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RESEARCH OF THE CUTTING MECHANISM AT ELECTRICAL DISCHARGE GRINDING

Abstract. *The paper presents the results of a study of the cutting mechanism during electrical discharge grinding of hard alloys. The cutting mechanism during electrical discharge grinding was studied using mathematical modeling. By means of geometric modeling, a method of grinding cup wear was developed. The functional dependence of the diamonds use factor in the Kw wheel on the technological parameters of processing, wear and tool characteristics were determined. Analysis of the results of the study shows that an increase in efficiency at electrical discharge grinding can be achieved by reducing the wear of S, and by corresponding variation in the concentration of diamonds and technological modes of processing.*

Keywords: *mathematical modeling;wheel wear; technological modes of processing***.**

Introduction. Combined processing methods can improve the performance of metal-bonded diamond wheels and expand the technological capabilities and areas of their effective application. One of these methods is the process of electrical discharge diamond grinding with a changing polarity of the electrodes over time in the cutting area [1, 2].

The intensification of the process of electrical discharge diamond grinding is carried out due to the formation of spark electrical discharges in the cutting area, which affect the processed material and the working surface of the diamond wheel on current-conducting bond, which contributes to the preservation of the high cutting capacity of the diamond wheel, as well as the stability of the relief [3].

The cutting mechanism during electrical discharge grinding of hard alloys has not been studied. In this regard, it is of interest to analyze such a process indicator as the number of active cutting grits within the contact area of the diamond-bearing layer with the processed surface. The cutting mechanism allows evaluating the qualitative side of the interaction of the processed material and the cutting surface of the tool [4]. The nature of this interaction largely depends on the technological parameters of the process, which affect the state of the working surface of the wheel and the surface layer of the part material.

Research Methodology. The cutting mechanism in electrical discharge grinding is convenient to study by modeling. To study the cutting mechanism during flat grinding with a wheel face, a geometric model of the process was chosen, and the results obtained were refined using a mathematical model [5, 6]. During the processing, the tool wears out in two directions: axial (parallel to the working surface) and radial. Axial wear of the diamond-bearing layer with thickness S_1 (Fig. 1) runs along the surface, which is formed by the helical motion of the rectilinear generator, which is an instantaneous cutting edge.

In the considered case, the lines generating a set located on the processed surface of the part will be parallel to the cutting surface of the wheel and perpendicular to its axis. As a result, we get a surface constructed according to the height of the diamond-bearing layer, which is a helical cylinder, obtained by the motion of a rectilinear generator sliding along two helical lines of the same pitch S and remaining parallel to the cutting surface of the tool.

During electrical discharge grinding, electric discharges remain in force in the cutting area, and they occur when the interelectrode gap between the chip or metal surface and the bond is broken. Therefore, the radial wear of the diamond-bearing layer of the wheel with a thickness of S_2 is assumed to be equal to the value of the interelectrode gap. Since radial wear occurs simultaneously with axial wear, the wear surface takes on a curved shape created by the motion of the generator sliding along two helical lines with a pitch S (Fig. 2).

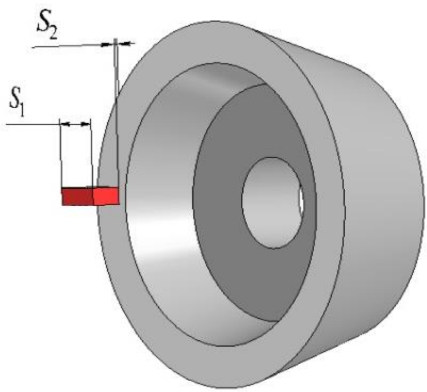

Figure 1 – Schematic diagram of the axial, radial wear of the diamond-bearing layer of the wheel

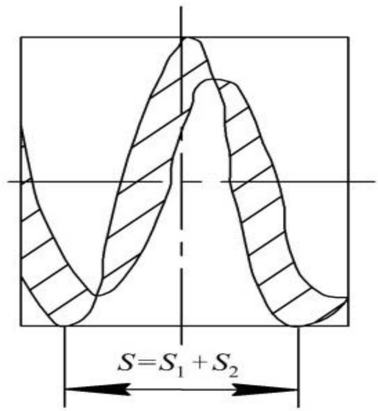

Figure 2 – Schematic diagram of formation of the surface of a helical cylinderalong the height of the diamond-bearing layer of the wheel

To determine the number of active Z_a grits directly involved in cutting, it is necessary to find their spatial (volume) distribution in the diamond-bearing layer. For this purpose, a mathematical model of the wheel working surface was developed (Fig. 3). It is based on the distribution of active grits in the volume of the working layer with a height equal to the S_1 pitch, within which the total number of diamonds Z_s is contained, including active grits in the intermediate layers Z_{s1}, Z_{s2}... Z_s.

As the Z_{s1} grits wear out, the vertices of the Z_{s2} diamonds come into operation, and so on to the point where they are fixed in the bond. As a result of the effect of electric discharges, the bond of the wheel wears out, another series of active grits is opened, and the process of exposing them in the same order is repeated in the same order by layers. If we assume that at the initial moment of cutting, the number of vertices of active grits on the surface of the diamond-bearing layer is determined by the function $Z_a=f(Z)$ given for a certain set of grits, then taking into account the accepted model, the function should be continuous for other layers of the working surface of the wheel.

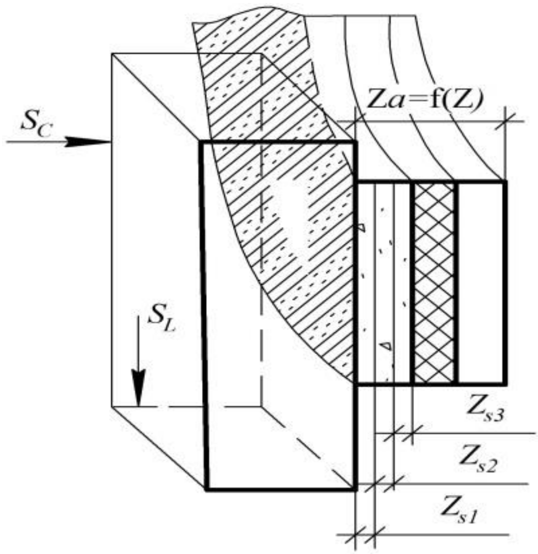

Figure 3 – Schematic diagram of the distribution of diamond grits within the cutting surface of the wheel

This is confirmed by a well-known rule in the set theory. If $Z_{1a} \in Z_{2a}$ and $Z_{2a} \in Z_{3a}$, then hence $Z_{1a} \in Z_{3a}$, i.e. this relation has transitivity. Thus, based on the transitivity property inherent in diamonds during the operation of the wheel, each of these active grits performs cutting, simultaneously wearing out, while the function $Z_a=f(Z)$ will be continuous. Provided that additional energy is supplied to the diamond wheel in the form of electrical discharges, and the grits are distributed over the volume of the working layer in accordance with the scheme shown in Fig. 3.

To determine Z_a, we first calculate the total number of Z_s grits located in the boundary layer of the working surface with S height for a grinding cup using the following ratio:

$$Z_S = 0.6 \cdot 10^6 \frac{\pi \left(R^2 - r^2 \right) KS}{K_V d^3}, \tag{1}$$

where R and r, respectively, are the maximum and minimum radii of the working layer of the wheel, mm; K is abrasive concentration in the tool; K_V is the filling coefficient of the grit volume; d is the average weighted cubic grit size.

Since in this case not all the grits are of interest, but only those that are located within the cutting surface. The wear of the diamond-bearing layer of the wheel corresponding to the average grit size of the main fraction $\bar{d}$ can be taken as the pitch of the helical surface S. As a rule [7], the grits of powders, in particular diamond, are divided by size into the main (quantitatively predominant), large and small fractions. Moreover, the percentage of each of them is strictly regulated for powders of a certain grit size. Knowing the distribution of grits by fractions and calculating their total number by formula (1), it is possible to calculate their content in the diamond-bearing layer.

Results. The results of calculating the number of grits located within the cutting surface of 125×5×3 grinding cups made of diamonds of grades A, ACB and AC6 on a metal bond M1B (diamond grit size 100/80) are shown in Table 1.

Next, we determine the instantaneous number of active grits acting within the contact area F_o per rotation of the wheel.

The instantaneous shear cross section F_Z, taken by the active grits in one rotation of the wheel, is calculated by the following formula:

$$F_Z = \frac{S_C S_L H}{60 \cdot V}, \tag{2}$$

where S_C is the cross traverse of the working machine, mm/rot; S_L is the longitudinal traverse of the working machine, mm/rot; H is the height of the grinding surface, mm.

The instantaneous shear cross section can also be determined from the following expression:

$$F_Z = f_1 Z_{Fo}, \tag{3}$$

where f_1 is the shear cross section area taken by a single grit; Z_{Fo} is the instantaneous number of grits involved in cutting within the site Fo.

Table 1 – The number of grits (thousand pieces), located within the cutting surface of the wheels

Fraction	A	ACB	AC6
Large	5.8	6.1	5.1
Main	43.1	41.4	37.5
Small	15.4	13.4	8.1
Total grits	64.3	60.9	50.7

Solving equations (2) and (3) with respect to Z_{Fo}, we obtain

$$Z_{Fo} = \frac{S_C}{f_1} \frac{S_L H}{60 \cdot V}, \tag{4}$$

In the case of flat grinding with a wheel face, the cutting surface area for one rotation is expressed by the following formula:

$$F_O = \frac{\pi D S_L H}{60 V Z_a}, \tag{5}$$

Jointly solving equations (4) and (5) with respect to Z_a, we obtain the total number of active grits within the entire area of the working surface of the wheel

$$Z_a = \frac{S_C S_L H \left(R^2 - r^2\right)}{f_1 F_O 60V}, \tag{6}$$

The area f_1 can be determined by experimentally examining the chip geometry or the residual roughness of the processed surface. Since it is difficult to measure the geometric parameters of the chips due to their small sizes, the value of f_1 was found by studying the residual roughness. For this purpose, experiments were carried out on microcutting with single grit and grinding with a grinding cup with dimensions 125×10×3 AC6 125/100-M1B-100% of plates made of hard alloy BK6 with cooling.

The depth of grit penetration into the processed surface and, consequently, R_{max} are mainly determined by the cross traverse, which in the experiments varied from 0.01 to 0.06 mm/double stroke; the longitudinal traverse was 2.0 m/min, the speed of rotation of the wheel was 16 m/s. As a result of the research, an exponential regularity of the change in the shearing section area f_1 as a function of R_{max} was established, which is expressed by the ratio $f_1 = 6.45 R_{max}^{1.6}$.

Figure 4 shows the graphical dependence of the instantaneous number of Z_{Fo} grits on the cross traverse S_C. As can be seen from Fig. 4, for the described operating conditions of the wheel, the instantaneous number of active diamond grits increases with an increase in the cross traverse, since the chip removal operation and the wear of the most protruding grit vertices increase.

If at a cross traverse of 0.01 mm/double stroke the instantaneous number of diamond grits is minimal (6), then in the case of traverses of 0.05 and 0.06 mm/double stroke, it increases up to 26-28 or 4.3-4.6 times, and there is a tendency to stabilize the number of grits, which indicates that the operating conditions of the wheel are close to optimal [6].

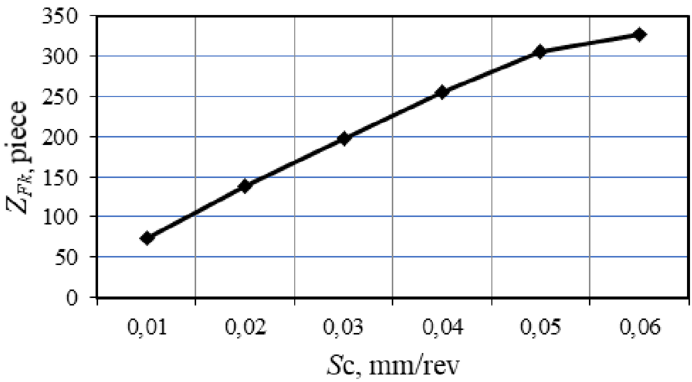

Figure 4 – Dependence of the instantaneous number of diamond grits on the cross traverse

Based on the data shown in Fig. 4, it is possible to calculate the number of active cutting grits Z_{Fk} within the contact area F_k (70 mm^2) of the diamond-bearing layer with the processed surface and, depending on the cross traverse, to estimate the diamond use factor in the wheel K_w, which is established as a result of the joint solution of equations (1), (5) and (6):

$$K_W = 0.6 \cdot 10^{-6} \frac{S_C d^3 K_V}{SK\pi D f_1}. \quad (7)$$

The values of Z_{Fk} and K_w with a cross traverse of S_C = 0.01-0.06 mm/double stroke can be taken from the graphical dependence of Fig. 5.

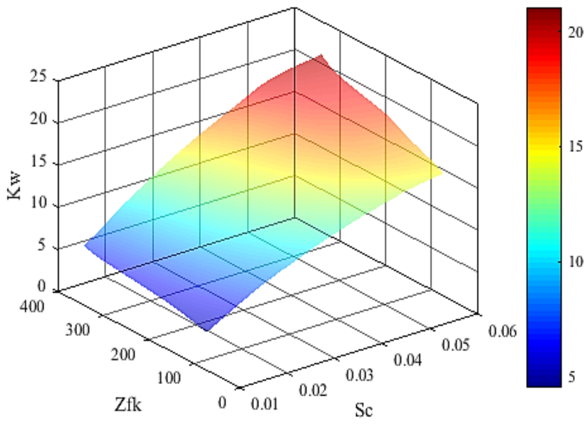

Figure 5 – Experimental values of Z_{Fk} and K_w from the cross traverse S_C.

Conclusions. The obtained results should be used when selecting the technological modes for grinding hard alloys of various grades and characteristics of diamond tools. It should be noted that even when operating under conditions close to optimal (S_C =0.06 mm/double stroke, S_L =2.0 m/min, V=16 m/s), the K_w factor is only 22.4 %, which indicates an incomplete use of the potential capabilities of diamonds in a metal-bonded wheel. This is even more evident when processing various materials in non-combined grinding conditions. According to the publications data [8, 9], about 8% of the potential cutting properties of diamond grits are used when grinding hard alloy BK8, about 12% when grinding steel, and no more than 10% when grinding cast iron.

The analysis of equation (7) shows that the increase in the efficiency of the application of diamonds in the wheel can be achieved with electrical discharge grinding due to the reduction of wear *S*, and the corresponding variation in the concentration of diamonds and technological modes of processing. This puts forward the task of further improving the process of electrical discharge grinding with bringing the diamond use factor to at least 40 %, as well as underlines the need for careful selection of the optimal diamond concentration in the tool and the grinding conditions.

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ДОСЛІДЖЕННЯ МЕХАНІЗМУ РІЗАННЯ ПРИ ЕЛЕКТРОЕРОЗІЙНОМУ ШЛІФУВАННІ

Анотація. *У роботі наведено результати дослідження механізму різання при електроерозійному шліфуванні твердих сплавів. Механізм різання при електроерозійному шліфуванні досліджували за допомогою математичного моделювання. Шляхом геометричного моделювання розроблено методику зносу шліфувального круга чашкової форми. Визначено функціональну залежність коефіцієнта використання алмазів у крузі* K_w *від технологічних параметрів обробки, зносу та характеристик інструменту. Аналіз результатів дослідження показує, що підвищення ефективності при електроерозійному шліфуванні можна досягти за рахунок зменшення зносу S і відповідним варіюванням концентрації алмазів і технологічних режимів обробки. Підвищити працездатність алмазних кругів на металевих зв'язках та розширити технологічні можливості та галузі їх ефективного застосування дозволяють комбіновані методи обробки. Одним з таких способів є процес електроерозійного алмазного шліфування зі змінною полярністю електродів у часі в зоні різання. Інтенсифікація процесу електроерозійного алмазного шліфування здійснюється за рахунок утворення в зоні різання іскрових електричних розрядів, що впливають на оброблюваний матеріал і на робочу поверхню алмазного круга на струмопровідній зв'язці, що сприяє збереженню високої ріжучої здатності алмазного круга, стійкості рельєфу. Механізм різання при електроерозійному шліфуванні твердих сплавів не вивчений. У зв'язку з цим цікавий аналіз такого показника процесу, як кількість активних ріжучих зерен в межах площі контакту алмазоносного шару з оброблюваною поверхнею. Механізм різання дозволяє оцінити якісну сторону взаємодії оброблюваного матеріалу та різальної поверхні інструменту. Характер цієї взаємодії багато в чому залежить від технологічних параметрів процесу, що впливають на стан робочої поверхні круга та поверхневого шару матеріалу деталей.*

Ключові слова: *математичне моделювання; знос круга; технологічні режими обробки.*