

## 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 work-piece. Modeling, 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 actual values of this dependence) and on the other hand, a decisive role is played both by the thermal regime of cutting speed, through component  $v_\gamma$  – 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 behaviour at the tool–chip interface in the area near the cutting edge.

**Key words:** tool-chip interface, cutting models, process simulation 3D, 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. The appropriate mechanical and thermal relations for phenomena of the cutting process must be formulated, especially plastic flow area (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  $\alpha_g$  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 and on the cutting feed [2]:

$$h = 17529 - 34.572p - 1010.01756p^2 + 0.000783T^2 \text{ [kW/m}^2\text{K]} \quad (1)$$

$$h = 442 - 2.36v_c - 7950f + 0.0276v_c^2 + 40600f^2 \text{ [kW/m}^2\text{K]} \quad (2)$$

Given the importance of the machining area in the last decade came new programs and appropriate (specialized modules) to simulate the cutting process. The package created by Deform is complex and incorporates

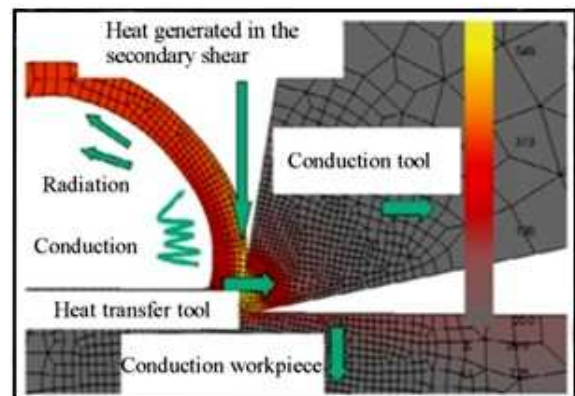


Fig. 1. Heat in the cutting process.

interactions between deformation, temperature, and heat treatment, phase transformations and diffusion of carbon.

### 2. DEFORM 3D MODELLING ENVIRONMENT

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 and 6].

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:

- *Cutting regime parameters* (see 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 transfer between the tool rake face

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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 <sup>2</sup> ·K]
765	235.4	0.06	1 085.1
765	235.4	0.12	1 046.6
765	235.4	0.24	1 846.5
955	293.9	0.06	1 801.2
955	293.9	0.12	1 762.7
955	293.9	0.24	2 562.6
1200	369.3	0.06	3 003.1
1200	369.3	0.12	2 964.6
1200	369.3	0.24	3 764.5

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]. 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 [5].

- *Defining the tool* – according to the data from Sandvik Tool Catalogue for tool PDJNR 2525M and cutting insert DNMG 15 06 04-PM.
- *Mesh cutting tool and setting thermal boundary conditions* – 25000 items (default).
- *Workpiece* – curved model with 98 mm diameter, the arc field analysis – 20°, meshing – 6 000 items. Heat transfer between workpiece and medium takes place in all of its free surfaces.
- *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 behaviour of the material being elastoplastic.
- *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.

For the cutting feed  $f = 0.24$  mm/rev and depth of cut  $a_p = 2$  mm, using the options in visual computing module of Excel application Microsoft Office 2007 software package, to determine the equation of variation of friction coefficient  $\mu$  in depending on the cutting speed (see Fig. 4):

$$\mu_\gamma = -0.22 \cdot \ln(v_c) + 1.632. \quad (3)$$

### 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. Figures 2 and 3 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 thousands 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 cutting feed, 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 cutting feeds and high cutting speeds, the durability of the tool edge in wear is less.

Based on the results obtained by simulation, it was performed a qualitative analysis for the variation of the values of the coefficient of friction  $\mu_\gamma$  between the chip and tool rake face depending on the speed of cutting (Fig. 4), cutting feed (Fig. 5) and depth of cut (Fig. 6).

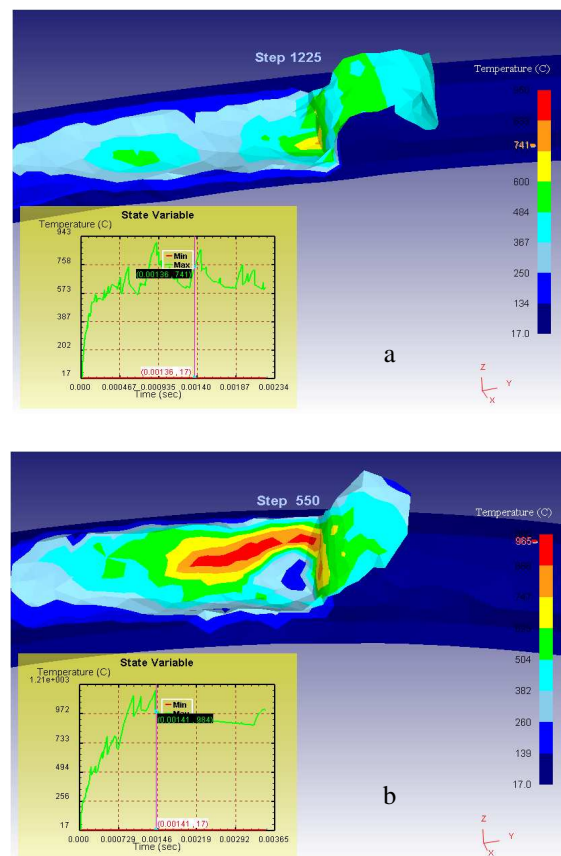
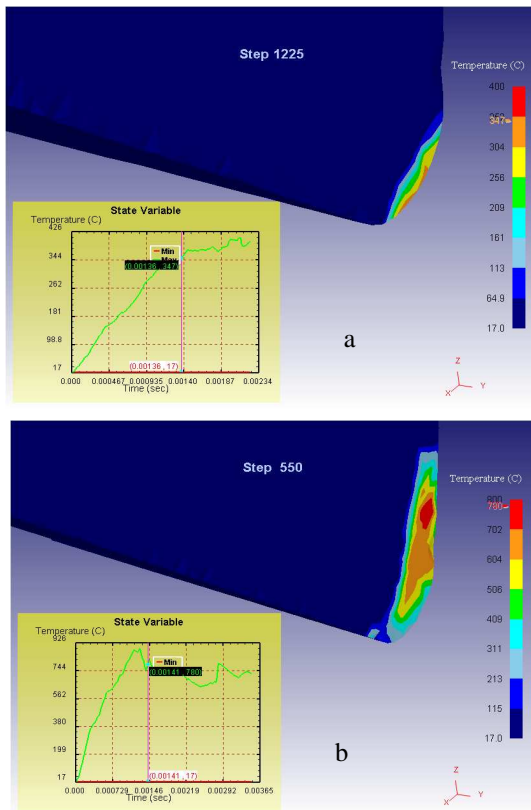


Fig. 2. Thermal field of workpiece:

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. 3.** Thermal field of tool:

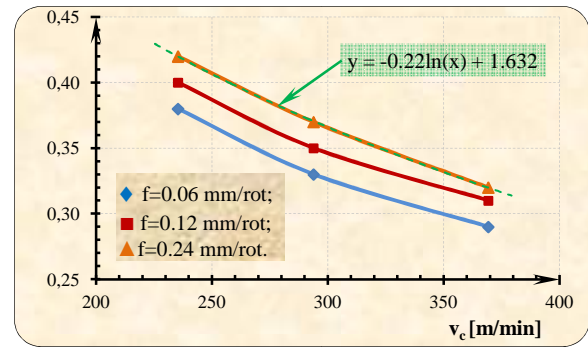
*a* –  $v_c = 235.4$  m/min,  $a_p = 0.5$  mm,  $f = 0.06$  mm/rot;  
*b* –  $v_{as} = 369.3$  m/min,  $a_p = 2$  mm,  $f = 0.24$  mm/rot.

For values above the cutting speed of 235 m / min, a value located in the medium to upper range conventionally found downward trend in the value of the friction coefficient with increasing cutting speed while maintaining constant parameter values cutting feed and depth of cut (Fig. 4).

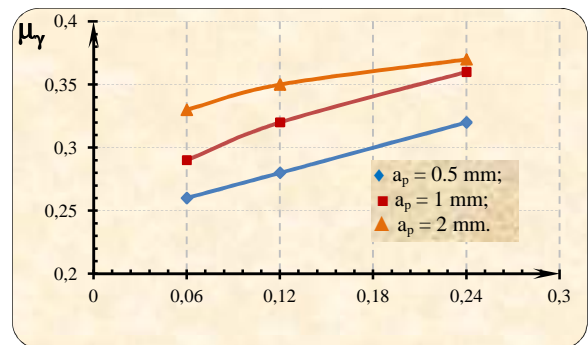
The friction coefficient  $\mu_\gamma$  is influenced by the growth of the cutting feed. For the same cutting speed, it was observed that the variation is greater for small values of the depth of cut (Fig. 5). For higher values of cutting speed and cutting depth the friction coefficient  $\mu_\gamma$  is higher, but the increasing gradient decreases.

The coefficient of friction  $\mu_\gamma$  depends to a less extent on the variation of the cutting depth (Fig. 6), observing that for the same values of the cutting feed, the smaller the values, the higher are cutting speeds (inverse relationship).

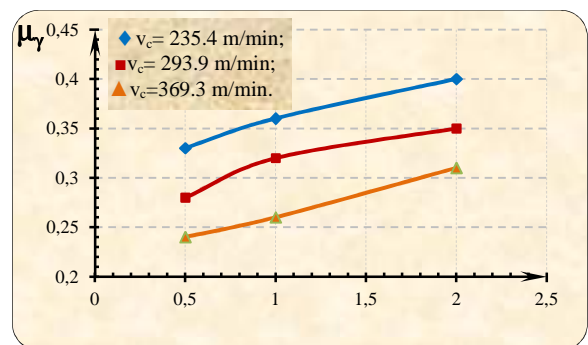
Using the results of simulations [3] relations established and given the manufacturer's recommendations on the maximum cutting regime parameters that can be used for cutting tool DNMG 15 06 04 PM, verification is carried out by simulating the model for longitudinal turning process parameter values of the HSC cutting regime. Were used to define the following parameters of the model:  $v_c = 646.2$  m/min,  $f = 0.24$  mm/rev,  $a_p = 2$  mm;  $\mu_\gamma = 0.208$  (determined by equation 3),  $h = 10.872$  kW/m<sup>2</sup>K (calculated with equation 2), mesh tool: 25 000 elements; mesh workpiece: 15000 elements; diameter workpiece: 98 mm material workpiece: Ck 45, arc value field of study: 25°, number of calculation steps: 2500. The results obtained from running the simulation model longitudinal turning operation parameters of the HSC



**Fig. 4.** The variation coefficient of friction  $\mu_\gamma$  depending on cutting speed ( $a_p = 2$  mm).



**Fig. 5.** The variation coefficient of friction  $\mu_\gamma$  depending on cutting feed ( $v_c = 293.9$  m/min).



**Fig. 6.** The variation coefficient of friction  $\mu_\gamma$  depending on depth of cut ( $f = 0.12$  mm/rot).

cutting regime are shown in Figs. 7, 8 and 9.

Given the assumptions taken into account in defining the model and analyzing the results presented, the following conclusions are appropriate:

- Time to reach maximum temperature for the workpiece (Fig. 8) is smaller by at least an order of magnitude than the tool (Fig. 9) [8].
- 839°C temperature attained by the chip in the simulation of the cutting process is credible and verifies the assumption that, at high cutting speeds, exhaust of heat from the primary shear zone is achieved mainly by transport through its takeover the chip (Figs. 7 and 8).
- Temperature values for the tool, chip and surface machined of the workpiece fit in existing literature data and the calculated value, with relation (3), of the friction coefficient  $\mu_\gamma$  is correct.

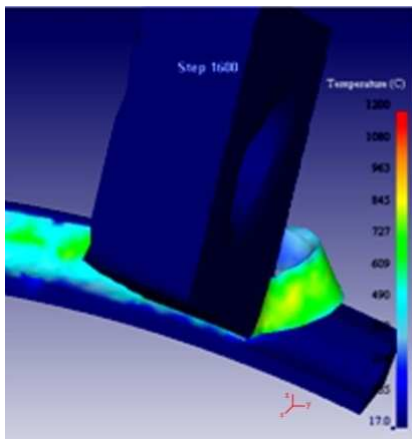


Fig. 7. The model of the longitudinal turning.

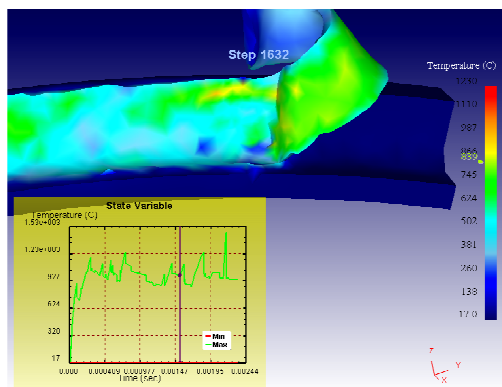


Fig. 8. Thermal field of workpiece.

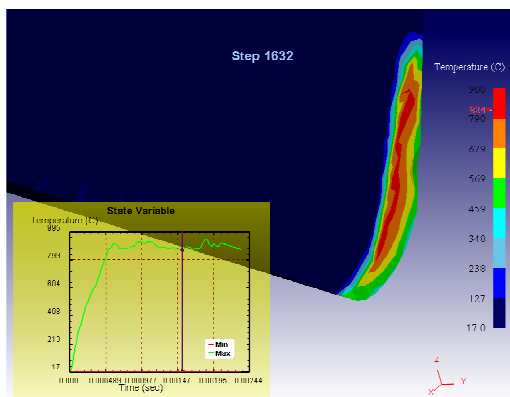


Fig. 9. Thermal field of the rake tool.

- The temperature of machined surface is much lower than chip temperature which confirms assumptions about how the dissipation of heat generated in the primary shear zone.
- The model trend of easy decreased tool temperature and workpiece temperature (Fig. 8 and 9) after the first moments of starting the cutting process, aspect relevant and the diagrams determined from experimentally measured data [3].

From experimental measurements for the cutting feed of 0.24 mm/rev, segmented chips were obtained, which model did not assess this aspect, but surprised because bending chip thermal deformation (Fig. 8).

Temperature values for the tool, chip and machined surface of the workpiece fit in the available data in the literature.

The temperature of the processed 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.

Hypothesis permanent thermal regime adopted in most models thermal cutting area is questionable because, before entering the tool material is ambient temperature and immediately start cutting process reaches a maximum temperature. There is therefore phase-tenths of milliseconds, during which there is a sudden rapid increase of the average temperature of the tool cutting edge (Figs. 3 and 9). From this value, the temperature evolves very slowly and do not reach a single value as the tool holder does. The tool holder and the machine holder are infinite mediums for heat transfer, the time constant being infinite compared to the machining time.

The model trend of decreased tool temperature and workpiece temperature (Fig. 3,b and 9) after the first moments of starting the cutting process, which is relevant and diagrams determined from experimentally measured data [3].

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 (eg. ANSYS), because the DEFORM3D *Machining* program, considers the tool a rigid body, as only option.

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