

Identification of Process Specific Size-Effects

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For the production of micro devices and for small quantities, machining is an alternative to conventional manufacturing techniques. However, it shows process specific size-effects upon miniaturization to the micrometer regime. In order to investigate these size-effects, thermo-mechanically coupled finite element simulations with a rate-dependent plasticity law were carried out in parallel to experiments. Frictional effects on the cutting process were studied using a friction coefficient μ based on experimental results. Size-effects observed experimentally were confirmed by numerical simulations.

The yield model of Vöhringer was used in the simulations. This material constitutive relation is based on the physical derivation of the thermal activated dislocation dynamics and allows for the description of the yield stress σ_y of ductile materials, like the steels AISI O2 and AISI 1045. The yield stress in this model is a function of the temperature T , the plastic strain rate $\dot{\epsilon}_{pl}$ and the plastic strain $\bar{\epsilon}_{pl}$, and can be determined over a wide range of parameters. For simulations with the finite element program, ABAQUS/Explicit, the relation is implemented in a user subroutine VUMAT.

The first simulations and their comparison with experimental results showed that the strain hardening exponent is overestimated in the original parameter set of AISI O2. Therefore, the localization of the shear strain in the domain of necking or the primary shear band did appear too late as compared to experimental observations. Refitting a new parametric reference to the original experimental data for AISI O2 gave a better correlation to the experimental results in the tensile tests.

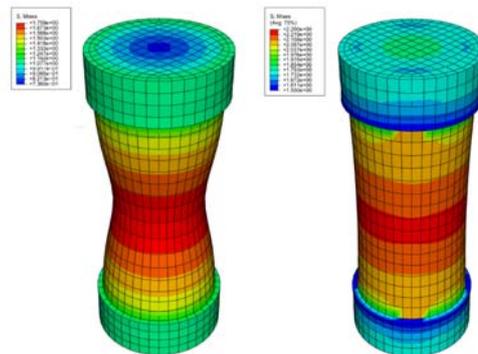


Fig. 1: Von-Mises-stress and deformation (necking) from the FE simulation of a tensile test; with improved parameters (left) and the original parameters (right)

The micro-cutting process is influenced by tribological phenomena like a high friction stress. From other simulations it is known that the specific cutting force k_c increases linearly with the friction coefficient μ . This influence of the friction coefficient was investigated in more detail with 2D simulations.

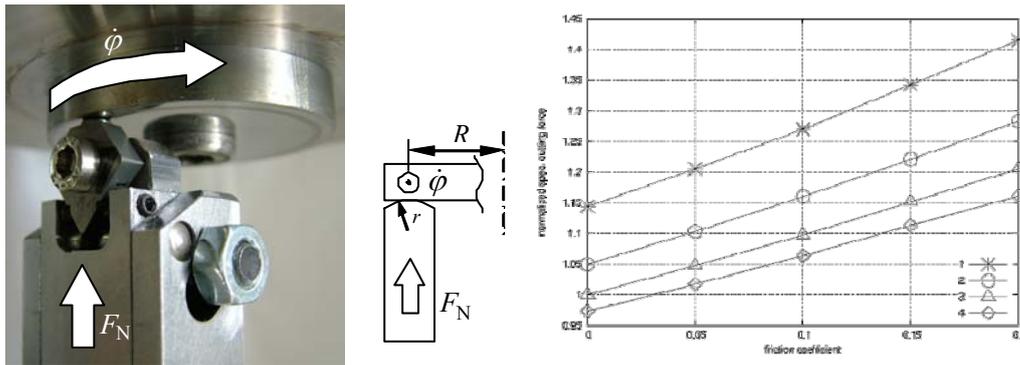


Fig. 2: Experimental setup (left) and simulation results of the normalized specific cutting force k_c / k_{c0} ; the scaling behaviour is weakly non-linear

As shown in Figure 2, in the simulations with the improved material parameters, a linear increase of the friction coefficient μ gives rise to a weak non-linear scaling behaviour of the specific cutting force k_c , even for simple geometries with an ideally sharp cutting edge.

As a further result, the normalized chip compression λ was investigated for a stationary micro-cutting process, in which – with respect to the material and the process parameters – no segmented chip shape could be observed.

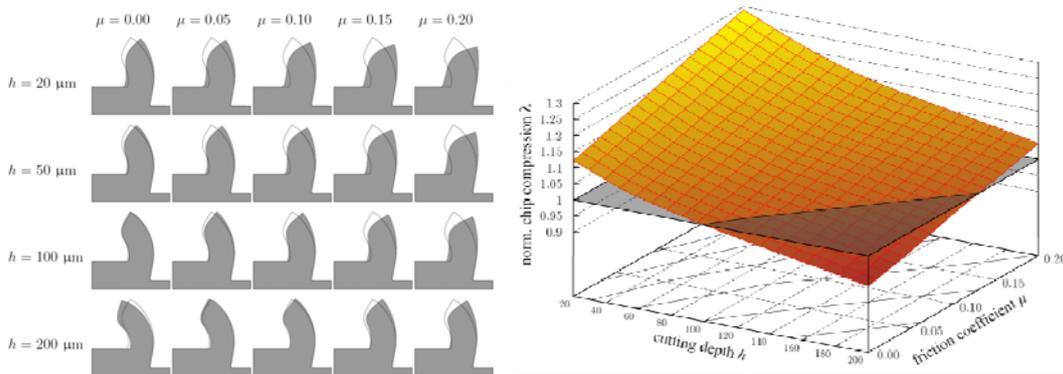


Fig. 3: Systematic investigation of the normalized chip compression λ as a function of the process parameters cutting depth h and friction coefficient μ

On the macroscopic scale, the friction coefficient μ is a function of the temperature T , the normal contact force F_c and the relative velocity v_{rel} . For the appropriate representation of the dependence of the friction coefficient μ on these parameters, corresponding experiments were conducted at the IWM (Freiburg). In these experiments no systematic correlations of the friction influencing parameters could be found. These investigations were presented on the CIRP-Workshop on modelling of machining operations, Calabria (Italy), and were awarded with the „Best Paper of Session“-Award.