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Determination of Material Resistance Characteristics in Cutting

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Abstract

It is proposed in this paper to use the specific deformation work considering the correlation between the strain, the strain rate of the cutting material and the cutting temperature as a characteristic of material resistance to cutting in the constitutive law.
The dependence of the specific deformation work and the yield stress on the deformation under adiabatic conditions is researched and determined due to its close connection with the deformation temperature. Moreover, the possibility of experimental determination in cutting is examined as well. The maximum value of the yield stress is established for the chip forming area and the accumulation zone on the rake face. The softening of the cutting material under isothermal conditions at a strain localisation is taken into account. In addition, it is described here how the material resistance changes due to the softening in the chip forming area and on the rake face of the cutting edge.

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Keywords: Machining; Constitutive law; Specific deformation work; Tangential force.

1. Introduction

The main reason for great differences between simulated and experimental machining characteristics is the insufficient agreement between the simulated and the real thermomechanical processes occurring in the shear zones [1]. This particularly concerns material models [2], [3] since assumptions about them greatly affect the accuracy when calculating resultant forces and cutting temperature.

Many researchers, among others [4], [5], direct great attention to modelling the material resistance to plastic deformation at large strains, high strain rates and temperatures prevailing in the cutting process. The dependence of the deformed material's yield point on strain, strain rate and temperature, which is widely known as constitutive law, is described here by an empirical function of the above-mentioned parameters, which is the same for different deformation zones. It is characteristic of these equations that they take the effect of strain, strain rate and temperature as independent variables into account. One example of such a constitutive equation is the Johnson-Cook model [5], used very often in the modelling of machining processes [5], [6] and others. These constitutive equations represent empirical dependences of the yield point on these three variables: the strain of the test material, the strain rate and the temperature. They are acceptable to describe the deformation of the material in standardised test methods. But in the case of cutting processes, such equations do not reflect the regularities of the machined material's deformation. That is because two of the three variables, namely the quotient of the strain rates and the increase in temperature, are not independent in cutting. Hence, they have to be established.

For modelling the dependence of yield point on strain in cutting, it is necessary to convert the increase in temperature from an independent into a dependent variable. It has to be taken into account here that the dependence of yield point on strain in cutting cannot be directly determined by experiment in principal. The dependence can merely be derived analytically by differentiating the dependence of deformation work according to strain. Using the specific deformation work as a characteristic of a material's resistance to deformation under adiabatic conditions, typical of the hardening during cutting, guarantees that it is not only possible to disregard the yield point

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at first but also to derive the increase in temperature from the specific deformation work [7]. The specific deformation work is established by experiment using the specific tangential forces in the chip forming area [8].

The temperature depends in a particular way on the distribution of the deformations in the chip forming area and in the accumulation zone, on the conditions of the heat dissipation from the shear zones as well as on the correlation between the temperature and the yield point of the machined material [7]. Moreover, identical constitutive equations, used for describing the regularities of the material's resistance to plastic deformation in tensile/compression tests, must not be applied to different deformation zones in cutting, since these dependences are established differently for varying deformation zones [7]. This has to be taken into account when determining the yield point for the modelling of material removal processes.

This paper presents the results of the analyses regarding the modelling of the material‘s resistance to cutting processes. The specific deformation work is assumed to be a characteristic of resistance, guaranteeing that the peculiarities of the material deformation in different shear zones during machining are taken into consideration.

Nomenclature

A_W	specific deformation work
τ_t	specific tangential force
τ_p	actual value of shear yield point
ε_w	final true deformation
R_t	true ultimate strength
R_m	conventional ultimate strength
$K_{\dot{\varepsilon}}$	dynamic factor
$\dot{\varepsilon}_0$	strain rates in tensile/compressions test
$\dot{\varepsilon}$	strain rates in cutting test
T'	homologous temperature
T	actual value of the deformation temperature
T_0	initial temperature (e.g. room temperature)
T_m	melting temperature
σ_0	yield point in tensile/compression tests
$\Delta\overline{T}'$	increase in homologous temperature
K_a	chip compression ratio
v	cutting speed
a	depth of cut
b	width of cut
γ	tool orthogonal rake angle
ϕ_t	shear angle
v_2	speed of chip flow
F_τ	tangential projection of the resultant force on the conditional shear plane

2. Deformation characteristics of the machined material in cutting

The distribution of strain and correspondingly of temperature in the chip forming area and in the zone of plastic contact between the rake face of the wedge and the chips can differ considerably at the same final temperature [9]. Due to this effect, the strain rates of roughly the same order of magnitude vary at different temperatures. The greatest effect of temperature on yield point as a function of strain rate is to occur in the area of the plastic contact between the rake face of the wedge and the chips. This is because the cutting temperatures reach their maximum in this zone. Consequently, different models of the material resistance to plastic deformation have to be developed for different areas of the deformation zones characterised by varying temperatures.

The specific peculiarity of material deformation when cutting at a heterogeneous shear is that areas of different deformation are formed. On the one hand, there are areas with relatively small strains and low temperatures, in which the material is hardened. On the other hand, areas with large strains and high temperatures are formed, where the material is softened. A substantial heat dissipation may lead to a stability loss of the adiabatic plastic flow in the chip forming area [10]. This is a necessary condition and a reason for localising deformations in a narrow region close to the boundary of the chip forming area [11]. Therefore, deformations cannot be localised in a narrow region if the hardening of the machined material predominates over its softening. Hence, the chip forming area (primary shear zone) can be represented schematically either as a relatively broad region with parallel boundaries or as two regions: a broad area in which adiabatic deformation conditions prevail and the material is hardened, and a narrow area in which isothermal deformation conditions predominate and the material is softened [10]. Fig. 1 depicts the texture in the chip during cutting [12] and the cutting layout for analysing the processes prevailing in different shear zones.

The figure shows the area of chip formation (*A*), the areas of the chip's contact with the rake face (*B*, *C* and *E*) as well as the areas of the tool's contact with the workpiece (*D* and *G*). The areas *B* and *C* here mark the plastic contact at the rake face, area E marks the elastic contact, area *G* marks the plastic contact at the clearance face, and area *D* marks the elastic-plastic contact. The chip forming area *A* is conditionally divided into two zones: a narrow zone with parallel boundaries, in which the main primary strains of the cutting material occur, and a wider zone with relatively small strains, occurring immediately before those in the primary zone. In the broad area is material adiabatic hardened and in the narrow area is material isothermal softened. When modelling the regularities of the material's softening in the chip forming area, it is necessary to take the stability loss of the adiabatic shear into consideration. This stability loss leads to the localisation of deformations in a narrow region close to the boundary of the chip forming area (s. Fig. 1, A_s).

The accumulation zone *B* of the contact between the rake face of the wedge and the chips is characterised by relatively small deformations. In the area of the plastic contact *C*, there are great plastic deformations and higher temperatures than in the area *B*. The deformation conditions in area *B* are nearly adiabatic if the temperature in the accumulation zone *B* is not higher than the deformation temperature of the chip particles. In the area of the plastic contact *C*, the thermal softening of the material predominates, which is partly compensated for by the hardening of the material under the influence of high temperatures due to the strain rate. The same mechanisms of changing mechanical properties of the machined material can be found in the area *G* of the contact between the flank face of the wedge and the workpiece. It can be noted here that the