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METHODOLOGY FOR DEVELOPING AN EXPERT SYSTEM FOR THE GRINDING OF SUPERHARD MATERIALS

Abstract. *An expert system of the grinding process has been developed, which makes it possible to predict and optimize the process of defect-free processing of both existing and newly created superhard materials. The expert system consists of two interconnected modules - theoretical and experimental. The theoretical module of the expert system allows, at a given level of significance, to determine the values of the output indicators and the kinetics of their change in the process of adaptability, depending on the physical and mechanical properties of the interacting materials and processing conditions. The experimental module of the expert system allows you to coordinate and correct the results of theoretical calculations when determining the optimal grinding and operating conditions for processing various grades of superhard materials. When optimizing the sharpening process of a blade tool, processing efficiency, consumption of diamond wheels, cost price and various quality indicators of its cutting elements can be selected as a criterion. The use of the expert system significantly reduces the amount of expensive and laborious researches in determining the optimal processing conditions for various grades of superhard materials (SHM), including newly created ones.*
Keywords: *Diamond grinding wheel; Finite element method; Knowledge base and database; grinding process optimization; grinding rate; Stress-Strain State; Tool Sharpening; Surface Roughness.*

1. Introduction

The main purpose of the expert system is to predict the level of output indicators when grinding various grades of SHM, including newly created ones, and to optimize the processing.

At certain stages of work, the expert system provides for the participation of an expert. The expert has knowledge of the process and how to influence its effectiveness.

2. Literature Review

An expert system is a computer program that uses expert knowledge to provide highly efficient problem solving in a narrow subject area [1]. When creating the expert system, a procedural knowledge base was used, that is, the author of the work acts as a knowledge engineer and subject expert.

The expert system uses both a database and a knowledge base in the subject area of diamond abrasive processing and blade processing with a SHM tool. The database contains reference data on the characteristics of diamond wheels (bond, grain grades, concentration, grain size, etc.), physical and mechanical properties of various grades of diamond grains and processed SHM. The expert system is developed on the basis of a procedural knowledge base. The knowledge base operates with such concepts as the reliability of a SHM blade tool, defects during its sharpening, the weight contribution of various factors to the efficiency of the processing and is built according to the proposed algorithm for determining the optimal conditions for micro-fracture of the elements of the “SHM - grain – bond” system, based on ensuring the load on single grain. Borland Delphi 5 was used as a programming language. The expert system includes a finite element method (FEM) software such as Cosmos and Ansys.

3. Research Methodology

Combining the elements of the grinding area into a single technical 3D system "SHM-grain-bond" made it possible to establish the mutual influence of their physical and mechanical properties and geometrical parameters on the intensity and nature of mutual micro-fracture [2]. On the basis of 3D modeling of the stress-strain state (SSS) of the grinding area, a scientifically grounded systematics of the destruction mechanisms of its elements is proposed, taking into account the degree of contact between the bond and the processed material. The systematics includes the types of interaction of elements and the types of their destruction. Fracture mechanisms during diamond grinding of superhard materials are determined by the anisotropy of the properties of diamond crystallites, the ratio in the contact of “soft” and “hard” faces of crystallites and grains. It has been proved that when calculating the processes of fracture of polycrystalline materials consisting of anisotropic elements, one should use not averaged physical and mechanical properties, but their most characteristic values, taking into account the specifics of a particular problem being solved. The fatigue-cyclic nature of mutual micro-fracture of both the processed superhard material and diamond grains has been confirmed by model and experimental studies. The number of cycles to fracture is determined by the degree of defectiveness of the interacting structures and the values of the crack resistance coefficient.

4. Results

The structural and logical diagram of the expert system algorithm is shown in Fig. 1.

According to the diagram, the expert system consists of several interconnected modules and subsystems, each of which solves its own specific problem. The operation of the expert system is based on the results of research carried out in previous works of the authors [2, 3,4].

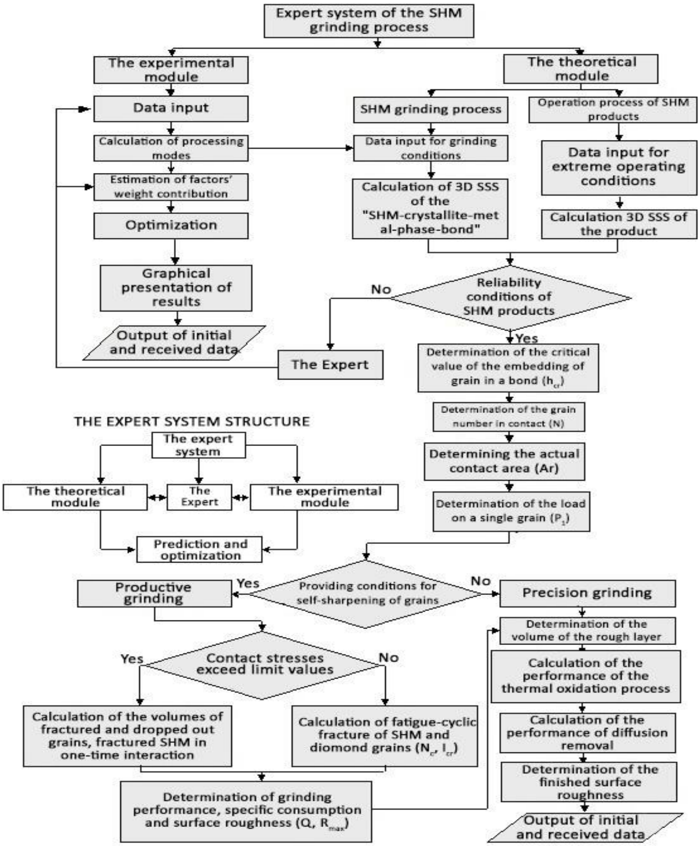

Figure 1 – Structural and logical diagram of the expert system of the grinding process

After entering the initial data into the expert system - physical and mechanical properties of SHM, grains and bonds, normal pressure or transverse feed, grinding speed, grain size and concentration of diamond grains, parameters of the working surface of the wheel (which can be controlled during grinding [2]), preliminary check of ensuring the defect-freeness of the processing. For this, the calculation of 3D SSS of the system “Bond - crystallite - metal phase – grain” is carried out. At this stage, 3D modeling of the stress-strain state of the SHM - grain - bond system, the level of thermal stress and / or strain energy in the polycrystal is analyzed and it is checked whether they do not exceed the critical values. An analytically similar problem was solved by N.V. Novikov. [5] in relation to the fracture of composite superhard materials, but without taking into account the force factor.

If the operating conditions of a SHM product are known (for example, a blade tool), then the calculation of the 3D SSS of a cutting wedge of an SHM blade tool is carried out under extreme operating conditions to ensure the reliability of an SHM blade tool at the stage of its manufacture.

The theoretical module includes subsystems: determination of the critical value of the embedding of grains in the bond (by the 3D SSS method); determining the number of working grains; determination of the relative value of the actual contact area in the WWS - SHM system; determination of the load on a single grain. If the load on the grain is sufficient to ensure its self-sharpening (micro-fracture), a productive process is implemented, if not, a precision one, where thermally activated processes are responsible for the rough tolerance removal. The volume of fractured SHM and diamond grains is calculated in two ways. If the loads in the grain - SHM contact are sufficient for their microfracture in one-step interaction, the calculation is carried out by the finite element method [6], if the load is not sufficient, the fatigue-cyclic contact problem is solved. In productive grinding, the process of microfracture of SHM and grains can be carried out with one-step (in one contact) interaction of a grain with a polycrystal or in the mode of fatigue-cyclic microfracture. In the first case scenario, the volumes of fractured SHM and grains are determined during 3D modeling of the stress-strain state of the system by the value of supercritical reduced stresses and / or deformation energy in individual elements. Based on these calculation results, the productivity of tolerance removal, specific consumption and wear of diamond grains are estimated.

If it is necessary to calculate the process of thermally activated finishing (precision processing) - the decision is made by an expert, the sequence of the subsystems includes: calculation of the intensity of thermo-oxidative and diffusion removal of the rough surface layer of SHM, during thermal-force interaction with an iron-containing metal bond obtained after preliminary treatment of SHM; determination of productivity and time required for removal of the volume of material located in a layer corresponding in thickness to the maximum roughness of the preliminary treated surface (determined by laser scanning).

In the case of processing a new superhard material (experimental data are absent), the initial data are entered directly into the theoretical module, and the output indicators of the diamond grinding process or finishing of new SHM obtained as a result of its operation can be corrected using the experimental module.

The theoretical module of the expert system allows, without costly and time-consuming experiments, to quantitatively evaluate the grinding performance, specific wear, roughness of the processed surface depending on the SHM grade, grain grade, grain size and concentration, normal pressure, load on a single grain, grinding speed, actual contact area, the relative support area of the wheel's working surface (WWS). Since the process of diamond grinding is carried out with a combined control of the parameters of the WWS, based on the metered removal of the bond and the forced formation of a cutting submicrorelief on diamond grains, it is necessary to determine the control parameters [7]. When assigning technological parameters for the forced formation of a submicrorelief on the areas of grain wear under ultrasonic action with an impactor tool, the grade of grains and grain size of the WWS and impactor and their bond are taken into account [2]. The concentration of the impactor is determined by the physical and mechanical properties and grain sizes of the WWS and the impactor. The grain size of the impactor should be 2 - 3 times less than the grain size of the WWS, the grain grade is as strong as possible (AS160T, $K_{IC} \geq 10$ MPa·m$^{1/2}$).

The experimental module of the expert system based on computer processing of a wide range of experimental studies allows, with / or without an expert, to determine the optimal conditions for the diamond grinding process of various SHM under specific limiting factors, i.e., under certain real production capabilities. The weighted contribution of various input parameters of the processing was determined by the method of regression analysis, which allows the system to make a decision without the participation of an expert.

The order of operation of the expert system in the general case for various options for its use determines the following sequence of user actions:

- If there are results of experimental studies for the processed SHM, we enter the initial data into the experimental module of the expert system, we obtain the optimal conditions (modes) for processing this SHM grade.
- If the product made of SHM is a blade tool, then data on the extreme conditions of its specific operation are entered into the theoretical module. For these conditions (cutting force, temperature), the calculation of 3D thermo-force SSS of the cutting edge is carried out. Then the inverse problem is solved for 3D thermo-force stress-strain state of the system "Crystallite of SHM - metal phase - grain – bond" and the loading conditions of this system (force and temperature) are determined, at which these stresses will slightly exceed operating ones during the sharpening of the tool.
- If the obtained modes of diamond grinding or thermally activated finishing in the experimental expert system cause defects during processing, the command "change modes" is issued; at this stage, the expert decides which input data should be changed. Subject to fulfillment of this requirement (which ensures the reliability of the SHM blade tool already at the stage of its manufacture), the calculation according to the theoretical module continues.
- In the event that the reduced thermal and force stresses and / or the deformation energy exceed the ultimate stress of SHM, there is a high probability of the formation of microcracks on the processed surface of the mesh, i.e., scrap,

for example, when sharpening a blade tool. In this case, it is necessary to change the initial data, for example, to reduce the value of the transverse feed or to intensify the process of controlling the parameters of the WWS [8]. If no defects are formed, then using the same technique in the package for the finite element method by calculating the reduced stresses in the "Grain – bond" contact, we determine the critical value of the embedding of grains in the bond with the selected initial data. Knowing the critical value of the embedding of grains in the bond, using the theoretical dependences obtained by us [9] and corrected by the experimental correction factor obtained when studying the parameters of 3D topography of the surface of the WWS and SHM by laser scanning, we determine the number of grains in the contact and the value of the actual contact area. For this purpose, a system developed by V.L. Dobroskok of 3D modeling of the working surface of the wheel is also applied [10]. Using the obtained results, we determine the load on a single diamond grain. If the load on the grain is sufficient for its micro-fracture (self-sharpening) or the process of forming a cutting submicrorelief on the grains is carried out purposefully by superimposing ultrasonic vibrations [11], (determined by the expert), then further calculations are carried out along the "productive grinding" branch. The process of productive grinding is analyzed in two stages. At the first stage, by the method of 3D modeling of the stress-strain state of the "SHM - grain – bond" system by the finite element method, elements are determined in which either the reduced stresses or the deformation energy exceed the critical values for STM and grains, predetermining their destruction. At the second stage, the fatigue-cyclic problem of microfracture of elements of the "grain – SHM" system is solved [2].

5. Conclusions

Thus, on the basis of a comprehensive theoretical and experimental study of the 3D topography of the processed surface and the working surface of the grinding wheel by laser scanning, modeling the 3D stress-strain state of the system "processed material - working surface of the abrasive diamond tool" and the dynamics of wear of its elements, an expert system of the grinding process has been developed. The expert system for the grinding process of superhard materials allows predicting and optimizing the process of defect-free processing of both existing and newly created superhard materials. The development of the expert system was carried out at the level of the finished software product.

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МЕТОДОЛОГІЯ РОЗРОБКИ ЕКСПЕРТНОЇ СИСТЕМИ ДЛЯ ШЛІФУВАННЯ НАДТВЕРДИХ МАТЕРІАЛІВ

Анотація. *Розроблено експертну систему процесу шліфування, що дозволяє прогнозувати та оптимізувати процес бездефектної обробки як існуючих, так і новостворюваних надтвердих матеріалів. Експертна система складається з двох взаємопов'язаних модулів – теоретичного та експериментального. Теоретичний модуль експертної системи дозволяє на заданому рівні значущості визначати значення вихідних показників та кінетику їх зміни у процесі пристосовуваності залежно від фізико-механічних властивостей взаємодіючих матеріалів та умов обробки. Експериментальний модуль експертної системи дозволяє узгоджувати та коригувати результати теоретичних розрахунків при визначенні оптимальних умов шліфування та управління для обробки різних марок надтвердих матеріалів. При оптимізації процесу заточування лезового інструменту як критерій може бути обрана продуктивність обробки, витрата алмазних кругів, собівартість та різні показники якості їх ріжучих елементів. Використання експертної системи істотно скорочує обсяг дорогих і трудомістких досліджень щодо оптимальних умов обробки різних марок надтвердих матеріалів (НТМ), зокрема новостворених. Таким чином на базі комплексного теоретико-експериментального вивчення 3D топографії оброблюваної поверхні та робочої поверхні шліфувального круга методом лазерного сканування, моделювання 3D напружено-деформованого стану системи "оброблюваний матеріал – робоча поверхня абразивно-алмазного інструменту" та динаміки зносу була створена експертна система. Експертна система процесу шліфування надтвердих матеріалів дозволяє прогнозувати та оптимізувати процес бездефектної обробки як існуючих, так і новостворюваних надтвердих матеріалів. Розробка експертної системи виконано на рівні готового програмного продукту.*

Ключові слова: *алмазний шліфувальний круг; метод кінцевих елементів; база знань і база даних; оптимізація процесу шліфування; продуктивність шліфування; напружено-деформований стан; заточка інструменту; шорсткість поверхні.*