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METHODOLOGY OF DEFINITION OF OPTIMAL DIAMOND WHEEL CHARACTERISTICS AT STAGES OF PRODUCTION AND OPERATION

Abstract. *The problem of increase of effectiveness of manufacturing and application of diamond-abrasive tool is still a challenging research subject. Development of computer facilities opens up possibilities for development of three-dimensional (3D) methodology of integrated study of the interconnected processes of manufacturing and exploitation of diamond-abrasive tool and improvement of the single-point tool reliability at the stage of tool sharpening. Creation of the methodology of 3D simulation of processes of diamond-abrasive tool sintering and processes of machining allows to increase essentially validity of the obtained results, to reduce volume of experimental researches for definition of optimum grinding conditions and to develop new technologies, tools and equipment. The developed methodology gives the opportunity to create expert system for assignment of rational characteristics of diamond wheels and grinding modes. The proposed 3D methodology to research processes of diamond-abrasive machining covers all basic stages of life cycle of the tool, including processes of manufacturing and exploitation. Subsystem of computer-generated determination of conditions of manufacturing of defect-free diamond wheels and grinding of superhard materials on the base of 3D simulation of deflected mode of elements of the "SHM crystal grain – metal phase – grain – bond" system at process of diamond wheel sintering and grinding is developed.*

Keywords: *simulation; system "Wheel working surface (WWS)-SHM"; grinding; destruction; system "polycrystal - grain - bond".*

1. Introduction

It is known that efficiency of diamond grinding process is defined both characteristics of diamond wheels and correct selection of grinding conditions. The former is mostly provided at the stage of manufacture of diamond wheels, the latter - at the stage of their production.

During grinding process of materials, hardness of which does not allow to provide the classic requirement of the cutting theory about twofold exceeding of tool material (TM) hardness above hardness of material to be machined (MM), the relation of «material to be machined - diamond grain – wheel bond» system element strengths can be determinant. For example, at diamond grinding of superhard materials (SHM), when hardness of TM and hardness of MM are practically identical, the efficiency of the process is completely defined by an optimal relation of strengths of SHM, diamond grains and wheel bond [1].

Now there are some hundreds brands of bonds applied in Ukraine for diamond wheels. These bonds essentially differ on strength properties. For example, only metal bonds have rather wide range of strengths from aluminium up to hard-alloys.

Similarly, diamond grinding powders from AC2 up to AC160T are characterized by the same wide range of strength properties which differ on hardness in hundreds time.

However, now there is no methodology for selection of an optimal combination of strength properties of diamond grains and metal bond as applied to processing of particular material to be machined.

The available recommendations on application of any diamond grains and metal bonds are of very common nature and have wide ranges. Such recommendations, taking into account that diamond grains are expensive (cost of diamond grains differs depending on a brand of a grain in hundreds times), lead to low efficiency of their usage and therefore to high production cost of the of diamond grinding process, that essentially restrains diamond grinding application during processing. Insufficiently grounded selection of concentration level of diamond grains in diamond wheels leads to disadvantageous grain usage too. So the concentration of diamond grains (25,50,100,150,200 %), traditionally applied in commercial wheels, should be defined more precisely. Our preliminary investigations have shown, that for processing of particular material to be machined one should select the specific on strength (and price) diamond grains, these grains should be placed in the specific on strength bond and amount (concentration) of the grains in the wheel should be strongly specific (calculated). Thus to save diamond grains their concentration should not be restricted to commercial one. At the same time the task of an optimal combination of strength properties of metal bond and diamond grains should be solved too from the point of view of saving their integrity during diamond wheel sintering.

2. Literature Review

Deliberate attempt has therefore been made in this work to elaborate the calculated methodology for solving given problem. The methodology of calculation is grounded on 3D simulation of deflected mode of grinding zone and analysis of fracture processes occuring in this zone depending on strength properties of diamond grains, bond and material to be machined.

The efficiency of the grinding process with SD and cubic boron nitride wheels using porous metal bonds is shown in [2,3]. In them, the authors studied the design and characteristics of metal-bonded diamond grinding wheels made by selective laser melting, studied the grinding temperature and wear of superabrasive boron wheels on a porous metal bond with highly efficient deep grinding.

The authors [4] found that the ultimate load causing the fracture of diamond grains depends not only on the compressive strength of the diamond grains, but also on the compressive strength of the bond, as well as on the coefficient of embedding of diamond grains in it. The classification of the types of wear of diamond wheels using various bonds and possible models of fracture of diamond grinding wheels is given in [5, 6].

M. Mahdi and L. Zhang [7] used the finite element method (FEM) to simulate stresses caused by mechanical loading, thermal cycling and phase transitions. H. Sakamoto [8] applied FEM to study the wear and deformation of diamond cutting wheels with different structures by determining the conditions that ensure the minimum temperature during grinding and its uniform distribution. In the works of V. Yadava [9,10] using the FEM, the residual stresses arising during high-speed grinding are determined. The generalization of a large number of experimental data and the results of model experiments [11, 12] made it possible to carry out a comparative analysis of the fracture criteria. The possibilities of using the theory of plastic fracture were considered by K. Iwata (1984), Cockroft and Latham (1968), K. Osakada (1984), R. Mises et al. (1939) [13,14]. When analyzing the behavior of plastic materials, the value of equivalent stresses according to von Mises is most often used as a fracture criterion [15].

To solve nonlinear finite element problems of mechanics of a deformed solid body and heat transfer, it is advisable to use the multipurpose software package LS-DYNA, intended for solving three-dimensional dynamic problems of mechanics of a deformed solid body. [16, 17].

3. Research Methodology

Available software packages based on finite element method (FEM) such as «Cosmos», «Nostran» and «Ansys» open new possibilities for study of deflected mode at sintering (production) of diamond wheels and grinding zone. The methodology of 3D simulation of deflected mode (DM) of SHM grinding zone, realized with using of such packages, has allowed to develop expert system of grinding process by calculated way (theoretically), without long-duration and laborious experiments. This expert system permit to predict and to optimize both available defect-free processes of machining of superhard materials, and newly-developed ones [18].

To determine optimal combination of strength properties of diamond grains, material to be machined and metal bond both at the stage of production of diamond wheels, and at the stage of their exploitation the investigations of sintering process of diamond wheels on metal bonds and grinding zone of various hard-to-work materials have been carried out using the developed methodology of 3D simulation of DM (fig. 1).

The task, solved in the process of 3D simulation of DM of sintering zone of diamond-bearing layer of wheel on metal bond is the definition of optimal combination of strength properties of diamond grains and bond, at which integrity retention of diamond grains is provided during diamond wheel sintering.

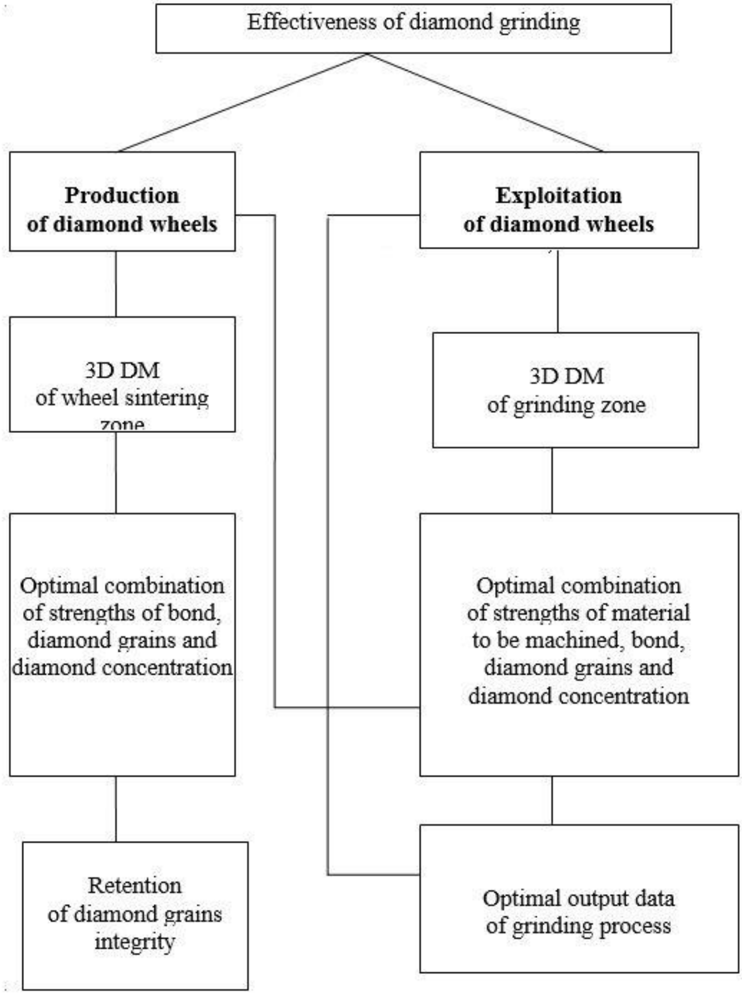


Figure 1 – Finding of optimal combination of strength properties of material to be machined, metal bond, diamond grains and diamond concentration in sequence

Contrary to available ideas, proposed to consider the model of diamond-bearing layer of wheel as perfect one [19,20], we have stated, that the structure of diamond layer of the wheels contains initial defectiveness in the form of damaged diamond grains, which can be quantitatively defined by damage degree of diamond grains [6].

It is established work [6], that the particle-size analysis of synthetic diamond grains AC50 400/315, extracted by recuperation from tvesal sample, has shown that during sintering only about 10-20 % of grains remain undamaged. So it is shown, that diamond grain concentration influences deeply on damaging rate of diamond grains when sintering composite diamond materials (CDM). The increase of concentration from 50 up to 150 % raises damaging of diamond grains at sintering process in 2,8 times.

Since the technology of sintering of diamond-bearing layer of the wheel, for example, on hard-alloy bond such as ВК, is practically identical with the technology of sintering of CDM, we think, that some part of grains at sintering of diamond wheels are damaged.

It is shown [21], that during sintering of diamond wheels the percentage of main fraction (coarse grains) is diminished by 20-30 %.

Apparently, the diamond grains of different strength will be differently fractured during sintering. Certainly, both metal bond composition, and as a consequence, technological parameters of wheel sintering will deeply influence on damaging rate of diamond grains.

At 3D simulation of sintering process the fragment of diamond-bearing layer of wheel was presented as a cube dimensioned 300x300x300 μm, in midpoint of which a diamond grain as an octahedron dimensioned 100x100 μm was placed, that corresponds to 100 % concentration of diamond wheel. At simulation of 50 % diamond grain concentration wheel the size of the cube was redoubled and so on. The model was loaded with stress and temperature appropriate to the real process of diamond wheel sintering. It is accepted, that if the reduced stress in diamond grain exceeds ultimate strength it will be considered as destroyed (defective) one. Sintering process of diamond-bearing layer was simulated for various metal bonds from aluminium up to hard-alloy ones, using diamond grains with various strength from AC2 up to AC160T. Varying combination of diamond grain strength and grain concentration in the wheel for various metal bonds one can determine such their combinations, at which retention of diamond grain integrity was provided i.e. grains should not fracture during sintering. It is established, that not all of commercial wheels with usable combination of brand of diamond grains and brand of metal bond can be manufactured with standard concentration of diamond grains without failure of their integrity. So, for example, at sintering of wheel on bond M6-14 with diamond grains of brand AC6 the grain concentration in the wheel should not exceed 7 %, otherwise grains will fracture as early as wheel sintering. It is shown, that for guaranteed retention of diamond grain integrity practically in all commercial wheels, their concentration should be much less than applied one. Such tendency coordinates well with possibility and necessity of lowering of diamond grain concentration for wheel up to level of 10-15 % at grinding of superhard materials [22].

4. Results

It is established, that for retention of diamond grain integrity during sintering of the wheels one must observe combinations of brand of diamond grains and brand of metal bond. So diamond grains with strength not less than indicated in table 1 should be included in various metal bonds for the wheel of 100 % grain concentration.

Table 1 – Maximum permissible strength of diamond grains for various bonds

Bond	M1-01	M2-09	M6-14	BK
Grain	AC6	AC32	AC50	AC160

Thus, at the first stage of the investigations the optimal combinations of strengths of metal bond and diamond grains with their maximum concentration limit in the wheel providing retention of diamond grain integrity during diamond wheel production are established. Optimal relation of strengths of bond, diamond grains and grain concentration, obtained at this stage, are only limiting parameters (characteristics) and should be defined more precisely for diamond grinding process depending on strength properties of material to be machined.

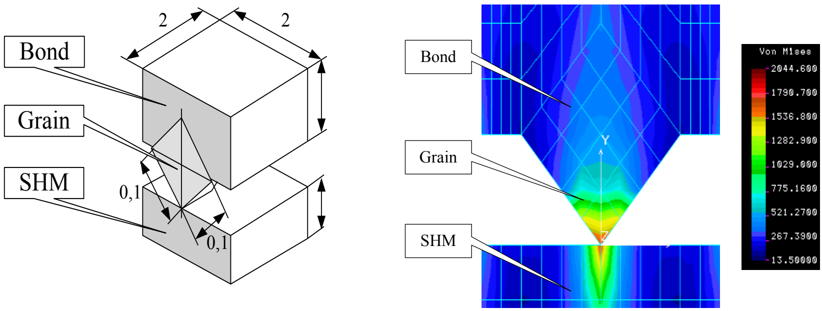
After obtaining of the prescribed limits one should determine optimal combination of strengths of material to be machined, bond, diamond grains and grain concentration in the wheel, which provides maximal efficiency of grinding process. During exploitation optimal combination of strengths of bond, diamond grains and grain concentration is determined depending on strength properties of MM. For this purpose the methodology of 3D simulation of DM, only for grinding zone, will be used too.

Optimal combination of strengths of bond, grains and grain concentration should provide such level of DM in grinding zone, when:

- Retention of diamond grains in bond is provided;
- Brittle microfracture of diamond grains (at grinding of "soft" materials) or self-sharpening of grains without forming of wear platforms (at grinding of "hard" materials) are eliminated;
- Maximal stresses in material to be machined (removal of allowance) are provided;
- Formation of inadmissible defect layer is eliminated.

If physico-mechanical characteristics of MM and strength of diamond grains and bond are used as initial data, then outcomes of computation will be concentration of diamond grains. In order to find strength of diamond grains as a result of computation, one should use physico-mechanical characteristics of MM and strength of bond and concentration of diamond grains, and so on.

Analytical model and example of computation data of 3D DM of the «SHM-grain- bond» system are shown in fig. 2.



a) b)

Figure 2 – 3D analytical model of grinding area (a) and example of DM computation data of «SHM-grain- bond» system (b)

Thus, space of optimal fracture of units of the «SHM-grain- bond» system elements, where the grain is kept and is not fractured, SHM is fractured in contact, but is not cracked owing to the total loading of all grains (except spoilage) is theoretically defined (fig. 3).

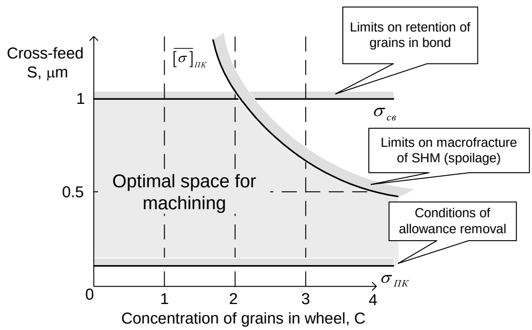


Figure 3 – Computation data of optimal concentration of diamond grains and cross-feed on strength properties of grinding zone elements

The space of optimal conditions of diamond grinding of different brands of SHM, including newly-produced brands can be theoretically defined. The further experimental researches with the purpose of curtailment of their size, will be carried out in this area.

Optimal characteristics of diamond wheels and conditions of processing (table 2) are defined as applied to diamond grinding of superhard materials

Table 2 – Optimal characteristics of diamond wheels at the stage of their exploitation

SHM to be machined	Strength of diamond grains	Strength of metal bond, GPa	Concentration of diamond grains in wheel	Grinding speed m/s	Normal pressure, MPa
АСПК	АС160	600	5-7	40-50	3-4
АСБ	АС85	500	8-11	35-40	2,5-3
ДАП	АС60	400	12-15	30-35	2-2,5
СКМ	АС32	300	17-22	25-30	1,5-2
Гексанит-Р	АС15	100	25-35	20-30	1-1,5
Эльбор-Р	АС15	100	35-50	20-30	1-1,5

Such relation of strength properties of materials to be machined, bond and diamond grains ensures defect-free processing under conditions of the maximum possible productivity and minimum specific consumption of grains during diamond grinding. One of the substantial reserve for effectiveness increase of given kind of processing is finding of similar optimal relations as applied to the process of diamond grinding not only SHM, but also hard alloys, ceramics, polymers and other materials.

5. Conclusions

Thus, methodology of definition of the scientifically proved recommendations on application of optimal combination of strengths of bond, diamond grains and grain concentration for effective grinding of materials of different hardness has been worked up. It is established, that strength of wheel bond is the major parameter defining not only degree of diamond retention, but also productivity of the grinding process. Concentration of diamond grains in wheel should be assigned starting from the relation of strength of the «material to be machined-grain-bond» system elements. The defectiveness level at diamond grinding of SHM is defined by relation of strength of SHM, bond, diamond grains and grain concentration in the wheel. Graininess selection of diamond wheel should be carried out taking into consideration strength properties of diamond grains, which differ in size.

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МЕТОДОЛОГІЯ ВИЗНАЧЕННЯ ОПТИМАЛЬНИХ ХАРАКТЕРИСТИК АЛМАЗНОГО КРУГА НА ЕТАПАХ ВИРОБНИЦТВА ТА ЕКСПЛУАТАЦІЇ

Анотація. *Проблема підвищення ефективності виготовлення та застосування алмазно-абразивного інструменту залишається актуальною темою досліджень. Розвиток обчислювальної техніки відкриває можливості для розробки тривимірної (3D) методики комплексного дослідження взаємопов'язаних процесів виготовлення та експлуатації алмазно-абразивного інструменту та підвищення надійності одноточкового інструменту на етапі його заточування. Створення методики тривимірного моделювання процесів спікання алмазно-абразивного інструменту та процесів механічної обробки дозволяє суттєво підвищити достовірність отриманих результатів, скоротити обсяг експериментальних досліджень для визначення оптимальних режимів шліфування та розробити нові технології, інструменти та обладнання. Розроблена методика дає можливість створити експертну систему для завдання раціональних характеристик алмазних кругів та режимів шліфування. Пропонована 3D-методика дослідження процесів алмазно-абразивної обробки охоплює всі основні етапи життєвого циклу інструменту, включаючи процеси виготовлення та експлуатації. Таким чином, розроблено методику визначення науково обґрунтованих рекомендацій щодо застосування оптимального поєднання міцності зв'язки, алмазних зерен та концентрації зерен для ефективного подрібнення матеріалів різної твердості. Встановлено, що міцність зв'язки круга є найважливішим параметром, визначальним і як ступінь алмазоутримання, і як продуктивність процесу шліфування. Концентрацію алмазних зерен у крузі слід задавати виходячи із співвідношення міцності елементів системи «матеріал–зерно–зв'язка». Рівень дефектності при алмазному шліфуванні НТМ визначають за співвідношенням міцності НТМ, зв'язки, алмазних зерен та концентрації зерен у крузі. Підбір зернистості алмазного круга слід проводити з урахуванням властивостей міцності алмазних зерен, що різняться за розміром.*

Ключові слова: *моделювання; система "робоча поверхня круга – оброблюваний матеріал"; шліфування; руйнування; система "полікристал – зерно – зв'язка".*