DETERMINATION OF TEMPERATURE DURING DEPTH GRINDING AND CONDITIONS FOR ITS DECREASE

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Abstract: *A theoretical analysis of the conditions for reducing the temperature of grinding has been carried out and it has been shown that temperature of deep grinding is greater than under conventional multi-pass grinding with the same processing capacity. It is possible to reduce the temperature of deep grinding by increasing the cutting ability of the wheel and providing abundant heat removal from the cutting zone by using coolant, as well as reducing the speed of the wheel to reduce the friction intensity in the cutting zone. With a significant increase in the speed of the wheel (to values of 300 m/s), the main part of the heat released in the cutting zone is carried away with chips, and the grinding temperature decreases. This allows efficient use of deep grinding scheme. It is theoretically established that in this case the heating temperature of the chips is determined solely by the conditional cutting* stress*. Therefore, reducing it can reduce the temperature of grinding. The obtained results of theoretical studies were used to create a high-performance technological process of diamond electro-erosive grinding (diamond-spark grinding) of cutting multiblade carbide tools with elevated grinding depths (up to 0.6 mm) and a relatively low part speed (0.5 ... 1 m / min). This ensures the high quality of the surfaces to be treated (there are no burns, microcracks and other temperature defects).*

Keywords: deep grinding, diamond grinding, grinding temperature, conventional cutting stress, processing performance, heat removal, wheel speed.

1. INTRODUCTION

Currently, the processes of deep diamond grinding of difficult-to-work materials have been applied. Their advantage is the possibility of a significant increase in processing performance without increasing the specific consumption of diamond and reducing the durability of the wheel [1-4]. This is evidenced by the production processes of flat and circular external grinding of carbide tools, parts with high-strength surfacing and coatings, parts made of ceramics and graphites, etc. At the same time, the high temperature mode of deep grinding, which leads to the appearance of temperature defects on the surfaces being treated, in some cases hinders the application of this progressive method of processing into production. Therefore, it is important to carry out a theoretical analysis of the temperature regime of the deep diamond grinding process and to substantiate the limits of its effective use according to the temperature criterion. To do this, one should analytically determine the temperature during deep grinding and the conditions for its reduction.

2. ANALYTICAL RESEARCH

To determine the temperature during deep grinding, it is necessary to use the dependency to calculate the grinding temperature given by Prof. A. V. Yakimov [4], Fig. 1:

$$\theta = \frac{q}{2} \cdot \sqrt{\frac{2\pi \cdot l}{\lambda \cdot c \cdot \rho_m \cdot V_{det}}}, \qquad (1)$$

where $q = \frac{P_z \cdot V_c}{F} \cdot \psi$ – heat flow density that characterizes the amount of heat passing through a unit surface of a part per unit of time, W/m^2; ψ – coefficient that shows how much work goes into the heat absorbed by the workpiece; P_z – tangential component of cutting force, N; V_c – speed of grinding wheel ("circle"), m/s; $F = B \cdot l$ – contact area of a wheel with a workpiece, m^2; B – wheel width, m; $l = \sqrt{2t/\rho}$ – arc length of contact of a wheel with a workpiece, m; t – grinding depth, m; $\rho = 1/R_c + 1/R_{det}$; R_c, R_{det} – respectively, radius of the wheel and workpiece ("detail"), m; λ – coefficient of thermal conductivity of the material being processed, W/(m · K); c – specific heat of the material being processed, J/(kg · K); ρ_m – density of the processed material, kg/m^3; V_{det} – workpiece speed, m/s.

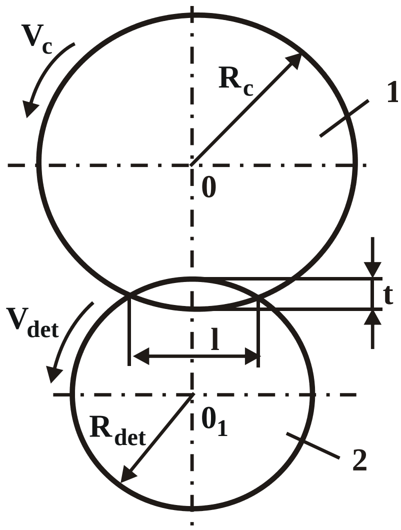

Fig. 1. *Design scheme of grinding process parameters: 1 – wheel; 2 – workpiece*

Tangential component of cutting force P_z is determined by dependence [5]:

$$P_z = \sigma \cdot S = \frac{2 \cdot \sigma_s \cdot Q}{K_g \cdot V_c} \qquad (2)$$

where $\sigma = 2\sigma_s / K_g$ – conditional cutting stress, N/m^2; σ_s – tensile strength of the treated material in compression, N/m^2; $K_g = P_z / P_y$ – grinding ratio (coefficient of cutting); P_y – radial component of cutting force, N; $S = Q / V_c$ – cross sectional area of cut (total instantaneous cross-sectional area of the cut by all simultaneously working grains of wheel), m^2; Q – processing performance, m^3/s.

After substitution of the dependence (2) in (1):

$$\theta = \frac{\sigma_s \cdot Q \cdot \psi}{K_g \cdot B} \cdot \sqrt{\frac{2\pi}{\lambda \cdot c \cdot \rho_m \cdot l \cdot V_{det}}}. \qquad (3)$$

Grinding temperature θ the more the more σ_s, processing performance Q, coefficient ψ and less parameters K_g, B, l, V_{det} (3). This is consistent with the practice of grinding. Taking into account $Q = S_f \cdot B \cdot V_{det} \cdot t$ grinding temperature θ will describe:

$$\theta = \frac{\sigma_s \cdot S_f \cdot t \cdot \psi}{K_g} \cdot \sqrt{\frac{2\pi \cdot V_{det}}{\lambda \cdot c \cdot \rho_m} \cdot \sqrt{\frac{\rho}{2t}}}, \qquad (4)$$

where S_f – fractional longitudinal feed ($S_f = 0 \ldots 1$).

Following dependence (4), an increase in the parameters of the grinding mode leads to an increase in the temperature of grinding θ. However, the parameters S_f and t have a greater effect on grinding temperature θ, than speed of workpiece V_{det}, so control the parameters S_f and t is more efficient.

The main factors to reduce the temperature of grinding θ for given values V_{det}, S_f and t are the increase in grinding ratio K_g and decrease the coefficient ψ. This is achieved through the use of diamond wheels on organic and ceramic bonds (ensuring work of wheel n self-sharpening mode) or through the use of electro-physicochemical methods for dressing diamond wheels on metal bonds, ensuring their high cutting ability and, accordingly, an increase in grinding ratio K_g. It is possible to reduce the coefficient ψ by providing an abundant heat removal rom the cutting zone by applying coolant.

Wheel speed V_c influences on grinding temperature θ by changing the grinding ratio K_g. Obviously, the greater the speed of the wheel V_c, the lower the grinding ratio (due to the reduction of slice thickness by cutting grains) and more grinding temperature θ, which is confirmed by the results of experimental studies of the process of diamond grinding of carbide tools [6]. From this point on the speed of the wheel V_c it is advisable to reduce it (for example, from 35 m/s to 20 m/s) in order to reduce the grinding temperature θ. To determine the processing performance Q taking into account the limitation on the temperature of grinding, it is necessary to resolve the dependence (4) with respect to the speed of the workpiece:

$$V_{det} = \frac{K_g^2 \cdot \theta^2}{\sigma_s^2 \cdot S_f^2 \cdot t^{1,5} \cdot \psi^2} \cdot \frac{\lambda \cdot c \cdot \rho_m}{2\pi} \cdot \sqrt{\frac{2}{\rho}}. \qquad (5)$$

To ensure treatment with a given grinding temperature θ, with increasing grinding depth t workpiece speed V_{det} should be reduced by more than a linear relationship. With decreasing S_f workpiece speed V_{det} increases, which is associated with a decrease in the nominal grinding depth per one revolution of the workpiece, i.e. in this case, actually multi-pass grinding is carried out with a nominal grinding depth that is significantly less than the installation grinding depth t.

Processing performance Q at a given grinding temperature θ determined taking into account the analytical dependence (5):

$$Q = S_f \cdot B \cdot V_{det} \cdot t = \frac{B \cdot K_g^2 \cdot \theta^2}{\sigma_s^2 \cdot S_f \cdot t^{0,5} \cdot \psi^2} \cdot \frac{\lambda \cdot c \cdot \rho_m}{2\pi} \cdot \sqrt{\frac{2}{\rho}}. \qquad (6)$$

As seen, processing performance Q decreases with increasing grinding depth t. This indicates that it is difficult to achieve an advantage in terms of the task of increasing the productivity of processing Q at a given grinding temperature value θ by using deep grinding. The use of conventional multi-pass grinding with a relatively small grinding depth t in this case it is more preferable, since it provides an increase in the productivity of processing Q. To increase processing performance Q during deep grinding it is necessary, firstly, to increase the grinding coefficient K_g by increasing the cutting ability of the wheel, secondly, to provide abundant heat removal from the cutting zone to reduce the coefficient ψ.

An important factor in improving the processing productivity Q for during deep grinding should be considered to reduce the fractional longitudinal feed S_f and increase the width of grinding B, those processing to produce by the wide wheel with the intake cone formed on it or to set the wheel at a certain angle of inclination φ (where $tg\varphi = t/B$), for example, to the direction of the longitudinal feed with a circular external grinding. Taken together, these factors will be able to offset the decline Q by increasing the depth of grinding t in dependence (5) and will allow to realize high depth grinding performance in practice, which follows from dependence [3]:

$$Q = \frac{S_f \cdot B \cdot k \cdot V_c \cdot a_{z_{max}}^3}{16{,}7 \cdot 10^2 \cdot \overline{X}^3} \cdot \sqrt{\frac{2t}{\rho}}\,, \tag{7}$$

where k – concentration of grains in a wheel; $\overline{X}$ – wheel graininess, m; $a_{z_{max}}$ – maximum slice thickness for a separate grain of wheel, m.

Based on the dependence (7), with a fixed value $a_{z_{max}}$ increased grinding depth t leads to increased processing performance Q, those the deep grinding method is more productive than the multi-pass grinding method with the same wear rate of the wheel defined by the parameter $a_{z_{max}}$. Workpiece speed V_{det}, providing grinding with a given value $a_{z_{max}}$, determined by dependence:

$$V_{det} = \frac{Q}{S_f \cdot B \cdot t} = \frac{k \cdot V_c \cdot a_{z_{max}}^3}{16{,}7 \cdot 10^2 \cdot \overline{X}^3} \cdot \sqrt{\frac{2}{t \cdot \rho}}\,. \tag{8}$$

To ensure the simultaneous fulfillment of two conditions $\theta = const$ and $a_{z_{max}} = const$ it is necessary to compare dependencies (5) and (8) and determine the speed of the wheel:

$$V_c = \frac{K_g^2 \cdot \theta^2}{\sigma_s^2 \cdot S_f^2 \cdot t \cdot \psi^2} \cdot \frac{\lambda \cdot c \cdot \rho_m}{2\pi} \cdot \frac{16{,}7 \cdot 10^2 \cdot \overline{X}^3}{k \cdot a_{z_{max}}^3}\,. \tag{9}$$

As can be seen, it is need to reduce speed of the wheel V_c with increasing grinding depth t (i.e. in the conditions of deep grinding). The speed of the workpiece V_{det}, according to (8), with an increase in the depth of grinding t will decrease more than for condition $V_c = const$. So, with increasing grinding depth t to 9 times, in accordance with dependence (9), the speed of the wheel V_c decreases by 9 times, and, in accordance with dependence (8), the speed of the workpiece V_{det} decreases by 27 times. As a result, processing performance Q, determined by dependence (7), decreases by 3 times.

Foreign literature provides data about the efficiency of deep grinding with the same calculated (regime) performance as multi-pass (pendulum) grinding [7], i.e. with increasing the depth of grinding t up to 1000 times it is necessary to reduce the speed of the workpiece V_{det} item to 1000 times, keeping the grinding width constant, equal, for example, to the width of the wheel when flat and round external grinding. The effect of improving the processing performance in this case is achieved by reducing the auxiliary time for wheel transitions and reversing the machine table. Following dependency (3), under condition $Q = const$ and significantly reduced workpiece speed V_{det}, grinding temperature θ increases and therefore for its reduction it is necessary to increase the grinding ratio K_g (for example, by reducing the speed of a wheel V_c) or reduce the coefficient ψ due to the abundant supply of coolant to the cutting zone [2, 8]. A variant of deep grinding with an increased wheel speed of V_c >300 m/s (ultra high speed deep grinding) is also proposed. It is noted that when the speed of the wheel V_c >300 m/s there is a decrease in the temperature of grinding θ due to the fact that the main part of the heat released in the cutting zone is carried away by the formed chips.

From dependence (4) it follows that in this case the coefficient $\psi \rightarrow 0$ and, accordingly, the grinding temperature $\theta \rightarrow 0$. As is known for ordinary grinding [8], the proportion of heat released in the cutting zone and going into the workpiece can be up to 90 %. In this case the coefficient $\psi = 0{,}9$ and grinding temperature θ takes significantly larger values than with ultra-high speed deep grinding. Therefore, when V_c > 300 m/s, it is effectively use the scheme of deep grinding, since the temperature of grinding θ is not a limiting factor for improved grinding performance. The main limiting factor in improving the performance of grinding in this regime situation, as it follows from relationship (8), should be considered a mechanical factor associated with the wear rate of the wheel.

In the case of complete transfer of heat released in the cutting zone to the formed chips (i.e., with ultra-high-speed deep grinding), their heating temperature is determined by the dependence [9]:

$$\theta = \frac{\sigma}{c \cdot \rho_m} . \qquad (10)$$

Chip temperature θ depends solely on the conditional cutting stress σ: the more σ, the higher the temperature θ, which can reach the melting point of the material being processed. The main condition for reducing the temperature θ and, accordingly, the thermal intensity of the grinding process in this case is to reduce the conventional cutting stress σ by reducing the intensity of friction in the cutting zone, mainly the intensity of friction of the bond of the grinding wheel with the material being processed.

With normal grinding $V_c < 300$ m/s), following the dependence (9), it is necessary to reduce the speed of the wheel V_c with increasing grinding depth t (i.e. with the transition to the area of deep grinding). Otherwise, this will lead to an increase in the grinding temperature θ, since under the condition of increasing the speed of the whell V_c, the speed of the workpiece V_{det} increases, that follows from (8), and, in accordance with dependence (4), the grinding temperature θ also increases.

This can explain the practical data on temperature rise under deep grinding when the speed of the wheel V_c set the same as in multi-pass grinding.

Based on the dependence (8), for the implementation of a relatively high speed of wheel V_c with deep grinding, comparable or equal to the speed of the wheel with multi-pass grinding, it is necessary to increase the graininess of the wheel $\overline{X}$, reduce the concentration of abrasive grains in the wheel k, increase the cutting ability of the wheel with increase the grinding ratio $K_{ш}$, improve heat removal from the cutting zone with reduce the coefficient ψ. This can be achieved through the use of coarse-grained, highly porous, impregnated or intermittent abrasive wheels with high cutting ability, as well as by supplying abundant coolant to the cutting zone. It is possible to increase the speed of the wheel V_c together with a decrease S_f, but it is associated with a decrease in processing performance as it follows from dependence (7), which is inefficient, i.e. it is preferable that the treatment be performed with a longitudinal feed of fractional to unity [10].

The obtained results of theoretical studies were used to create a high-performance technological process of diamond electro-erosive grinding (diamond-spark grinding) of cutting multiblade carbide tools with increased grinding depths (up to 0.6 mm), a relatively small workpiece speed (V_{det} = 0,5 … 1 m/min) and fractional longitudinal feed S_f closed to one. Wheel speed V_c installed within 35 m/s. Due to the continuous maintenance during grinding of the high cutting ability of the diamond wheel on the metal bond (as a result of its electro-erosive dressing), the machining performance at the level of 20 thousand mm^3/min is realized, which is several times higher than the performance of ordinary multi-pass grinding. At the same time high quality of the processed surfaces is provided (there are no cauterizations, microcracks and other temperature defects).

3. CONCLUSION

There are defined the conditions of reducing for the temperature during deep grinding, consisting in increasing the cutting ability of the wheel and providing abundant heat removal from the cutting zone by using coolant, as well as reducing the speed of the wheel to reduce the intensity of friction in the cutting zone. It is shown that with a significant increase in the speed of the wheel (to values of 300 m/s), the main part of the heat released in the cutting zone is carried away by chips, and the grinding temperature decreases. This allows effectively use the scheme of deep grinding due to reducing of the conditional cutting stress.

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