Quality assurance for the production of metal-cutting tools from high-speed steels

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Abstract. The paper presents an analysis of the state of metal cutting tools production in Russia, and it provides an assessment of the main trends in the development of this industry on the example of tools produced under conditions of domestic engineering enterprises. The developed and tested methods of quality control of high-speed steels of traditional and powder versions are described. Based on the undertaken studies, typical structural defects of high-speed steels in the delivery state and after heat treatment are identified. Recommendations aimed at improving the tool quality were developed and formulated taking into account an analysis of their operating conditions and in accordance with specific conditions of production and quality of steels in the delivery state. A methodological approach to solving the problem of improving the quality of metal-cutting tools made from traditional and powdered high-speed steels is presented.

1. Introduction
The importance of cutting tool production from domestic tool steels increases due to intensification of the mechanical engineering development. Meanwhile, an analysis of the state of the tool market for the production of cutting tools from high-speed steels indicates the presence of a tendency to displace domestic tools with foreign ones. At the same time, there is loss of competitiveness of the domestic tools, both in price and in quality.

A modern world tool market is constantly evolving. The main reserve for improving the quality of tools is improvement of tool materials, as well as their production technology.

Analysis of the problem of cutting tool production shows that there are the following main trends in improving the materials for their manufacture:

- creation of cast tool materials with a narrow specialization of their use;
- development and implementation of powdered tool steels and hard alloys;
- creation of tools with coatings and improvement methods for applying coatings to tool materials.

High-speed steel is currently one of the main tool materials. This is explained by a fairly acceptable combination of basic and technological properties. In terms of their basic properties, high-speed steels occupy an intermediate position between non-heat-resistant alloyed tool steels and hard alloys. Compared to non-heat-resistant steels, high-speed steels can work in more severe cutting conditions; with respect to hard alloys, they have advantages in technological properties. This allows to produce a variety of metal cutting tools of complex design and a large range out of them. [1]

The tool quality is formed at all stages of its production. In this work, we analyzed the formation of tool quality depending on the method of production of high-speed steels, as well as on the quality of the steels in the state of delivery and subsequent heat treatment.
Research was conducted in the field of production of cutting tools from high-speed steels in the following areas:

- analysis of the tool production state;
- improvement of in-process monitoring of steel quality in the delivery state, as well as heat treatment quality in tool manufacture;
- identification of typical deviations of the microstructure and properties of steels, as well as their elimination methods;
- development of recommendations for the use of modern promising high-speed steels.

2. Research technique

High-speed steels are complex alloyed steels of carbide class. They are subjected to specific heat treatment, namely, high-temperature hardening in the temperature range 1180-1280 °C with subsequent two-three-time tempering at temperatures 550-560 °C one hour each. The chemical composition and heat treatment of steels to a large extent determine their basic properties - rigidity, heat resistance, durability and impact hardness. To ensure quality in the production of metal cutting tools from high-speed steels, it is necessary to take into account the chemical composition and microstructure parameters of steel in the delivery state. Heat treatment modes must be adjusted taking into account the quality of metal in the delivery state, as well as depending on the operating conditions of the tool. It is necessary to conduct a comprehensive quality control of heat treatment not only of basic properties, but also of microstructure parameters.

The studies consisted of quality control of high-speed steels in the delivery state, at the main technological stages of heat treatment, and included the following types of work:

- visual and measuring control;
- determination of chemical composition;
- control of basic properties;
- metallographic studies of microstructure.

To carry out these studies, a quality control technique for traditional and powdered high-speed tool steels in accordance with current domestic standards was developed. The control parameters are presented in Table 1.

3. Research results

3.1 Analysis of the tool market state in Russia

The conducted analysis of the tool market state in Russia showed that four large enterprises are engaged in the production of metal cutting tools from high-speed steels: Kirzhach Tool Plant OJSC, TVINTOS Serpukhov Tool Plant, Sverdlovsk Tool Plant, and Tomsk Tool Plant. In the production of domestic tools, high-speed steels of moderate heat resistance of grades P6M5 and P18 are mainly used. P6M5K grade heat-resistant steel is rarely used, and sometimes imported powdered high-speed steels are used. [2-5].

As for imported metalworking tools, the analysis shows an increase in the presence of foreign manufacturing companies on the Russian market. These include enterprises such as: MEGA-TEC, Simnek, INOVATOOLS, HAIMER GmbH, Johs.Boss GmbH & Co. KG, FAHRION, ESA EPPINGER (Germany); SAU (Italy); Microna (Sweden); PIBOMULTI S.A. (Switzerland); PINZBOHR (Spain); JR-TOOLS (Finland); Tanoi (Japan); ACROW (Taiwan) and others [6]. On the whole, the number of firms engaged in the sale of imported instruments has increased in Russia [6–9].

Foreign manufacturers offer to sell a wide range of their products. The most famous in this field is a French company ERASTEEL, the largest producer of high-speed steels in the world (up to 30% of the world market). For a domestic consumer, this company offers up to 30 brands of high-speed steels, while about 20 of them are analogues of domestic brands of high-speed steels according to GOST 19265.

The German Concern SANDVIK is actively working on the domestic market together with such companies as SANDVIK COROMANT and SECO TOOLS [10,11]. The German company BOHLER,
in addition to high-speed powdered steels, produces a powdered version of cold-formed die steel K190 ISOMATRIK [12].

Table 1. Quality control parameters for high-speed steels

| No. | Control parameters                                              | Traditional high-speed steels (GOST - All Union State Standard 19265–73) | Powdered high-speed steels (GOST - All Union State Standard 28393–89) |
|-----|---------------------------------------------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------|
| 1   | Determination of chemical composition                        | +                                                                      | +                                                                   |
| 2   | Control of size and surface conditions                       | +                                                                      | +                                                                   |
| 3   | Macrostructure                                               | +                                                                      | +                                                                   |
| 3.1 | Break-down point according to GOST 10243–75                  | +                                                                      | +                                                                   |
| 3.2 | Sulphur segregation                                         | +                                                                      | +                                                                   |
| 4   | Depth of decarburized layer according to GOST 1763–68         | +                                                                      | +                                                                   |
| 4    | Austenite grain size according to GOST 5639–82               | +                                                                      | +                                                                   |
| 5   | Microstructure                                               | +                                                                      | +                                                                   |
| 5.1 | Micropores                                                   | –                                                                      | +                                                                   |
| 5.2 | Oxygen segregation                                           | –                                                                      | +                                                                   |
| 5.3 | Carbide heterogeneity                                        | +                                                                      | +                                                                   |
| 5.4 | Structural bandedness                                        | –                                                                      | +                                                                   |
| 5.5 | Foreign powder particles                                     | –                                                                      | +                                                                   |
| 5.6 | Rigidity on delivery according to GOST 9012–59               | +                                                                      | +                                                                   |
| 5.7 | Rigidity after hardening or hardening and tempering according to GOST 9013–59 | +                                                                      | +                                                                   |
| 6   | Basic mechanical properties                                  | –                                                                      | +                                                                   |
| 7   | Heat resistance (red hardness)                               | +                                                                      | +                                                                   |

Against the backdrop of the developing global tool production, on the domestic tool market there are such trends as reduction in the range of domestic steel grades, decrease in the quality of steels, increase in the cost and shortage of high-speed steels with increased productivity, and an almost complete cessation of the production of powdered high-speed steels.

Lack of inexpensive blade tools made from high-speed steels of domestic production and high cost of imported tools make machine-building enterprises try and partially solve this problem on their own. In this regard, relevance of the quality problem of the manufactured tools is increasing.

3.2 Study of the production state of metal cutting tools from traditional high-speed steels

An analysis of the production of metal-cutting tools under the conditions of existing engineering enterprises revealed a number of general trends:

- relatively low quality of high-speed steel billets delivered to enterprises;
• lack of comprehensive quality control of steels in the delivery state;
• low quality of heat treatment and lack of its comprehensive control;
• appointment of the strengthening treatment without taking into account the tool operating conditions.

An analysis of production of end mills from P6M5 steel at one of the engineering enterprises can be given as an example. Here, during operation, the tooth of the end mill along the tool was being destroyed. Judging by the nature of the fracture, the tool destruction had a fragile mechanism.

In order to find out the causes of tool destruction, comprehensive studies were carried out that identified the disadvantages associated with the quality of P6M5 steel in the delivery state and with violations of the strengthening heat treatment technology. Thus, for P6M5 steel a mismatch of GOST 19265 in chemical composition was revealed. The reduced content of main alloying elements — tungsten and molybdenum is noted in comparison with the permissible value. According to the results of metallographic studies, higher than possible deviations of the steel structure in the delivery state in the form of carbide heterogeneity were found - 5-6 points with individual inclusions of angular carbides with a size of up to 15-25 microns instead of 1-2 points.

A low quality of the strengthening heat treatment, namely overheating of steel during strengthening process, is confirmed by metallographic studies. The presence of heterogeneity and an excess of the grain point in the structure of hardened steel was found (6-7 points instead of the permissible 10-11 points). The reduced strength of hardened steel (58-59 HRC) indicates an increased amount of residual austenite, and, indirectly, confirms overheating of steel.

A subsequent drawing-back worsened the situation, because the rate of drawing-back was increased up to five times. This provided a decrease in the amount of residual austenite, and as a result, led to an increase in hardness to regulated values. In general, as a result of poor-quality heat treatment, there was a decrease in strength, impact hardness, and a damage to heat resistance occurred, which led to destruction of the tool by brittle fracture [13].

Thus, during production of this tool, the basic principle was violated - an integrated approach to ensuring the basic properties of steel. Only one indicator was chosen as a control parameter - strength. As a result, this led to a decrease in tool life.

The identified causes of the tool destruction formed the basis of recommendations for the aforementioned engineering company on increasing the requirements for quality control of high-speed steels in the delivery state and on adjusting the regimes of strengthening heat treatment.

### 3.3 Study of the production state of metal cutting tools from powdered high-speed steels

Powder technology for the production of tool steels opens up the prospect of introducing high-performance high alloy steels into the industry, as well as for the production of bimetallic tools. The use of powdered tool steels is especially effective when cutting hard materials of increased hardness (up to 40 HRC), as well as high viscosity. The resistance of tools made of them in comparison with ordinary steels of moderate heat resistance increases by several times.

An analysis of the chemical composition of powdered high-speed steels (Table 2) shows that they are highly alloyed steels similar in composition to standard high-speed steels, but containing an increased amount of carbon, carbide-forming elements, especially vanadium, as well as cobalt. According to traditional technology, it is problematic to produce a tool of complex shape with a ground profile from these steels. The use of powder technology for the manufacture of high-speed steels can significantly improve the basic and technological properties of these materials, and it also opens up the prospect for the development of new grades of high-performance high-speed steels. [14.15]

The technology for the production of powdered high-speed steels has a number of specific features. Despite the variety of methods, it boils down to two stages: obtaining the initial powders and their subsequent compaction into a billet [13].
Table 2. Chemical composition of ERASTEEL powdered high-speed steels and their hardness in the state of delivery

| ERASTEEL name | Russian analogue brands | Mass fraction of the element, % | Hardness upon delivery, HB |
|---------------|-------------------------|--------------------------------|---------------------------|
|               |                         | Carbon | Tungsten | Molybdenum | Vanadium | Chromium | Cobalt | Soft-annealed | Cold rolled or drawn |
| ASP 2005      | 15Р3М3Ф4-МП             | 1,50   | 2,50     | 2,50       | 4,00     | 4,00     | –      | 260           | 310                  |
| ASP 2015      | 15Р12К5Ф5-МП             | 1,55   | 12,00    | –          | 5,00     | 4,00     | 5,00   | 280           | –                    |
| ASP 2017      | P3M3К8-МП                | 0,80   | 3,00     | 3,00       | 1,00     | 4,00     | 8,00   | 260           | 320                  |
| 2023          | P6М5Ф3-МП                | 1,28   | 6,40     | 5,00       | 3,10     | 4,20     | –      | 260           | 320                  |
| ASP 2030      | P6М5Ф3К8-МП              | 1,28   | 6,40     | 5,00       | 3,10     | 4,20     | 8,50   | 300           | 320                  |
| ASP 2052      | 16Р11М2К8Ф3-МП           | 1,60   | 10,50    | 2,00       | 5,00     | 4,80     | 8,00   | 300           | 320                  |
| ASP 2053      | 25Р4М3Ф8-МП              | 2,45   | 4,20     | 3,10       | 7,90     | 4,20     | –      | 300           | 340                  |
| ASP 2060      | P6М7Ф6К10-МП             | 2,30   | 6,50     | 7,00       | 6,50     | 4,20     | 10,50  | 300           | –                    |

Metal powders are made by spraying liquid steel of a given chemical composition in an inert gas atmosphere of nitrogen or argon. A jet of liquid metal is broken into drops by gas, which is supplied through nozzles under a pressure of 2-3 MPa. The result is a powder with a grain size of 50-800 microns, which provides a high cooling rate (10³-10⁶ deg/s), which means a high crystallization rate of the powder. Due to nonequilibrium crystallization, quenching from a liquid state occurs, martensite is formed in the structure of the powders, as well as an increased amount of residual austenite (up to 30-60%) and finely dispersed carbides, the composition and structure of which differ from equilibrium ones. The structure of the powders is characterized by a high dispersion of structural components and a uniform, almost ideal, distribution of carbides.

Dense billets are made by two methods: by hot isostatic pressing of capsules under the pressure of 100-200 MPa in the temperature range of 1100-1200 °C followed by forging or hot extrusion of evacuated capsules with powder and their subsequent forging. After compaction, the steel must be annealed to the isothermal annealing mode, which is normal for high-speed steels. In powdered steels, the dispersion of structural components and partially the nonequilibrium structure are inherited - supersaturation of solid solutions, presence of carbides nonequilibrium in composition. [13]

The strengthening heat treatment of powdered high-speed steels is similar to traditional steels, but due to peculiarity of their structure, it differs by a quenching temperature of 40-60 °C lower (1160-1180 °C); by an exposure time, which is 15-30% shorter, when heated for strengthening; by a drawing-back frequency reduced to 2 (at temperatures 550-560 °C for 1 hour each). As a result, a secondary hardness in the range of 65-66 HRC and heat resistance of at least 620 °C, σизг=2800-3000 MPa, KCU of at least 0.25-0.30 MJ/m² (grain point of at least 13, carbide heterogeneity better than 1 point [13]).

At the Metal-cutting Machines and Tools Department of KuzGTU, a quality control method for powdered high-speed steels was developed taking into account the requirements of GOST 28393, according to which higher requirements were imposed on powdered steels in terms of microporosity, oxygen segregation, structural banding, presence of foreign powder particles, and basic mechanical properties (Table 1). This technique was used to study powdered high-speed steels without tungsten of types M6Ф7-МП, 10Р7М5Ф2-МП, etc. [16]

Thus, at present, Russia has scientific and practical experience in the field of powdered high-speed steels. A standard was developed for powdered high-speed steels (GOST 28393-89), which formulated the technical requirements for them (Table 1).

The domestic industry currently has a certain potential for production of powdered steels: there are...
enterprises that produce alloy powders by gas spraying, including high-speed steels (for example, POLEMA JSC, which is a powder metallurgy plant) [17] and enterprises that use technologies of isostatic pressing and extrusion [9, 18 - 20].

An obstacle to the introduction of powdered high-speed steels is the lack of experience with them. At the same time, a decrease in tool quality occurs for similar reasons as when working with traditional high-speed steels. These include: lack of comprehensive quality control of steels; quality assessment of heat treatment is carried out only according to one parameter - hardness [21]; when choosing a quenching mode, lower temperature values (lower by almost 100 °С) are not taken into account, as well as the need to replace a triple drawing-back with a double drawing-back, etc.

Conclusion.
The analysis of the market conditions for metal cutting tools made of high-speed steels indicates high competition. To increase the competitiveness of domestic tools, it is necessary to establish our own production, improve the quality of tools by improving the culture of production, introduce modern methods of quality control of tools in the technological process in accordance with current standards.

In this paper, a method for controlling the quality of high-speed steels according to the basic parameters of structure and properties is proposed and tested. Based on the studies, typical shortcomings of high-speed steels associated with their quality in the state of delivery and subsequent heat treatment are identified and some measures are proposed to eliminate them.

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