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DEFINITION OF THE AMOUNT OF HEAT RELEASED DURING METAL CUTTING BY ABRASIVE GRAIN AND THE CONTACT TEMPERATURE OF THE GROUND SURFACE

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Предметом дослідження є процес теплоутворення при шліфуванні металів і сплавів, а об'єктом дослідження – визначення кількості теплоти, що виділяється при різанні металу окремими абразивними зернами, підсумовування теплових потоків від окремих зерен і формування потужності теплового джерела в зоні контакту шліфувального круга зі шліфованої деталлю. Знання теплонапруженості процесу шліфування дає можливість не допускати шліфувальних прижогів і тріщин. Це різко знижує міцність, надійність і довговічність деталі

Ключові слова: шліфування металів, кількість теплоти, теплові потоки, кількість теплоти, теплонапруженість процесу

Предметом исследования является процесс теплообразования при шлифовании металлов и сплавов, а объектом исследования – определение количества теплоты, выделяющееся при резании металла отдельными абразивными зернами, суммирование тепловых потоков от отдельных зерен и формирование мощности теплового источника в зоне контакта шлифовального круга со шлифуемой деталью. Знание теплонапряженности процесса шлифования дает возможность не допускать шлифовочных прижогов и трещин. Это резко снижает прочность, надежность и долговечность детали

Ключевые слова: шлифование металлов, количество теплоты, тепловые потоки, теплонапряженность процесса

1. Introduction

To improve the service life of components operating in harsh conditions, it is necessary that the working surfaces of these parts have the required complex of properties. Increasing requirements for precision of machine parts, the use of new hard manufactured materials, sharply raised the question of an effective fine treatment of blanks, giving them the ultimate accuracy and the necessary range of physical-mechanical characteristics. One type of such treatment and often only one possible is grinding.

Formation of the physical properties of the surface layer of the ground parts largely depends on the temperature range in the contact zone of a wheel with the workpiece that provides a certain phase – structural composition and the texture of the layer, its state of stress. All this has a great influence on the performance of the parts – reliability and durability.

The temperature that occurs in the contact area of the grinding wheel with the workplace can have maximum values reaching up to 1200–1300 °C, which causes defects of grinding – profound changes of phase – structural composition of the surface layer, which creates favorable conditions for the formation of residual stresses, and as, a result, cracks [1]. As it is known from the literature [2], thermal defects of grinding reduce the durability of items in 3–4 times. Currently, due to the emergence of numerous new steels and alloys that are processed by grinding, a very topical issue is creating a regulatory framework of processing modes, which, along with the high enough performance, ensure the high quality of the surface layer. This task may be performed using analytical analysis of heat generation in the grinding process, observing the cutting process with abrasive grain with its inconsistent laws.

2. Literature review and problem statement

Contact grinding temperature affects almost all the grinding metals and alloys mainly negatively, because it is as if an unscheduled heat treatment with distorted parameters [1, 2].

The fundamental papers [1, 2] observed the issues of heat generation during grinding. But these studies do not have information because these works are of the 60ies on the processes of heat generation in the case of grinding with diamond and CBN wheels. Besides, the authors were unable either analytically or programmatically to link the conflicting characteristics of the grain cutting process. Moreover, these works are mainly dedicated to the grinding of carbon steels only.

The paper [4] simulates the grinding process, but from the point of view of the optimum surface roughness.

The papers [4, 5] show the results of mathematical modeling of thermal fields in grinding, but the causes of the temperature and the change in its values, depending on the grinding parameters are not available.

The paper [5] considers the issues of internal transformation of maraging steels at different heating conditions. However, the transformations in surface heating that occur during grinding are not covered.

The paper [6] presents the results of studies of creep of maraging steel after prolonged heating, which also does not correspond to the heating conditions during grinding.

The sources [7, 8] deal with the influence of alloying elements on the process of hardening of maraging steels. However, it is almost impossible to correlate the results with the heating conditions during grinding.

The papers [9, 10] consider the issues of structural heredity and exit conditions of dispersed intermetallic particles from the solid solution under heat, which also does not explain the behavior of these steels during grinding heating.

The papers [11, 12] present the results of studies of changes in the strength properties of maraging steels as a result of structural changes, which in turn are the result of changes in temperature. Despite the interesting data, these materials cannot be used to predict the behavior of these steels during heating by the temperature of grinding, as in these sources heating is volumetric and prolonged, and in the case of grinding – heating is surface and short.

Thus, analyzing the data available in the literature, we can conclude that the issues of the behavior of steels when changing the operating temperature are well covered. There is little data on changes in the properties of steels and alloys after being subjected to grinding temperature, the values of which can be higher those of operational temperatures.

Maintaining the temperature of grinding within the limits which provide a high quality of the surface layer is an important technological problem. Analytical determination of the grinding temperature, despite the powerful mathematical tool, is impossible without the knowledge of the two basic values:

1) the amount of heat given off by grain to the ground material during the cutting (chip removal);

2) the number of cutting grains in the contact area of the wheel with the workpiece.

Both of these values form the thermal source power, which determines the contact temperature of grinding.

Both of these issues are hardly considered in the literature.

The cutting grain in contact with the material being processed describes the trajectory – a prolate trochoid. Thus, at any given time the depth of grain penetration into the metal or the thickness of chips removed by the grain vary and depend on the position on the grain on the path. Thus, we can talk about the current depth of introduction of the grain in the metal and its maximum and minimum values. In addition, the specificity of the process of cutting by abrasive grain is in the fact that high-speed cutting process causes hardening of the metal and so-called "metal hardness alignment" [2], and on the other hand – released temperature causes the metal-softening.

The present paper considers contradictory abrasive grain cutting factors with the help of numerical solutions, which virtually is not done in the literature that gives an opportunity to get reasonably accurate data on the temperature of grinding and the laws of its origin and change. This makes it possible to make a prediction about the temperature value when changing the treatment process parameters.

3. Goals and objectives

The goal of the paper is to establish the regularities of formation of the heat source power in the contact area of a wheel with a part of any materials with different mechanical and thermal characteristics

To achieve this goal, the following objectives are set:

– to analyze the models of the cutting part of the grain and choose the most appropriate;

– to create mathematical relationships that reflect changes in the mechanical characteristics of steels of different classes depending on the cutting speed and temperature; to create the system of the numerical calculation of the amount of heat given off by the grain at any stretch of its trajectory;

– to create mathematical relationships reflecting the grain penetration depth into the metal as it moves along the track at any time;

– to create mathematical relationships and show regularities in the formation of the total heat source with all the grains running in the contact area of the wheel and the workpiece, on the basis of which to be able to calculate the contact temperature of grinding of any material such as iron-carbon alloy.

4. Materials and methods of research

In order to solve the problem, you need to know the following characteristics of the cutting process: V_w – rotation speed of the wheel, V_p – movement speed of the part, D_w – diameter of the wheel, t – cutting depth during the grinding, S – the value of the cross-feed or “band width”, the length of the arc of contact of the wheel with the metal or the grain path length [1]:

$$L=\sqrt{D_{кр}\cdot t}. \tag{1}$$

The papers [1–3] have investigated analytically the cutting part of the grain, which can be represented as a pyramid, or a cone surface or the ball surface. These models make it possible to determine the force P_y by the depth of the indentation of the grain, and then P_z is determined by the known relations between P_y and P_z forces with sufficient accuracy.

If we take the model of the grain in the form of a pyramid, the force P_y is determined by the formula:

$$P_y=\frac{H\cdot M}{2}, \tag{2}$$

where M – the surface area of the pyramid, forced back into the metal; N – microhardness, N/m^2.

If we take the model of the cutting part of the grain in the form of the ball surface, you can obtain the value of the force of indentation P_y based on the following ratios:

$$P_y=H\cdot\pi(h^2+2h(2R-h)), \tag{3}$$

where h – the thickness of the chip removed or the depth of indentation of the grain into ceramics, R – the radius of curvature of the cutting part of the grain.

If we take the model of the cutting part in the form of a cone, the pressing force value P_y is possible to obtain based on the following relations:

$$P_y=H\cdot\pi\cdot h\cdot tg60°\left(h\cdot tg60°+\frac{h}{\sin 60°}\right). \tag{4}$$

Analysis of the models made by calculating the force of indentation P_y has shown that changes in the estimated values of forces at different depths in grinding are quite close to each other (Fig. 1).

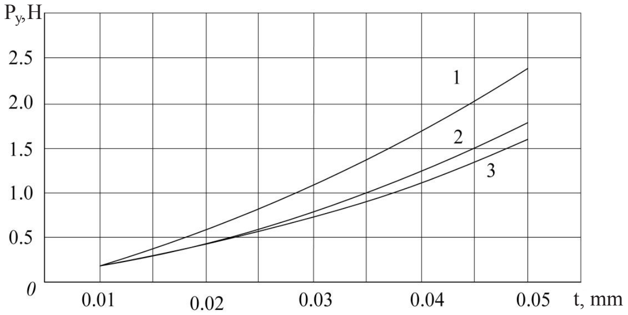

Fig. 1. Changes in the calculated values of the force P_y on the depth of grinding depending on the adopted model of the form of the cutting part of the grain: 1 — cone, 2 — ball, 3 — pyramid

The model of the cutting part of the grain in the form of a ball more accurately reflects the ongoing process, because it includes the radius of curvature of the cutting part of the grain.

Currently, attempts are being made to introduce the top of the grain in the form of an ellipsoid of revolution or a spheroid. However, in this case, the contact area of the grain with the metal during cutting with a recess in the latter into the metal to a depth of 1–5 mm is virtually identical to the area of contact of the ball with the same values of the recess.

Accordingly, the model of a ball has been adopted, which greatly simplifies the calculations as compared to an ellipsoid of revolution.

If we take the data from the source [3]:

$$P_z=0.55P_y. \tag{5}$$

We can say that

$$P_z=0.55\cdot H\cdot\pi\cdot(h^2+2h(2R-h)). \tag{6}$$

Consequently, the value of the cutting force P_z can be determined knowing the radius of the grain, depending on the grain size, and depth of pressing of the abrasive grain or the mid-section of chips, removed by the grain.

$R_{g\ abr}$ – the radius of the top curvature of the abrasive grain can be taken from [3] where:

$$R_{fig}=10^{-6}\cdot N_z^{0.85}. \tag{7}$$

Consequently

$$R_{zKBN}=0.8\cdot R_{fig}, \tag{8}$$

$$R_z=0.7\cdot R_{fig}. \tag{9}$$

N_z – the grit number of abrasive wheels. The grit size of wheels of synthetic superhard materials should be brought to the abrasive grain size. F_z – the contact area of the grain with the metal from the ratios of the spherical sector, considering that only half the sector is in contact with the metal, is equal to:

$$F_з=\pi R_з h, \tag{10}$$

where R_c – the grain radius of curvature, h – the depth of introduction of the grain to the metal.

5. Analytical studies of the amount of heat released when metal cutting by abrasive grain and the contact temperature of the ground surface

At high strain rates, the resistance to plastic compression and extension of the metal increases. Due to metal heating, deformation resistance decreases and there is the so-called “metal hardness equalization alignment”. Thus, the deformation force during chip forming is determined by the action of both factors simultaneously. The paper [2] introduced the concept of temperature, modified by the cutting speed. The strain rate is associated with the temperature by the ratio:

$$T_{mod}=T_{abc}\left(1-C\cdot\ln\frac{\varepsilon}{\varepsilon_0}\right), \tag{11}$$

where T_{mod} – the temperature, modified by velocity; T_{abs} – absolute temperature, C – the constant depending on the material being tested (for the steel and brass C=0.017); ε – the strain rate at which the temperature is determined, ε_0 – the strain rate at a standard test method.

It is believed that the temperature as if falls at high strain rates. So if it is equal to 900 °C when grinding, and the strain rate is 10^6 1/s, the deformation of the metal will occur at [2]:

$$T_{mod} = 1173\ K\left(1 - 0.017 \ln \frac{10^6}{10^{-3}}\right) = 501\ °C. \tag{12}$$

Thus, the steel heated to 900 °C at a given strain rate will have the strength that it would have at 501 °C [2].

Simple counting shows that for normal cutting speed of 30–35 m/s during grinding and at the transition from K to °C, the expression (12) is transformed into a simple formula:

$$T_{mod} = 0.647 \cdot T_s, \tag{13}$$

That is for the wheel speed of 35 m/s $v_{def}=10^6$ 1/s; for the velocity of 25 m/s $v_{def}=0.71\ 10^6$ 1/s; for the velocity of 15 m/s $v_{def}=0.43\ 10^6$ 1/s; for the velocity of 50 m/s $v_{def}=1.43\ 10^6$ 1/s.

Fig. 2 shows the typical tensile strength-temperature curves of carbon and low-alloy steels (the total amount of alloying elements is not more than 5 %) σ_{vr}. Analysis of these dependences shows that they with a sufficient degree of accuracy can be described by the expression:

$$\sigma_t = \sigma_{20} \cdot \exp\left(-0.8 \cdot 10^{-3} T_t\right). \tag{14}$$

Or, if we talk about the tensile strength at the modified temperature, it can be written as follows:

$$\sigma_{mod} = \sigma_{20} \exp\left(-8 \cdot 10^{-4} \cdot T_{modt}\right). \tag{15}$$

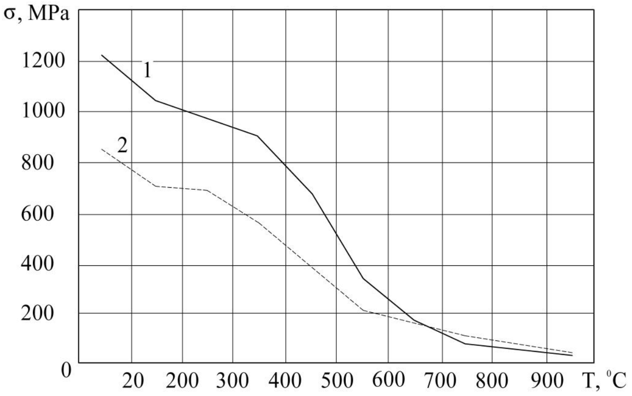

Fig. 2. A typical dependence of the tensile strength of steel on temperature: 1 – 30HGSA steel; 2 – 45 steel

For maraging steels, this dependence is somewhat different and can be presented in the following form

$$\sigma_{tmcc} = \sigma_{20} \cdot \exp(-0{,}4 \cdot 10^{-3} T_t). \tag{16}$$

For stainless austenitic steels, we have a similar pattern:

$$\sigma_{tayc} = \sigma_{20} \cdot \exp\left(-0{,}3 \cdot 10^{-3} \cdot T_t\right). \tag{17}$$

From (6) it follows that the amount of heat given off by grain when moving on its path at a depth of indentation h_i will be:

$$q_i = 0{,}55 \cdot H \cdot \pi\left(h_i^2 + 2h_i\left(2R - h_i\right)\right) \cdot v_{cur}. \tag{18}$$

Based on the known relationships between the Vickers hardness and the tensile strength of steels [3], it can be argued that the Vickers hardness of structural carbon and low alloy steels, depending on the modified temperature will be:

$$H_{mod} = H_{20} \cdot \exp\left(-8 \cdot 10^{-4} \cdot T_{modt}\right). \tag{19}$$

For maraging steels, it will be

$$H_{tmcc} = H_{20} \cdot \exp\left(-0{,}4 \cdot 10^{-3} T_t\right). \tag{20}$$

For stainless austenitic steels

$$H_{tayc} = H_{20} \cdot \exp(-0{,}3 \cdot 10^{-3} \cdot T_t). \tag{21}$$

Taking into account the depth of cut it can be said that the grain describes a cycloidal curve in the treated metal (Fig. 3), the law of movement of which in a rectangular coordinate system is described by the system of equations:

$$x^2 + \left(y - R\right)^2, \tag{22}$$

$$x = \frac{v_д \cdot R_к}{v_л} \cdot \arccos \frac{R - y}{\varphi \cdot R} + \sqrt{2 \cdot R \cdot y - y^2}. \tag{23}$$

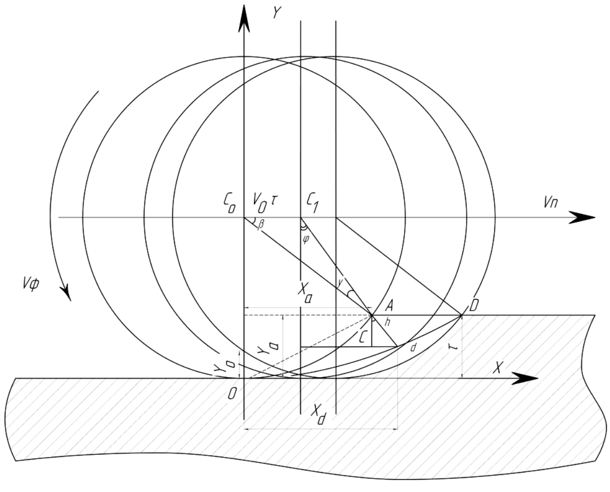

Fig. 3. The scheme of movement of a single grain to determine the deepening of the grain in the metal in the surface grinding with the wheel periphery

The value of deepening of the grain into the metal is defined as the instantaneous value of the distance between the arc of contact of the grinding wheel with the metal to be treated and the cycloidal trajectory of the grain. This distance is measured by the normal to the curve. The normal passes through the instantaneous position of the grinding wheel center. From the C_0C_1A triangle on the law of sines we get

$$\frac{R_к}{\sin\left(90 - \varphi\right)} = \frac{v_д \cdot \tau}{\sin \psi} = \frac{C_1 A}{\sin\left(90 - \varphi - \psi\right)}. \tag{24}$$

From it:

$$\sin \Psi = \frac{v_д \cdot \tau \cdot \cos \varphi}{R_k}. \tag{25}$$

Using formulas (24) and (25) we find the value of the C_1A segment:

$$C_1A = \frac{v_д \cdot \tau \cdot \sin(90 - \varphi - \psi) \cdot R_к}{v_д \cdot \tau \cdot \cos\varphi} = \frac{R_к \cdot \sin(90 - \varphi - \psi)}{\cos\varphi}. \quad (26)$$

After appropriate transformations, neglecting small quantities of a higher order, and because of the small value of the angle ϕ, believing $\sin\phi=\phi$, we get:

$$h = R_{кр} - C_1A = 9{,}3 \cdot v_д \cdot \phi \cdot \tau_{зм} \cdot \sin\left(\frac{v_{кр}}{R_{кр}} \cdot \phi\right) \quad (27)$$

or after additional transformations:

$$h = 9{,}3 \cdot v_d \cdot \varphi \cdot \tau_m \cdot \sin\left(\frac{v_{cur}}{R_{cur}} \cdot \varphi\right). \quad (28)$$

Here $\tau_м$ – the contact time of a grain with the metal, namely:

$$\tau_m = \sqrt{D \cdot t} / v_{cur}, \quad (29)$$

$$\varphi = \frac{2L}{D_{cur}} = 2 \cdot \sqrt{\frac{t}{D}}. \quad (30)$$

The temperature of any point of the metal, which is at the path of movement of a grain, can be adopted as follows [2]:

$$T_s = \frac{q_з \cdot \sqrt{\alpha\tau}}{2 \cdot \lambda \cdot \sqrt{\pi}} \cdot \left(1 - \exp\left(-\frac{R \cdot h}{2 \cdot \alpha \cdot \tau}\right)\right). \quad (31)$$

Here q_i is determined by the expression (18).

The contact time τ of a grain with an arbitrary point in its movement along the route is determined from the following considerations.

Grain movement at a speed V_w along its track is shown in Fig. 4.

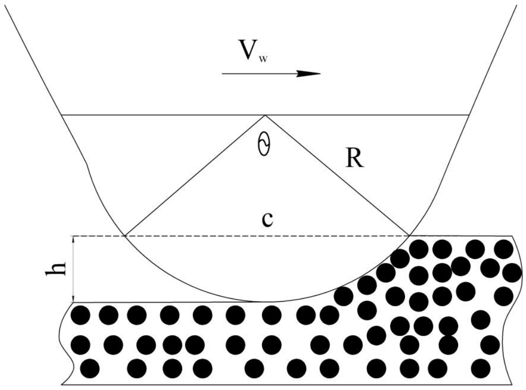

Fig. 4. The scheme of movement of a grain along its track: h — the average depth of introduction of the grain in metal; c — the chord of the sector formed

It can be said that the duration of the thermal effects of grain on an arbitrary point of metal is

$$\tau = \frac{c}{2 \cdot v_{cur}}, \quad (32)$$

and

$$c = 2\sqrt{h(2R - h)}. \quad (33)$$

Accounting contradictory factors that occur when cutting metal by grain is analytically impossible, but it can be done using numerical methods.

For numerical results, we set the following parameters of the grinding process.

Surface grinding. The material of the part – case-hardened and martempered 12KH2N4A steel, + low tempering. Hardness HRC=60–62. Tensile strength $\sigma_в$ 1220 MPa. $\varepsilon=12.5 \cdot 10^3$ J/m^2 ^{0}C s$^{0.5}$; $\alpha=8 \cdot 10^{-6}$ m^2/s; wheel E9A25SM1K8; D=450 mm; $\varepsilon=1.1 \cdot 10^3$ J/m^2 ^{0}C s$^{0.5}$; $\alpha=5.3 \cdot 10^{-6}$ m^2/s; grinding modes: V_w=35 m/s; V_d=0.25 m/s; t=0.03mm; S=2 mm.

The trajectory of movement of grain in the metal has the form shown in Fig. 5.

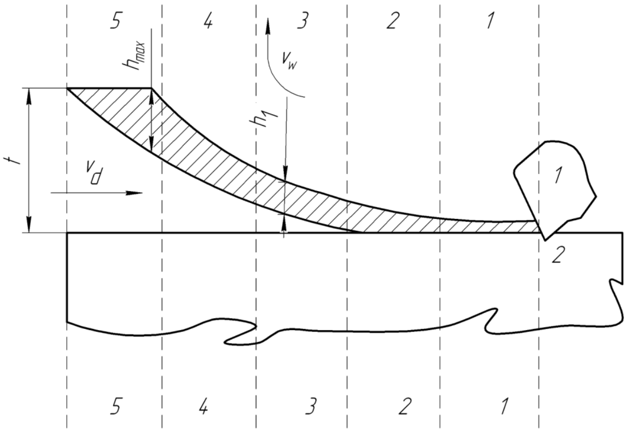

Fig. 5. The scheme of movement of grain on the track and changes in the depth of its penetration into the metal

The trajectory of movement of grain can be divided into i number of plots (5 such sites in the figure). At each site, you can calculate all of the cutting parameters on the condition that the deformation temperature of the metal at the site i will be equal to the temperature of cutting at the site i–1. In these conditions, it is easy to determine T_{mod}, σ_{mod} and power of the heat flux q_i. Summing q_i values, you can determine the amount of heat given to the metal accurately, as well as the variation of this amount during the motion of a grain. The calculation results are shown in Fig. 6, 7.

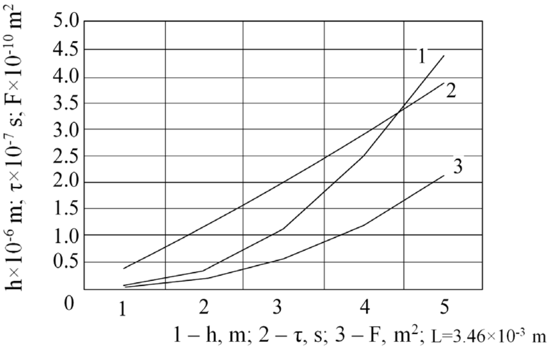

Fig. 6. h — deepening value of a grain, τ — the time of contact of the grain with any metal point on the trajectory; F — the area of contact of a grain with the metal; L — the length of the arc of contact of a wheel with a part

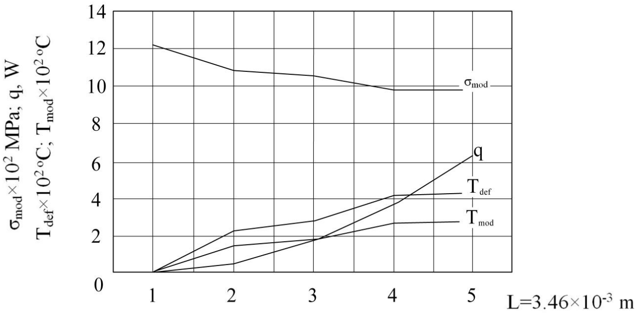

Fig. 7. Deformation temperature values T_{def}; temperature T_{mod} modified by speed; tensile strength σ_{mod} at a modified temperature; q — thermal capacity of the grain at various sections of the route of its movement in the metal

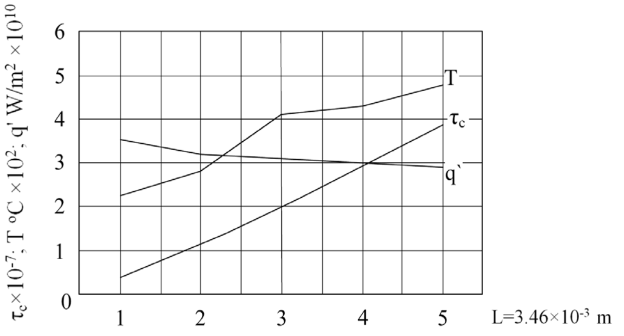

Fig. 8. The values of the contact time of the grain with an arbitrary point of metal τ; surface temperature T^0 and intensity of the heat flux q', depending on its position on the track

Totally during the grain movement in the metal it gives 12.33 W of power. However, when determining the surface temperature, we are interested in the average heat transfer coefficient of each grain present in the given time in the contact of the wheel with the product. Fig. 6 shows that the heat transfer in the first two sections of the trajectory of movement of grain is only 5.7 % of the total heat transfer. Therefore, the main contribution to the energy is made by the grains, located on 3/5 of the length of the contact arc, counting from the end of the trajectory. The total energy contribution is 11.29 W, and the average value is 3.76 W. Thus, the length of the contact arc, "heating" the metal will be 3/5 L or 0.6 L (the effective length of the arc), or in our case 2.10^{-3} m.

With these data, it is easy to determine the grinding contact temperature. The total heat flow into effective contact surface area is equal to:

$$q_\Sigma = z_f \cdot F_{ef}, \tag{34}$$

where q_Σ is total heat flow, W, z_f – the actual number of working grains per unit surface area of the wheel pc/m², F_{ef} – effective contact area. The temperature can be determined by the repeatedly checked expression [2]:

$$T = \frac{1{,}12 \cdot \eta \cdot q \cdot \sqrt{\tau}}{F \cdot \varepsilon_{met}} \left[e^{\frac{-y^2}{4\alpha\cdot\tau}} + y \cdot \Phi \cdot \left[\frac{y}{2 \cdot \sqrt{\alpha \cdot \tau}} \right] \right], \tag{35}$$

where ε – thermal activity coefficient of the material according to (5) [J/m² °C $s^{0.5}$], η – the amount of heat passing in the part.

According to [2, 5] we can take:

$$\eta = \frac{\varepsilon_{met}}{\varepsilon_{met} + \varepsilon_{com}}, \tag{36}$$

where τ_{ef} – effective contact time of the effective arc length with the metal, F_{ef} – effective contact area of a wheel with the piece:

$$\tau = \frac{0{,}6\sqrt{D \cdot t}}{V_{det}}, \tag{37}$$

$$F_{ef} = \sqrt{D \cdot t} \cdot S. \tag{38}$$

Here y – the coordinate directed to the depth of the material [m], a – thermal diffusivity coefficient [m2/s], Zf – the actual number of working grains per unit of surface area of a wheel pc/m2, which may be determined by the actual distance between the cutting grains, which, in turn, is determined by the thermal pulses from microthermocouples [3] (Fig. 9).

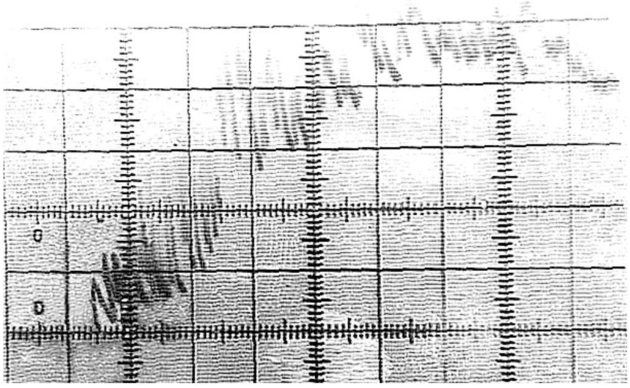

Fig. 9. The characteristic oscillogram of the heat pulse when grinding

Using the oscilloscope sweep speed, it is easy to determine the contact time of the wheel with microthermocouple, the length of the circumference of a wheel, passed over the microthermocouple, and the waveform allows determining the number of grains that cut the thermocouple. Based on the fact that

$$z_f = \frac{1}{l_f^2}, \tag{39}$$

multiple measurements allowed to obtain the dependence

$$z = 16{,}6 \cdot 10^9 N_з^{-1{,}3} N_{str}^{-0{,}2}. \tag{40}$$

The intensity of the total heat source in the area of the effective contact patch is

$$q_\Sigma = \frac{z_f \cdot F_{ef} \cdot q_\Sigma}{F_{ef}} = z_f \cdot q_\Sigma. \tag{41}$$

Then the expression (35) can be converted to the form:

$$T = \frac{1{,}12 \cdot q_\Sigma \cdot z_f \cdot \sqrt{\tau}}{(\varepsilon_{met} + \varepsilon_{cur})} \cdot \left[e^{\frac{-y^2}{4a\cdot\tau}} + y \cdot F\left[\frac{y}{2 \cdot \sqrt{a \cdot \tau}} \right] \right]. \tag{42}$$

The temperature value calculated by the specified expression in the modes, specified in the present paper is 583 °C, which agrees well with the experimental results, in particular, with the temperature in Fig. 8, the oscillogram of which is obtained in the above conditions.

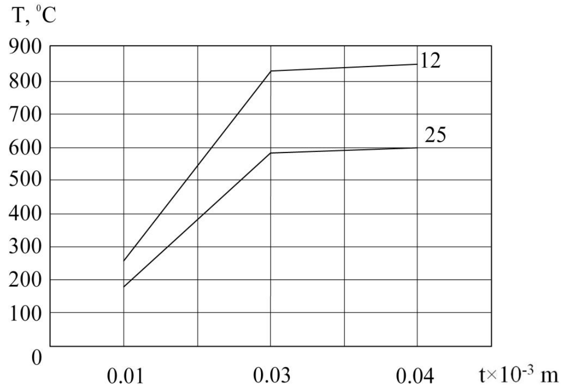

Fig. 10. The magnitude of the contact temperature of grinding for the grit sizes 25 and 12. V_w=35 m/s; V_d=0.25 m/s; t=0.03.10^{-3} m; S=2.10^{-3} m/stroke. Wheel E9A25 SM1K5. Material – 12KH2N4A steel, carburizing, hardening, low tempering

Using these dependences, the values of the contact temperature it can be calculated for any of the parameters of the grinding process.

6. Discussion of the results of the study of the amount of heat released during the metal cutting with abrasive grain and the contact temperature of the ground surface

For the chosen parameters of the grinding process, during the movement of grain in the metal it gives 12.33 W of power in total. However, when determining the surface temperature, we are interested in the average heat transfer coefficient of each grain present in the given time in the contact of the wheel with the product. Fig. 5 shows that the heat transfer in the first two sections of the trajectory of movement of grain is only 5.7 % of the total heat transfer. Therefore, the main contribution to the energy is made by the grains, located on 3/5 of the length of the contact arc, counting from the end of the trajectory. The total energy contribution is 11.29 W, and the average value is 3.76 W.

Thus, the length of the contact arc, “heating” the metal will be 3/5 L or 0.6 L (the effective length of the arc), or in our case 2.10^{-3} m.

Heat flows from the cutting grains, when summed, form a powerful heat source, whereby the surface temperature of the ground member may increase to significant values. Fig. 10 shows that the surface temperatures of about 450–500 °C, which give rise to the martensite-to-perlite transformation in hardened steels begins for the wheel grit size 16–25 with 0.025–0.03 mm of grinding depths.

A comparison of the surface temperature values, determined according to the developed method, and experimental values obtained using microthermocouples shows that these values are in good agreement, and therefore the analytical models considered in the present paper, adequately reflect the processes occurring.

In the case of maraging steels, it is necessary to increase the actual experimental data, which will require additional research.

7. Conclusions

1. The model of the cutting part of the grain in the form of a ball is adequate to the process of cutting by the grain and allows to determine the cutting forces by the value of the grain deepening in the metal.
2. The mathematical relationships, reflecting the grain depth of penetration into the metal as it moves along the route are created. It is shown that the metal temperature is increased considerably when the grain movement from the beginning to the end of the path due to the increase in the penetration depth of grains in the metal.
3. The mathematical relationships that reflect changes in the mechanical characteristics of steels of different classes depending on the cutting speed and temperature, and the system of numerical calculation of the amount of heat given off by the grain at any section of the trajectory are created. It is shown that the tensile strength of the metal during cutting by grain is significantly reduced when movement of the grain from the beginning to the end of the track, which leads to “hardness alignment” in grinding of various alloys.
4. The mathematical relationships of regularities in the formation of the total heat source with all the grains running in the contact patch of the wheel and the workpiece, which gave the opportunity to calculate the contact temperature of grinding of any material, such as iron-carbon alloy are created. It is shown that the main contribution to the formation of the contact temperature value is made by the grains located at 3/5 length of the contact arc, measured from the end of the motion path.

The mathematical relationships and the system of numerical calculation adequately reflect the actual thermal cutting process in grinding.

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