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FEM MODEL OF CHIP FORMATION PROCESS WITH FAILURE EFFECTS

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ABSTRACT

When cutting allowance is removed as chips. During this process material undergoes a deformation at high rates. Heat is generated as a results of plastic work and friction processes, and this heat is transferred to chip, tool, work material and environment. Taking into account these processes it is a minimum that must be satisfied to obtain a correctness of results of simulations, for example FEM. However, in many cases that approach is sufficient, but it is not the complete model description of chip formation process. When cutting failure effect of work material are present. This situation takes place when allowance is separated from work material or when during cutting chips another than continuous are formed. Presented paper is focused on modelling of the onset of material failure and its evolution. The paper shows some preliminary results of simulations with applying some of these techniques too.

Keywords: cutting, FEM modeling, chip formation

1. INTRODUCTION [1]

Failure of material is related to a loss of material capability to carrying loads. The failure phenomena corresponds to advancing losing of stiffness of material. It can be demonstrated by chart (fig. 1) where stress-strain response is shown.

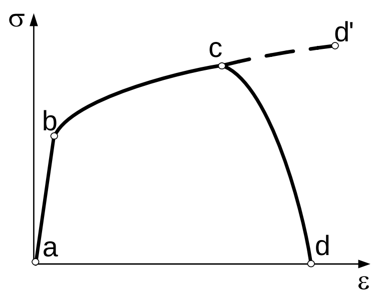

Figure 1. Uniaxial stress-strain response of a metal specimen.

At first the material response is initially linear elastic according to Hooke's law (stage *a*-*b*). Next is the plastic yielding with strain hardening (stage *b*-*c*). Point *c* indicates loosing of load carrying ability of material what corresponds with necking of specimen. Point *c* refers to an initiation of material damage. Two next stages relate to two different kind of material responses. The stage *c*-*d* describes the material response with continuation of material damage, and the *c*-*d'* stage shows material response without the degradation.

2. INITIATION OF MATERIAL DAMAGE [1]

The paper shows modeling of two kinds of mechanisms causing the fracture of a ductile metal. First, called *ductile criterion* corresponding to the nucleation, growth, and coalescence of voids in material and second e.g. *shear fracture* describing shear band localization.

2.1. Ductile criterion

The *ductile criterion* assumes that the equivalent plastic strain at the beginning material damage, $\bar{\varepsilon}_D^{pl}$, depends on stress triaxiality and strain rate according to function:

$$\bar{\varepsilon}_D^{pl} = f(\eta, \dot{\bar{\varepsilon}}^{pl}) \tag{1}$$

and:

$$\eta = -\frac{p}{q} \tag{2}$$

where: p – normal stress,

q – Huber's (von Mises) stress,

$\dot{\bar{\varepsilon}}^{pl}$ - equivalent plastic strain rate.

The onset of the material damage is reached when following equality is satisfied:

$$\omega_D = \int \frac{d\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_D^{pl}(\eta, \dot{\bar{\varepsilon}}^{pl})} = 1 \tag{3}$$

where: ω_D – state variable connected with plastic deformation. During analysis it is determined from:

$$\Delta\omega_D = \frac{\Delta\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_D^{pl}(\eta, \dot{\bar{\varepsilon}}^{pl})} \geq 0 \tag{4}$$

In case of application of Johnson-Cook criterion the function (1) is:

$$\bar{\varepsilon}_D^{pl} = [d_1 + d_2 \exp(-d_3\eta)]\left[1 + d_4 \ln\left(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0}\right)\right](1 + d_5\hat{\theta}) \tag{5}$$

where: $d_1 \div d_5$ – failure parameters,

$\dot{\varepsilon}_0$ – reference strain rate,

$\hat{\theta}$ – temperature.

2.2. Shear criterion

The *shear criterion* is a way for modeling of predicting the onset of damage due to shear band localization. This modeling is connected with an assumption that the onset of material damage, $\bar{\varepsilon}_S^{pl}$, can be expressed as a function of the shear stress ratio and strain rate:

$$\bar{\varepsilon}_S^{pl} = f(\theta_s, \dot{\bar{\varepsilon}}^{pl}) \tag{6}$$

In the equation (6) θ_s is computed from:

$$\theta_s = \frac{(q + k_s p)}{\tau_{\max}} \tag{7}$$

where: τ_{max} – maximum shear stress,
k_s – material constant.
The criterion for damage initiation is met when the following condition is satisfied:

$$\omega_S = \int \frac{d\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_S^{pl}(\theta_s, \dot{\bar{\varepsilon}}^{pl})} = 1 \tag{8}$$

where: ω_S – variable of state connected with plastic deformation. At every analysis increment ω_S is determined as:

$$\Delta\omega_S = \frac{\Delta\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_S^{pl}(\theta_S, \dot{\bar{\varepsilon}}^{pl})} \geq 0 \tag{9}$$

3. DAMAGE EVOLUTION [1]

The damage evolution is related to a description of the way of the material stiffness degradation and is applied when one or more criterion of damage initiation is satisfied. Reaching the state of the initiation of the material damage influences on stress tensor in the material. This tensor can be expressed as:

$$\sigma = (1 - D)\bar{\sigma} \tag{10}$$

where: D – overall damage variable (taking into account all possible damage initiation effects),
$\bar{\sigma}$ – stress tensor without damage effects.
For D = 1, according to equation (10), material has no capacity to carry loads.

3.1. Defining damage evolution based on effective plastic displacement $\bar{u}^{pl}$

After reaching the damage initiation criterion the effective plastic displacement, $\bar{u}^{pl}$, as parameter of loosing the material stiffness is computed from:

$$\dot{\bar{u}}^{pl} = L\dot{\bar{\varepsilon}}^{pl} \tag{11}$$

where: L – characteristic length of the element.
$\bar{u}^{pl} = 0$ denotes that material rapidly loses stiffness. For ductile materials like steel it does not seem to be a good way for modeling the failure of material.
The damage evolution can possess a various form. A linear form of the damage evolution takes place according to equality:

$$\dot{d} = \frac{L\dot{\bar{\varepsilon}}^{pl}}{\bar{u}_f^{pl}} = \frac{\dot{\bar{u}}^{pl}}{\bar{u}_f^{pl}} \tag{12}$$

After reaching the state for $\bar{u}^{pl} = \bar{u}_f^{pl}$ material can not carrying loads (d = 1) and this form is applied for materials demonstrating constant yield stress.
An exponential form of the material damage is connected with equation:

$$d = \frac{1 - e^{-\alpha(\bar{u}^{pl}/\bar{u}_f^{pl})}}{1 - e^{-\alpha}} \tag{13}$$

3.2. Defining damage evolution based on energy dissipated when the damage process

The damage evolution can be also described with the aid of energy, G_f. This is the energy dissipated when the damage process takes place. Like in the case of using the effective plastic displacement, this kind of description of the damage evolution has a linear or an exponential form.

In case of a linear evolution of the rate of the damage variable is described as:

$$\dot{d} = \frac{L\dot{\bar{\varepsilon}}^{pl}}{\bar{u}_f^{pl}} = \frac{\dot{\bar{u}}^{pl}}{\bar{u}_f^{pl}} \tag{14}$$

and the equivalent plastic displacement at failure state is determined from:

$$\bar{u}_f^{pl} = \frac{2G_f}{\sigma_{y0}} \tag{15}$$

where: σ_{y0} – yield stress at point of reaching the failure criterion.
This form is applied for materials demonstrating constant yield stress.
The exponential form of the damage variable is expressed as:

$$d = 1 - \exp\left(- \int_0^{\bar{u}^{pl}} \frac{\bar{\sigma}_y \dot{\bar{u}}^{pl}}{G_f} \right) \tag{16}$$

4. MODELING RESULTS

This chapter shows some results of preliminary modeling with using the modeling of damage material. The modeling presents a simulation of cutting carbon steel. Figure 2 presents effects of modeling without using material failure effects. The field of stress and, what is important here, the shape of the formed chip are shown. The value of maximum stress is very high, e.g. about 1100 MPa, and the chip and surface after cutting possess unnatural shape.

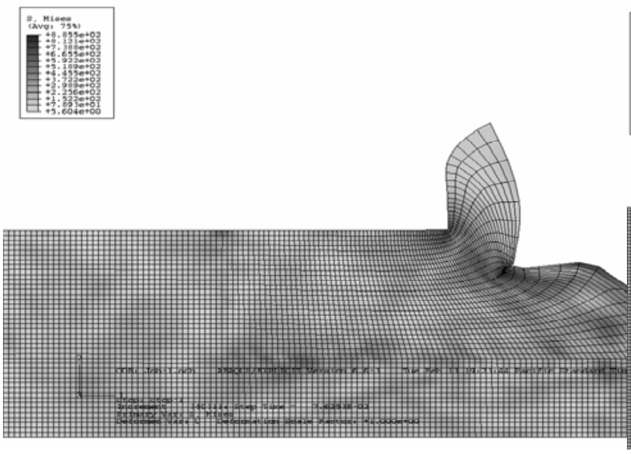

Figure 2. Von Mises stress without applying material damage effects.

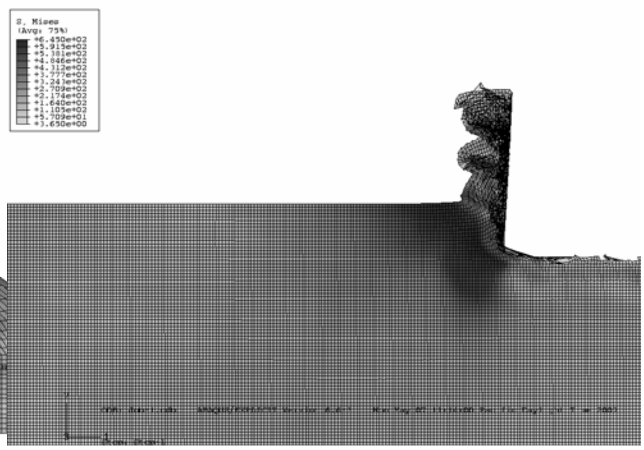

Figure 3. Von Mises stress with applying material damage effects.

Entirely different modeling effects are presented (fig. 3) where modeling of material failure was applied. The Johnson-Cook damage initiation criterion has been applied and the damage evolution based on dissipating fracture energy. It's clear that the values of stresses obtained are different, probably more realistic (about 650 MPa) and the shape of chip is natural.

5. REFERENCES

[1] Abaqus v.6.6 Documentation.

6. ACKNOWLEDGEMENTS

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