Simulation of the performance properties of cutting tools with coatings for specified operating conditions

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Abstract. The paper presents the results of solving the problem of choosing a cutting tool with coatings for the given conditions of its subsequent operation using the capabilities of computer modeling of the architecture of coatings of hard-alloy tool materials. The results of the predictive tool material design for the specified operating conditions with a high degree of reliability allow us to evaluate the performance of tool materials in actual operating conditions. The developed computer models of cutting tools multilayer coatings are adequate, and the results of the calculations correspond to the experimental data obtained under the specified operating conditions of the tools. The novelty of the proposed approach consists in the development of the methodological foundations for the design of multilayer coatings of tools based on the analysis of computer simulation results of its stress-strain state during the cutting process.

1. Introduction

In the modern variety of the range of metal-cutting tools the technologist finds it difficult to choose the best tool for the given operating conditions, therefore the search for new compositions of wear-resistant coatings, the study of the mechanical properties and performance characteristics of the cutting tool are widely covered in modern scientific literature [3, 4, 6].

The capabilities of computer technology and modern software make it possible to reveal 2–3 of the most promising tools due to computer modeling, taking into account baseline conditions and constraints, and then compare them experimentally and select the most effective.

ANSUS and DEFORM possess methodological possibilities to implement this approach. Mastering these software environments is quite difficult. In addition, the environment provides the input of only 3–5 parameters of operating conditions, and for practical use, much more are necessary for example, consideration of tool geometry features, information about the multilayer coating, especially its architecture: the thickness and structure of each layer of the coating. Since there are many models of the alleged mechanisms of destruction and wear of metal-cutting tools, it is necessary either to give preference to one of them, or to compare several models among themselves. In any case, it is faster, easier and cheaper than an experimental search for an effective tool.

2. Methods

To solve the problem of choosing a cutting tool with coatings for the given conditions for its subsequent operation in a software environment, the stress-strain state of the cutting system elements was simulated, and pictures of stress fields and strains were obtained, including in the tool material.
The parameters of stresses and deformations are used for the program evaluation of the cutting process quality, for example, by tool durability, surface roughness, machining performance, etc. Then, by changing the operating conditions (variation of the cutting speed, cutting layer depth, coating architecture, etc.), similar results were obtained for other choices of the cutting tool. According to the results of the comparison, the most effective tool is selected in the software environment or by an expert method or the design of a new tool with the specified performance characteristics is predicted.

The function and role of coatings are well explained and illustrated by S. N. Grigoriev [2]. The architecture of coatings and their contribution to increasing the cutting process efficiency were investigated in [8, 9, 10], the issues of calculating the stress-strain state of the cutting system elements were considered in [1, 5, 7].

3. Results
At the first stage of research, the stress-strain state of the cutting tool was simulated depending on the operating conditions (figure 1).

From figure 1 it follows that the greatest displacement for the cutter with a cutting force of 3000 N is approximately 0.4 mm. The magnitude of the deformations causes a certain alertness, however, it should be borne in mind that this value has a conditional character of deviation of the mill axis along the length of its cantilever, and exceeds the possible error in the position of the workpiece surface machined by a mill at least three times. The obtained value of the cutter deformation in terms of the deviation of the machined surface fits into the specified accuracy requirements for the manufacture of pockets, sinuses, chamfers, etc. of aviation parts.

The analysis of the stress fields in the cutting tool, in the machined surface, in the chips makes it possible to judge about the effect of a coating on reducing or increasing cutting force. Stress fields for different cutting ranges in the case of applying nitride-silicon (Si3N4) coating with a thickness of 7 μm on BK8 hard alloy when processing 40X structural steel with a cutting speed of 80 m/min are shown in table 1.

From figure 2 it follows that in the presence of coverage stress is less, and as the cutting process develops, the influence of the coating increases.

Using the simulation results (figure 2), allows us to identify preferred tool materials for various specified operating conditions during processing, for example, structural steels and titanium alloys (turning and milling with different modes: speed, feed, depth of cut).

In figure 2 the following coatings are conventionally indicated:

1 – carbide tool material of the BK8 brand in the state of delivery5 - BK8 with diamond thermogrinding [7] on the front surface and polishing on the back surface of the plate;

![Figure 1](image1.png)

**Figure 1.** Fields of stress and strain in the model of a compound milling cutter: (a) – stresses; (b) – deformations.
Table 1. Stress patterns of the cutting process when using coated and uncoated tools at different time intervals.

| Tool material | Stress distribution in the workpiece at the time of cutting on a quarter of the workpiece length | Stress distribution in the workpiece at the time of cutting on two-thirds of the workpiece length |
|---------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Tool material BK8 | ![Image](image1.png) | ![Image](image2.png) |
| Tool material BK8 + Si$_3$N$_4$ | ![Image](image3.png) | ![Image](image4.png) |

Figure 2. Resistance tests results of various tool materials up to the amount of the back surface wear of 0.5 mm when turning high corrosion-resistant stainless steel 09X17H7IO with interchangeable SNMM-150416 hard-alloy plates (cutting speed – 50 m/min, feed – 0.21 mm/rev, cutting depth – 0.5 mm).
2 – the above instrumental material BK8 + Ti (up to 1 µm) + TiN (1 µm) + (NbZrTiAl) N (2.5 µm) is marked (coating by ion bombardment condensation (IBC) method with droplet filtration and assisted accelerated ions), which means that BK8 carbide material is coated with metal titanium Ti layer with a thickness of 1 µm on which the intermediate layer of titanium nitride TiN with a thickness of 1 µm is applied, a working layer 2.5 µm thick of composite niobium nitride Nb, zirconium Zr, titanium Ti, aluminum Al is applied on it. The features of the filtration process of the droplet phase and assisted accelerated electrons are described in [9];

3 – tool material BK8 + Ti (up to 1 µm) + TiN (1 µm) + (TiAl) N (2 µm) + TiN (0.5 µm) with the application of coating layers by ion bombardment condensation (IBC) with droplet filtration and assisted by accelerated ions;

4 – BK8 + (AlCr) N (1.5 µm) + (AlTi) N (2 µm) with the application of coating layers by ion bombardment condensation (IBC) with droplet phase filtration without assisted accelerated ions;

5 – BK8 with diamond thermo-sharpening [7] on the front surface and polishing on the back surface of the plate.

At the second stage of the research, the inverse problem was solved i.e. the predictive design of the tool for the given operating conditions that would provide the required quality of the cutting process was performed. For a hard-alloy base of the same cutting plates, we designed a multi-layer coating, based on the physical model, made it and performed resistance tests. Data on the structure and phase analysis of coatings (figure 3).

![Figure 3](image_url)

Figure 3. Investigation of the structure parameters of coatings for instrumental materials: (a) – multilayer coating; (b) – multilayer nanostructured coating.

The results of wear resistance tests confirmed that modeling the coating architecture makes it possible to create effective tool materials for the given operating conditions.

Thus, the novelty of the proposed approach consists in the development of the methodological foundations for designing multilayer coatings of a tool based on the analysis of computer simulation results of its stress-strain state during the cutting process.

4. Conclusions

1. The results of the tool material predictive design for a specified operating conditions, allow us to evaluate the performance of tool materials in actual operating conditions with a high degree of reliability.

2. The developed computer models of the cutting tool multilayer coatings are adequate, and the results of the calculations correspond to the experimental data obtained under the tool specified operating conditions.

References

[1] Artamonov E V, Tveryakov A M and Shtin A S 2018 Control. Diagnostics 12 54–7
[2] Grigoriev S N, Maslov A R and Sinopalnikov V A 2008 Metal cutting in automated production (Moscow: “STANKIN” Publishing Center of Moscow State Technical University)

[3] Holleck H and Schier V 1995 Surface and Coatings Technology 76–77 1 328–36

[4] Hörling A, Hultman L, Odén M, Sjölén J and Karlsson L 2005 Surface and Coatings Technology 191 384–92

[5] Mokritsky B Y, Vereshchagin V Y and Vereshchagina A S 2018 Metalworking 1 14–9

[6] Tabakov V P and Chikhranov A V 2018 Russian Engineering Research 38 105–9

[7] Vereshchagin V Y, Mokritsky B Y and Vereshchagina A S 2018 Metalworking 2 (104) 19–22

[8] Vereschaka A S and Vereschaka A A 2005 Strengthening technologies and coatings 9 9–19

[9] Vereschaka A S, Grigoriev S N, Sotova E S and Vereschaka A A 2013 Advanced Materials Research 712–715 391–4

[10] Vereschaka A A, Sotova E S, Batako A D, Sedykh M and Vereschaka A S 2014 Journal of Friction and Wear 35(6) 483–8