THE ANALYZE OF THE TEMPERATURE FIELD AT THE TOOL NOSE, DURING THE CUTTING PROCESS

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Abstract. During the cutting process, between tool and work piece appear friction couple which can be considered a system with interconditioned elements. Using an global model regarding the calculus of the heat fluxes and the finite element analysis method (CosmosWorks programmer) it is determined the temperature field at the nose of cutting tool.

Keywords: cutting tool, temperature, tool nose, finite elements analyze, heat flux

1. Introduction

When two surfaces are in contact and when contacting asperities are in relative motion, an amount of mechanical work is required to over come in friction. Most of this frictional work transforms into heat during a sliding contact.

The temperature rise due to frictional contact also changes the material properties. In general, material field strength decreases as temperature increases.

When the normal load acting at the interface is large and the contact pressure is very large, the real area of contact is nearly equal to the apparent area of the contact and the heat transfer is one dimensional. This situation exists at the chip tool interface in metal cutting.

The concept of energy partition was developed by Blok (1938). The fraction of heat generated at the sliding interface goes into each one of the sliding bodies.

Major sources of energy dissipated in cutting are shear energy in workpiece and friction energy of chip with the tool and the workpiece with the tool [1, 2].

The temperature distribution in each body due to the heat conducted into the solid it is assumed that the interfacial temperature is the same for both bodies [3 ÷ 6].

In this paper it is realised a study to the tool nose behaviour under process loads (thermal flow), in order to determine the values from thermal conduction and the establishing the thermal field distribution.

The solving of these problems, based on the analytical calculus model, represent the object of finite elements analysis, in order to solve the energetically equilibrium equation, the allow to find the temperature distribution at the point of the tool nose, in the orthogonal cutting.

2. Distribution of the temperature generated by friction during the cutting process

It is considered the bi dimensional tool as subject of two heat sources: Q_1 on the rake face of the tool in contact with the chip and Q_2 on the flank face of the tool in contact with the workpiece.

The distribution of the two heat sources (figure 1) is exponential ($q_1 \neq$ ct., $q_2 \neq$ ct.).

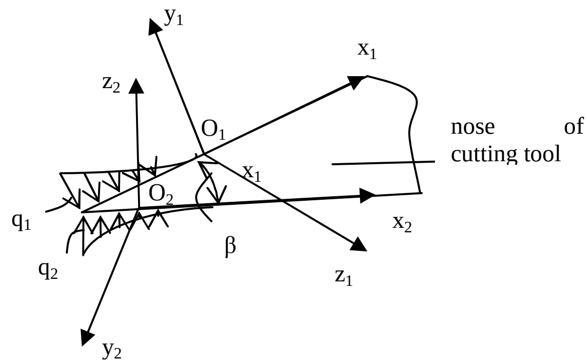

Figure 1. The distribution of the heat sources

The temperature variation θ_a as function of different no dimensional parameter is obtained using the Mathcad 2000 software, beginning from the relations [7]:

$$q_0 = \mu p_0 v \Big/ \left[1 - \exp\left(-\frac{1}{2 \cdot B_{22}}\right)\right] \qquad (1)$$

and no dimensional:

$$q_e(X_a, L_a, u, B_{22}) = 1 - \exp\left(\frac{X_a - \frac{u}{L_a}}{2 \cdot B_{22}}\right) \qquad (2)$$

where: μ - friction coefficient, p_0 – the maximum contact pressure, v – velocity, B_{22} – parameter (= 0.01 ÷ 10) [8].

In this case, the expression for the temperature becomes:

$$\theta_a(L_a, X_a, Y, Z, B_{22}) = \int_{L_a(X_a-1)}^{L_a(X_a+1)} K_0\left(Z^2 + Y^2 + u^2\right)^{1/2} \cdot \exp(-u) q_e(X_a, L_a, u, B_{22}) du \qquad (3)$$

In figure 2 it is presented the temperature variation θ_a, function of no dimensional parameter X, when the depth Z increases.

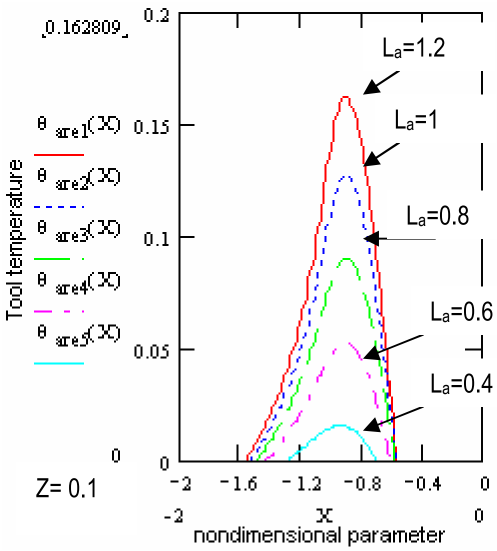

Figure 2. Temperature variation function on no dimensional parameter X

3. The cumulate effect of the heat sources from the rake and flank faces

Due to the importance of knowledge, the temperatures on the tool surfaces in contact with the chip and the workpiece, or in their close neighbourhood, it is considered applicable the effects superimposing principle for the two heat fluxes on the temperature. Thus, the rake face temperature (or close to the rake face) is determined using the relations determined function of the variation type of the flux, and considering as the initial temperature, the temperature generated by the heat source from the flank face. Analogue can be obtained the flank face temperature.

In order to apply this method, it is necessary the geometrical correlation of the points from the interior of the tool with the rake and flank faces.

The following coordinates systems were attached to the bi dimensional tool (figure 3).

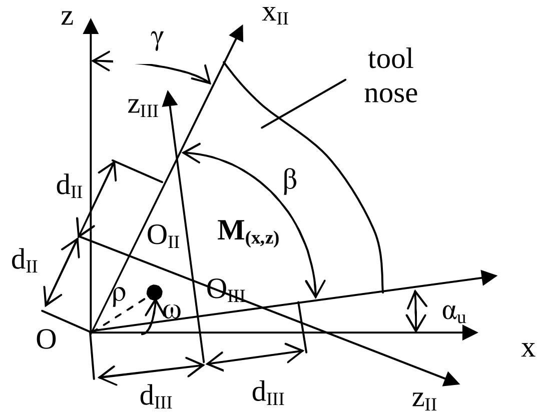

Figure3. The coordinates system on the tool, for temperature determination

- xOz system – with specific angles α, β, γ and the origin in the nose of the tool; a point M(x,z) is located at distance ρ and at angle ω, from the origin O and Ox axis respectively.

$$x = \rho \cdot \cos\omega$$
$$z = \rho \cdot \sin\omega \qquad (4)$$

The ω angle can vary between α and α + β or (π/2-γ).

- the $x_{II}O_{II}z_{II}$ system, attached to the rake face, with origin O_{II} located in the centre of the heat source $q_{II} = q_1$; the distance d_{II} is known;

The coordinates for the point M, in this system, are:

$$x_{II} = \rho \cdot \cos(\alpha_u + \beta - \omega) - d_{II}$$
$$z_{II} = \rho \cdot \sin(\alpha_u + \beta - \omega) \qquad (5)$$

where: $\alpha_u = \alpha$

- the $x_{III}O_{III}z_{III}$ system, attached to the flank face, with origin O_{III} located in the centre of the heat source $q_{III} = q_2$; the distance d_{III} is known;

The coordinates for the point M, in this system, are:

$$x_{III} = \rho \cdot \cos(\omega - \alpha_u) - d_{III}$$
$$z_{III} = \rho \cdot \sin(\omega - \alpha_u) \qquad (6)$$

Considering the friction between chip and tool as the main heat source (q_{II}), for the tool it will be analyzed the effect of the heat source from the flank face, in the point M. Between the coordinates of the point M in the $x_{III}O_{III}z_{III}$ and $x_{II}O_{II}z_{II}$ system can be established the following relations:

$$x_{3a} = \frac{x_{32a}}{\sin\left(arctg\frac{z_{2a}}{x_{2a}+1}\right)} \cdot \cos\left(\beta - arctg\frac{z_{2a}}{x_{2a}+1}\right) - 1$$

$$z_{3a} = \frac{z_{32a}}{\sin\left(arctg\frac{z_{2a}}{x_{2a}+1}\right)} \cdot \sin\left(\beta - arctg\frac{z_{2a}}{x_{2a}+1}\right) \tag{7}$$

where:

$$x_{3a} = {x_{III}}/{d_{III}};\ z_{3a} = {z_{III}}/{d_{III}};$$

$$x_{32a} = {x_{II}}/{d_{III}} = \frac{x_{II}}{d_{II}} \cdot \frac{d_{II}}{d_{III}} = x_{2a} \cdot d_{32};$$

$$x_{2a} = {x_{II}}/{d_{II}};\ z_{32a} = {z_{II}}/{d_{III}} = \frac{z_{II}}{d_{II}} \cdot \frac{d_{II}}{d_{III}} = = z_{2a} \cdot d_{32}; \tag{8}$$

$$z_{2a} = {z_{II}}/{d_{II}};\quad d_{32} = \frac{d_{II}}{d_{III}}$$

are the no dimensional coordinates of the point M.

In this case, can be determined the temperature on the surfaces and in their neighbourhood.

For a point M of coordinates (x_{II}, z_{II}) or (x_{III}, z_{III}) the no dimensional parameters are:

$$X_2 = \frac{v_2 x_{II}}{2a_3};\quad Z_2 = \frac{v_2 z_{II}}{2a_3};\quad L_2 = \frac{v_2 d_{II}}{2a_3};$$

v_2 – *the chip velocity*;

$$X_3 = \frac{v_1 x_{III}}{2a_3};\quad Z_3 = \frac{v_1 z_{III}}{2a_3};\quad L_3 = \frac{v_1 d_{III}}{2a_3}; \tag{9}$$

v_1 – *the workpiece velocity.*

where:

$$x_{II} = x_{3a} d_{III};\quad z_{II} = z_{3a} d_{III};\quad x_{a2} = \frac{x_{II}}{d_{II}} = x_{2a};$$

$$x_{a3} = \frac{x_{III}}{d_{III}} = x_{3a};\quad L_{a2} = L_2;\quad L_{a3} = L_3. \tag{10}$$

The temperature in point M from the tool, determined from the two heat fluxes q_{II} and q_{III}, is:

$$\theta_3 = \theta_{II} + \theta_{III} \tag{11}$$

where:

$$\theta_{II} = \theta_{aII} \cdot \frac{2q_{II}a_3}{\pi\lambda_3 v_2}$$

$$\theta_{III} = \theta_{aIII} \cdot \frac{2q_{III}a_3}{\pi\lambda_3 v_1} \tag{12}$$

After some elementary mathematical transformations, the expression for the total no dimensional temperature from the point M of the tool becomes:

$$\theta_{at1} = \frac{\theta_3 \pi\lambda_3 v_2}{2q_{II}a_3} = \left(\theta_{aII} + \theta_{aIII}k_v\right) \tag{13}$$

where: k_v is the velocity and heat flux effect of the source from the flank face of the tool, on the total temperature.

4. The heat fluxes partition between tool-chip-workpiece

The Blok principle application for the partition of the heat flux between the two pieces with heat source on the interface of the two couple elements, must consider that the cutting tool is subjected, simultaneously, at two heat fluxes: the friction on the rake face with the new formed chip (q_{II}) and the friction on the flank face with the new machined surface of the workpiece (q_{III}).

Because the contact length between the study tool and the mobile machined workpiece is small, the partition of the heat flux from zone III (q_{III}) into the tool can be considered like in case of the steady heat source; thus, the heat partition coefficient ($\beta_{III\text{-}3}$) expression for the tool is:

$$\beta_{III-3} = \frac{\lambda_3}{\lambda_3 + \lambda_1} \tag{14}$$

where: λ_3 – the thermal conductivity for the tool material, λ_1 – the thermal conductivity for the workpiece material.

For the heat partition coefficient determination in the zone of chip-tool friction (zone II), in the tool ($\beta_{II\text{-}3}$), it was analyzed the total temperature on the rake face of the tool:

$$\theta_3 = \frac{2q_{II}a_3}{\pi\lambda_3 v_2} \cdot \left(\beta_{II-3}\theta_{aII} + \frac{\lambda_3}{\lambda_3+\lambda_1}\frac{q_{III-3}}{q_{II-3}}\frac{v_2}{v_1}\theta_{aIII}\right) = \frac{2q_{II}}{\pi\rho_3 c_3 v_2}\left(\beta_{II-3}\theta_{aII} + k_{vo}\theta_{aIII}\right) \tag{15}$$

where: $q_{II\text{-}3}$ – the heat flux generated in the zone II (chip-tool) for the tool, $q_{III\text{-}3}$ – the heat flux generated in the zone III (tool-workpiece) for the tool, $\theta_{aII\text{-}3}$ – the no dimensional tool temperature on the rank face, $\theta_{aIII\text{-}3}$ – the no dimensional tool temperature on the flank face.

5. The analysis of the thermal filed to the cutting tool with finite elements methods

Starting from the analytically model for calculation the thermal flux that appears during the cutting process on the active faces of the tool, using the COSMOS/Works6.0 programmer, can determine the thermal field at the cutting edge of the lathe tool [7].

The obtained result (figure 4) is according the real cutting conditions during the dry machining of steel workpiece.

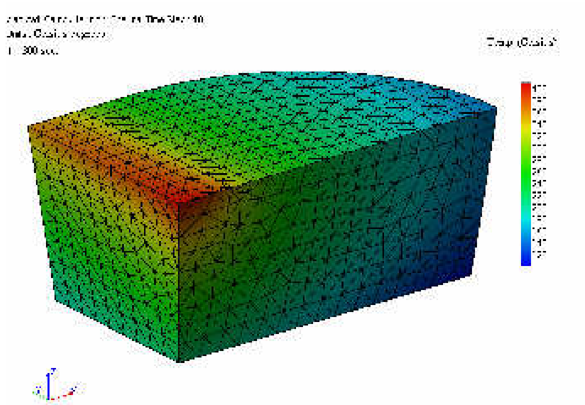

Figure 4. The temperature field obtained using finite elements method

6. Conclusions

The momentary temperature (θ_a) on the rake face of the tool reaches a maximum near the tool nose, in the chip-tool contact zone.

The FEM analysis of the temperature distribution on the tool active surfaces, demonstrates the existence of a maximum peak near the centre of the heat source (due to the friction between chip-tool and tool-piece).

This result confirms the qualitative analysis of the temperature fields at the cutting tool nose that states that the maximum temperature of the cutting edge is located in the centre of the contact surface between the chip and the rake face, and on the flank face near the cutting edge and the tool nose [9].

5. References

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