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Meshing strategies in FEM simulation of the machining process

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ABSTRACT

This paper presents some methods of mesh smoothing when using cutting tool inserts with complex geometry of the cutting edge and the rake face. Several sets of meshing parameters are proposed and their influences on the performance of FEM simulation of the cutting process are presented. In addition, both mechanical and thermal characteristics of the cutting process are compared for four groups of meshing parameters. The simulations were carried out for a Ti6Al4V alloy using TiAlN coated carbide commercial cutting tool insert. It was documented that accurate representation of the tool micro-geometry influences the simulation results.

1. Meshing problems in FEM modeling of machining process

Modeling of technological processes is an important part of the implementation of new technology into production process and in the case of machining processes a dominant role is played by FEM-based numerical simulation. Its wider and successful application is now limited by inaccurate constitutive material models and, in particular by the lack of the relevant input data [6,10]. These data include both geometrical and physical properties of the machined workpiece and the cutting tool insert used. The first group includes geometrical, predominantly 3D CAD models of these elements with particular emphasis on the cutting edge radius [1]. The second group aggregates the choice of constitutive laws and their constitutive models which characterize the mechanical and thermophysical properties of the workpiece and tool materials [3,9,11].

In this paper the focus was made on the definition of geometrical input data and, in particular, on the numerical models of cutting tool inserts including active parts performing the machining process. It is obviously known that in this area the most important is the meshing procedure of a CAD model generated. Its goal is to generate a finite solid element defined by the nodal points represented by the nodes of basic finite elements whose structure and localization should be adequate to the simulated cutting process using FEM technique [2,5].

Simulation of the cutting process using cutting tools with geometrically complex rake faces requires the boundary minimum and maximum dimensions/scales of basic finite elements to be defined in order to guarantee the correct

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iteration/computation process. It is also known that in order to obtain a CAD model with satisfactory accuracy both the cutting edge micro geometry (its roundness with the radius r_n) and the grooved chip breaker should be modeled properly.

Taking this fact into consideration the modeling procedure was essentially focused on the quantification of meshing of tool wedge CAD model on the results and quality of 3DFEM simulation of a turning process representing a non-orthogonal model of the cutting process. The CAD model of a commercial cutting tool insert was used in this investigation. A Ti6Al4V titanium alloy, which is one of the most popular aerospace materials, was selected as the workpiece material. The FEM simulation undertaken in this study is strongly oriented on the optimization of technological processes of such difficult-to-machine materials.

2. Investigation methodology

In the FEM simulations carried out the special focus was on the accurate cutting tool model as well as adequate constitutive material model. The tool wedge model was implemented as the CAD model of a cutting tool insert applied (in the case study it was CNMG 120412-UP insert produced by Kennametal). The visualization of the complete CAD model implemented is shown in Fig. 1a, whereas the magnified fragment of the corner with the cutting edge and grooved chip breaker is depicted in Fig. 1b.

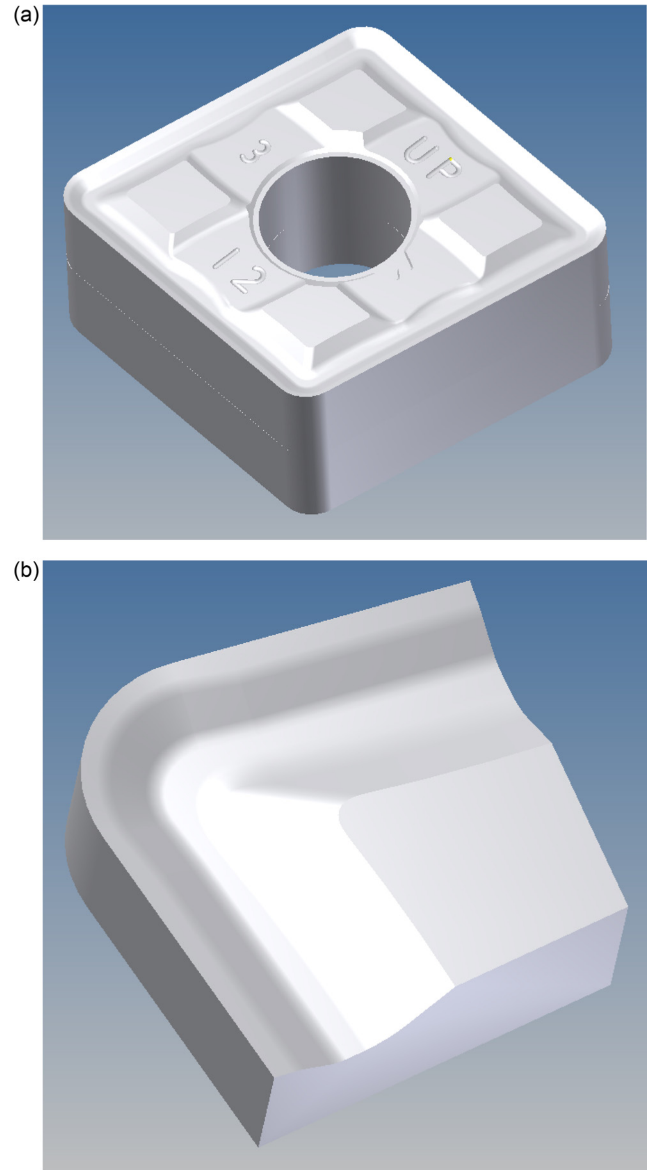

Fig. 1 – CAD model of CNMG 120412-UP cutting tool insert by (a) Kennametal and (b) tool rake model used in FEM simulation.

In order to compare the 3D CAD model with the real configuration of the cutting tool insert used, the insert shape was measured using an ALICONA IFM optical microscope. Exemplary dimensioned profile of the cutting wedge of CNMG 120412-UP insert including the cutting edge (detail A) and the groove (chip breaker) on the rake face is shown in Fig. 2. The optical image of the insert generated is presented in Fig. 3a. In addition, Fig. 3b illustrates the localization of cross-sections 1–3 in which the wedge profiles were separated and magnified using MountainsMap and Geomagic Design software.

The comparison of the model and real shape of the insert gives good shape and dimensional agreement. In particular, dimensional errors were not higher than 7 μm. It should also be noted that the thickness of deposited TiAlN coating was about 3 μm which also influences the model accuracy.

In these investigations FEM simulations were performed for standard constitutive model named Power Law (PL). It should be noted that the flow stress in the cutting zone is predicted using equations incorporating the material behavior under high strain rate and temperature [7]. As a result, the constitutive PL model is mathematically expressed by the power equation, as follows

$$\sigma_f(\varepsilon_p) = \sigma_o \Theta(T)\left(1+\frac{\varepsilon_p}{\varepsilon_p^0}\right)^{1/n} \quad (1)$$

where σ_o is the initial yield stress, ε_p is the plastic strain, ε_p^0 is the reference plastic strain, $1/n$ is the strain hardening exponent and $\Theta(T)$ is thermal softening index (factor) defined as a function of temperature according to (2). In Eq. (2) the c_0 through c_5 are coefficients for the polynomial fit, T is the temperature, T_{cut} is the linear cut off temperature, and T_{melt} is the melting temperature. The Eq. (2a) is defined for $T < T_{cut}$, where Eq. (2b) for $T \geq T_{cut}$.

$$\Theta(T) = c_0 + c_1 T + c_2 T^2 + c_3 T^3 + c_4 T^4 + c_5 T^5 \quad (2a)$$

$$\Theta(T) = \Theta(T_{cut})\left(1-\frac{T-T_{cut}}{T_{melt}-T_{cut}}\right) \quad (2b)$$

In a typical machining event, extremely high strain rates in excess of $10^4\ s^{-1}$ may be attained within the primary and secondary shear zones, while the remainder of the workpiece deforms at moderate or low strain rates. In order to account for a variation in the strain rate sensitivity at low and high strain rates, AdvantEdge software incorporates a stepwise variation