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Numerical Model of Cutting Tool Blade Wear

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Abstract. The article investigates a numerical model of wear for cutting tools. The use of the parametric model of the cutting tool blade, under the required values of angles γ, α, α_1, φ, φ^1, and λ forms the corresponding working part, the dependences of the wear of the blade on the flank on the size of the worn surface. This allows analyzing the effect of blade geometry and wear parameters on the flank on energy consumption during tool wear calculate the work of blade wear at any amount of tool wear. It turned out that the dependences of wear on the flank h_3 on the main φ and the auxiliary φ^1 angles in the plan are linear. With increasing angles φ, φ^1, α, and α^1 decreases the work U_h required to achieve given wear on the flank h_3, and with increasing angles γ and λ, such work increases. Thus, mechatronics combines knowledge and mechanics of wear, electronic parametric model, empirical dependence of wear of the cutting tool.

Keywords: wear, cutting tool, parametric model, blade geometry, wear work.

1 Introduction

Modern metalworking equipment consists of machines, cutting tools, mechanization, and automation tools and devices. Machines and tools are the main components of the technological system of cutting, providing the technological process in dynamic interaction with all other system components.

Modern CNC machine tools are based on integrating mechanical, electronic, and information devices: mechanisms and tools, electronic channels and sensors of direct and feedback, microprocessors, controllers, and computers.

Thus, modern CNC machine tools are mechatronic systems. As you know, “mechatronics is a synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of industrial products and processes. Mechatronics combines mechanical systems (mechanical elements, components, and machines), electronic systems (microelectronics, sensor, and executive technology), and information technology. Thus, mechatronic systems are a complex integration of extremely advanced technological components that can perform tasks with high accuracy and flexibility” [1].

Accordingly, the mechatronics of machining materials is a science that integrates knowledge of the process of chip formation and wear of cutting tools, machine tools, electronics, computers, computer science, and software. It consists of logical and didactic building from fundamental concepts to modern theories.

The quality of machining and process productivity largely depends on the stability of cutting tools, so the analytical determination of wear at given radial and rear wear values is crucial for developing software for CNC machine tools. Determining the tool’s wear on the flank will allow you to develop such software to apply the optimal parameters of the technological process with the available geometry and tool material of the cutting wedge. This will help ensure the necessary product quality parameters with maximum productivity and duration of the cutting process.

2 Literature Review

In the cutting process, different types of blade wear are possible [2-4]. Temperature wear is possible because the blade loses its geometric shape under the action of temperature exceeding the critical value for this tool material. The blade may crack with a sharp change in temperature on its surfaces or break when struck and the formation of stresses exceeding the strength of the tool material. These types of wear can be prevented by adjusting the power and heat loads.

Many research works are devoted to studying blade wear [5-9]. However, there are no non-wearing kinematic pairs. When rubbing two materials of different strengths, both materials wear out (break down). This is since the friction is a cyclic loading of the contact areas and weakens the surface of even stronger material. Thus, the wear of tool material at contact with the process is inevitable, even at the minimum thermal and power loadings in a cutting zone. But, as you know, the formation of chips occurs under conditions of high temperatures and pressures.

Figure 1, under [10, 11], shows the foci of the setting of the processed (top) and tool (bottom) materials. At the single interaction, the processed material is destroyed. Tool material (as stronger) is not damaged. But repeated this process causes fatigue on the surface of the blade. The tensile strength of the tool material in the cyclic field setting is reduced, and there is destruction at some point. The most significant number of such seizures is the maximum number of load cycles of micro-areas. Avalanche of micro destruction – wear.

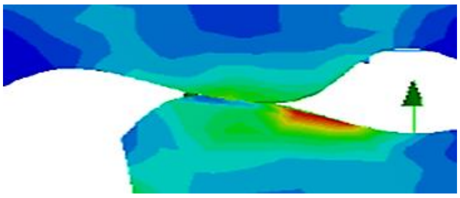


Figure 1 – Contact of surfaces of the processed and tool materials

This is adhesive fatigue wear. Fatigue wear can be observed without adhesion. This occurs during periodic (cyclic) contact of the micro protrusion of the tool material with the processed during their relative movement.

Therefore, with proper technological and instrumental training, which eliminates critical forces and temperatures on the blade surfaces, its wear occurs because of fatigue, which develops under the influence of cyclic loading of micro protrusions on its surface by the volume of the processed material.

3 Research Methodology

3.1 Complete wear work

The work performed can be defined as follows. Let the area of the surface layer of the tool material on area F with a thickness (or height) dx, according to Figure 1, under cyclic bending. Then the elementary work done in its destruction, J:

$$dU = \sigma_c \cdot dx \cdot F \cdot z = \sigma_c \cdot dW \cdot z, \qquad (1)$$

where σ_c – the compressive strength of the tool material (for T15K6 – 4.12 GPa); dW – destroyed the elementary volume because of wear; z – the maximum, destructive number of cycles for tool material (for VK8, and T15K6 – $z = 10^5$–10^6 [12]).

From here, it is possible to write that the entire work of wear, J:

$$U = \sigma_c z \int dW = W \sigma_c z. \qquad (2)$$

The shape and size of the wear surface the worn volume depend on the shape of the cutting wedge. Wear primarily develops at the top of the blade (Figure 2).

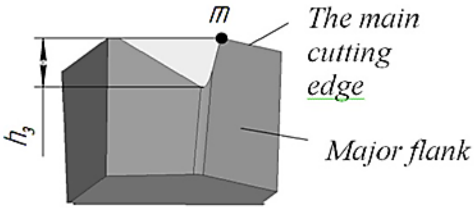


Figure 2 – Wear on the flank

The development of the wear area on the flank along the main cutting edge is limited by the depth of cut (point m). By cutting the blade material with a plane parallel to the cutting speed passing through the point m at different distances from the top, it is possible to simulate the development of blade wear on the flank. The wear criterion is often taken to be the maximum size of the worn surface, measured in the direction of the cutting speed, h_3.

By choosing the value of the blade geometry (rear angles α and α^1, angles in plan φ and φ^1, rake angle γ, cutting edge angle λ), using the capabilities of modern graphic editors, you can calculate the worn volume at given wear on the rear surface h_3. But it is quite difficult.

For engineering calculations, it is necessary to have a simple mathematical dependence, which can be created based on the analysis of the electronic model of blade wear (Figure 2).

3.2 Dependence of blade wear parameters on its geometry

In the graphic editor, we will form a blade of the cutting tool from preparation in the form of a parallelepiped. Let its initial geometry be: $\gamma = 0°$, $\alpha = 12°$, $\alpha^1 = 12°$, $\varphi = 45°$, $\varphi^1 = 15°$, and $\lambda = 0°$. Then we obtain an electronic parametric model of the blade of the cutting tool, which when setting the required values of angles (γ, α, α^1, φ, φ^1, and λ) forms the corresponding working part (Figure 3).

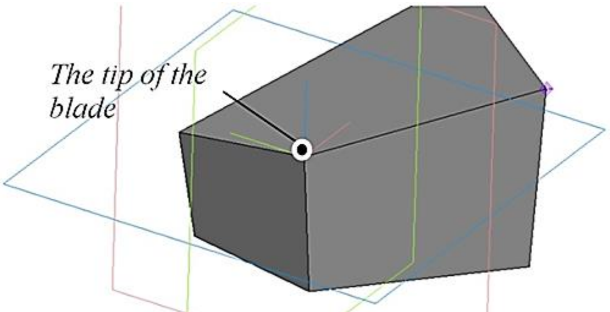


Figure 3 – Parametric model of the blade

Set the value of radial wear, h_r, as the distance from the coordinate plane *YZ* to the created parallel to it plane and cut the blade on this plane.

As a result, we get the worn volume of tool material *W* (Figure 4 a) and wear flank (Figure 4 b), the value of which is estimated as "wear on the back surface" h_3 (Figure 4 c) when the radial wear h_r.

Determine the amount of worn volume *W*. The values of worn volume and wear on the rear surface when changing the blade's geometry are entered in the appropriate tables and built the appropriate graphs in Microsoft Excel.

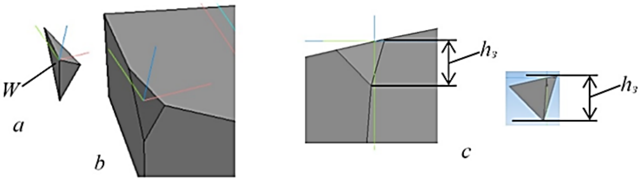


Figure 4 – Wear volume and wear on the tool flank

Construct the power dependences of the worn volume *W* on the main angle in plan *φ* at different values of radial wear h_r and find the arithmetic mean of all the established exponents:

$$x_\varphi = \frac{-0.507 - 0.527 - 0.479 - 0.512 - 0.51}{5} = -0.508.$$

Construct the power dependences of the worn volume *W* on the auxiliary angle in plan φ^1 at different values of radial wear h_r allow to determine the arithmetic mean of all the established exponents:

$$x_{\varphi^1} = \frac{-0.969 - 0.961 - 0.922 - 0.947 - 0.949}{5} = -0.950.$$

The power dependences of the worn volume *W* on the main rear angle *α* at different values of radial wear h_r have an exponent:

$$x_\alpha = -0.269.$$

The power dependences of the worn volume *W* on the auxiliary rear angle α^1 at different values of radial wear h_r have an exponent:

$$x_{\alpha^1} = -0.730.$$

We construct the power dependences of the worn volume *W* on the anterior angle *γ* at different values of radial wear h_r. Because the anterior angle can be negative, the exponential trend line and the corresponding equation cannot be constructed. Therefore, we set the value (45 + *γ*) along the horizontal axis. As a result, we obtain the dependence

$$W = C_\gamma \cdot (45 + \gamma)^{x_\gamma}, \tag{3}$$

the exponent of which:

$$x_\gamma = -0.103.$$

We construct the power dependences of the worn volume *W* on the angle of the main cutting edge *λ* at different values of radial wear h_r. Since the angle *λ* can be negative, the trend line of the power dependence and the corresponding equation cannot be constructed. Therefore, we set the value as (45 + *λ*) along the horizontal axis. As a result, we obtain the dependence

$$W = C_\lambda \cdot (45 + \lambda)^{x_\lambda}, \tag{4}$$

the exponent of which:

$$x_\lambda = -0.102.$$

The influence of radial wear h_r on the value of the volume wear *W* at the initial values of the geometry of the blade in the power dependence has an exponent:

$$x_{h_r} = 2.999.$$

The exponent of the degree dependence of the volume wear *W* on the wear on the rear surface h_3 has the same value.

4 Results

4.1 Determination of the volume wear depending on the radial wear and wear on the flank

Determined exponents allow you to write an expression for calculating the volume wear at different values of the geometric parameters and of the flank wear and radial wear:

$$\begin{gathered} W_r = C_r \varphi^{x_\varphi} (\varphi^1)^{x_{\varphi^1}} \alpha^{x_\alpha} (\alpha^1)^{x_{\alpha^1}} \times \\ \times (\gamma + 45)^{x_\gamma} (\lambda + 45)^{x_\lambda} {h_r}^{x_{h_r}}. \end{gathered} \tag{5}$$

In this case, considering expressions (3) and (4): $x_\varphi = -0.508$, $x_{\varphi^1} = -0.950$, $x_\alpha = -0.269$, $x_{\alpha^1} = -0.730$, $x_\gamma = -0.103$, $x_\lambda = 0.102$, $x_{hr} = 2.999$.

The value of *C* is determined by the value of the volume wear *W* at the original geometry of the blade ($\gamma = 0°$, $\alpha = 12°$, $\alpha^1 = 12°$, $\varphi = 45°$, $\varphi^1 = 15°$, $\lambda = 0°$), and radial wear h_r = 0,25 mm. Under such conditions $W = 0.520$ mm^3. Then:

$$\begin{gathered} C_r = W_r / [\varphi^{x_\varphi} (\varphi^1)^{x_{\varphi^1}} \alpha^{x_\alpha} (\alpha^1)^{x_{\alpha^1}} \times \\ \times (\gamma + 45)^{x_\gamma} (\lambda + 45)^{x_\lambda} {h_r}^{x_{h_r}}]. \end{gathered} \tag{6}$$

After substituting the values of all parameters in formula (6), it can be obtained:

$$C_r = 3622.$$

Finally, mm^3:

$$\begin{gathered} W_r = 3622 \varphi^{-0.508} (\varphi^1)^{-0.950} \alpha^{-0.269} (\alpha^1)^{-0.730} \times \\ \times (\gamma + 45)^{-0.103} (\lambda + 45)^{0.102} {h_r}^{2.999}. \end{gathered} \tag{7}$$

The determined exponent allows also to write the expression for calculation of the volume wear-out at various values of geometrical parameters of a blade and wear on a flank h_3:

$$\begin{gathered} W_h = C_h \varphi^{x_\varphi} (\varphi^1)^{x_{\varphi^1}} \alpha^{x_\alpha} (\alpha^1)^{x_{\alpha^1}} \times \\ \times (\gamma + 45)^{x_\gamma} (\lambda + 45)^{x_\lambda} h_3^{x_{h_3}}. \end{gathered} \tag{8}$$

As before $x_{\varphi} = -0.508$, $x_{\varphi^1} = -0.950$, $x_{\alpha} = -0.269$, $x_{\alpha^1} = -0.730$, $x_{\gamma} = -0.103$, and $x_{\lambda} = 0.102$.

The value of C_h is also determined at radial wear of 0.25 mm at the original geometry of the blade γ = 0°, α = 12°, α^1 = 12°, φ = 45°, φ^1 = 15°, λ = 0°. The wear on the flank h_3 = 1.05 mm, and the volume wear W = 0.520 mm^3. Then:

$$C_h = W_h / [\varphi^{x_{\varphi}} (\varphi^1)^{x_{\varphi^1}} \alpha^{x_{\alpha}} (\alpha^1)^{x_{\alpha^1}} \times \\ \times (\gamma + 45)^{x_{\gamma}} (\lambda + 45)^{x_{\lambda}} {h_r}^{x_{h_3}}]. \tag{9}$$

After substituting the values of all parameters in formula (9), it can be obtained:

$$C_h = 48.97.$$

Finally, mm^3:

$$W_h = 48.97\varphi^{-0.508} (\varphi^1)^{-0.950} \alpha^{-0.269} (\alpha^1)^{-0.730} \times \\ \times (\gamma + 45)^{-0.103} (\lambda + 45)^{0.102} {h_r}^{2.994}. \tag{10}$$

4.2 Empirical dependences to determine the work of blade wear

The formula for calculating the wear of the blade on the flank at different values of radial wear hr is obtained by substituting the expression (5) to (2):

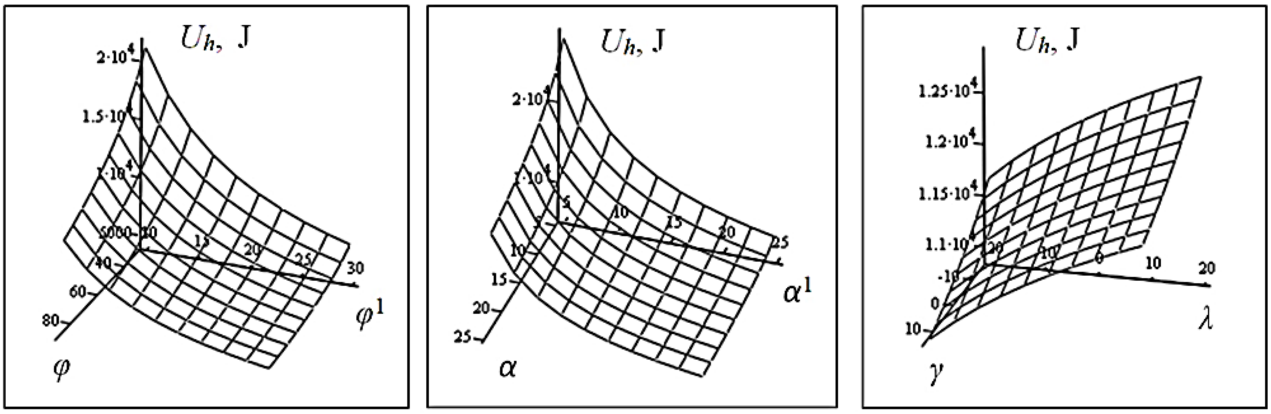
$$U_r = W_r \sigma_c z = 3622\varphi^{-0.508} (\varphi^1)^{-0.950} \alpha^{-0.269} \times \\ \times (\alpha^1)^{-0.730} (\gamma + 45)^{-0.103} (\lambda + 45)^{0.102} {h_r}^{2.999} \sigma_c z. \tag{11}$$

Using for substitution expression (10) to (2), we obtain the formula for calculating the wear of the blade at different values of wear on the flank h_3:

$$U_h = W_h \sigma_c z = 48.97\varphi^{-0.508} (\varphi^1)^{-0.950} \alpha^{-0.269} \times \\ \times (\alpha^1)^{-0.730} (\gamma + 45)^{-0.103} (\lambda + 45)^{0.102} {h_3}^{2.994} \sigma_c z. \tag{12}$$

Figure 5 shows the effect of blade geometry on the amount of wear at h_3 = 0.4 mm. The calculations were performed according to formula (12). In Figure 5 a, φ = 30°–90°, φ^1 = 10°–30°. In Figure 5 b, α = 5°–25°, α^1 = 5°–25°. In Figure 5 c, γ = –15°–15°, λ = –20°–20°.

As an example, the wear of the hard alloy T15K6 in which σ_c = 4.12 GPa and $z = 10^6$ is considered.



a b c

Figure 5 – Influence of blade geometry on wear work

5 Conclusions

Studies of the influence of the blade's geometry and the wear parameters on the flank on the work performed show.

Formulas (11) and (12) allow you to calculate the value of the wear work of the blades with different geometries for any amount of wear of the tool material.

The dependence of wear on the flank h_3 on the value of the main angle in plan φ and the auxiliary angle in plan φ^1 is linear.

The dependences of the volume wear and the wear on the flank on the values of the main and auxiliary rear corners have the same exponents.

The exponent of the degree of dependence of the value of the volume wear W on the radial wear h_r coincides with the exponent of the degree of dependence of the value of the volume wear W on the wear on the flank h_3.

With increasing angles φ, φ_1, α, and α_1 decreases the work U_h required to achieve given wear on the flank h_3, and with increasing angles γ and λ, such work increases.

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