Thermophysical processes in thermofriction working of surfaces

Nikolay Pokintelitsa* and Elena Levchenko

Sevastopol State University, Department of Mechanical Engineering, Sevastopol, Russia

*nik.pokintelitsa@mail.ru

Abstract. There are results of thermophysical processes of thermofrictional working of details by the disk tool. Results of mathematical modeling of heat distribution in a processing zone at thermofrictional working of details are presented. It is found that the size of Q2 heat quantity going to the cutting disk in unit of time has the considerable impact on firmness of a disk, and the quantity of Q2 heat cutting going to the cutting disk under various conditions can make up to 50-60% of all warmth of cutting.

1. Introduction

At a research of regularities of thermofrictional working process and the solution of practical tasks, connecting with the choice of the technological mode, it is necessary to consider the regularities inherent in processes of a sliding friction at high speeds of sliding. In process there are combined such phenomena as heat release at a sliding friction, high speeds of sliding of the contacting bodies, the continuous updating of the contacting surfaces, education and immediate destruction of communications between the conjugate surfaces at their continuous relative driving, the almost instant heating and fast cooling of small volumes of metal in the conditions of the significant pressures, elasto-plastic deformations in macrovolumes of the metal layers, adjacent to these surfaces, plastic deformation of the warmed metal under the influence of normal efforts with office of drain chips.

2. Main text

Heat release at a sliding friction takes place not only on surfaces of physical contact points. Deformation of microledges for which some share of energy at a sliding friction is spent also is the reason of heat generation. Under the influence of cutting efforts there is a deformation of the surface layer with some thickness. As a result of deformation energy will be transformed to heat. Thus the feed forward is formed: warmth – temperature – deformation and feedback coupling: deformation – warmth - temperature.

Existence of such communication leads to a closure of a cycle of heat release that is the reason of its self-regulation and aspiration to the established value.

According to the widespread point of view [1-3] when heating of steels by a sliding friction the temperature in contact section is lower than fusion point and lies in temperatures’ area 800 °C …1200 °C. It is also known that durability depends on temperature [4]. At a temperature over 1000 °C the ultimate strength at a gap is approximately identical to all steel grades and makes 40 … 50 MPas.
At thermofrictional working the main component is warm, cutting, necessary for heating of a zone, it turns out due to external friction between an external edge of the cutting disk and preparation. At the same time the processed material adjoins to the cutting disk at larger speeds through a layer of the material which is in plastic condition.

The properties of this interlayer depend on temperature – than temperature is higher, properties of this interlayer will be closer to those to properties of very thick greasing liquid.

At thermofrictional working the amount of heat which should be brought to the place of processing at the first moment turns out due to dry friction which at a constant temperature in the contact place of cutting instrument with material is replaced with semi-dry due to the plastic film and passes at a temperature close to the melting point into fluid friction. After removal of the heated metal the cycle is repeated.

Process of thermofrictional working (Fig. 1) develops within 3 periods:

– in the first period – preparatory – there is a preparatory stage, connected generally to obtaining temperature of contact volumes of a defined value. In this period either process of setting, or oxidizing process of a sliding friction is partially observed;
– in the second period – processing – the cutting zone is heated, there is a steady working process;
– in the third period – finale – there is a completion of processing, there is no heat sink, the zone of cutting is heated on 50 … 70 °C higher in comparison with the second period.

TFW provides the equal distribution of heat on all volume of the metal deformed in cutting. As experiences and preliminary theoretical calculations showed, control of heat at thermofrictional working can be exercised by means of the correct purpose of cutting speed \( V_3 \), speed of disk rotation \( V_4 \), thickness of chips and geometry of the cutting disk.

Sources of heat are friction surfaces of the processed metal with the blade of the cutting disk. The direction of heat fluxes can be regulated by arrangement of friction surfaces, i.e. sizes of front and back corners of the cutting disk blade.

For the foregoing reasons, there is of particular interest not the amount of heat which transferred into chips, cutter or the processed workpiece, but the nature of temperature profiles and their strength in disengaging zone of chips and formation of the new (processed) surface.

Table 1. Heat distribution, %.

| In chips | In cutting tool | In workpiece |
|---------|----------------|-------------|
| 20-30   | 45-65          | 10-20       |

Figure 1. Thermofriction working of surfaces

Heat distribution at TFW of steel 45 is represented in table 1. [5]
Cutting work or any of its components $E_i$ and the corresponding amount of heat released $Q_i$ is determined by the formula [6]:

$$Q_i = \frac{E_i}{427}. \quad (1)$$

The amount of $Q$ heat generated during cutting can be determined by the formula

$$Q = Q_c + Q_T + Q_P. \quad (2)$$

Heat of $Q_b$ deformation is formed in a shifts zone on the conventional surface of shift; heat of $Q_T$ friction – on a front surface of the cutting disk blade – within the platform of contact with chips; heat of $Q_f$ friction on a back surface of the cutting disk blade – within the platform of contact with the surface of cutting.

The formed heat extends from the heat generation centers to colder areas, being distributed between chips, workpiece and the cutting disk, forming heat fluxes. A part of heat of $Q_d$ deformation from the conventional surface of shift passes into chips. Part of friction heat, equal to $Q_T - Q_b$, where $Q_b$ – heat leaving in the cutting disc, goes into chips from the friction zone along the front surface of the blade.

Thus, chips temperature is defined by a total heat flux

$$Q_c = Q_b + Q_T - Q_H. \quad (3)$$

Part of $Q_b$ deformation heat turns into workpiece from the conventional surface of shift. Part of heat friction, equal $Q_P - Q_z$, where $Q_2$ heat going into the cutting disk, passes there from friction zone on a back surface. As a result of it, the intensity of a heat flux in workpiece of $Q_j$ is defined.

$$Q_j = Q_b + Q_P - Q_H. \quad (4)$$

The temperature field of a wedge of the cutting disk is established in a result of action of a total heat flux of $Q_H$ by intensity.

$$Q_H = Q_T + Q_{3P}. \quad (5)$$

On the base of this it is possible to write the formula describing the flow formed during the cutting of heat.

$$Q = Q_c + Q_j + Q_H + Q_{CP}, \quad (6)$$

where $Q_2$– amount of heat going to the workpiece; $Q_{CP}$– amount of heat released into the environment.

In total the expression (6) describes the heat balance in cutting materials.

In the process of working the maximum temperature is on the friction surface, and its value depends on the thermal conductivity of the workpiece and the tool. The decrease of heat part that passes into the workpiece with increasing of cutting speed is caused by the change in the ratio between the cutting speed and the speed of heat propagation from the deformation zone. If the cutting speed, i.e. the speed at which the blade of the cutting disk crosses the heat flux is small, then the heat from the heat source will flow smoothly into the chips and the workpiece. With increase of cutting speed the blade of cutting disk intersects the heat flux more and more quickly. Therefore, it has time to transfer a smaller amount of heat into the chips and the workpiece and an increasing amount of heat remains in the cutting disk.

In a result of friction of cutting disk with the taxiway the disk heats up to $T_2$ temperature. Arising heat flux will be directed in the radial direction to the colder parts of the disk with a $T_1$ temperature that is equal to the ambient temperature.

The amount of $Q_2$ heat going into the cutting disk depends on the radius of the tool wedge tip, temperature gradient $(T_2 - T_1)/l$, contact time of the disk section with allowance and can be determined by the formula (Fourier law)
\[ Q_2 = l \cdot F \cdot \frac{T_2 - T_1}{\lambda} \cdot \tau \cdot z, \]  

where \( F \) – is the average value of the allowance contacting area with cutting disk, m²; \( \lambda \) – heat transfer coefficient of the cutting disk material RD, BT/(m·K); \( l \) – distance (m) in the radial direction between parts of a disk with a temperature of \( T_1 \) and \( T_2 \), K; \( z \) – average number of the contacting outgrowths.

Time of contact of the disk \( \tau \) with an allowance depends on cutting speed \( V_3 \). With increase of feed the time of contact decreases and therefore \( Q_2 \) quantity of heat decreases also. Time of \( \tau \) contact can be determined by a formula

\[ \tau = \frac{L_K}{V_\partial}, \]

where \( L_K \) – length of contact arc of a disk with an allowance \((L_K = (\pi \cdot D \cdot \delta)/360)\), m; \( V_\partial \) – peripheral velocity of a disk, m/s.

It is important at calculating to choose correctly the size of average heat conductivity \( \lambda_\partial \) and temperature gradient \((T_2 - T_1)/l\).

For improvement of cutting and maintenance of firmness of the tool there are created the conditions of the maximum heating of workpiece at minimum heating of a disk.

The frictional contact of a disk with workpiece, as well as any other solid bodies, is always discrete and happens on separate actual spots of contact on which maximum temperature of \( \Theta \) significantly exceeds the average temperature of a nominal frictional surface of \( \Theta \) by a quantity of flash point \( \Theta_r \).[7-10]

\[ \Theta_{\text{max}} = \Theta + \Theta_r. \]  

For determining of flash temperature the plastic microcontact of thermofrictional interaction of the workpiece with the disk should be taken as the basis. Let imagine the plastic microcontact as motion of half-space with the ridge on a smooth half-space without including the final sizes of the workpiece and the disk.

Then area of plastic microcontact

\[ A_r = \frac{P}{HB}, \]  

where \( P \) – the full load on nominal contact, H; \( HB \) – the Brinell hardness of material, H/mm².

The second parameter of contacting characterizing the flash temperature is the diameter of an average spot of contact \( d_r \), that at plastic microcontact is determined by a formula

\[ d_r = \left( 8rh / \sqrt{V} \right)^{1/2} \cdot \left( P / HB \cdot b_0 \right)^{1/2}, \]

where \( r \) – edge radius of the microasperity of workpiece, m; \( h \) – height of microasperity of the workpiece surface, m; \( v \) and \( b_0 \) – parameters of the supporting curve of the cutting disk surface of the cutting disk, which is built on the basis of profilogram of longitudinal and transversal roughness; \( P \) – pressure on nominal frictional contact of a disk with the workpiece, Pa.

By the found \( A_r \) and \( d_r \) values it is possible to determine flash temperature \( Q_r \) of microcontacts by the formula

\[ Q_r = \frac{\sqrt{F} + 1}{\sqrt{2}} \cdot \frac{N_F \cdot d_r \cdot \sqrt{A_r} \cdot \sqrt{3t - r^2 / 2}}{A_r \cdot (4\lambda_\partial \cdot \sqrt{a_b} + \lambda_3 \cdot \sqrt{\pi d_r V_\partial})}, \]

where \( N_F \) – friction power, W; \( t \) – contact time, s; \( \lambda_\partial \) – heat-transfer coefficient of the cutting disk material, W/(m·K); \( \lambda_3 \) – heat-transfer coefficient of the workpiece material, W/(m·K); \( a_b \) – cutting depth, m; \( V_\partial \) – surface velocity of disk sliding related to the workpiece, m/s.
Conclusion
On the actual spot contact of the disk with the workpiece it arises excess flash temperature, which significantly increases the average temperature of the friction surface of the workpiece (up to 225 °C). In the process of flash temperature there has been observed the phenomenon of the transfer of elastic frictional contact into a plastic with subsequent flowing, which leads to the closeness of the disk with the workpiece.

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