Modelling of the Tools' Power Interaction during Mechanical Machining by Cutting

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***Abstract:** The article deals with modelling of force interaction between tool and workpiece during machining. The dependences were obtained for determination of the workpiece material's deformation under the cutting wedge, as well as the value of the rear corner of the instrument.*

***Index Terms:** Cutting Efforts, Rear Corner of the Instrument, Elastic Displacements, Relative Deformation,*

I. INTRODUCTION

Products modern engineering industry requires that construction materials should have high performance characteristics that determine their working capacity and service life. Traditional constructional materials based on the metals and their alloys sometimes cannot meet these requirements. Therefore, polymer and composite materials also receive wide application as these materials have a number of positive properties such as high specific strength and elastic characteristics, resistance to aggressive chemical environments, low thermal and electrical conductivity, high tribological characteristics, and others [1], [2].

1. Main part

Blanking operations do not provide the specified accuracy and quality of functional surfaces of details. Cutting of material with a diamond and waterjet cutting leads to the appearance of a large defect layer, which also requires the subsequent machining. Therefore, when expanding areas of use for polymeric and composite materials in various branches of mechanical engineering, it is relevant to develop a science-based technology of mechanical processing by blade; this theory should be based on modelling of failure processes by cutting with differentiated view of their specific physical and chemical properties [3], [4], [5].

In the process of cutting blank's material deforms under the tool's cutting edge. Deformation disappears after the tool's passage. As a result of tool's blunting, the effort of cutting increases. In this case the value of the rear corner has a significant impact on firmness of the tool and value of cutting force. Choosing of the value of optimal rear angle should be carried out taking into account the deformation of the surface layers of the preform. When a value of rear corner is small then the material is being pressed to rear surface of the tool. This leads to an increase in cutting force due to friction between the material which is being processed and the rear surface of the tool. It results in tool heating, also occurs an undesirable "brining" of the surface or burn marks of the material appear.

When studying power interaction of a tool and a workpiece, it is usually considered [6], [7]; that the resulting cutting force acts at the workpiece from the top of the cutting wedge; this resulting cutting force (Fig. 1) is equal to the sum of its normal component (*P*) and tangential component (*R*). However, the component *R* of the cutting force determines processes in the chip formation area and operates from the front surface of the tool. Only normal component *P* and the friction force *Q*, which is caused by *P*, act on the treated surface (frictional force at the front surface of the tool is not shown in Figure 1).

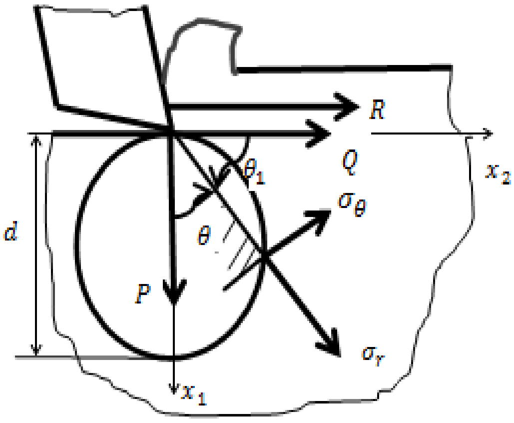

Figure 1. The forces acting on the surface layer of the preform

According to work [8], the movement of the points of an elastic half-plane under the action of only one concentrated vertical force P on its boundary is:

$$u_r = A\sin\theta + B\cos\theta - \frac{2P}{\pi E}\chi_1 \ln r\cos\theta - \frac{P}{\pi E}(\chi_1 - \chi_2)\theta\sin\theta\,, \qquad (1)$$

$$u_\theta = Cr + A\cos\theta - B\sin\theta + \frac{2P}{\pi E}[\chi_1 \ln r\sin\theta + \chi_2\sin\theta + + \frac{1}{2}(\chi_1 - \chi_2)(\sin\theta - \theta\cos\theta)]\,. \qquad (2)$$

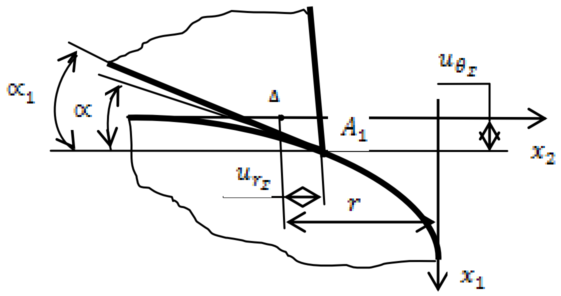

Figure 2. The deformation of the workpiece surface

In our case, as it is plane strain, then

$\chi_1 = 1 - \nu^2, \;\; \chi_2 = \nu(1+\nu)$

where ν – transverse deformation ratio (Poisson's ratio).

To find the integration constants *A, B, C* let's assume that the fixing conditions are such that points of axis x_1 do not have transverse displacements, i.e. $u_\theta = 0$ when $\theta = 0$. Therefore, $A = C = 0$.

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To find the constant *B* let's assume that at a depth $x_1 = d$ when $\theta = 0$, then the vertical displacement is zero.

Then we'll receive:

$$u_{r\binom{\theta=0}{r=d}} = B - \frac{2P}{\pi E}\chi_1 \ln d = 0\,, \tag{3}$$

From this we get:

$$B = \frac{2P}{\pi E}\chi_1 \ln d\,, \text{a} \qquad u_{r(\theta=0)} = \frac{2P}{\pi E}\chi_1 \ln\frac{d}{r}\,. \tag{4}$$

After that we find the vertical movement of the half-plane border behind force *Q*. Assuming that $\theta = -\pi/2$, we get the following expression:

$$u_{\theta\left(\theta=-\frac{\pi}{2}\right)} = \frac{2P}{\pi E}\left[\chi_1 \ln\frac{d}{r} - \frac{1}{2}(\chi_1 + \chi_2)\right]. \tag{5}$$

In the similar way we can get the movements of the half-plane border from the horizontal force *Q*. It can be shown that the displacement components in this case are defined by the same equations (1) and (2). However angle θ_1 should be measured from the direction of force Q.

To find the constants of integration in this case, we assume that points of axis x_2 (half-plane borders) have no vertical displacements, i.e. $u_\theta^{|} = 0$ for $\theta_1 = 0$, and when $x_2 = d$ and $\theta_1 = 0$ then horizontal displacements are equal to zero ($u_r^{|} = 0$).

From this we get:

$$A = C = 0\,, \qquad B = \frac{2Q}{\pi E}\chi_1 \ln d\,. \tag{6}$$

Movements of the half-plane border are:

$$u^{|}_{r\left(\theta=\frac{\pi}{2}\right)} = \frac{2Q}{\pi E}\chi_1 \ln\frac{d}{r}\;; \qquad u^{|}_{\theta\left(\theta=\frac{\pi}{2}\right)} = 0\,. \tag{7}$$

Having solutions for vertical and horizontal concentrated forces, we obtain the total displacement for the points of the elastic half-plane border:

$$u_{r_\Sigma} = \frac{2}{\pi E}\chi_1 \ln\frac{d}{r}(P + Q)\,, \tag{8}$$

$$u_{\theta_\Sigma} = \frac{2P}{\pi E}\left[\chi_1 \ln\frac{d}{r} - \frac{1}{2}(\chi_1 + \chi_2)\right]. \tag{9}$$

Then point *A* of the elastic half-plane border behind the tool will be moved to the position A_1 (Figure 2).

The curved surface under the wedge will be described by a curve defined by the following equations:

$$x_1 = \frac{2P}{\pi E}\left[\chi_1 \ln\frac{d}{r} - \frac{1}{2}(\chi_1 + \chi_2)\right], \tag{10}$$

$$x_2 = -r + \frac{2}{\pi E}\chi_1 \ln\frac{d}{r}(P + Q)\,. \tag{11}$$

We define the slope of the tangent to this curve:

$$\frac{dx_1}{dx_2} = \frac{dx_1}{dr}\bigg/\frac{dx_2}{dr}\,. \tag{12}$$

Then we determine the value of the derivatives:

$$\frac{dx_1}{dr} = -\frac{2P\chi_1}{\pi E r}\,, \quad \frac{dx_2}{dr} = -1 - \frac{2(P+Q)\chi_1}{\pi E r}\,.$$

And we get:

$$\frac{dx_1}{dx_2} = \frac{2P\chi_1}{\pi E r + 2(P+Q)\chi_1}\,. \tag{13}$$

Since $Q = fP$, where f – coefficient of sliding friction of the treated material and the material of tool, then we get:

$$tg\alpha = \frac{dx_1}{dx_2} = \frac{2P\chi_1}{\pi E r + 2P(1+f)\chi_1}\,. \tag{14}$$

It is obvious that when $r \to 0$, then $\sigma_r \to \infty$. This means that a plastic deformation zone of the material appears near the point the forces are applied. The diameter of the plastic zone circle at the boundary of the elastic half-plane is:

$$d = \frac{2Q}{\pi\sigma_{r_{max}}}\,, \tag{15}$$

where $\sigma_{r_{max}}$ is the maximum value of the normal stress at which the material has elastic deformations.

In particular, for metals $\sigma_{r_{max}} = \sigma_y(\sigma_{0,2})$.

Therefore:

$$tg\alpha = \frac{\chi_1}{\frac{fE}{\sigma_{r_{max}}} + (1+f)\chi_1}\,. \tag{16}$$

The second summand in the denominator can be neglected. Finally, we get:

$$tg\alpha = \frac{\sigma_{r_{max}}}{fE}(1 - \nu^2) = \frac{\varepsilon(1-\nu^2)}{f}\,, \tag{17}$$

where ε is corresponding relative deformation of the material.

To eliminate friction between the rear surface of the tool and the processed material it is necessary that the rear corner of the tool α_1 greater than the angle α, which is defined by equation (17).

When cutting metals the coefficient of external sliding friction of the treated material and material of the tool *f* can reach high values, some about one or more. In this case we have:

$$tg\alpha \approx \frac{\sigma_\tau}{E} = \varepsilon_{elast}\,, \tag{18}$$

where ε_{elast} is relative deformation corresponding to the border of the elastic zone on the chart of tension of a material.

In particular, for the conditional yield strength $\sigma_{0,2}$ we have $tg\alpha \approx 0{,}002$, and $\alpha_{min} \approx 0{,}15^\circ$. Calculations show that for most of the metals used in mechanical engineering, the minimum required rear corner of tool does not exceed $0{,}5^\circ$. However, to reduce the deterioration the average values of the rear corners of feed through turning cutters designed for cutting metal with inflow $S \le 0{,}25$mm/rev, $\alpha_{av} = 12^\circ$. With an increase of inflow in the average value of the rear angle is being reduced to $\alpha_{av} = 8^\circ$.

For polymer materials the value of the minimum rear angle of tool is greatly increased. The average values of the rear corners $\alpha_{av} = 10^\circ \ldots 30^\circ$.

In a composite material matrix has higher elastic properties, and that is the reason for the material's elastic after-effect.

The value of the tool's rear angle corresponding to the modulus of normal tension for epoxide resin (30 ... 50 MPa) is equal to $\alpha_{av} = 24^\circ \ldots 36^\circ$.

II. CONCLUSIONS

A technique for calculating the necessary values of the rear corners of the tool for processing various materials (composites, metals) has been developed. For metal structural materials, the actual values of the rear corners of the instruments are calculated. The received data strongly differ from the accepted values used in the literature, which are greatly overestimated. Using the proposed methodology can save expensive instrumental material and optimize the shape and dimensions of the instrument.

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