INTRODUCTION TO THE ANALYSIS OF THE MECHANICS OF THE DIAMOND GRINDING PROCESS WITH THE ACCOUNT OF WEAR OF WHEEL GRAINS

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Abstract: *The work is devoted to the theoretical analysis of the mechanics of the diamond grinding process, taking into account the wear of the wheel grains for scientifically based choice of optimal processing conditions. A multiplicative probabilistic approach to the generalization of the cutting profile of a diamond grinding wheel in its consideration in a state of some steady wear during processing is considered. This is achieved by working the wheel in a mode of properly established self-sharpening or with the use of effective dressing methods. In this case, the linear wear of individual grains of diamond abrasive located on the working surface of the grinding wheel and opened to mechanical contact with the material being processed is assumed to proportionally to the depth of the introduction of grain into it. The analytical dependence of the maximum thickness of the cut is presented, and the relationship between the maximum grain wear and the accepted universal relative characteristic of the steady wear with the operational parameters of the tool and the grinding mode is shown. The obtained results can be used in the development of analytical models of processing productivity and microgeometric engineering of the treated surface, new approaches to increasing the efficiency of diamond grinding. The research is based on modern technical possibilities of controlling the state of the cutting relief of diamond-abrasive tools, especially in electro-physical-mechanical grinding technologies, for example, using the diamond-spark method developed at the Kharkov Polytechnic Institute.*

Keywords: mechanics, diamond grinding, tool characteristics, machining modes, cutting relief of wheel, wear of the wheel grains, maximum thickness of the cut.

1. INTRODUCTION

The grinding process is characterized by considerable technological capabilities in terms of ensuring the quality and accuracy of the treated surfaces. This is especially true for diamond grinding with the high hardness and sharpness of the cutting edges of the wheel grains which allows the efficient processing of materials of increased hardness (hard alloys, ceramic materials, high-strength steels, etc.), with operations as final, and preliminary processing when taking significant allowances [1-3]. At the same time, the parameters of the cutting relief of the diamond wheel change in the process of grinding in connection with the wear of grains and bonds. A very specific cutting relief of the wheel determined by the level of energy balance of the "wheel-workpiece" system is a corresponding for each mode of grinding, processed material and the characteristics of the wheel. The effect of grinding consists mainly in maintaining in the process of treating the optimum steady-state cutting relief which ensures the achievement of high grinding parameters [4].

In connection with this, in the present paper the problem of theoretical analysis of the mechanics of the diamond grinding process is solved, taking into account the wear of the wheel grains and scientifically based choice of optimal processing conditions.

2. ANALYTICAL RESEARCH

Analysis of regularities in the formation of the diamond's cutting relief in the grinding process is based on the design scheme, in which the wear rate of the bond is equal to the wear rate of the grains. A layer dn of grains with a protrusion height $(b - y_s)$ above the bond on the working surface of the wheel (Fig. 1 [5]) is allocated for calculations, and the formation of the profile from their superposition on the sample cross section which coincides with the diametral plane of the wheel is considered. With mutual grain's horizontal movement dn and radial movement of the sample, the cut sections of different thickness are formed on its cross section, obeying the uniform distribution law. The relative completeness of the profile of the elementary cut section from dn grains takes the form:

$$\varepsilon_i(y) = \frac{dn[a_s + 2tgy \cdot (y - y_i)]}{B}, \tag{1}$$

where a_s – the value of the wear area on the grain, m; $dn = n \cdot \frac{1}{b} dy_i$.

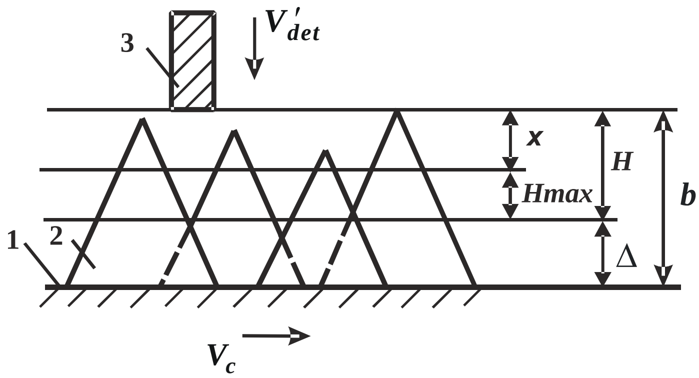

Fig. 1. Calculation scheme of the grinding process parameters:
1 – the level of the bond;2 – cutting grain; 3 – processed sample

2. ANALYTICAL RESEARCH

The total profile of such cut sections can be obtained by probabilistic summation, for which it is necessary to pass from a probability function $\varepsilon_i(y)$ to the opposite function $\Phi_i(y) = 1 - \varepsilon_i(y)$ and use the theorem of multiplication of independent random variables, integrating expression $[a_s + 2tg\gamma \cdot (y - y_a)]$ in the range from y_a to y:

$$\Phi(y) = \prod_{i=1}^{\infty} \Phi_i(y) = e^{-\frac{dn}{B}\cdot\left[a_s(y-y_a)+tg\gamma(y-y_a)^2\right]}, \quad (2)$$

where y_a – coordinate of the wear area on the grain.

The relative completeness of the profile from all the grains which participate in the cutting can be obtained by multiplying the probability function $\Phi(y)$ for all elementary layers of grains, representing the value a_s by expression $a_s = 2tg\gamma(y_a - y_s)$ and replacing the factor $(y_a - y_s)$ on $\eta \cdot (y_a - y_s)$, where $\eta =$ 0 … 1 – dimensionless coefficient, determining the value of linear wear of grain before its volumetric destruction. After simple transformations, we have

$$\Phi_{\Sigma} = e^{-\frac{n\cdot tg\gamma\cdot\left(1-\eta^2\right)}{b\cdot B}\cdot\frac{y^3}{3}}. \quad (3)$$

Total number n of grains which participate in cutting when the sample moves in a grain layer with height b for diamond grinding wheel surface grain's concentration k equally

$$n = k \cdot B \cdot V_c \cdot \frac{b}{V'_{det}}. \quad (4)$$

The maximum penetration depth of the sample into the working surface of the wheel, at which a full profile is formed at its cross section, i.e. the complete removal of the metal is determined from the condition $\varepsilon(H) = 0{,}95$:

$$H = \sqrt[3]{\frac{9 \cdot b \cdot V'_{det}}{tg\gamma \cdot k \cdot V_c \cdot \left(1-\eta^2\right)}}. \quad (5)$$

Applying the notation $H_0 = \sqrt[3]{\frac{9 \cdot b \cdot V'_{det}}{tg\gamma \cdot k \cdot V_c}}$ **it is received** $H = \frac{H_0}{\sqrt[3]{1-\eta^2}}$ **.**

As can be seen, the dimensionless coefficient η depends on the attitude x / H_0: the more it is, the more η (Fig. 2). Thus, when $x / H_0 < 0{,}8$ dimensionless coefficient η takes values close x / H_0, while $x / H_0 > 0{,}8$ – values close to unity ($\eta \to 1$). With an increase in the ratio x / H_0 the values η asymptotically approach unity. As follows from Fig. 2, under the condition $x = H_0$ the values η=0,75. Setting the value H_0 (for example, H_0=1 mkm), from Fig. 2, one can establish the relationship between the quantities x and η. Starting from the dependence (5), it is easy to determine the parameter H. The calculated values of the parameter H for H_0=1 mkm shows in Table 1.

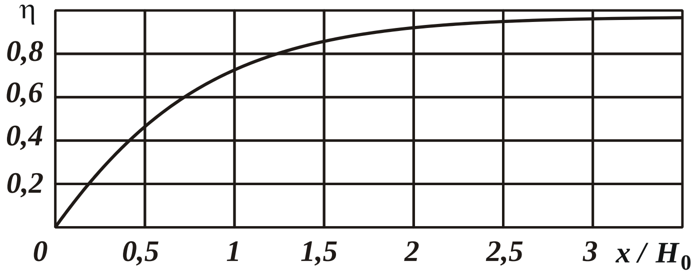

Fig. 2. Dependence of the dimensionless coefficient η on the attitude x / H_0

***Table 1**: The calculated values of the parameter H (H_0 = 1 μm)*

x, μm	0	0,25	0,55	0,99	1,55	2,05	3,7	∞
H, μm	–	1,0	1,1	1,32	1,72	2,16	3,74	∞

Parameter H increases with increasing of linear grain wear x at $H_0 = const$. And, since x=2 mkm parameter values x and H are approximately equal in connection with increase of the maximum grain wear and, correspondently, the asymptotic approximation of the dimensionless quantity η to unity ($\eta \to 1$). If there are known the values of the parameters x and H, it is easy to determine the parameter H_{max} from the $H_{max} = H - x$ (Fig. 2 and Table 1).

As follows from Fig. 3, parameter H_{max} decreases with increasing x. When $x \to \infty$ the condition $H_{max} \to 0$ is true. Taking into account the boundedness of x, parameter H_{max} takes finite values.

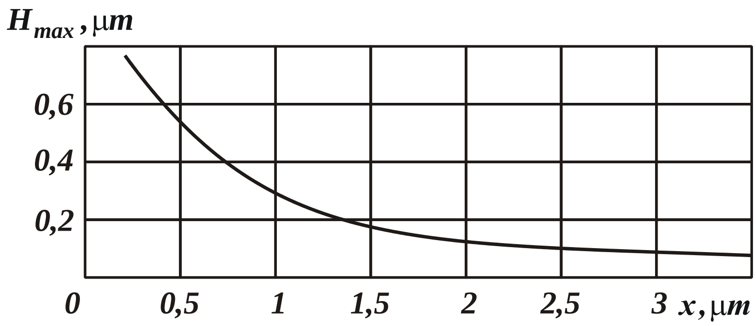

Fig. 3. Dependence of the maximum probabilistic (reduced) thickness of the cut H_{max} from the value of linear wear of the wheel grain x

In this way it is shown that the quantity x has the significant influence to the value of a maximum thickness of the cut H_{max}, changing it practically within unlimited limits. This indicates that it is necessary to take into account the linear wear of grains x along with the traditional parameters (grinding modes and wheel characteristics) when calculating the parameter H_{max}. In the general form, the parameter H_{max} is determined as

$$H_{max} = (1-\eta)\cdot H = H_0 \cdot \sqrt[3]{\frac{(1-\eta)^2}{(1+\eta)}} \; . \qquad (6)$$

Parameters H_{max} and H_0 are linearly related, and H_{max} and η by nonlinear dependence. Parameter H_{max} the more, the more H_0 and a smaller dimensionless coefficient η. Proceeding from the dependence (6), the factor $\sqrt[3]{(1-\eta)^2/(1+\eta)}$ can be considered as a correction factor, depending on the degree of blunting of the cutting grains. The calculated values of the parameter H_{max} in dependence on the dimensionless coefficient η for H_0 =1 μm are shown in Table 2.

Table 2: The calculated values of the parameter H_{max} (H_0 = 1 μm)

η	0	0,25	0,5	0,75	0,9	0,95	0,99	1,0
H_{max}, μm	–	0,75	0,55	0,33	0,17	0,11	0,04	0

As it can be seen, the parameter H_{max} decreases with an increase in the dimensionless coefficient η, and $H_{max} \to 0$ when $\eta \to 1$. On the one hand, as the grains wear out, the parameter H_{max} decreases, which allows to improve the finish. On the other hand, this leads to a cessation of material removal, since the parameter $H_{max} \to 0$ with the decrease of the dimensionless coefficient $\eta \to 0$. In Table 2 parameter H_{max} is equal to the multiplier $\sqrt[3]{(1-\eta)^2/(1+\eta)}$, because the H_0 =1 μm. Thus, the factor $\sqrt[3]{(1-\eta)^2/(1+\eta)}$, acting as a correction factor in the dependence (6), decreases down to zero with an increase in the dimensionless coefficient η. This shows that the wear of grains determined by the quantities x and η has a significant influence on the regularities of the grinding process.

When determining the dimensionless coefficient η we must proceed from the condition that linear wear of the wheel occurs as a result of bulk destruction of grains with their surface destruction before this, which precedes necessarily [6]. The loss of grains from the bond is not considered in the calculations initially. The ultimate (destructive) load is assumed to be proportional to the cut-shear area S which depends on $H_{max} = (1-\eta)\cdot H$ and the dimensionless coefficient η (Fig. 1):

$$S = tg\gamma \cdot H^2 \cdot \left(1-\eta^2\right). \qquad (7)$$

Solving the dependences (5) and (7) with allowance for $\gamma = 45^0$, we have

$$\eta = \sqrt{1 - \frac{k^2 \cdot V_c^2 \cdot S^3}{81 \cdot tg\gamma \cdot b^2 \cdot V_{det}'^2}} \; . \qquad (8)$$

As follows from the dependence (8), dimensionless coefficient η increases with increasing V'_{det}, and stabilization of the cutting relief of the wheel occurs at a greater distance from the top of the original maximum protruding grain. Consequently, before the grain is volumetrically destroyed, it undergoes considerable wear from abrasion and edge micro cracking. Radiuses of rounding at the tops of such grains increase, and the cutting relief of the wheel becomes smoother. The result is due to the fact that with increasing V'_{det} the maximum cut-off area corresponding to the destructive load is located at a greater distance from the top of the original (non-intact) grain

$$H = \frac{9 \cdot b \cdot V'_{det}}{k \cdot V_c \cdot S}. \quad (9)$$

Linear wear of grain x and the maximum thickness of the cut H_{max} on condition $tg\gamma = 1$ are determined by the following dependencies:

$$x = \eta \cdot H = \sqrt{1 - \frac{k^2 \cdot V_c^2 \cdot S^2}{81 \cdot b^2 \cdot V_{det}^2}} \cdot \frac{9 \cdot b \cdot V'_{det}}{k \cdot V_c \cdot S}; \quad (10)$$

$$H = (1-\eta) \cdot H = \left[\left(1 - \sqrt{1 - \frac{k^2 \cdot V_c^2 \cdot S^3}{81 \cdot b^2 \cdot V_{det}^2}} \right) \cdot \frac{9 \cdot b \cdot V'_{det}}{k \cdot V_c \cdot S} \right]. \quad (11)$$

Analysis of dependences (8), (10) and (11) showed that the stabilization of the relief of the wheel occurs under the condition $V'_{det} > \frac{k^2 \cdot V_c^2 \cdot S^3}{81 \cdot b^2}$. Otherwise, the loads acting on the grains do not reach the limit values, and grain destruction does not occur. The grains are subjected, in the main, to abrasion and micro cracking with the formation of wear areas, causing an increased strength and thermal tension of the grinding process and blunting the wheel. This pattern of wheel wear occurs when the wheel characteristics are incorrectly chosen, especially at the finish operations, when the grains are firmly held in a bond, and the cutting relief is not renewed with new edges. The received solution is fully supported by practical recommendations on grinding, according to which on "soft" cutting conditions it is effective to use wheels with reduced strength of grains and bonds, providing a mode of self-sharpening of the wheel and excluding the formation of significant areas of wear on grains.

3. CONCLUSION

The geometric model of the steady cutting relief of wheel with allowance for grain wear in its probabilistic treatment with respect to the grinding mechanics made it possible to obtain basic analytical interrelations of the parameters of influence on the wear of the cutting grains and the maximum thickness of the cut. This makes it possible to carry out a theoretical analysis of the mechanics of the diamond grinding process taking into account the wear of the wheel grains for scientifically based selection of optimal processing conditions.

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