Improving the cutting tool durability by applying multi-layer coatings

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Abstract. The interrelation between the stress values in the cutting tool and the working efficiency of the instrument materials, particularly the durability period is considered. The possibility of applying the cutting force as a parameter for assessing the efficiency of using one or another hard-alloy tool, including the choice of the optimal coating is shown. It appears possible because the cutting force, on the whole, reflects the value and the distribution of stress. The graphical illustration of the results obtained is presented.

1 Introduction

Creating the new and improving the existing constructions of details, which meet the requirements of the normative documents on operating characteristics, gives the possibility of using materials that possess the increased strength and, therefore, reduced processibility. The necessity of decreasing the production costs requires the reduction in the instrument expenditures. One of such ways is the use of the cutting tool with the improved durability. The effective method of improving the cutting tool durability is applying both one-layer and multilayer coatings on its working surfaces. The efficiency of their use is different, so the increase in the tool working capacity can be evaluated only by experimental research. There are no methods of choosing the coating for particular conditions of the tool application. But it is known [1-4] that changing the composition and thickness of the layers it is possible to manufacture the tool effective for processing certain materials or carrying out particular operations. Because of that, the urgent problem is searching the methods of forecasting the working capacity at a stage of the coating development for certain operating conditions of the cutting tool.

2 Methodological concept

According to Papers [5-7], the main directions of improving the tool efficiency can be the following:
1) improving the coating material hardness and the composite – "coating – instrumental basis" by optimizing the coating composition and construction;

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2) reducing the value of heat and stress loads acting on the tool by changing the contact interaction of the tool working surfaces with the processed material, choosing the coating material or changing its properties.

It follows that to improve the cutting tool efficiency up to maximum it is necessary to manufacture a coating, simultaneously possessing a high hardness and crack-resistivity and the property of minimizing the level of heat and stress loads on the tool [8]. To describe the influence of temperature and power loads the dependence of the stress value on the cutting force is used [9, 10]:

$$\sigma_{max} = 2 \cdot \frac{P_y \cdot \left[\cos\gamma \cdot \sin(\gamma + \Theta) - \sin\alpha \cdot \cos(\alpha - \Theta) + \beta \cdot \cos\Theta\right] + P_z \cdot \left[\sin\alpha \cdot \sin(\alpha - \Theta) - \right.}{r \cdot \left[\left(\sin^2\alpha - \cos^2\gamma\right) - \beta^2 + \right.} \dots$$

$$\dots \frac{\cos\gamma \cdot \cos(\gamma + \Theta - \beta \cdot \sin\Theta)}{+ \left(\sin\alpha \cdot \cos\alpha - \sin\gamma \cdot \cos\gamma\right)^2}\Bigg]$$

where P_y – a radial component of the cutting force; P_z – the main component of the cutting force; α – the main back angle; γ – the front angle; r,Θ – polar coordinates.

The dependence mentioned is used as a parameter to forecast the durability period of the cutting tool and to choose the corresponding tool material.

3 Discussion of the results obtained

In studying the stress distribution in the cutting tool the contact stresses σ_z and σ_y, which act in the direction parallel to the front surface and perpendicular to it, respectively, are considered. The investigation of the stressed state of the cutting tool was conducted by computer modelling based on ANSYS programs.

Such tool materials as substrate – solid alloy WC-Co8 and GC4230; a one-layer coating of titanium nitride TiN with a thickness of 5 μm; a one-layer composition coating (TiAl)N with a thickness of 5 μm; a three-layer coating Ti + TiN + (TiAl)N with a total thickness of 7 μm; a three-layer coating Ti + TiN + (TiAlCr)N with a total thickness of 6 μm; a three-layer coating Ti + TiN + (TiAlCr)N with a total thickness of 10 μm were considered. The choice of the coating is due to the recommendations [8, 11].

The stress fields (the distribution figures) in the cutting tool made of BK8 with different wear-resistant coatings are presented in Figure 1. The values on the stress field lines show the value in MPa.

The similar distributions of stress in the cutting edge of the solid alloy tool made of GC4230 with coatings are shown in Figure 2.

Determining the values of normal and tangential stress allowed calculating the equivalent stresses:

$$\sigma_{eq} = \sqrt{\sigma_{z\,max}^2 + \sigma_{y\,max}^2} \ ,$$

where σ_{zmax}– the maximum calculated stresses on the front surface of the cutting edge; σ_{ymax}– the maximum calculated stresses on the back surface of the cutting edge.

The comparison of the calculation results of the equivalent stresses with the experimental data concerning the cutting tool durability is conducted to check the suggested hypothesis (Figures 3, 4).

The research of durability was conducted by end milling the blank parts made of steel 12H18N10T for the cutting speed of V = 70 m/min and the feed S equal to 0.1 mm/per rev.

The comparison of the experimental data on the wear-resistance of end milling tool made of BK8 and GC4230 with the results of modelling the maximum equivalent stresses showed

the reverse dependence of the durability and equivalent stresses in every case. It proves that the suggested hypothesis is valid: the reduction in the equivalent stresses results in increasing the tool durability.
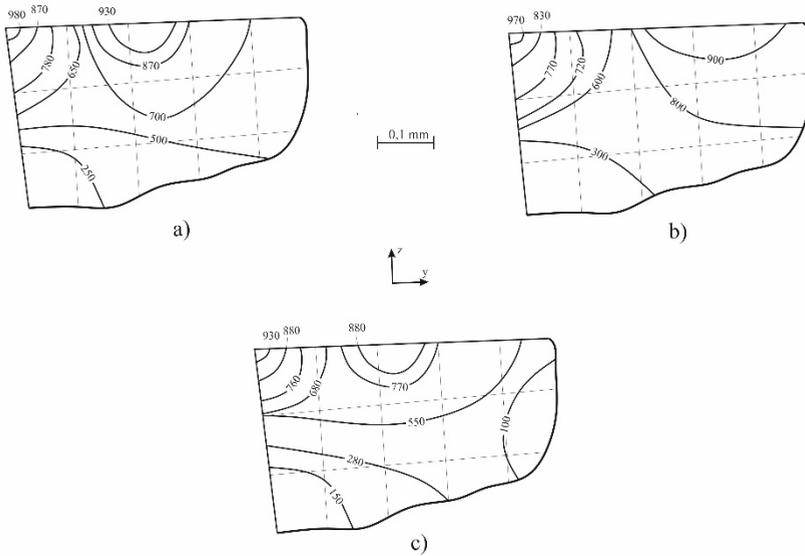

Fig. 1. Stress fields σ_z in the cutting edge of the solid alloy tool BK8: a – without a coating; b - with a one-layer coating TiN with a thickness of 5 µm; c – with a three-layer coating Ti + TiN + (TiAlCr)N with a total thickness of 10 µm.
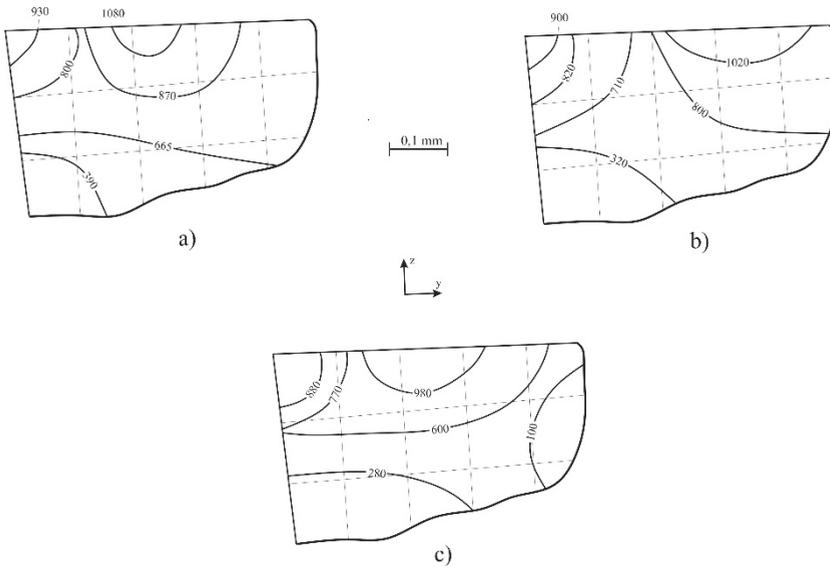
Fig. 2. Stress fields σ_z in the cutting edge of the solid alloy tool GC4230: a – without a coating; b - with a one-layer coating TiN with a thickness of 5 µm; c – with a three-layer coating Ti + TiN + (TiAlCr)N with a total thickness of 10 µm.
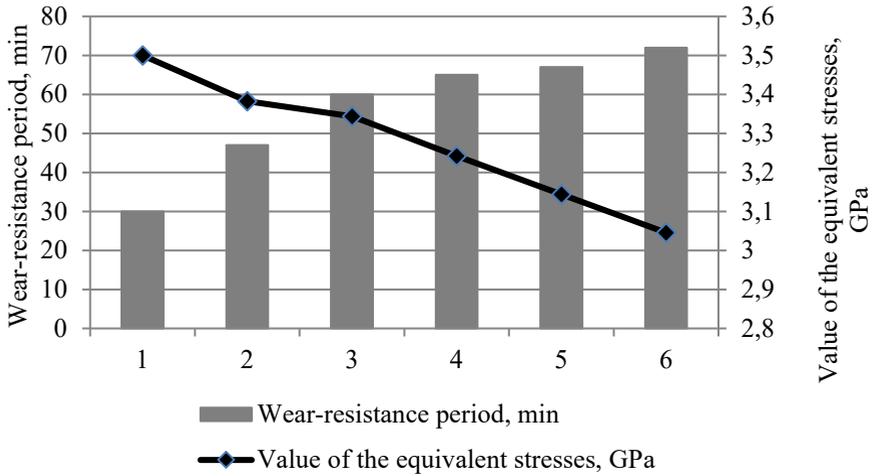
Fig. 3. Comparison of the cutting tool durability (columns) and the maximum values of the equivalent stresses (the line) for the tool hard alloy WC-Co8: 1 – without a coating; 2 - with a TiN coating with a thickness of 5 μm; 3 - with a (TiAl)N coating of a thickness of 5 μm; 4 - with a Ti + TiN + (TiAl)N coating with a total thickness 7 μm; 5 - with a Ti + TiN + (TiAlCr)N coating with a total thickness of 6 μm; 6 - with a Ti + TiN + (TiAlCr)N coating of a total thickness of 10 μm.
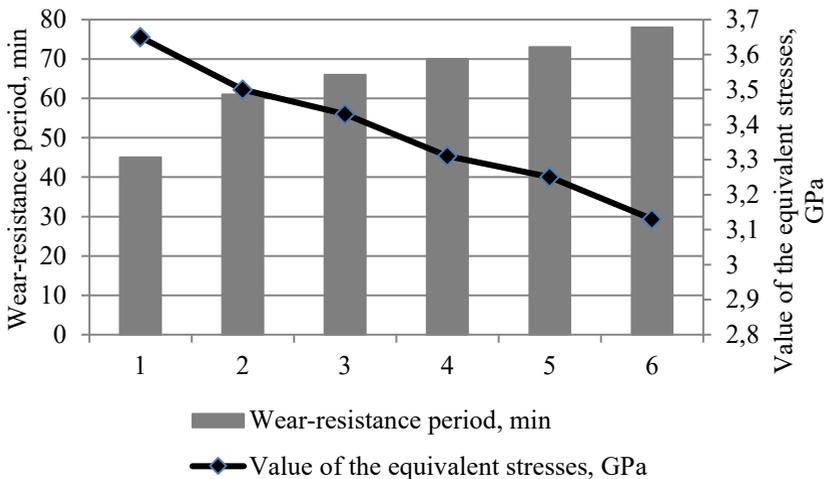
Fig. 4. Comparison of the cutting tool durability (columns) and the maximum values of the equivalent stresses (the line) for the tool hard alloy GC4230: 1 – without a coating; 2 - with a TiN coating with a thickness of 5 μm; 3 - with a (TiAl)N coating of a thickness of 5 μm; 4 - with a Ti + TiN + (TiAl)N coating with a total thickness 7 μm; 5 - with a Ti + TiN + (TiAlCr)N coating with a total thickness of 6 μm; 6 - with a Ti + TiN + (TiAlCr)N coating of a total thickness of 10 μm.

4 Conclusions

The investigation made confirms the hypothesis on the possibility of changing the stresses (by values and the distribution character) in the cutting tool by manufacturing the wear-resistant coatings. Such changes can be accomplished in choosing or manufacturing the tool material. It is possible to do by computer modelling the operating conditions.

The obtained results are the following:

1. The use of coatings changes the picture of stress fields and decreases the value of the maximum stresses by 10-15%, which results in reducing the cutting force.

2. Insignificant change in the values of the maximum stresses in tools with and without a coating by 1.2 times increases considerably the operating ability of the tool materials by twice and more times.

3. The coating Ti + TiN + (TiAlCr)N appeared to be the most effective as a wear-resistant coating with a total thickness of 10 μm for the operating conditions mentioned.

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