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CUTTING EDGE TEMPERATURE PREDICTION USING THE PROCESS SIMULATION WITH DEFORM 3D SOFTWARE PACKAGE

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Abstract: *High speed machining is submitted to economical and ecological constraints. Optimization of cutting processes must increase productivity, reduce tool wear and control residual stresses in the workpiece. Modelling, as close to reality of the cutting process, cannot be done without taking into account thermal phenomena. On the one hand, material mechanical parameters depend greatly on temperature (although it is difficult to obtain concrete values of this dependence) and on the other hand, a decisive role is played both by the thermal regime of cutting speed, through component* v_γ *– chip speed tool rake face – and by the amount of heat that occurs in the area of occurrence and formation of the chip. This paper proposes a new approach for describing the friction behavior at the tool–chip interface in the area near the cutting edge.*

Key words: *tool-chip interface, FEM, 3D cutting models, process simulation, global heat transfer coefficient.*

1. INTRODUCTION

In the most practical cases, the heat is transmitted between bodies by combined heat transfer processes that occur simultaneously in two or three of the fundamental modes of heat exchange. For modelling the cutting process phenomena, the basic relations of the law of continuity in the mechanical and thermal fields represent the starting point for the grounding of the corresponding calculation models. As a result, the appropriate mechanical and thermal relations for phenomena of the cutting process must be formulated, especially in the plastic flow areas (Fig. 1).

Considering the presence of simultaneous calculations of individual processes of conduction, convection and radiation is done by defining a global heat exchange coefficient, denoted by α_g or h. For determining the global heat transfer coefficient, more researchers – being based on experimental results and applying the inverse method of research – have proposed several relations based on the contact pressure p and the temperature of the rake face T [10] or depending on the cutting speed v_c and on the cutting feed f [2]:

$$h = 17529 - 34.572p - 1010.01756p^2 + 0.000783T^2, \quad (1)$$

$$h = 442 - 2.36v_c - 7950f + 0.0276v_c^2 + 40600f^2. \quad (2)$$

both in [kW/m^{2}K].

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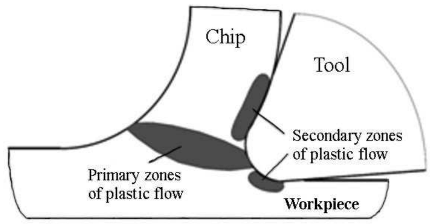

Fig. 1. Areas of plastic flow in the cutting process.

By the late ′90, most researchers have developed and used their finite element model. Given the importance of machining area, in the last decade new and appropriate programs (specialized modules) appeared in order to simulate the cutting process, namely: 2D and 3D AdvantEdge and Deform. The model created by Deform package is complex and integrates interactions between deformation, temperature and, concerning heat treatment, phase transformations and diffusion of carbon (Fig. 2).

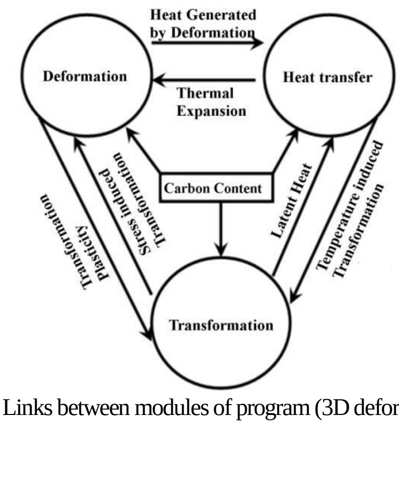

Fig. 2. Links between modules of program (3D deformations).

2. MODELING THE TURNING PROCESS

Using the specialized *Machining* module from DEFORM 3D software, the analysis of the friction coefficient in the tool rake face – chip interface was performed using the inverse method, based on the previous experimental results [3, 5].

Unlike conventional systems of 3D modelling, the DEFORM3D program includes a special template that simplifies the model definition by using an adequate language for engineers who work in the cutting field:

Cutting regime parameters: are given in Table 1.

Conditions for the cutting process: constant ambient temperature - 17°C, convection coefficient between system and environment - 20 N/(m·s·K), the global coefficient of heat tderansfer between the tool rake face and chip *h* - calculated with equation (2). The used values are presented in Table 2. The closer simulation of the true friction between chip and tool rake face is a very important issue in the calculation model, because the correct evaluation of contact conditions is crucial for each simulation of forming and detaching of the chip. For each set of parameters of the cutting regime, the coefficient of friction between the chip and the tool rake face was initially chosen constant, as recommended in the specialized literature [1, 7]. Depending on the temperature value obtained by simulation and comparing to that obtained experimentally, the adjustment of the value of this coefficient was done, in order to obtain comparable values of the cutting temperature.

Defining the tool – according to the data from Sandvik Tool Catalogue for tool DNMG 15 06 04-PM (fig. 3) and cutting insert PDJNR 2525M (Fig. 4).

Mesh cutting tool and setting thermal boundary conditions – 25 000 items (default). Coatings are automatically meshed. Heat transfer between the cutting tool and the environment takes place in all areas except tool contact surface between the chip and estimated the clearance of the tool, for which the global heat exchange coefficient *h* was used (Fig. 5).

Workpiece – curved model with 98 mm diameter, the arc field analysis–20°, meshing – 6 000 items (Fig. 6).

Heat transfer between workpiece and medium takes place in all of its free surfaces.

Table 1

The values of the cutting parameters

Level	v_c [m/min]	f [mm/rot]	a_p [mm]
-1	235,4	0,06	0,5
0	293,9	0,12	1
1	369,3	0,24	2

Table 2

Values of the global heat exchange coefficient *h*.

n [rot/min]	v_c [m/min]	f [mm/rot]	h [N/m·s·K]
765	235.4	0.06	1085.1
765	235.4	0.12	1046.6
765	235.4	0.24	1846.5
955	293.9	0.06	1801.2
955	293.9	0.12	1762.7
955	293.9	0.24	2562.6
1200	369.3	0.06	3003.1
1200	369.3	0.12	2964.6
1200	369.3	0.24	3764.5

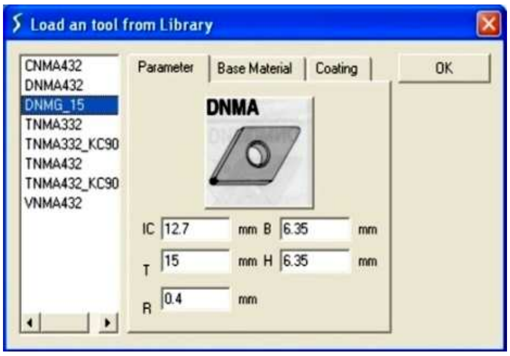

Fig. 3. Geometric size cutting tool.

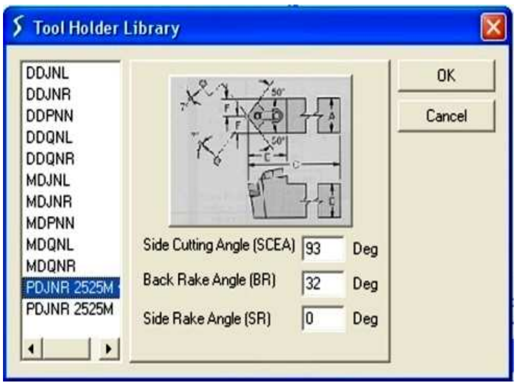

Fig. 4. Construction of the tool angle.

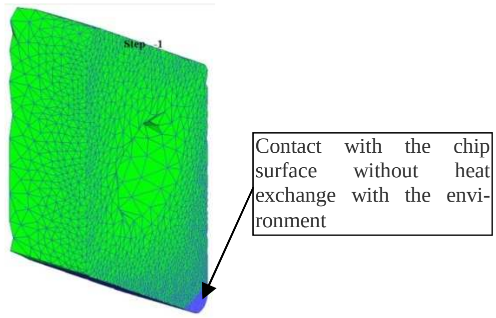

Fig. 5. Mesh cutting tool and heat transfer conditions of the environment.

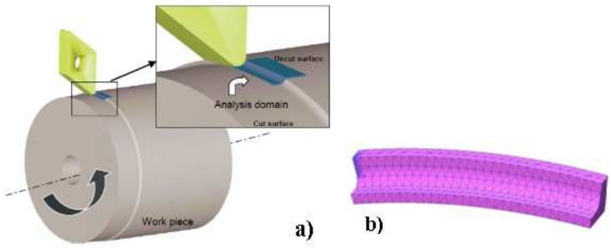

Fig. 6. Defining workpiece model:
a – model components; *b* – model meshed.

Workpiece material – Ck 45 of DIN 17200 with physical and mechanical properties defined in the program library. The material law is Johnson-Cook type, the behavior of the material being elasto-plastic.

Simulation parameters – 2 000 iterations without the option of calculating the tool wear.

Next, simulations were performed for each combination of values (see Table 1) of the cutting regime parameters.

3. RESULTS AND DISCUSSION.

Each simulation was performed by entering the tool in the workpiece at the specified cutting speed. The chip detaches from the machined surface when the relations with it unfold and contact with the seating of the cutting tool is established, according to the method of Lagrange separation. To avoid numerical instability caused by the imbalance of forces in model surface nodes that are separated, the program provides a distribution of forces gradually reduced by reducing their value to zero.

Due to strong deformations of the elements near the top tool, more remeshing models were needed. Figures 7 and 8 present the results obtained for the minimum and maximum cutting regime parameters.

The time to reach the maximum temperature is of the order of tenths of thousandths of a second for the semi-fabricated workpiece and of thousandths of a second for the tool. For the tool, this time is in inverse relationship with the cutting feed, and for the semi-fabricated workpiece the time does not depend on the cutting regime parameters.

Temperature distribution in the cutting process is uneven, showing areas with different temperatures.

The position of the maximum temperature zone (warm point) on the tool rake face depends only on the, the warm point departing from the tool edge to increase the cutting feed. The temperature at this point is influenced most by the cutting speed. In conclusion, for small feeds and high cutting speeds, the durability of the tool edge in wear decreases.

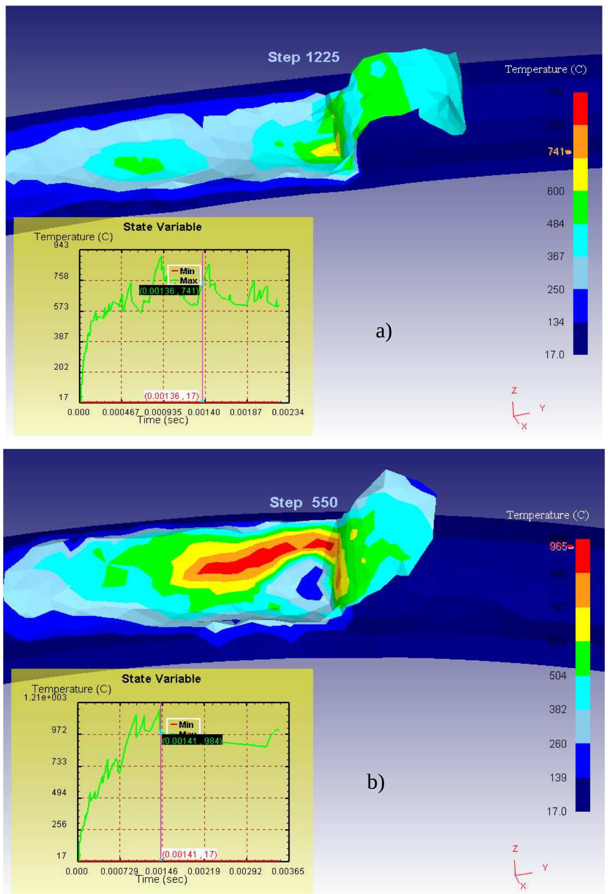

Fig. 7. Thermal field of workpiece:
a – v_c=235.4 m/min, a_p=0.5 mm, f =0.06 mm/rot,
b – v_{as}=369.3 m/min, a_p=2 mm, f =0.24 mm/rot.

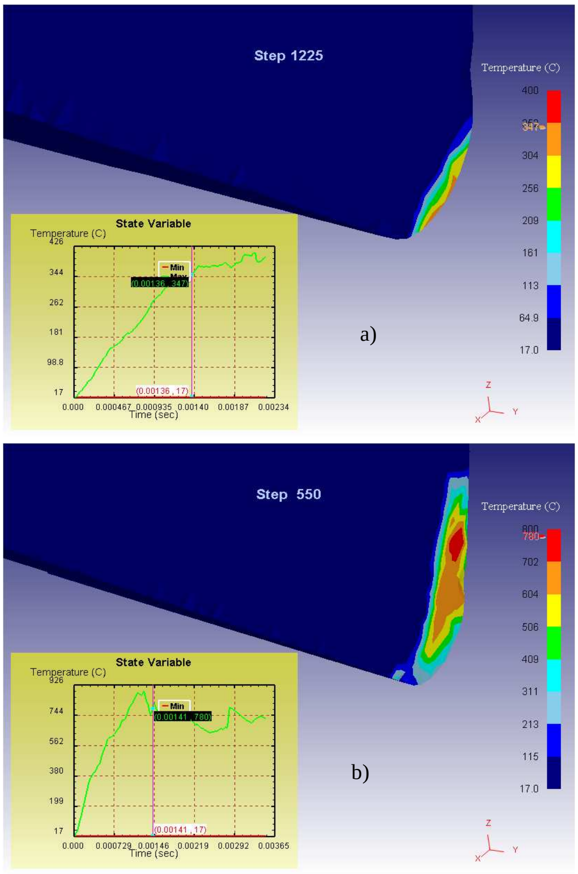

Fig. 8. Thermal field of tool:
a – v_c=235.4 m/min, a_p=0.5 mm, f = 0.06 mm/rot,
b – v_{as}=369.3 m/min, a_p=2 mm, f = 0.24 mm/rot.

Based on the results obtained by simulation, it was performed a quality analysis for the variation of the values of the coefficient of friction μ_γ between the chip and tool rake face depending on the cutting speed (Fig. 8), cutting feed (Fig. 9) and depth of cut (Fig. 10).

For small values of cutting speed, at the bottom of the conventional range, friction coefficient μ_γ increases with increasing the cutting speed (Fig. 9), the increase being greater for larger values of the cutting feed.

For values above the cutting speed of 235 m/min, value located in the upper medium-range of the conventional range, a downward trend was found in the value of friction coefficient μ_γ with increasing cutting speed while maintaining constant the parameter values cutting feed and depth of cut.

The decrease of the value of the friction coefficient between the chip and the tool rake face at increasing the cutting speed above a certain value was found by other researchers too.

The friction coefficient μ_γ is influenced by the growth of the cutting feed. For the same cutting speed, it was observed that the variation is greater for small values of the depth of cut (Fig. 10). For higher values of cutting speed and cutting depth the friction coefficient μ_γ is higher, but the increasing gradient decreases.

The coefficient of friction μ_γ depends to a less extent on the variation of the cutting depth (Fig. 11), observing that for the same values of the cutting feed, the smaller the values, the higher are cutting speeds (inverse relationship).

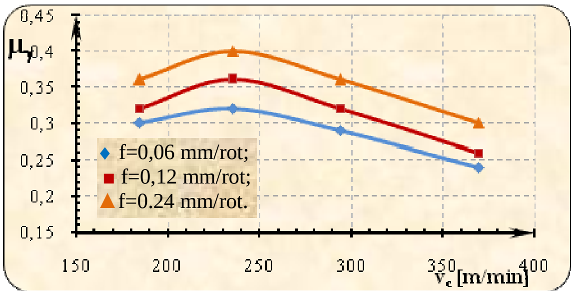

Fig. 9. The variation coefficient of friction μ_γ depending on cutting speed ($a_p = 1$ mm).

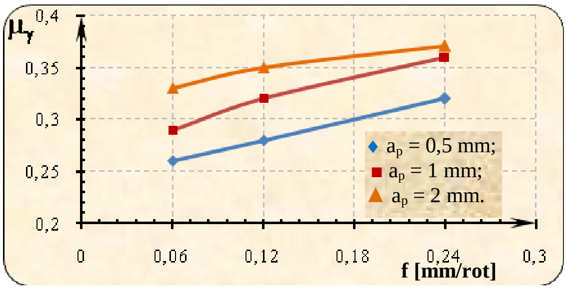

Fig. 10. The variation coefficient of friction μ_γ depending on cutting feed (v_c = 293.9 m/min).

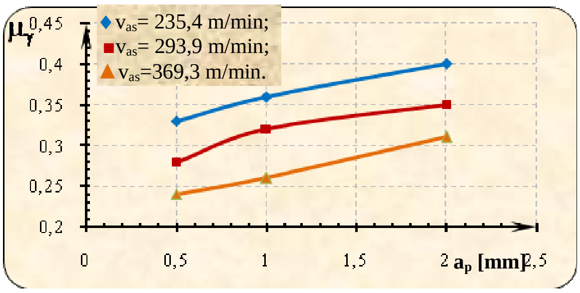

Fig. 11. The variation coefficient of friction μ_γ depending on depth of cut (f = 0.12 mm/rot).

4. CONCLUSIONS

Finite element analysis program DEFORM3D and the *Machining* module (Cutting) provides a good simulation of longitudinal turning process, highlighting the point of maximum pressure on the tool rake face and hence the maximum temperature and heating tool chip temperatures, comparable to those determined experimentally.

The time to reach the maximum temperature for the semi-fabricated workpiece (Figs. 7 and 8) is lower by at least an order of magnitude compared to the tool.

Temperature values for the tool, chip and machined surface of the workpiece, fit in the existing data in the literature [6, 8, and 9].

The temperature of the machined surface is much smaller than the chip temperature, which confirms the assumptions concerning the evacuation of the heat produced in the primary shear zone. According to these assumptions, at high speed cutting, the evacuation of the heat from the primary shear zone is achieved mainly by transport through its acquisition by the chip.

The model captures the trend of slightly decreased temperature of the storing tool and workpiece (Figs. 7b and 8b) after the first moments of starting the cutting process.

The database generated by simulating the cutting process can be transferred to analyzing the state of stress and strain of the tool, using another finite element program (e.g. ANSYS), because the DEFORM3D *Machining* program, considers the tool a rigid body, as only option.

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