax) and their cleaning from the stuck borax and boron carbide presents certain difficulties. In addition, such a backfill must be ground and mixed with a fresh mixture before reuse. Therefore, it was necessary to investigate the possibility of replacing the sintering borating backfill with a non-baking one.

It was found in [7–9] that when boriding cast steels, a dense boride layer is formed in technical boron carbide, the powder is not sintered and can be repeatedly used without any additional operations.

However, boriding sintering in boron carbide in flowing dry hydrogen with a dew point of -30 °C of porous samples made of PKh23N18 steel led to their partial detachment.




*a*)

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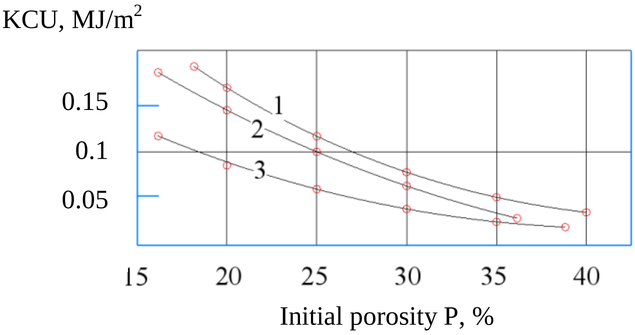


*c*)

Fig. 1. Dependence of changes in electrical resistivity (a), shear strength (b) and impact strength (c) of steel PKh23N18 on the initial porosity and boriding method: 1 — a sample containing borax, sintering in a hydrogen flow with a dew point of -30 °C; 2 — a tempered B4C sample, sintering in containers with a fusible seal; 3 — a tempered B4C sample, sintering in a hydrogen flow with a dew point of -30 °C

This is evidenced by the reduced strength and higher electrical resistance of samples subjected to boriding sintering in boron carbide (Fig.1 *a*, curve 3), compared with samples that underwent the same boriding sintering, but in a backfill containing borax (curve 1). Therefore, it seemed appropriate to use containers with a fusible seal for boriding sintering in boron carbide, which, as shown in [10], allow sintering stainless steel without traces of oxidation. Samples of their stainless steel PKh23N18 (5×4×40 mm in size) of different porosity were sintered in an autonomous gas medium (in a container with a fusible seal) in a backfill of boron carbide.

The study of the depth of the boride layer, shear strength, impact strength and electrical resistance of samples subjected to boriding sintering shows (Fig. 1 *a*, curves 1-3) that these characteristics, despite the identical temperature and holding time, significantly depend on the combination of properties of the borating backfill and the protective medium.

The studies of the boriding regime were carried out at different temperatures. The samples were heated to temperatures of 1050-1150 °C in increments of 50 °C. The processing time at all temperatures was 240 seconds, the current density was 0.4‒0.7 A/cm$^2$.

The analysis of the data obtained shows that when the samples were heated to a temperature of 1150 °C, it contributed to the formation of boride eutectic, the microhardness of which is 16 hPa (light zones) and ferritocarbide base, the microhardness of which is 5 hPa (Fig. 2). This is followed by a transitional carbonized sublayer, behind which the initial ferrite-pearlite structure of the sample is formed.

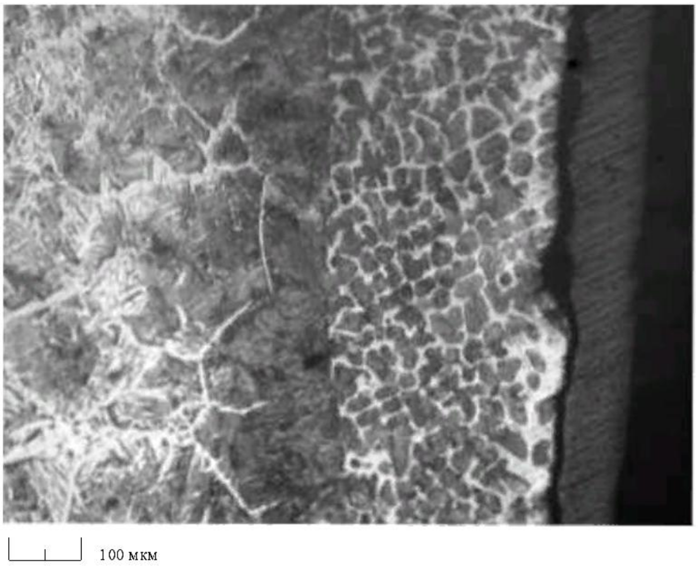


Fig. 2. Boride eutectic and the initial ferrite-perlite structure of the sample after heating to a temperature of 1050 °C

To determine the content of elements in boride eutectic and ferritocarbide-based layer, an electron microprobe analysis was performed. Figure 3 provides images of the borated layer obtained on a scanning electron microscope.

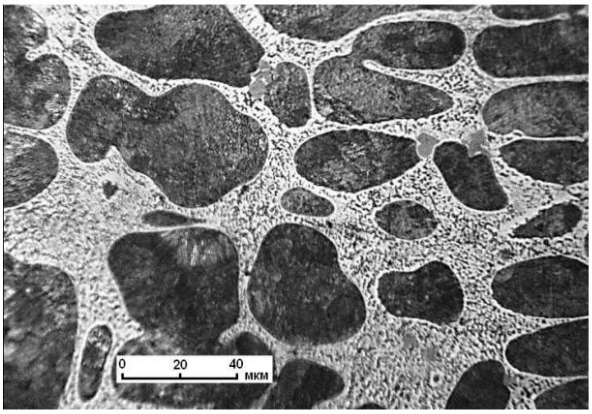


Fig. 3. Microstructure of boride eutectic after heating to a temperature of 1050 °C, obtained on a scanning electron microscope

X-ray phase analysis shows the presence of boron borides $Fe_2B$ and cementite $Fe_3C$ in the diffusion layer (Fig. 4). In addition, X-ray diffraction lines of boron carbide $B_{11.5}C_{2.85}$ with the ratio B:C were detected on the diffractogram, slightly different from the normal stoichiometry of $B_4C$ carbide.

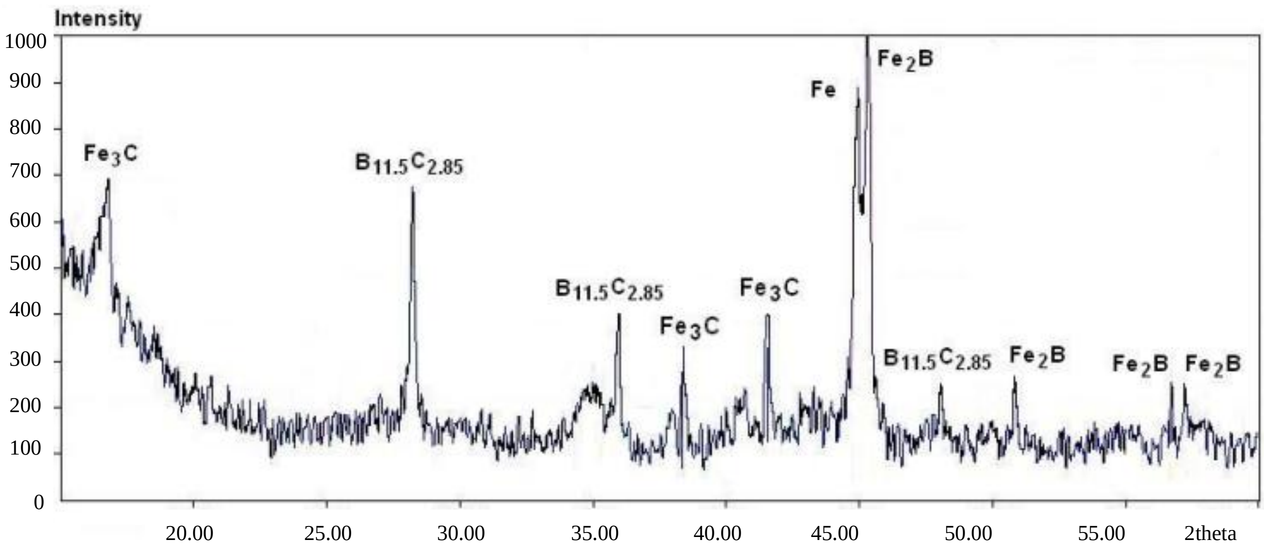


Fig. 4. X-ray diffractogram of the sample surface after boriding

The results of the experiment have showed that when the samples were heated to a temperature of 1250 °C, no boride layer was detected (Fig. 5). During the macrostructural analysis of the surface of the samples, the following defects were revealed in the form of penetration of the ends and the radial surface (the diameter change was 0.5 mm at the heating point and 0.3 mm at the ends). This is explained by the fact that under the influence of high temperature, the formed boride eutectic melts and shifts to the edge of the sample (to the end). Without a boride layer, the microhardness of the steel material was 3.5 hPa.

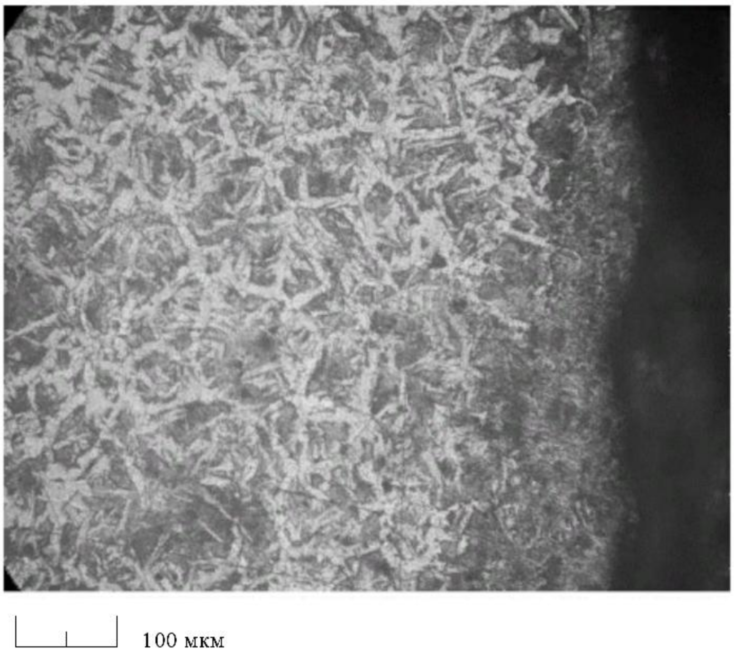


Fig. 5 Microstructure of the surface of a steel sample obtained at a temperature of 1250 °C

The experimental data analysis has showed that the formed boride layers on the material under consideration have a eutectic basis. At the same time, the samples were subjected to temperature exposure for 240 seconds. Samples heated to a temperature of 1160 °C have a high concentration of boron at the grain boundaries, as a result of which more liquid phase is formed, which contributes to the formation of a better layer. In the temperature range of 1050-1150 °C, a boride layer is obtained on the surface of the samples with places of boride eutectic along grain boundary sections of a solid solution of boron and carbon in Feα. A further increase in temperature leads to oversaturation of the surface boundaries with boron to the state of maximum eutectic concentration, melting of boride eutectic and its grain boundary slippage.

Unlike boriding sintering in flow hydrogen, sintering in a container with a fusible seal in an autonomous gas medium created by additives decomposing during heating (for example, paraffin or titanium hydride) allows you to completely protect porous stainless steel from oxidation and promotes mass transfer as a result of saturating diffusion of boron into unsealed porous material along pores and grains boundaries inside the product, and due to the sintering itself. The samples subjected to boriding sintering in a container with a fusible seal in a non-baking borating backfill have the greatest shear strength (Fig. 1, curve 2).

**Conclusions.** In addition to the temperature effect on the value of the interparticle melting of the surface of the material, the exposure time of the samples at the temperature conditions under consideration also has a great impact. With an increase in the temperature of the boriding process, boron oversaturation occurs to the maximum eutectic concentration and its grain boundary slippage. It is obvious that in order to obtain high-quality layers with boride eutectic sections along the grain boundary sections of the ferritocarbide matrix, constant monitoring of the process temperature and the holding time of the material at a given temperature should be carried out.

The obtained test results show that the strength increase in the samples subjected to boriding sintering in an autonomous gas medium occurred due to the absence of oxidation and deep saturation with boron (volumetric hardening) by means of the vapor-gas phase [11, 12]. The use of container (autonomous) technology for boriding sintering of porous stainless steels in a non-baking borating backfill makes it possible not only to simplify the technology, but also to ensure the preservation of material properties, regardless of the presence of a protective gas environment in the hardening shop.

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*Claimed contributorship:*

M. S. Egorov — formulation of the main concept, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions, Y. M. Dombrovsky — formulation of the main concept, goals and objectives of the study, academic advising, text preparation, formulation of the conclusions; G. G. Tsordanidi — calculations, analysis of the research results, revision of the text, correction of the conclusions; R. V. Egorova — academic advising, analysis of the research results, revision of the text, correction of the conclusions.