Various methods of thermodiffusion saturation with boron [1-3] are recommended for the hardening of tool steels: liquid and gas boriding, as well as boriding using powder mixtures, which ensure high hardness and thermal stability of the diffusion layers.

In selecting the method of boriding tool steel 4Kh5MFS, it was established that this steel is a basic material for the fabrication of aluminum and magnesium alloys that are complex with respect to the configuration of the injection mold. The molds are later subjected to quenching and tempering for a hardness of 45-48 HRC; the working surfaces of the molds should exhibit high purity, and uniformity and continuity of the thermodiffusion layer after boriding. The purpose of this study is to search for a method and procedure for the boriding of the structural components of molds, which soften thermally under the metal being poured under pressure.

Analysis of methods of saturating the surface layer with boron indicated that a significant drawback of electrolysis boriding is warping of the mold components as a result of the nonuniform deposition of boron on the different sides of the components, which is associated with the complex character of the distribution of equipotential current lines in the electrolyte. In addition to a whole series of advantages, boriding from pastes in an oxidizing-reducing medium has certain significant disadvantages: high-temperature drift of paste from projecting elements of the impressions on the mold components and the poor quality of the borided surface.

Liquid and gas boriding requires appropriate apparatus to conduct saturation, and in the case of gas boriding, moreover, it is necessary to synthesize the boron-containing gaseous products, for example, diborane.

It is proposed to conduct the boriding of mold components from the gas phase to eliminate direct chemical interaction between the boriding mixture and surface being treated.

Boriding from the gas phase occurs as a result of disproportioning reactions, which take place with the formation of a solid solution of boron and corresponding borides on the surface of the steel [4]. In this case, saturation with boron may take place both directly from the gas phase, and also form the melt of the $B_2O_2$-$B_2O_3$ system, which is formed during condensation of vapors on the articles being borided and which contain bivalent and trivalent boron ions.

The introduction of sodium fluoride-type activators to the saturating mixture changes the composition of the gas mixture. The compounds $BF_2$ and $BF_3$ become boron-containing components in this case. To shift the reaction in the direction of the formation of iron borides, it is necessary to minimize interaction between the boron ions and oxygen and to remove the gaseous products $O_2$, $CO$, and $CO_2$ from the reaction zone.

Boron carbide, sodium tetraborate, and sodium fluoride were introduced to the composition of the boriding mixture. The percentage of sodium tetraborate ranged from 5 to 20 by mass, and the sodium fluoride content was maintained at a constant 15%. The temperature interval of boriding was 950-1050°C, and the boriding lasted for up to 5 h.

The boriding mixture, which consisted of 65% of boron carbide, 20% of sodium tetraborate, and 15% of sodium fluoride was found most effective. Boriding was carried out in container 1 (Fig. 1), inside of which was placed cast iron frame 2 having notches on the flat surface, which are required for the installation of components 3 being treated. The thickness of the layer of mixture 4, which was placed on the bottom of container inside the cast-iron frame,
was selected so that the effective surfaces of the components being treated could not come in direct contact with the boriding mixture. At the same time, the gases that formed during interaction between the components of the boriding mixture ascended toward the top and washed the effective surfaces of the components being treated. Cover 5 with openings, which was filled with dry cast-iron chips 6, was installed in the container from above.

The diameter and number of holes in the cover and the height of fill layer 7 (treated powder mixture) were calculated to ensure the unrestricted venting of gases from the container; the cast-iron chips, which were burned at high temperatures, were introduced to protect the cavity of the container from the penetration of air from the furnace space.

The effective surfaces of the components being treated had a roughness of not less than Class 7 in accordance with GOST 2789-73, and the formation of a layer of scale 0.1-0.3 mm thick was observed on the surfaces in direct contact with the boriding mixture.

Metallographic analysis indicated that a continuous and uniform diffusion layer 80-130 μm deep, which differs markedly from the metallic base in terms of the structure itself, formed on the surface of steel 4Kh5MFS steel. The results of microhardness measurements (with a load of 0.1 N on the indentor) across the thickness of the borided layer are presented in Fig. 2. The maximum microhardness of 1400-1500 H was observed on the surface of the diffusion layer, and the microhardness diminishes to 400-500 H on advancing into the depth of the metal. A stable anomaly in the sectional distribution of the microhardness of various specimens is observed in this case — a microhardness "trough" was detected on the boundary between the diffusion layer and metallic base.

Hardening with this method of treatment is achieved as a result of the formation of super-hard iron borides in the diffusion layer. It is known that the solubility of boron in ferrite is 0.0020% at t = 850°C; above this concentration, therefore, boron will form two compounds with iron: high-boron (FeB) and low-boron (Fe₂B) phases.

The high-boron and low-boron phases possess different properties [5, 6, 7]. The introduction of boron to the surface of the metal gives rise to the development of significant compressive stresses in the layer and on the layer/metal boundary, which convert to tensile stresses at a certain distance. Voroshnin and Lyakhovich [3] point out that a developed transition zone, which is a solid solution of alloying elements in iron and which exceeds the "boride" zone in terms of thickness, can form beneath the continuous layer of borides from the start of saturation to the moment of formation of this layer.

The results of investigations that we conducted by the method of Auger spectroscopy on an EOL10 instrument confirm the data of this study (Fig. 3). The thermodiffusion layer actually consists of two zones: immediately, a boride zone with a thickness δ = 25-30 μm, and a transition zone with δ = 55-90 μm. No boron is detected in the transition zone. The formation of the transition zone is most likely associated with the complex mechanism of the diffusion redistribution of alloying elements over the entire thermodiffusion layer.