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TWO DIMENSIONAL PHYSICAL MODELING OF THE CUTTING WEDGE

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ABSTRACT: *Modeling chips formation is a highly complex task because numerous mechanical, thermal, hydrodynamic, tribological and chemical phenomena are present in a coupled way. In three dimensional simulations also the contact problem may bring extra numerical complications. That's why many simulation work deals with the two dimensional model of cutting. In this paper we demonstrate our model calculations on the cutting wedge as it works in planning. We have built up a two-dimensional model and solved it. Result are in good agreement with general experiments, describes thermal fluxes, temperature and stress peaks, typical places of wear.*

KEYWORDS: *cutting, chips formation, simulation, finite element method*

INTRODUCTION

Chips formation accompanies all cutting processes. Although chips is waste in this type of machining, the chips forming phenomena itself substantially impacts almost all technical features of cutting and the quality parameters of the product: power demand, highest allowable cutting speed, accuracy, surface roughness, residual stresses and deformations, local material properties of the machined surface, thermal effects, what influences all above.

Chips formation is one of the most complex phenomena occurring in technical practice. It has physical, chemical, tribological, thermo-dynamical and in some cases hydro-dynamical aspects. Additionally, dynamics of cutting is often stochastic or chaotic, which means that in a real system there are large scale, rapid and unpredictable changes in mechanical quantities as forces or torque [1].

Therefore it is highly interesting and important to look into chips forming, but it is a great challenge. Because of the practical interest on cutting, studies are mostly experimental [5] [6] [7] [8].

In this paper we report on pilot simulations of chips formation. A two-dimensional finite element model of planning was built up. Stress, deformation, thermal state of the workpiece and the tool, and the wear of the tool was calculated.

THE CONTACT PROBLEM

In cutting processes the contact between specimen and the tool results in chips forming. So simulation of cutting is a typical contact problem, which has a solution strongly sensitive for features of the contact. We mean this in at least two sense. Contact has to be featured by physical (and chemical) quantities, like mechanical model, in the sense bodies are deformable or rigid, material properties, frictional law, a heat transfer and emission model, in case of lubrication, a tribological model. One can meet a swarm of different constants and functions needed to describe what happens when two body contacts. At this point we face the exciting challenge of idealization of the physical problem, which means, we have to decide what we consider and how, and what we neglect. This is a typical human task it can not be done by computers. We decided to take into account the friction described by the arctangent approximation of the Coulomb law, heat transfer processes by a contact, a near contact and a distance dependent heat transfer coefficient.

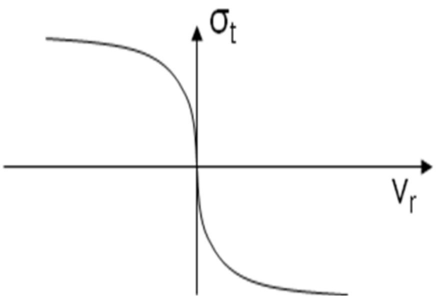

Figure 1. The arctangent approximation of the Coulomb law

The arctangent approximation of the Coulomb law (Figure 1) can be formulated as

$$\sigma_t = -\mu\sigma_n \frac{2}{\pi}\arctan\left(\frac{|v_r|}{c}\right), \qquad (1)$$

where σ_t tangential component of stress (coming from friction), σ_n normal stress, μ frictional coefficient, v_r the relative velocity of *contacting bodies at the contact point, c a constant quantity with speed dimension.*

The governing equation of the heat transfer problem is

$$C(T)\dot{T}+K(T)T=Q, \tag{2}$$

where C denotes specific heat matrix, K the thermal conductivity matrix, T the nodal temperature vector, and Q the heat flux vector.

From a numerical point of view contact is a source of instability. Contact status and possible penetration is checked in each iteration, cut back is made if necessary. While geometry is rapidly changing where chips is formed, nodes may go far from their position within an iteration. That's why small time steps have to be used. The contact tolerance was let to be automatical. This means that it started with value 0,01, and then changed iteration by iteration. The bias factor was set to be 0,95.

PROCESSING AND CALCULATION

Commercial software was applied for our calculations. The MSC Mentat was used for preprocessing and post-processing, and MSC Marc was used for solving the model.

A two-dimensional model of planning was built up. The specimen had dimensions of 200mmx40mm and 1 mm thickness. The material of it was C45, properties of it were read in from the software's database. This involves thermal change of material properties. The tool was supposed to be made of hard metal.

Five contact bodies were defined in the model. The specimen ("munkadarab") and the tool ("szerszám") were deformable bodies. Contact properties of them were highly important in the model, because these determined the time evolution of physical quantities. For frictional coefficient we set 0,4 and Coulomb friction law with arctangent model was applied. This value represents dry or near-dry machining, because we interested in environmentally conscious cutting. Thermal properties are hard to explore in literature. We had to suppose certain values, as 100 mJ/mm^2 for contact heat transfer coefficient, 50 mJ/mm^2 for near contact heat transfer coefficient and 20 mJ/mm^2 for distance dependent heat transfer coefficient.

Deformable bodies were built up from 4-node isoparametric quadrilateral plane strain elements associated with 4-node heat transfer planar element for modeling thermal processes.

The other three contact bodies were rigid bodies and represented boundary conditions. The contact body "feed" ("elotolas") represented the body of the tool, and the speed was prescriben for it. The "support" ("tarto") prevented the specimen from moving horizontally. The "base" ("alap") was a symmetry body representing a mirror plane, so it was necessary to model only the 20 mm high upper part of the specimen. This contact body prevented the modeled part of the specimen from leaving it (Figure 2). The cutting speed was 50 mm/s. because of sensitivity of iterative procedure fir this speed, we had to apply time ramp up for this speed. It started from 5 mm/s and rose up during 1s to the desired value (50 mm/s).

A transient thermo-mechanical calculation was performed. We applied adaptive time stepping in the solution procedure. In each second iteration step global remeshing was required. It was necessary because of large distorsion of finite elements around the cut zone due to large deformation.

For computation a 2,5 MHz dual processor with 3 GB RAM was used. Time demand of this calculation was 4 hours. Peak memory usage was 328 MB.

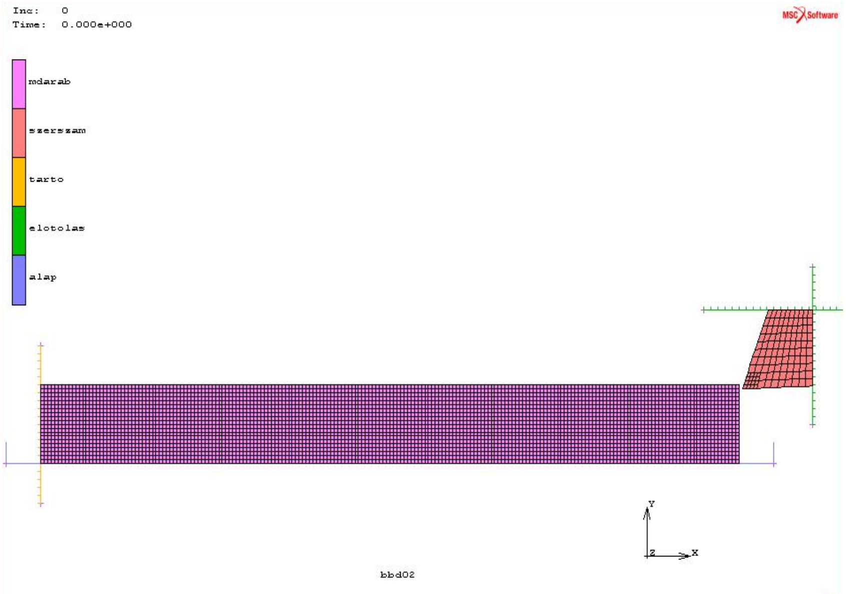

Figure 2. Five contact bodies in the model

RESULTS

For evaluation we choose the time instance t=1,658s, because it is a typical state of the process, when the cutting speed was the desired value.

Figures 3 and 4 show the stress state of the system. The von Misses stress distribution provides a general overview. There is a stress peak around the cut (shorn) zone of the specimen. It is in good agreement with experiments and basic theory of chips formation. The shear stress distribution supports it (Figure 4). On the machined surface we can see residual stress.

$$\sigma_{Mieses} = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_3)^2+(\sigma_3-\sigma_2)^2\right]} \tag{2}$$

Figure 5 demonstrates temperature distribution in the specimen and the tool. The maximum is on the front surface of the tool near above the edge. This maximum plays an important role in wear process.

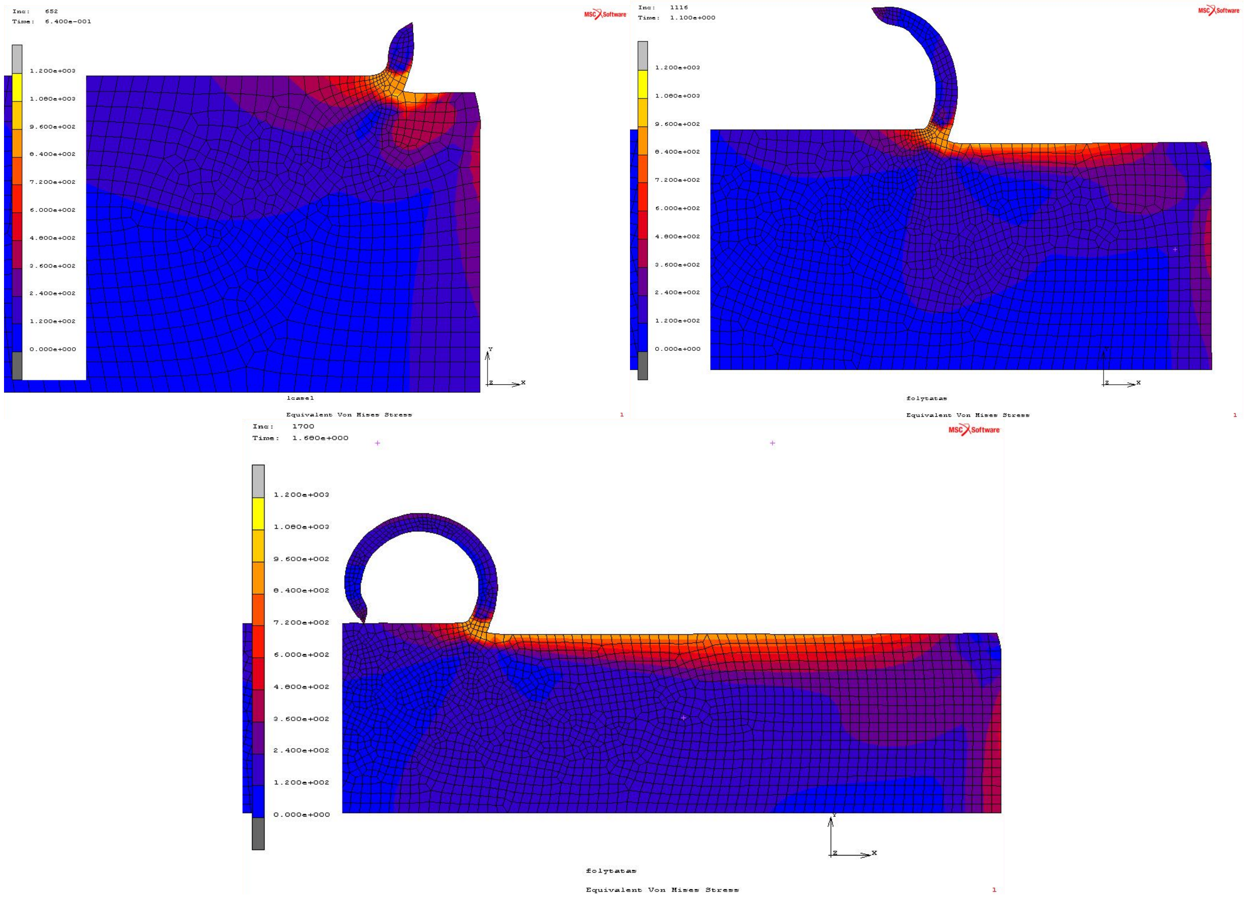

Figure 3. The von Mieses equivalent stress distribution in the specimen at time instants t= 0.64s, 1.10s and 1.68s. Large stress in the cut zone and residual stresses on the machined surface are well visible.

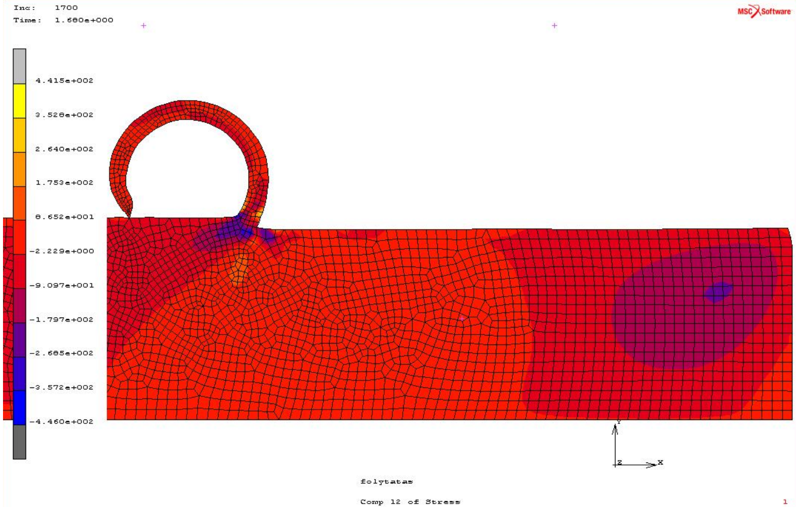

Figure 4. The shear stress distribution in the specimen, the shorn zone is grown up at the bottom of the chip.

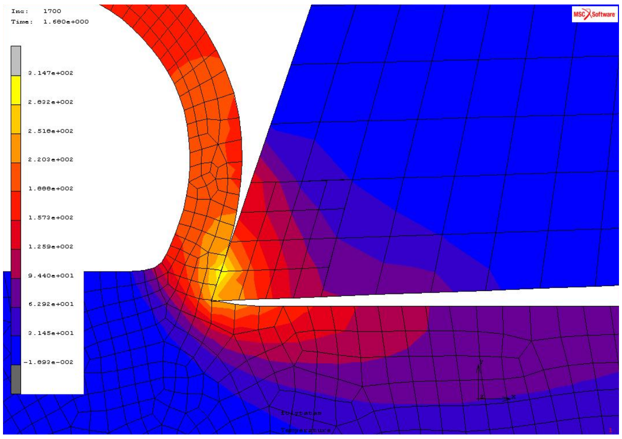

Figure 5. The temperature distribution in the specimen and the tool. The maximum is on the front surface of the tool near above the edge

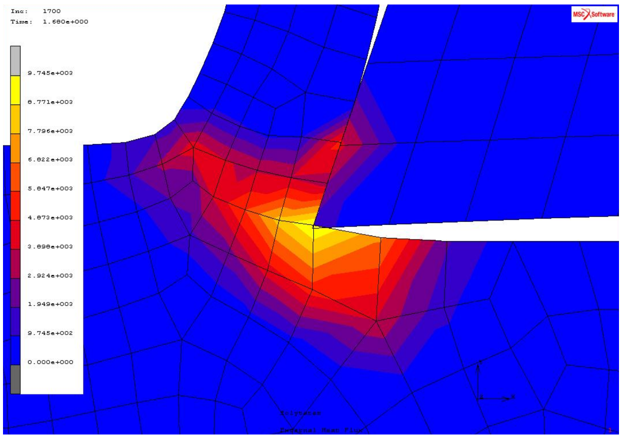

Figure 6. Heat flux sources: the plastic deformation work and the friction

CONCLUSIONS

Two dimensional cutting problems were treated in this paper. Friction and heat transfer was involved in the model.

Our results are in good agreement with experiments. Shear stress maximum was pointed out in the shear zone, residual stresses can be observed on the machined surface. The temperature distribution shows the peak on the front surface of the tool near above the edge. Heat flux sources are deformation work and friction between the tool and the chips.

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