ANALYTICAL DETERMINATION OF CONDITIONS FOR SURFACE ROUGHNESS REDUCTION IN DIAMOND GRINDING

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Abstract: The article contains analytical dependences for determination of main parameters of surface roughness in diamond grinding. It is shown that the accounting values of linear wear of grains range matches the theory and practice of grinding. This indicates the effectiveness of reducing surface roughness by adjusting the values of linear wear of grains range. Lack of dependency of surface roughness parameters calculated depth of sanding attests to the effectiveness of deep grinding, which allows you to combine the operations of the preliminary and final grinding in one operation, while providing increased in 10 ... 100 times the processing performance and execution of technological requirements on quality of processing.

Keywords: diamond wheel, deep grinding, surface roughness, grain linear wear, processing performance, treatment quality.

1. INTRODUCTION
Application of diamond grinding has opened the new technological features of high-quality processing of machine parts made of composite materials. This is connected with reduced power and thermal tension of grinding process and exclusion of forming of burn marks, cracks and other temperature defects on processed surfaces due to the unique physical and mechanical properties of synthetic diamond [1-2]. Along with this, the process of diamond grinding leads to a decrease in microroughnesses on the machined surfaces, that positively affects the operational properties of the treated parts [3]. It is essential to know the functional relationships of the main parameters of surface roughness with grinding mode, characteristics of diamond wheel and other conditions of processing for its regulating from the point of view of a given surface roughness. In this work has been provided a simplified kinematic and refined physical model of diamond grinding. Their usage allows to identify and justify the most perspective directions of decrease surface roughness in diamond grinding by calculation without complex experiments.

2. ANALYTICAL RESEARCH
Kinematic model of the grinding process based on analytical solution for description of the boundary of the complete dispersion of material by cutting grains in the cutting zone along the arc of contact wheel with workpiece has been developed for the solution of the assigned task. According to Fig. 1, the boundary is been drawn along the tops of machined material roughness and has a complex configuration, links wheel and workpiece surfaces as well as defines the position of the conditional (probabilistic) cutting surface in grinding as in edge
cutting processing. Characteristic points of a boundary are the basis for the calculating of the physical and technological parameters of grinding (the maximum cutoff thickness, roughness parameters, the actual length of the arc of wheel contact with workpiece, etc.) that allows to describe patterns of process analytically and quite unambiguously from common positions and in all possible cut depth range including multi-pass and deep grinding.

As it follows from Fig. 1, the essence of kinematic models is an establishing of the patterns of material removal and surface forming along the arc of wheel contact with workpiece. The need to develop such a model due to the fact that the known settlement schemes, for example, proposed by E. N. Maslov [5], present the grinding zone as a wheel "contact spot" with workpiece within which all grains are uniformly loaded and work under the same conditions. In real a grinding process is subject of the more complex patterns and cannot be fully described by averaged parameters such as the average thickness of the cutoff and the like due to the curvilinearity of a wheel contact with workpiece, different in height arrangement of grains on the working surface and their probabilistic participation in cutting. Important theoretical results obtained by different researchers of the grinding process with usage of the probability-theoretic approach show this [6, 7].

It has been established by calculations with use the estimated scheme (Fig. 1) that the position of the boundaries of the complete material dispersion by cutting grains in cutting zone along the arc of wheel contact with workpiece is defined by a ratio of two parameters – maximum (given probabilistic) thickness $H_{\text{max}}$ of a cut and grinding depth $t$. In a case $t < H_{\text{max}}$ (multipass grinding) the boundary accepts approximately a symmetric form of rather axial plane of grinding, in a $t > H_{\text{max}}$ (deep grinding) – an asymmetric form.
By calculations it is established that the percent of working grains for a case \( t > H_{\text{max}} \), makes about 50\%, and for a case \( t < H_{\text{max}} - 5 \ldots 10 \% \), i.e. grains pass almost "a trace in a trace" that is an important reserve of increase in productivity of processing as it will be shown. In a case \( t > H_{\text{max}} \) analytical dependence for definition of provision of border assumes a simple air

\[
H = H_{\text{max}} \sqrt[6]{\frac{t_f}{t}},
\]

where \( t_f \) – the coordinate of the current elementary cylindrical cover by which the removed allowance is conditionally presented in the settlement scheme, m.

Respectively, parameters of boundary \( H_{\text{max}} \) and \( R_{\text{max}} \) (parameter of a roughness of processing, m) are described by analytical dependences

\[
H_{\text{max}} = \left( \frac{630 \cdot \pi \cdot \bar{X}^3 \cdot V_{\text{det}} \cdot t^{0.5} \cdot \rho^{0.5}}{m \cdot V_c} \right)^{0.33};
\]

\[
R_{\text{max}} = 10 \left( \frac{\pi \cdot \bar{X}^3 \cdot V_{\text{det}} \cdot \rho^{0.5}}{m \cdot V_c} \right)^{0.4},
\]

where \( \bar{X} \) - granularity of a wheel, m; \( m \) - volume concentration of grains in a wheel (dimensionless size); \( V_c, V_{\text{det}} \) - according to the speed of a wheel and a workpiece, m/s; \( \rho = \frac{1}{R_{\text{det}}} + \frac{1}{R_e} \); \( R_e, R_{\text{det}} \) - respectively radiuses of a wheel and a workpiece, m.

Values of thickness of the cut received on settlement dependences of a number of authors (Table 1 [4]) show on a big divergence of settlement and experimental data. For example, this divergence exceeds 1000 times for the settlement dependence offered by E. N. Maslov. The most correct result is received with use of dependence (2). The divergence of calculated and experimental \( H_{\text{max}} \) values available here to 40\% is connected with disregarding a wear of cutting grains of a wheel in kinematic model of grinding process.

**Table 1**: Calculated values of thickness of a cut \( H_{\text{max}} \) (basic data: \( R_{\text{pr}} = 80 \cdot 10^{-3} \) m; \( R_e = 150 \cdot 10^{-3} \) m; \( \bar{X} = 0.225 \cdot 10^{-4} \) m; \( m = 100; V_c = 30 \text{ m/s}; V_{\text{pr}} = 1 \text{ m/min}; t = 0.1 \cdot 10^{-3} \) m)

<table>
<thead>
<tr>
<th>Authors</th>
<th>( H_{\text{max}} ), MKM</th>
<th>Experiment data</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. N. Maslov [5]</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>G. B. Lurye [8]</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>A. N. Reznikov [9]</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>F. V. Novikov [10]</td>
<td>14.7</td>
<td>10.5</td>
</tr>
</tbody>
</table>
The obtained results are clarified in the development of the physical model of the grinding. According to this model the relationship between input and output (technological) parameters is achieved by units of the kinematics and physical parameters as well as the value of linear wear of grain \( x \). It is possible to change the kinematic, physical and, consequently, output (technological) or, on the contrary, the input parameters in a wide range with a view to achieving the required output parameters by \( x \) value changing and taking into account the feedback. New calculated dependencies are established on this basis. They contain a dimensionless coefficient \( \eta = x / H \) that defines the degree of linear wear of grains within 0…1. For the "sharp" cutting topography of the wheel \( \eta \to 0 \) and conversely, i.e. \( \eta \to 1 \) for the blunted wheel. In the interpretation [4] these dependences have the following forms:

\[
H_{\text{max}} = \left[ \frac{630 \cdot \pi \cdot X^3 \cdot V_{\text{det}} \cdot t^{0.5} \cdot \rho^{0.5} \cdot (1-\eta)^2}{m \cdot V_c \cdot (1+\eta)} \right]^{0.33}; \quad (4)
\]

\[
R_{\text{max}} = 10 \cdot \left[ \frac{(1-\eta)^2 \cdot \pi \cdot X^3 \cdot V_{\text{det}} \cdot \rho^{0.5}}{(1+\eta) \cdot m \cdot V_c} \right]^{0.4}. \quad (5)
\]

It follows from (4) and (5) that the values of the \( H_{\text{max}} \) and \( R_{\text{max}} \) parameters decrease with wear of the cutting grains and, correspondingly, a decrease in the dimensionless coefficient \( \eta \) (\( \eta > 0 \)). Therefore divergence between calculated and experimental values \( H_{\text{max}} \) (Table 1) decreases and even it is eliminated. Comparison of experimental values of the maximum thickness of chip with the corresponding calculated values of parameter \( H_{\text{max}} \) showed their approximate coincidence at \( \eta = 0.2 \) [4]. It follows from this that the accounting of size \( x \) of linear wear of grain by means of \( \eta \) parameter in settlement dependences allows to bring the theory and practice of grinding into accord.

The change of a value of the dimensionless coefficient \( \eta \) has greatest influence on values of \( H_{\text{max}} \) and \( R_{\text{max}} \) from all parameters into dependences (4) and (5). It indicates a prevailing role of the wear state of the grains in formation of the key physical and technological parameters of grinding and confirms the hypothesis of effective management of grinding process on the basis of size regulation \( \eta \).

In the executed analysis the experimental data of the current level of development of the diamond grinding techniques and technologies from laboratory and production experience were taken into account. This experience is presented by the authors in monographs [6, 11, 12] and is widely based on the successes of the Kharkov Scientific School of Physics of the Cutting and cooperation of universities in the development and applications of stable processes of high-performance diamond grinding, in particular with electrophysical stimulation of processing [13] and on the basis of improvement and use of machine tools [14], tool maintenance [15] and kinematics-parametric organization of advanced technologies [4].

It is ascertained that surface roughness parameter \( R_a \approx 0.2 \cdot R_{\text{max}} \) in external cylindrical diamond grinding has been described by the analytical dependence [10]:

\[
R_a \approx 0.2 \cdot R_{\text{max}}.
\]
When the flat grinding ($R_{det} \to \infty$) the maximum height of the machined surface voids $R_{\text{max}}$ and, consequently, surface roughness parameter $R_a \approx 0.2 \cdot R_{\text{max}}$ has been defined by the dependencies:

$$R_a = 2 \cdot \frac{(1-\eta)^2}{(1+\eta)} \cdot \frac{\pi \cdot \overline{X}^6 \cdot V_{\text{det}} \cdot R_c^{0.5}}{m \cdot V_c^0.4}.$$  \hfill (6)

It follows from (8) that $\eta$ and $\overline{X}$ have the greatest influence on parameter of surface roughness $R_a$. So, the greater the ratio $\eta$ (i.e. the cutting relief of diamond wheel is more smoothed), the smaller $R_a$. $R_a$ takes the maximum value for a wheel with sharp grains before they wear, when condition $\eta=0$ is met. The usual calculation practice is based precisely on this condition and does not take into account the wear of grains.

The granularity $\overline{X}$ of the diamond powder in wheel provides significant impact on option $R_a$ that indicates the effectiveness of the solution to the problem of quality of treatment through the application of abrasive wheels with optimal grain size.

A grinding depth is not included in the dependence (8). This confirms the effectiveness of the application deep grinding, because an increase in performance occurs without compromising the quality of machined surfaces.

It is known that the speed of a workpiece in the practice of deep grinding is 10 ... 100 times less than in multi-pass machining. The roughness of the surface with respect to the parameter $R_a$ can be reduced in 3 ... 10 times under such decrease in the speed of the workpiece in conditions of deep grinding as this follows from (8).

Thus, theoretically it is shown that the use of deep grinding to reduce the surface roughness at the same time increasing processing performance.

This confirms the possibility of single-pass deep grinding not only as a preliminary, but also as a final grinding process which reduces the surface roughness in 3 ... 10 times compared to multi-pass grinding by the abrasive wheel with the same characteristic.

Consequently, the use of deep-seated flat grinding allows to combine the operations of preliminary and final grinding in one operation, while ensuring a 10-100-fold increase in the processing capacity and the fulfillment of technological requirements for processing quality.
Presented analysis is valid for an ideal wheel when the parameter $\eta$ (ratio $x/H$) is 0. In real conditions of grinding $\eta$ changes within 0 ... 1. This leads to a decrease of the surface roughness calculated on the basis of the dependence (8), Fig. 2.

![Graph showing dependence of surface roughness $R_a$ on the ratio $\eta$ for different values of $R_{a0}$:](image)

$1 - R_{a0} = 0.05 \mu m; 2 - R_{a0} = 0.2 \mu m; 3 - R_{a0} = 0.5 \mu m; 4 - R_{a0} = 1 \mu m.$

3. CONCLUSION

Thus, the article contains analytical dependences for determination of parameters of surface roughness in diamond grinding. It is shown that the accounting of values of linear wear of grains harmonizes the theory and practice of grinding. This indicates the effectiveness of reducing surface roughness by adjusting the values of linear wear of grains range. Indifference of the adequate calculated procedure to the depth of grinding attests to the effectiveness of deep grinding which allows to combine the prior and final machining operations in one with providing as increase the processing performance in 10 ... 100 times and so execution of technological requirements on quality of processing.

REFERENCES


