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NUMERICAL SIMULATION OF METAL FORMING PROCESSES WITH APPLICATION OF MODIFIED ELASTIC-PLASTIC MODEL

***Z. Nowak*[1], *M. Nowak*[1] *and R.B. Pęchersk*[1]**

[1] *Institute of Fundamental Technological Research, Warsaw, Poland*

1. Introduction

Finite element method is an efficient numerical tool to analyse problems of the sheet metal forming processes including cup drawing and stamping. Proper description of material properties is crucial for accurate analysis. In particular, the anisotropy and asymmetry of elastic range, related with strength differential effect (SDE), of considered materials play an important role in finite element simulation.

The paper presents a new yield criterion for the transversal isotropy of metal sheets under plane stress conditions which is an extension of the isotropic yield function proposed by Burzyński (1928) (Studium nad hipotezami Burzyński's doctoral dissertation "Study on material effort hypotheses", *Engng. Trans*., 2009, t. 57, nr 3–4, s. 185–215) . One additional coefficient has been introduced in order to allow a better representation of plastic behavior of metal sheets. The proposed yield condition includes the influence of first invariant of the stress tensor and also the strength differential effect. The system of equations describing the sheet metal forming process is solved by algorithm using the return mapping procedure. Plane stress constraint is incorporated into the Newton-Raphson iteration loop. The proposed algorithm is verified by performing a numerical test using shell elements in commercial FEM software ABAQUS/EXPLICIT with a developed VUMAT subroutine. To perform FE simulations of cup deep drawing processes, three independent yield stresses (σ_Y^T, σ_Y^C, τ_Y) are required. Those yield stresses can be obtained from: directional uniaxial tensile test, directional uniaxial compression test and shear test.

The aim of this paper is to evaluate the finite element predictions of the yield function, in particular the modified Burzyński plasticity model.

2. Constitutive equations

Our material is described by a modified J_2 plasticity which includes influence of the first invariant of stress tensor and strength differential effect. We presume that the strain rate is additively decomposed into the elastic part obeying the isotropic Hooke's law and the plastic part governed by the associated flow rule with isotropic hardening.

3. Yield condition

Plastic deformations in numerical analysis of sheet metal forming operations can be described by means of analytical yield functions. The proposed yield condition is based on the analysis of limit condition for transversally isotropic solids. In case of plane stress state the yield condition is in the following form:

(1) $$f = \frac{1}{2k_1}\left\{3(k_1 - 1)p + \sqrt{9(k_1 - 1)^2 p^2 + 4k_1 q^2}\right\} - \sigma_Y^T\left(\bar{\varepsilon}_p\right) = 0$$

where $p=\dfrac{\sigma_x+\sigma_y}{3}$, $q=\sqrt{\sigma_x^2+\sigma_y^2+R_B\sigma_x\sigma_y+(2-R_B)\sigma_{xy}^2}$, $R_B=2-\dfrac{1}{k_1k_2^2}-\dfrac{2}{k_2}+\dfrac{2}{k_1k_2}$

$k_1=\sigma_Y^C/\sigma_Y^T$ and $k_2=f(\sigma_Y^C,\sigma_Y^T,\tau_Y)$. σ_Y^C is the initial yield stress in uniaxial compression, σ_Y^T is initial yield stress in uniaxial tension and τ_Y is initial yield stress in shear.

4. Cup deep drawing process

In order to verify the implementation of the new yield function as well as its performance, cup drawing test simulations were carried out for steel sheet. The geometric parameters of the deep drawing operation are: the punch diameter 70.0 mm with rounded-off corner radius 8.0 mm, rounded-off corner radius 5.0 mm, the die diameter 74.0 mm and the initial sheet thickness 0.78 mm. The friction coefficient between the interface and the punch is set to 0.1, while that between the die and the blank holder is taken as 0.1 accounting for a certain degree of lubrication. The characteristic dimensions of the square cup drawing process are as follows: size of the blank 150x150 mm; thickness of the blank 0.78 mm and the blankholding force 19.6 kN. The blank is modelled by four-nodes shell element (ABAQUS elements library type - S4R), whereas the die, punch and holder are modelled by rigid elements (ABAQUS elements library type - R3D4). In numerical simulations of the deep drawing process we used DP600 steel. Mechanical properties of the material of the blank DP600 steel used in the simulation are as follows: Young's modulus 206 GPa, Poisson ratio 0.3, σ_Y^T = 330 MPa, σ_Y^C = 370 MPa. For steel DP600 the material parameters k_1 and k_2 are as follows: k_1 =1.12 and k_2 = 1.078. The uniaxial true stress–strain data measured in the tension test for steel were fit to the power law Swift equation and the obtained coefficients are: A= 1040.4 MPa, B= 0.00262, C= 0.16. The blank is composed of 1849 elements with 1936 nodes. In order to minimize the influence of the blankholding force in this calculation, a cup formed with a minimum blank-holder force to prevent buckling under a well-lubricated condition was simulated. The influence of the yield stress only in uniaxial tension σ_Y^T and k_2 anisotropy parameter, i.e., the signature of the yield function, on the cup height profile was investigated. The deformation of the square blank at the punch stroke 40 mm for the cup deep drawing with application of ABAQUS/EXPLICIT for proposed modified Burzyński yield condition Eq. (1) with the isotropic hardening law was presented.

5. Conclusions

Using a newly-developed yield condition, plastic deformation of a square steel blanket has been studied during cup deep drawing process. It has been demonstrated that the proposed yield function calibration involving two directional uniaxial tests for tension and compression and one shear test gives satisfactory results at least in the cases when anisotropy effects are not advanced. The comparison of the deformation predictions with the proposed yield condition results shows a good agreement from an engineering point of view; however, the evaluation of the local strain and stress histories indicates that the yield condition needs to be improved further.

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