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THEORETICAL CORROBORATION FOR THE TEMPERATURE REDUCTION CONDITIONS IN THE CUTTING ZONE DURING TREATMENT

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ABSTRACT: *This paper presents new analytical relationships that can be used in the evaluation of cutting resulting temperature during finishing while using the multiple-pass grinding method, considering heat distribution, which affects the work piece and the resulting facings. It has been shown that most of the heat generated during multiple-pass grinding permeates into the work piece and a small fraction goes to the resulting facings. Therefore, estimating heat passing to the treated work piece will help correlate between theory and practice of the process of grinding. It was theoretically determined that changing the type of heat flux density going inward the surface-layer of the treated work piece had an irrelevant effect on the absolute values or trend of the cutting temperature during grinding, as well as the depth of heat penetration into the surface layer of the work piece. This is consistent with the results of experimental studies for heat penetration depth in the surface layer of the work piece, which indicates the validity of the obtained theoretical solution and the possibility of its practical application in determining the optimum temperature during multiple-pass grinding. It is shown that the main requirement for reducing cutting temperature during grinding is a decrease in the conventional cutting stress, which was found to have the greatest impact on cutting resulting temperature. Theoretically, cutting temperature during grinding can be lowered by reducing the grinding depth at a given specific productivity, i.e. by using multiple-pass grinding.*

KEYWORDS: Multiple-Pass Grinding, Cutting Temperature During Grinding, Surface Layer of The Work Piece, Heat Penetration Depth, Conventional Cutting Stress, Heat Flux Density.

INTRODUCTION

Problem Statement

Mechanical processing of hard-to-cut materials is faced with the problem of reducing stress during the treatment process. This problem appears, firstly, due to the need to increase the resistance of the cutting tool because of the effect of temperature, and secondly, in order to improve treatment quality, because elevated cutting temperatures can form burn marks, microcracks, and other temperature-resulting defects on a treated surface. Particularly the grinding process which, on the one hand, provides high levels of accuracy and surface roughness but, on the other hand will lead to a decrease in quality as a result of high tension resulting from heat generated in the treatment process. This is associated to the processing of materials like hard alloys, high strength steels, coating materials, and so on. Therefore, finding techniques that reduce the thermal stress of mechanical treatment is of a great practical importance and requires further research.

Identifying appropriate conditions that will reduce treatment temperatures has gathered great attention in the scientific literature [1-4]. The fundamentals of thermal physics of cutting and the effective methods which provide a reduction in thermal stresses during grinding processes were developed. However, there is no simple and reliable engineering method for calculating the value of cutting temperature at this time, which if obtained will allow for a reasonable and consistent approach in selecting the most rational methods and treatment conditions through temperature criterion. Therefore, it is imperative to develop a solution to this problem by using a general theoretical approach that utilizes heat balance equations and related temperature during the treatment process. This will allow for a satisfactory comparison of various treatment methods, and to assess their technological capabilities in terms of reducing cutting temperatures.

The aim of the work presented in this paper was to theoretically substantiate techniques that will reduce the work piece temperature during mechanical treatment of machine elements.

MATERIALS AND METHODS

In general, the average cutting temperature T can be determined from the equation of heat generation during cutting: $Q = c \times m \times T$, and the mechanical work required for cutting: $A = P_z \times L$:

$$T = \frac{P_z \cdot L}{c \cdot m}, \tag{1}$$

where $P_z = \sigma \times S_{cut}$ is the main component of the cutting force (N), σ is the conventional cutting power (N/m^2), S_{cut} is the cross-sectional area of the cut (made by an edge tool) (m^2), and L is the cutting length (m).

$$T = \frac{\sigma \cdot S_{cut} \cdot L}{c \cdot p \cdot \vartheta},$$

where c is the thermal capacitance of the treated material (J/kg·K), $m = \rho \times \vartheta = \rho \times S_{cut} \times L$ is the mass of loose material (i.e. mass of the chips produced) (kg), ρ is the density of the treated material (kg/m^3), and ϑ is the volume of loose material (m^3).

After transforming formula (1), the following can be obtained:

$$T = \frac{\sigma}{c \times \rho} \tag{2}$$

An analytical relation for determining turning σ was obtained [5]:

$$\sigma = 2 \times \sigma_c \times tg \times (\psi - \gamma), \tag{3}$$

where σ_c is the compressive strength of treated material (N/m^2); ψ is the conventional friction angle on the front face of the cutter ($tg \times \psi = f$ is the friction coefficient); and γ is the positive rake of the cutter.

Substituting the equation (3) into (2) will obtain the following:

$$T = \frac{2 \times \sigma_c \times tg \times (\psi - \gamma)}{c \times p} \tag{4}$$

According to the equation (4), the cutting temperature T can be reduced by decreasing the difference of angles $(\psi - \gamma)$. A more conservative friction angle ψ corresponds to a greatly positive cutter rake γ. In the case of an assumed negative grinding angle γ, equation (4) transforms into:

$$T = \frac{2 \times \sigma_c \times tg \times (\psi + \gamma)}{c \times p} \tag{5}$$

Figure 1 shows a schematic for the processes of edge cutting machining and an abrasive treatment in the cutting zone.

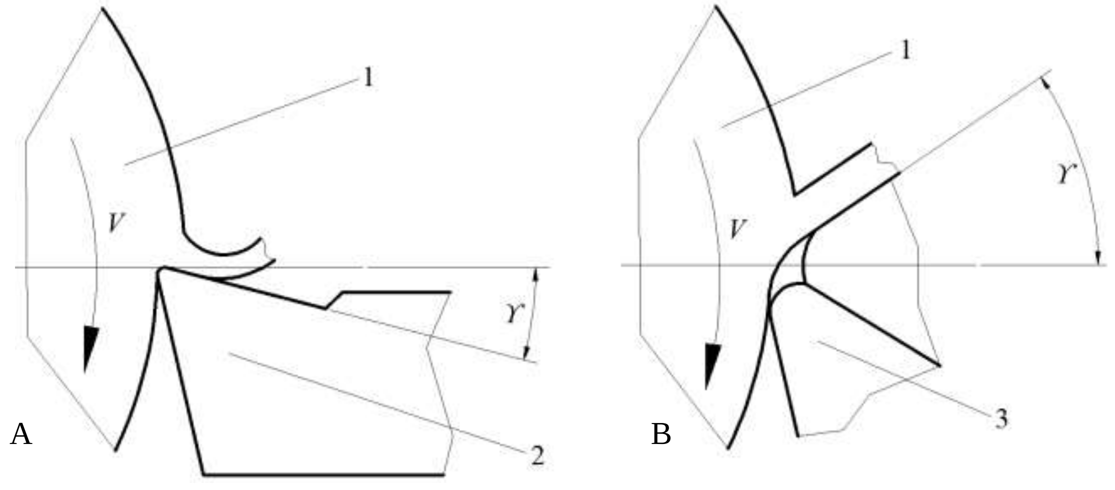

Figure 1: The cutting zone during: edge cutting machining (A) and an abrasive treatment (B); 1 - the work piece, 2 is the cutter, 3 is the abrasive grain, V is the cutting speed, and γ is the rake.

In this case, cutting temperature T can be reduced by decreasing ψ and rake angles approaching zero; i.e. $\gamma \to 0$. Obviously, during grinding the conventional cutting stress σ and cutting temperature T is always greater compared to turning. This is attributed to the presence of friction between the grinding wheel and the treated material during grinding, which is not taken into account in the equation (5), but its intensity may exceed the cutting power stress of abrasive wheel grains defined by the equation (5). Therefore, reducing the values of σ and T during grinding is possible by the means of maintaining a high cutting capability of the disc in order to provide, firstly, reduction in friction between the wheel and treated work piece. This can be achieved by various methods within the industrial environments such as using high-porous abrasive wheels, which are characterized by a significant volume of intergranular space capable of containing chips that are generated during grinding. In case of grinding with diamond wheels using high tensile metal post, it is useful to use electro-erosion or electrochemical wheel grooving, providing intensive thermal destruction (or chemical dissolution) of metal post while maintaining a developed cutting relief on the wheel which helps high-performance and high-quality treatment without the formation of burn marks and other temperature defects on the treated surfaces.

It should be noted that the equation (1) ignores the heat removed from the grinding zone to the surface layer of the work piece. Therefore the obtained solution should be rectified. Heat generated in the grinding process has to be considered as a combination of two components: heat removed from the cutting area to the surface layer of the work piece (Q_1) and heating chips (Q_2):

$$Q = Q_1 + Q_2 . \tag{6}$$

Taking into consideration that $Q_1 = \lambda \times F \times \frac{T}{l_2} \times \tau$ and $Q_2 = Q - Q_1 = c \cdot m \cdot T$, according to the equality of temperatures on the surface of the work piece, the following is obtained:

$$T = \frac{(Q - Q_1)}{c \cdot m} = \frac{Q_1 \cdot l_2}{\lambda \cdot F \cdot \tau} , \tag{7}$$

where l_2 is the heat penetration depth into the surface layer of the work piece (m), λ is the thermal conductivity of the work piece material (W / m · K), F is the area in contact between with the cutting tool (grinding wheel) and treated surface (m^2), and τ is the contact time of the fixed point on the treated surface with the cutting tool (s).

Parameter l_2 is defined according to the equation [6]:

$$l_2 = \sqrt{\frac{2 \cdot \lambda \cdot \tau}{c \cdot \rho}} . \tag{8}$$

The mass of chips m can be defined as following:

$$m = \rho \cdot t \cdot F , \tag{9}$$

where t is the grinding depth (m).

After explicitly solving equation (7) for Q_1, and considering equations (8) and (9), the following is obtained:

$$Q_1 = \frac{Q}{\left(1 + t \cdot \sqrt{\frac{2}{a \cdot \tau}}\right)}, \tag{10}$$

where $a = \lambda / (c \cdot \rho)$ is the temperature conductivity coefficient of the treated work piece material (m^2/s).

Apparently, the amount of heat permeating to the surface layer of the treated work piece is less than the overall amount of heat developed during grinding by $\left(1 + t \cdot \sqrt{\frac{2}{a \cdot \tau}}\right)$ times. For the quantitative evaluation of the Q_1 / Q ratio in equation (10) the t / τ ratio will be considered as the metal removal rate in the radial direction V_{cut}, i.e. $V_{cut} = t / \tau$. Then equation (10) cans be rewritten as the following:

$$Q_1 = \frac{Q}{\left(1 + \sqrt{\frac{2 \cdot t \cdot V_{cut}}{a}}\right)}. \tag{11}$$

According to scientific literature [7], in the case of flat grinding:

$$V_{cut} = V_w \cdot \sqrt{\frac{t}{2 \cdot R_w}} = \frac{Q_c}{\sqrt{2 \cdot t \cdot R_{wh}}}, \tag{12}$$

where V_w is the moving speed of the work piece (m/s), R_{wh} is the wheel radio (m), and $Q_c = V_w \cdot t$ is the conventional treatment productivity (m^2/s).

The Q_1 / Q ratio for the flat creep-feed grinding is defined as ($t_1 = 10^{-3}$ m) and for a multiple-pass grinding ($t_2 = 0.01 \times 10^{-3}$m) of steel with grade ШХ15 (ShH15) for the bench-mark data: R_{wh} =0.15 m, Q_c = 600 mm^2/min = 10^{-5} m^2/s, and a = 8.4×10^{-6} m^2/s.

It was estimated that for the flat plane creep-feed grinding $V_{cut} = 0.58 \cdot 10^{-3}$ m / s, and according to the equation (11) $Q_1/Q = 0.73$. As a result, virtually all heat generated during grinding goes into the work piece. Only an insignificant amount of heat goes to the chips.

According to calculations, $V_{cut} = 5.8 \times 10^{-3}$ m/s during flat, multiple-pass grinding. Then, according to the equation (11), $Q_1/Q = 0.9$. Thus, the amount of heat which goes to the outgoing chip during multiple pass grinding is even less, so even more heat goes into the work piece. Therefore, in the case of grinding with sufficient accuracy for practical purposes, the amount of heat generated in the outgoing chip (Q_2) can be neglected as an initial approximation, safely assuming that $Q_1 \cong Q$. Taking this assumption into consideration, equation (7) can be modified to obtain the cutting temperature:

$$T = \frac{Q \cdot l_2}{\lambda \cdot F \cdot \tau}. \tag{13}$$

Expressing the total amount of heat generated during grinding as: $Q = N \cdot \tau$, where $N = P_z \cdot V_{wh}$ is grinding power (W), and V_{wh} is the wheel speed, (m/s).

The tangential component of the cutting force $P_z = \sigma \cdot S_{inst}$, in which $S_{inst} = \frac{B \cdot V_w \cdot t}{V_{wh}}$ is the instantaneous total cross sectional area of the slice made by simultaneously operating all grains of the wheel (m^2); and B is the grinding width (m). Therefore the following formula can be obtained:

$$Q = \sigma \cdot B \cdot V_w \cdot t \cdot \tau. \tag{14}$$

The contact time of the grinding wheel and a fixed point located on the treated surface is considered as $\tau = l / V_w$, where $l = \sqrt{2 \cdot t \cdot R_{wh}}$ is the length of the grinding wheel contact with the treated material (m) [5]. If the contact area of the grinding wheel and the work piece is defined as $F = B \cdot l$, and taking into account equations (8) and (14), equation (13) can be expressed as follows:

$$T = \sigma \cdot t \cdot \sqrt{\frac{2}{c \cdot p \cdot \lambda} \cdot \frac{V_w}{\sqrt{2 \cdot t \cdot R_{wh}}}}. \tag{15}$$

Equation (15) is an approximate formula that can be used for determining the grinding temperature T, with the assumption that all heat produced during cutting will only permeate into the work piece.

However, in order to obtain an accurate determination for the grinding temperature T, which will consider the balance of the heat permeating into the work piece and the generated chips; it is necessary to express the heat capacity Q_1 in the equation (7) through equation (11). This is equivalent to multiplying equation (15) by a following factor:

$$\frac{1}{\left(1 + \sqrt{\frac{2 \cdot t \cdot V_{cut}}{a}}\right)} = \frac{1}{\left(1 + \sqrt{\frac{2 \cdot t \cdot V_w}{a} \cdot \sqrt{\frac{t}{2 \cdot R_{wh}}}}\right)}.$$

By doing so, equation (15) transforms into the following form:

$$T = \sigma \cdot t \cdot \sqrt{\frac{2}{c \cdot p \cdot \lambda} \cdot \frac{V_w}{\sqrt{2 \cdot t \cdot R_{wh}}}} \cdot \frac{1}{\left(1 + \sqrt{\frac{2 \cdot t \cdot V_w}{a} \cdot \sqrt{\frac{t}{2 \cdot R_{wh}}}}\right)} . \qquad (16)$$

Grinding temperature value (T) calculated using equation (15) will differ slightly from temperature values calculated using equation (16). Therefore, equation (15) can be used for approximate calculations of grinding temperature, while equation (16) for more accurate ones.

The Q_1 / Q ratio was estimated for the turning process according to the equation (11). V_{cut} in this case is defined as $V_{cut} = V \cdot tg\beta$ [7], where V is the cutting speed (m/ s), and β is the conventional shear angle of treated material.

Instead of grinding depth t the slice thickness Π must be considered according to equation (11). For the bench-mark data: $\Pi = 0.2 \times 10^{-3}$ m; V = 20 m/s; $tg\beta = 0.3$; $a = 8.4 \times 10^{-6}$ m^2/s (steel grade ШХ15 was used as the treated material), a ratio of Q_1 / Q = 0.059 was obtained.

Consequently, the work piece will absorb only 5.9% of generated heat, and the resulting chips will absorb the majority of generated heat, which is 94.1%. These results are the opposite of the results obtained for the grinding. Therefore, the use of turning instead of grinding will provide a solution for the problem of heat dissipation by directing the majority of generated heat towards the resulting chips. Reducing the cutting temperature and consequently improving the treatment quality, by avoiding the formation of thermal defects on treated surfaces.

Obtained results were consistent with known practical data that indicates the validity of the presented theoretical solutions. Evaluation of cutting temperatures during turning, unlike grinding, should be carried out according to equation (4); i.e. using both assumptions $Q_1 \to 0$ and $Q_2 \approx Q$

CONCLUSIONS

1. A general theoretical approach to the determination of heat balance and temperature during treatment was developed. Analytical relationships for defining the amount of heat permeating into the work piece and chips during blade tool cutting (using turning as an example) and grinding were derived. Calculations revealed that the majority of resulting heat will permeate into the work piece during grinding, while for turning, the majority of resulting heat will virtually goes into the chips.

2. The analysis showed that reducing the grinding temperature can be mainly obtained by decreasing the cutting stress (energy-output ratio) by the means of increasing the cutting ability of the cutting wheel and the reduction of friction intensity in the grinding zone. Decreasing the difference between the conditional friction angle on the front surface and the front corner of the tool will reduce surface temperature while performing cutting machining.

REFERENCES

[1] Re*znikov A.N.* Thermophysics of mechanical treatment processes of the materials / A.N. Reznikov. – Moscow: Mechanical engineering, 1981. – p. 279.

[2] Yakimov A.V. Grinding process optimization / A.V.Yakimov – Moscow: Mechanical engineering, 1975. – p. 175.

[3] Sipajlov V.A. Thermal processes of grinding and surface quality management / V.A. Sipajlov. – Moscow: Mechanical engineering, 1978. – p. 166.

[4] *Silin S. S.* Similarity method for cutting of the materials / S.S. Silin - Moscow: Mechanical engineering, 1979. – p. 152.

[5] Physico-matematical theory of material treatment processes and the mechanical engineering technology / under the general editorship of F. V. Novikov and A. V. Yakimov. In ten volumes. – T. 1. ”Material cutting mechanics” – Odessa: ONPU, 2002. – p. 580.

[6] 6. Theory of material cutting and grinding: study guide / A. V. Yakimov, F. V. Novikov, G. V. Novikov, B. S. Serov, A. A. Yakimov. – Odessa: OGPU, 1999. – p. 450.

[7] Progressive machining technology: monograph / F.V. Novikov, A.G. Kryuk, V.G. Shkurupij etc.; under the general editorship of Professor Novikov F.V. – H.: Vid. HNEU, 2012. – p. 372.

[8] Novikov *F.V.* Improving the efficiency of finishing technology of friction pair piston pump elements / *F.V. Novikov, S.M. Yatsenko* // Physical and computer technologies: International scientific conference, April 19-20, 2007: writings - Kharkov. HNPK "FED", 2007. - pp. 8-20.

[9] Novikov F.V. A mathematical model for determining the temperature during creep-feed grinding / F.V. Novikov, O.S. Klenov // Cutting and tools in technological systems: International scientific collection. - Kharkov: NTU "HPI", 2009. - Vol. 76. - pp. 133-141.