Research on the chance of increasing the wear resistance of high-speed steel Using chemical thermal treatment methods

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Abstract. The thermal borating methods from powder environment under heating conditions in a chamber furnace in order to determine their effect on the change in the structure and wear resistance properties of high-speed steel P6M5 was simulated by using Al2O3 to form neutral saturating environment. The simulated borating conditions included both saturation without heat treatment, and saturation with twin complex heat treatment in the form of quenching directly after borating, followed by tempering at a temperature of 200 °C for decrease tensions. The structures were researched in the directions of along and across the rolling, because this steel is prone to structural heterogeneity. The chamber with an operating temperature of 1250 °C was used as heat treatment device. It is shown that thermal treatment modes, used in boronizing steels, slightly changes the structure of the core of P6M5 steel and does not lead to a significant decrease in its mechanical properties, which makes it possible to successfully combine boronization with the final heat treatment of high-speed steel. Regardless of the speed of cooling, the hardness of P6M5 steel is decreased insignificantly. It was noted that heat treatment in powdered saturating environment without a fuse or the use of a protective atmosphere does not lead to negative consequences for the structure and wear resistance properties.

1. Introduction

The cutting processing is the most commonly used to shaping operation, therefore increasing the resistance of tool materials for machining is one of the main tasks of modern materials science. High-speed tungsten-containing steel is widely used as a material for the manufacture of cutting, punching and other tools due to the high complex performance properties: hardness, viscosity, red hardness, etc. [1, 2].

Increasing the resistance of the high-speed tool is possible by diffusion saturation of the surface layer with such elements as boron, titanium, chromium, etc. [1, 2]. At the same time, the operating conditions of a particular tool are taken into account. It is considered that the time-temperature method of thermochemical processing (TCP) of these steels, such as carburizing, borating, titration, silicification, etc. is incompatible with the standard method of their heat treatment and can lead to a significant deterioration in the structure and a decreasing in mechanical properties[1, 2]. The behavior of PVD coatings in the turning of austenitic stainless steels was studied, four coatings were tested:
AlTiSiN (nACo®), AlCrSiN (nACRo®), AlTiN and TiAlCrN [2, 3]. Research on Dry turning of AISI 304 austenitic stainless steel using AlTiCrN coated insert produced by HPPMS technique was carried out [3, 4]. In this paper, we investigated the possibility of increasing the wear resistance of high-speed steel which is used to create a cutting tool.

2. Research material and methods
The high-speed steel P6M5 was used as the example in our research work, which is the most used steel for cutting tools (drills, taps, reamers, etc.). Hardening was carried out by thermochemical processing (TCP) - complex diffusion saturation with boron and chromium-borochromination. According to the recommendations [5, 6], saturating coatings based on boron carbide containing activated boron and chromium atoms were used as the diffusant-containing substance. The saturation temperature was 1150°C, the saturation time was 2.5 hours. The processing of samples of steel P6M5 was carried out according to recommendations [7, 8]. Samples was removed from the oven after heat treatment, and quenched in oil. Samples of steel P6M5 were not tempered, because thin surface layer, which is no more than 0.5 mm in thickness, was treated. Cutting of samples for metallographic research was carried out with abrasive wheels based on cubic boron nitride on a precision cutting machine "MicroCut-201", and then pressed into a phenolic resin on an automatic press "MetaPress" [7, 8]. Mechanical grinding was performed on an automatic polishing machine "DigiPrep", after which electrolytic polishing and etching were carried out. The obtained microstructures were examined on an optical microscope "Carl Zeiss Axio Observer Z1m" zooms x200 and x500 with fotofixation by the digital camera AxioCAM.

The resulting structures are shown in Figures 1(a)-(d). The structure (see Figure 1 (a)) and microstructures (see Figure 1 (b, c, d)) show that a diffusion layer with a thickness of 15-25 μm was formed. The structure of this layer is classical for boride diffusion coatings, needle-like, but the needles are strongly blunted and form an almost continuous layer, which is explained by the high content of alloying elements: carbon, tungsten and molybdenum, which limit the diffusion of boron deep into the interior [9, 10].
The thickness of the diffusion coating, according to durometric research, is 30 μm, and the total thickness of the strengthened layer, including both the diffusion layer itself and the transition zone, reaches 60 ± 65 μm. Thus, the possibility of hardening the cutting tool from high-speed steels by thermochemical processing (TCP) is shown. Subsequently, in order to generate objective data on the effect of heat treatment on the structure and properties of high-speed steel, a simulation of the process of thermal impact on samples of steel P6M5 was carried out.

To simulate a saturating environment, chemically and thermochemically neutral medium was used with Al2O3 aluminum oxide [11, 12]. Thermophysical parameters (thermal conductivity, heat capacity, heat transfer) of aluminum oxide are approximate to the thermophysical parameters of saturating mixtures based on boron carbide, often used for borating steels throughout the temperature range of the thermochemical treatment [13-15]. The simulated borating conditions included both saturation without conjugate heat treatment and saturation with conjugate heat treatment in the form of quenching directly after borating, followed by tempering at a temperature of 200 °C to decrease tensions [16-18].

In the process of modeling, a chamber high-temperature furnace of the SNOL type equipped with a programmable PID controller "THERMODAT-16E3" with a maximum operating temperature of 1250 °C was used as the heating device. The samples were cylinders with 15 mm in diameter and 15 mm high from the rolled steel of high-speed steel P6M5. Structural research had been carried out in the directions along and across the rolling because the steel P6M5 is prone to structural heterogeneity. The initial structural heterogeneity (banding) of rolled metal corresponded to 1 point. The choice of the modes of thermal and thermochemical treatment was carried out in accordance with the recommendations given in [19, 20]. The mode that combines quenching in oil at a temperature of 1250 °C and a three-fold tempering at 550 °C [21] had been chosen as reference version. The simulated boration modes were for heating the samples, placed in an aluminum oxide container, up to 950 °C of and holding at this temperature for 1.5 hours, after which some of the samples were cooled together with the furnace to a temperature of 300 °C. Then the containers with samples were removed from the furnace, cooled on air to a temperature of 60-80 °C, and unpacked. Another part of the samples to be quenched: was extracted from the furnace, immediately unpacked, cooled in oil and tempered at a temperature of 200 °C to decrease tensions. The residence time of the quenched samples in the open air did not exceed 2 sec, because self-shielding saturating media [22-24] are planned to be used for further borating, not involving the use of a fusible shutter. Metallographic researches were carried out through the Thixomet Pro software and hardware system [25, 26]. Quantitative and qualitative research results, such as the density of carbides, their average size, hardness, are presented in Table 1.

3. Results and discussion

Conducted metallographic researches have shown that after traditional heat treatment in steel P6M5, it remains an insignificant structural heterogeneity corresponding to 1 point. The hardness of the sample is 64.2 HRC. The density of carbides in the direction along and across the rolling direction was 3.0 and 1.2 million pieces / mm², respectively; the average diameter of the carbide particles was 2.39 and 1.62 μm, respectively.

The microstructure of the sample core after heat treatment in mode 2 is shown in Figure 2. The microstructure of the steel after heating, placed in a container with aluminum oxide, together with the furnace to a temperature of 950 °C, holding at this temperature for 1.5 hours and then cooling with the furnace at a rate of 50 °C / h to a temperature of 300 °C, and then cooling the container with the packed samples in the air to a temperature of 60-80°C with an average speed of 30 °C / h.

During tempering, there is a growth in the size of the carbide particles due to their coagulation, as well as an increase in their quantity due to the precipitation of carbide particles from the solid solution [27, 28]. In this case, the density of carbide particles decreases by a factor of 4 along the rolling direction, while across the rolling direction it increases by a factor of 6. Meanwhile, the hardness of steel decreases to 61 HRC. The average size of the carbide particles decreases, and the volume fraction
of the carbide phase increases by 1.5 times along the rolling direction and decreases by 1.4 times across the rolling direction. Structural heterogeneity (banding) also increases, but is within 1 point in accordance with GOST 5640-68.

**Table 1.** Physical and mechanical properties of P6M5 steel after heat treatment.

| Direction of microstructure research | Grain score | Hardness, HRC | Density of carbides, pcs/mm² | Average size of carbides, microns | Volume fraction of carbides, % |
|-------------------------------------|-------------|--------------|------------------------------|----------------------------------|------------------------------|
| Along rolling                       | 11          | 64.2         | 3 043 509                    | 2.39                             | 14.3                         |
| Across rolling                      | 12          | 64.0         | 1 216 913                    | 1.62                             | 15.7                         |
| Quenching with 1250 °C at oil and 3 fold tempering for 550 C (mode 1) | | | | | |
| Along rolling                       | 12          | 60.8         | 759 841                      | 2.13                             | 21.3                         |
| Across rolling                      | 10          | 61.0         | 7 472 743                    | 1.30                             | 10.9                         |
| Annealing at 950 °C for 1.5 hours, cooling with oven to 300 °C and then - in air (mode 2) | | | | | |
| Along rolling                       | 12          | 60.7         | 940 340                      | 2.46                             | 28.60                        |
| Across rolling                      | 11          | 60.5         | 753 539                      | 1.96                             | 8.98                         |
| Quenching from 950 °C, 1.5 h, oil. Leave at 200 °C, 2 hours (mode 3). | | | | | |

When quenched from temperature of 950°C followed by tempering, there is an increasing in the size of carbide particles due to their coagulation, as well as decreasing in their quantity by braking the process of separation of carbide particles from a solid solution due to abrupt cooling [29, 30]. The density of carbide particles decreases by a factor of 3 along the rolling direction, and by 1.6 times across the rolling direction. The hardness of steel decreases to 60.5 HRC. The average size of carbide particles increases, and the volume fraction of carbide phase - increases by 2.0 times along the rolling direction and decreases by 1.7 times across the rolling direction. Structural heterogeneity (banding) is decreased. At the same time, there is a precipitation of darker particles, presumably complex carbides of tungsten and molybdenum, in larger parts of the carbides.

![Figure 2](image-url)
4. Conclusions
Thus, we have determined that irrespective of the cooling rate with a temperature of 950 °C, the hardness of P6M5 steel is reduced insignificantly (no more than 3.5 HRC) compared to the hardness after cooling with the higher heating temperature traditionally used for this steel. Researches of steel samples Р6М5 after heat treatment through thermochemical processing (TCP) don’t contradict earlier results on various steels, and lead to the conclusion that there is the possibility to recommend heating and holding at a temperature of 950 °C with direct quenching from this temperature for boriding of high speed steel P6M5.

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