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MODELLING OF CONTACT INTERACTION FOR A TOOL IN THE CONDITIONS OF OUTGROWTH

Modelling of machining processes with a cutting tool is currently an important stage for determining machining performance, cutting tool wear, and ultimately evaluating the effectiveness of its use. Such virtual studies make it possible to predict the service life of the cutting tool. Modern CAE systems allow such calculations to a certain extent, but cannot always take into account all the specific properties of the processing process, in particular, such a phenomenon as growth formation. The growth phenomenon makes serious changes in the cutting process itself by changing the actual angles and affecting the heat transfer processes. Therefore, the task of machining processes with a cutting tool in the conditions of growth formation is relevant. These processes occur in one way or another during processing with almost all types of cutting tools, in particular cutters.

The paper substantiates that, regardless of the initial shape of the cutting blade, the main part of the contact zone can be reduced to the contact between the chip and a flat full or shortened front surface, and a method of thermophysical analysis of the cutting zone is proposed, which takes into account the equivalent coefficients of thermal conductivity of the cutting blade, composed of materials of growth and tool

The practical implementation of this approach made it possible to determine that the stable shape of the wear chamfer and the associated valid law of tangential stresses take place when the back surface of the tool and the cutting surface are in full contact and the wear intensity is uniform at each point of contact.

Key words: modelling, cutting, growth, cutting tool, contact processes.

МИЛЬКО ВОЛОДИМИР, СОКОЛАН ЮЛІЯ, САВИЦЬКИЙ ЮРІЙ, РОМАНІШИНА ОЛЬГА
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МОДЕЛЮВАННЯ КОНТАКТНОЇ ВЗАЄМОДІЇ ДЛЯ ІНСТРУМЕНТУ В УМОВАХ НАРОСТОУТВОРЕННЯ

Моделювання процесів обробки різальним інструментом є наразі є важливим етапом для визначення продуктивності обробки, зношування різального інструмента та зрештою оцінки ефективності його використання. Такі віртуальні дослідження дозволяють спрогнозувати ресурс роботи різального інструменту. Сучасні CAE-системи в певній мірі дозволяють виконувати такі розрахунки, але не завжди можуть врахувати усі специфічні властивості процесу обробки, зокрема таке явище як наростоутворення. Явище наросту вносить серйозні зміни в сам процес різання змінюючи дійсні кути та впливаючи на процеси переносу тепла. Тому задача моделювання процесу обробки різальним інструментом в умовах наростоутворення є актуальною. Ці процеси відбуваються в тій чи інщій при обробці практично усіма типами різальних інструментів, зокрема різців.

У роботі обґрунтовано, що незалежно від початкової форми різального леза основна частина контактної зони може бути зведена до контакту між стружкою і плоскою повною або вкороченою передньою поверхнею та запропонована методика теплофізичного аналізу зони різання, яка враховує еквівалентні коефіцієнти теплопровідності різального леза, складеного із матеріалів наросту та інструменту.

Практична реалізація даного підходу дозволила визначити, що стійка форма фаски зношування і зв`язаний з нею дійсний закон дотичних напружень мають місце при повному приляганні задньої поверхні інструменту і поверхні різання та рівномірній інтенсивності зношування в кожній точці контакту.

Ключові слова: моделювання, обробка різанням, наріст, різальний інструмент, контактні процеси.

Introduction

For the analytical determination of contact stresses on the front and rear surfaces of the tool in combination with temperature phenomena, the cutting edge is divided into several areas, both real and reflected, the conditions of which are equated to free cutting. At each section, the chip element, bounded on one side by the shear surface, and on the other by the front surfaces of the tool, is in stable force equilibrium conditions. We established that the property of the cutting system to restore a state of stable equilibrium with a random change of any parameter of the cutting process is also characteristic of its adequate mathematical model. Then, without knowing any parameters of plastic deformation during cutting or contact stresses, a "random disturbance" can be introduced into the mathematical model in the form of an initial approximation of the friction coefficient. If it is adequate, it should come into equilibrium with some new value, the value of which satisfies all the conditions of the relationship, and can serve as a new, more accurate approximation, etc. The state at which the system stabilizes will determine the set of all parameters characterizing the stress and temperature state of the cutting system [1]. It is interesting to use the developed model for tools with a strengthening chamfer on the cutting blade and a shaped front surface.

Presentation of main material

According to the results of V.S. Kushner [2], the role of the chamfer, the dimensions of which are smaller than the length of the contact area, consists in the formation of a rigid retarded body with a height of h_2 on it, which begins to perform the functions of a cutting blade (Fig. 1). In addition to it, on the other part of the front surface, a thin inhibited layer of chips with a length of l_0 is formed, and at the very top - a wedge-shaped body, the shape of which is determined by the conditions of continuity of deformation rates in the zone of primary plastic deformation [2]. Thus, regardless of the initial shape of the cutting blade, the main part of the contact zone will be equivalent to the contact between the chip and the cutting wedge with a flat front surface. The parameters of the inhibited body - growth were determined in the works of Kushner [2] and Zorev [3] and are:

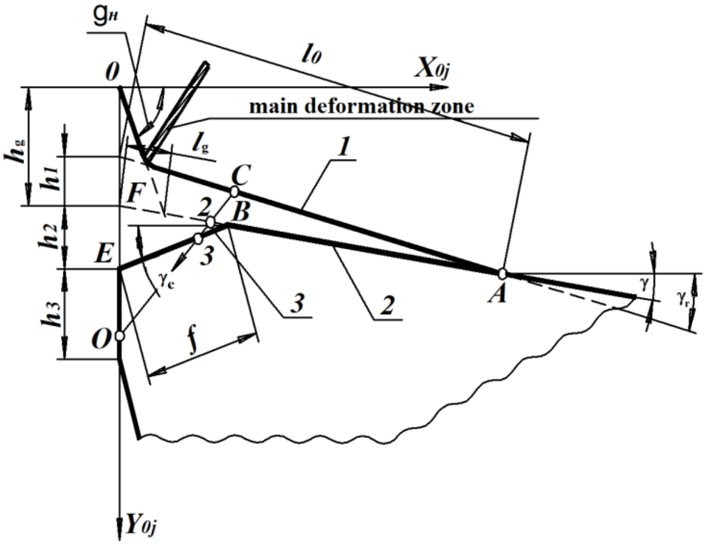

Fig.1. The shape of a valid cutting blade for a chamfered tool

$$h_{\cdot} = (0{,}5...0{,}9)a\,;\ l_{\cdot} = 0{,}1\cdot a\,;\ h_1 \approx 0{,}1\cdot a\,;\ h_2 = f\cdot(\cos\gamma_c\cdot tg\gamma - \sin\gamma_c),$$

where a - is the thickness of the sheared layer;

γ, γ_c - front angle and chamfer angle.

Hence, the front angle of the retarded layer surface is valid:

$$\sin\gamma_r = \frac{h_1}{l_0}\cos^2\gamma + \sin\gamma\cdot\sqrt{1-\left(\frac{h_1}{l_0}\cos\gamma\right)^2}\,.$$

However, such a calculation scheme can be implemented only when the plastic zone covers the entire chamfer and extends to the main front surface, which is expressed by the ratio:

$$l_0\cdot\cos\gamma_r \geq f\cdot\cos\gamma_c \qquad (1)$$

In the case when the calculated values l_1 i l_0 for the front angle do not meet the condition (1), the chip after the plastic zone continues to move along the surface of the chamfer, as along the front surface. Since the plastic deformation in the chip is already complete, it is unlikely that it can bend further to continue sliding along the very front surface. If $l_0\cdot\cos\gamma_r < f\cdot\cos\gamma_c$ and $l_1\cdot\cos\gamma\ \leq f\cdot\cos\gamma_c$, then the entire contact area is located on the chamfer and the thermomechanical model [1] can be used without modification, only with a simple change of angles $\gamma = \gamma_r$ (Fig. 2).

If $l_0\cdot\cos\gamma_r < f\cdot\cos\gamma_c$ and $l_1\cdot\cos\gamma\ > f\cdot\cos\gamma_r$, then cutting with a tool with an artificially shortened front surface takes place. The method of calculating plastic deformation parameters for this case is described in [4]. All other components of the thermomechanical model will function without changes.

The analysis of cited cases of cutting with a tool with a strengthening chamfer made it possible to reduce them to two that are of practical interest:

1. Cutting with a tool with a flat full front surface, consisting of a braked "rigid body" with a plastic zone and a part of the front surface of the tool,

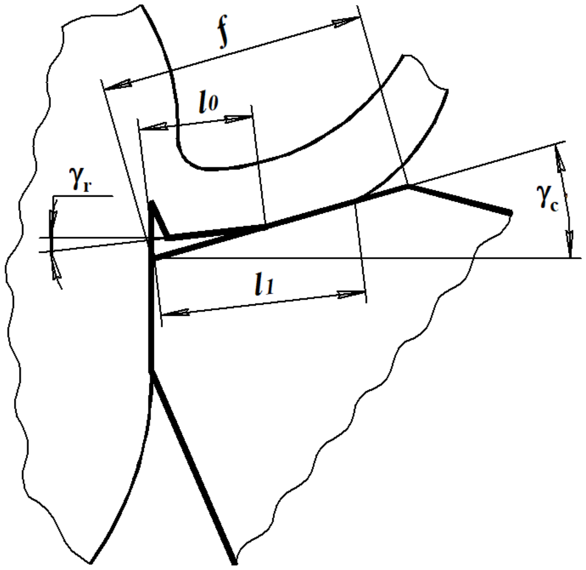

Fig. 2. The shape of the actual cutting blade when cutting with a large chamfer

inclined at an angle γ or γ_r. The length of the folded front surface is greater than the length of the contact area.

2. Cutting with a tool with a flat shortened front surface consisting of the same parts.

The results of the calculation based on the developed model will be the stress at each point of the front surfaces of the tool and the degree of deformation of the sheared layer. This makes it possible to calculate new, refined values of contact temperatures on front and rear surfaces of the tool. For this purpose, the method of heat sources acting on the area of the cutting edge is used. On each of the sections along the curvilinear front and rear surfaces of the tool, there are elementary resulting heat sources of variable intensity and q_{1j} та q_{2j}, which are represented by a combination of **N1** of constant intensity q_{1jk} and q_{2jk}, $j = 1 \ldots N_y$, $k = 1 \ldots N_1$ (Fig. 3). Thus, the temperature at the *i*-th point of the *m*-th section is defined as the sum of temperatures created by all sources and acting on the sections. The intensities of these sources are determined from the condition of equality of contact temperatures at the boundaries: chip-front surfaces of the tool, cutting surface-rear surfaces of the tool. Moreover, for the first zone, data on the intensity of tangential stresses between the chip and the front surfaces of the tool obtained from the solution of the above model [1] are used.

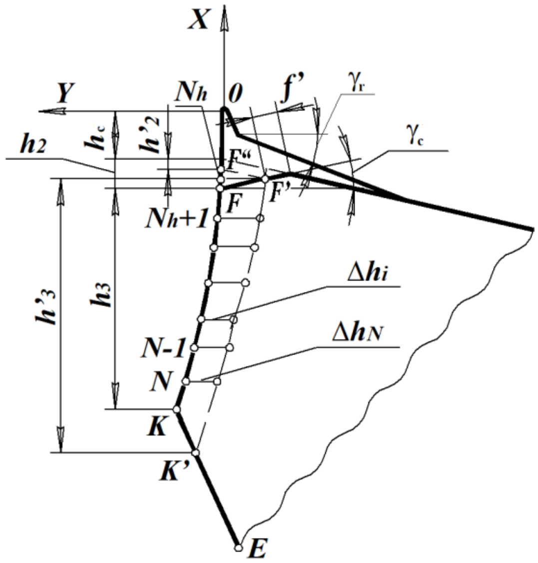

Fig. 3. Scheme for calculating the shape of the wear surface

Representation of the cutting zone with the participation of a composite tool with different thermophysical properties of its parts requires a change in the method of thermophysical analysis of the contact surfaces of the tool. First of all, this concerns the conditions of heat transfer between the k-heat source of the *j*-th section to the *i*-th point of the *m*-th contact section. In general, this problem requires consideration of the volume picture of heat transfer, which is extremely difficult and hardly possible at the current stage. But, taking into account the small influence of the change in the coefficient of thermal conductivity of the tool on its contact temperature, it is suggested to use an approximate method that takes into account the equivalent coefficient of thermal conductivity of the composite body λ_e.

$$\lambda_e = \frac{\delta_\Sigma}{\dfrac{\delta_i}{\lambda_i} + \dfrac{(\delta_\Sigma - \delta_i)}{\lambda}}, \tag{2}$$

where λ_i i λ - respectively, coefficients of thermal conductivity of tool material and chips;

δ_Σ - the total distance between the heat source and a given point of the composite body;

δ_i - the distance travelled by the heat flow in the body of the tool.

Let's assume that the heat flow passes from the source, whose coordinate center is at point *C* (see Fig. 1) to point *D* of the rear surface. Depending on the position of points *C* and *D*, line *CD* can cross lines 2 and 3 at points 2 and 3 with coordinates:

$$x_2 = \frac{y_D - h_{,}}{K_c + tg\gamma};\ y_2 = y_D - K_c \cdot x_2;\ x_3 = \frac{y_D - h_{,} - h_2}{K_c + tg\gamma_c};\ y_3 = y_D - K_c \cdot x_3,$$

where $K_c = \dfrac{y_D - y_C}{x_C}$; x_C, y_C, y_D - corresponding point coordinates *C* i *D*.

Then the position of the CD line relative to the inhibited layer on the front surface will determine the following calculation options λ_e:

1. If $y_D < h_{,}$ i $x_C < x_A$, then $\lambda_e = \lambda$ (that is, the heat flow goes through the chip), and if $y_D < h_{,}$ i $x_C \ge x_A$ $\lambda_e = \lambda_i$ (that is, the heat flow goes through the tool).
2. If $h_{,} \le y_D < h_{,} + h_2$ i $x_C < x_4$, then $\lambda_e = \lambda$,

where $x_4 = \dfrac{h_1 + h_2}{tg\gamma_r - tg\gamma_c}$ - coordinate of the point of intersection of the continuation of the chamfer with the line 1.

3. If $h_{,} \le y_D < h_{,} + h_2$ i $x_A > x_C \ge x_4$, then $\lambda_e = \dfrac{\delta_{CD}}{\dfrac{\delta_{23}}{\lambda_i} + \dfrac{\delta_{CD} - \delta_{23}}{\lambda}}$,

where δ_{CD} i δ_{23} - distances between the corresponding points.

4. If $h_{,} \le y_D < h_{,} + h_2$ i $x_A < x_C$, then $\lambda_e = \dfrac{\delta_{CD}}{\dfrac{\delta_{C3}}{\lambda_i} + \dfrac{\delta_{CD} - \delta_{C3}}{\lambda}}$.

5. If $y_D \ge h_{,} + h_2$ i $x_B > x_C$, then $\lambda_e = \dfrac{\delta_{CD}}{\dfrac{\delta_{3D}}{\lambda_i} + \dfrac{\delta_{CD} - \delta_{3D}}{\lambda}}$.

6. If $y_D \ge h_{,} + h_2$ i $x_B \le x_C < x_A$, then $\lambda_e = \dfrac{\delta_{CD}}{\dfrac{\delta_{2D}}{\lambda_i} + \dfrac{\delta_{CD} - \delta_{2D}}{\lambda}}$.

If $y_D \ge h_{,} + h_2$ i $x_A \le x_C$, then, $\lambda_e = \lambda_i$.

In the case when points *C* and *D* are located either only on the front or on the back surfaces, the value is found similarly depending on the position of points *C* and *D* in relation to point *A* (on the front surface) or to point *E* (on the back surface). It is known that the temperature on the back surface of the wear is the result of the combined effect of friction processes on the front and back surfaces of the tool.

As for the magnitude and law of distribution of tangential stresses on the back surface, there are currently no reliable dependencies. Therefore, it was proposed to determine them by the method of superposition of stress fields from the zone of primary deformation and the zone of elastic recovery, each of which is calculated by the method of finite elements [5]. This takes into account the variability of the active contact length depending on the shape of the worn rear surfaces of the tool, the presence of friction between the rear surfaces of the tool and the cutting surface, the coefficient of which in general can be variable along the rear surfaces of the tool, as well as the fact that the surface layer of the cutting surface, which has passed through the zone of primary deformation, was strengthened. It was established by calculations that the law of change of tangential stresses on the rear surfaces of the tool q_{F2} is determined by the shape of the contact chamfer. Since no hypotheses about its profile have received the necessary confirmation, a mathematical model of wear of rear surfaces of the tool was developed, which is based on the structural energy theory of wear.

Conclusions

Thus, the proposed model allows you to determine temperatures, frictional stress, and then allows you to calculate the amount of wear at each *i*-th point of the contact surface and the parameters of the new cutting blade. Substantiates that, regardless of the initial shape of the cutting blade, the main part of the contact zone can be reduced to the contact between the chip and a flat full or shortened front surface, and a method of thermophysical analysis of the cutting zone is proposed, which takes into account the equivalent coefficients of thermal conductivity of the cutting blade, composed of materials of growth and tool

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