Optimizing the Properties of Tool Materials by Means of the Mathematical Modeling of their Fracture Processes

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Abstract. The article deals with the modern approaches to the study of physical and mechanical properties of materials. A brief description is given on the express method for metal-cutting tool health assessment that has been developed within the framework of this approach. The paper suggests ways to improve the performance of by modeling the properties of materials. It presents the methodology for assessing the tool material performance of coated surfaces by acoustic emission.

Keywords: mathematical modeling, optimizing the properties, tool material performance, modeling of properties, computer program

1 Introduction

The modern development in mechanic engineering involves creating new tools and construction materials with predetermined properties, expanding the range of these materials and improving their technical and economic characteristics.

The widespread use of metals and their alloys requires a thorough and comprehensive study of their physical and mechanical properties in a wide range of temperatures. There is a number of abnormal physical phenomena, at high temperatures especially in the area of structural and phase transitions. At that, changes in physical parameters of the material may occur, which cause the reduction in operating span of expensive engineering products [1].

Performance and efficiency of metal processing depend on the strength and endurance of metal-cutting tools. More than 50 % of failures in technological cutting systems are due to the loss of functional of a metal-cutting tool. The modern models of tool fracture mechanisms are based on the structure-and-energy approach to the analysis of the strength of material. This approach describes the tool material fracture in terms of the thermodynamics and dislocation notions. In this paper the author suggests new ways to increase the productivity of metal processing by improving the properties of tool materials [2] and [3].

The article attempts to develop the approach which considers a tool as a component of a technological cutting system and, thus, its productivity can be determined by the properties of tool material and the processes in the others parts of the cutting sys-

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tem. Let us now look at the of process fracture formation and changes in the condition of the elastic system in a metal-working machine. The choice of these processes is explained by cyclic loading on the tools, which influences their working capacity [4].

At present, there is no full and adequate information about the dependence of the physical properties for a number of construction and instrumental steels and other metals in a wide range of temperatures depending on their deformation extent and heat treatment conditions. Comprehensive studies into the properties of materials are very important for the fundamental knowledge and search for solutions to a number of issues in materials science, solid state physics, and physics of metals [5].

The author approached this problem by creating new methods, systems and devices that use the latest achievements of fundamental sciences, such as materials science, thermal physics, acoustics, and mathematical modeling.

The practical relevance of the studies consists in the unique software and expresses assessment methods that have been developed. These methods assess the working capacity of a coated tool to ensure the non-destructive quality control for mechanical engineering products.

2 The mathematical modeling of the process of compound material fracture

Since the tool loading in metal cutting has a cyclic nature, we suggest a mathematical model of stabilizing the changes in loading conditions by optimizing the properties. To perform the express-assessment of coated tool materials, we suggest methods that provide an authentic modeling of real operating conditions for compound tools.

The model of optimal control of the tool's productivity consists of four tasks:

1– optimization of properties tool material;
2– development of materials with predetermined properties;
3– modeling the unstable pattern of fracture;
4– increase in the dynamic quality of metal-cutting machine.

The structure-and-energy approach was applied to take the optimal decision [2]. As a part of if studies with the use of transmission and raster electronic microscopy, X-ray structural analysis were performed. Within the structure-and-energy approach, a model of grain interaction has been developed for compound tool materials. This model describes the dynamics-and-energy interaction of grains when impulse application of a load is performed on the surface layers of the cutting tool. Based on the model, a mathematical formula (correlation) has been obtained that makes it possible to examine the accumulation and distribution of energy in microvolumes of a tool material. Also, the formula determines the critical number of grain interactions n_{cr} before the critical energy E_{cr} is accumulated in a gain that collapses once the energy is exceeded.

In article number of interactions can be considered as an objective to be maximized

$$n_{cr} = \int_{E_0}^{E_{cr}} \left\{ 4E \left[\alpha^2 - \int_{E_0}^{E_{cr}} [j(E)/(2E)] \right] dE \right\} dE \to \max, \qquad (1)$$

where, E_0 is the initial impulse energy, J; E is the current value of residual impulse energy at the investigated distance from initial impulse application point; j is the parameter which describes the correlation between the size of the grains and the distance between them (of the layer thickness between them); α is the grain interactionangle.

The analysis of dynamics-and-energy model and the dependence (1) allows to develop models of tool material fracture mechanisms in terms of optimizing the energy condition of micro volumes once the critical value of energy is reached in cutting.

This allowed to formulate (1) as a number of requirements for the shape, size and location of the grains, as well as to clarify various mechanisms of tool material fracture. Since the productivity of a tool is primarily determined by the condition, wear rate, micro-chipping, etc. of its upper layers, it is important to assess the strength of the structural components in the material coating when optimizing the properties of the tool material. This assessment will make it possible to detect the weakest point in the structure, which will help to forecast the fracture of the tool on every stage.

The results of assessing the strength of hard-alloy tools showed that their edges are their weakest point. The edges are inter-granular in some hard alloys and inter-phasic in others. Let us consider the role of the material structure in the process of hard-allow tool fracture using, as an example, the explanation of externality of a well-known classic correlation between the tool durability T and the cutting speed v (cutting temperature θ). Based on the example of this correlation, a model has been developed that demonstrates the influence of the cutting speed (temperature) on the changes in the structure of a hard-alloy material and the impact of the emerged structures on the mechanism of material fracture.

3 Methods for modeling materials with predetermined properties

In this section we describe the methods for increasing the tool working capacity by improving and optimizing the properties of coated tool materials.
Modeling the properties of tool materials is based on the express methods of assessing the tool working capacity. In addition to the common methods for assessing the physical, mechanical, and operational characteristics of tool materials [1], there have been developed several express methods to assess the additional parameters (such as crack resistance). These methods using acoustic emission (AE) to exercise control, assess the quality, diagnose and forecast the working capacity of a metal-cutting tool with a wear-resistant coating.

The similarity of kinetics and fracture mechanisms under the loading conditions has been proved by fractographic studies. The relation to the tool fracture kinetics is proved by the comparison of kinetograms. Test for the compliance with the real mechanisms has been performed by comparison with the results of fractographic studies in well-known works such as [4].

The basic results of the performed studies can be summarized as follows:

- the temperature dependence of the sound velocity, ultrasonic vibrations, the elastic modulus and internal friction for a number of ferromagnetic materials, and titanium alloys under various degrees of deformation and heat treatment conditions was determined;
- the behavior of the acoustic and mechanical parameters in phase and magnetic transitions in metals and alloys was studied;
- the dependence of elastic of thermal coefficient for the modulus of a number of pure metals, structural and tool steels and alloys on the degree of deformation and heat treatment was found out ;
- the activation energy for defect modulus for cobalt, nickel, steel that were heat-treated was determined.

The practical significance of the work consists in:
- the development of the technique for investigation of the temperature dependences of the acoustic parameters for pure metals and their alloys [3];
- creation of the original equipment for high-precision measurements of sound velocity and ultrasonic vibration at various frequencies in a wide temperature range for the wire samples [5];
- construction of the experimental system that allows to study the mechanical properties and performance of materials and record AE signals;
- development of software that allows the acoustic path and fixing the details of PC, keeping all thread data of modeling nondestructive control method on the basis of these settings;
- collection of a unique experimental data on the elastic modulus and internal friction in the high-temperature aviation materials [6].

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