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SOME ASPECTS ON MATERIAL MODELING IN INDUSTRIAL SHEET FORMING SIMULATIONS

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Summary. *Although great progress has been made in the area of material modeling for anisotropic metal sheets during the last decade, still the vast majority of industrial sheet forming simulations are based on the well-known, quadratic Hill'48 yield condition. The present work is part of an ongoing project at Volvo Cars and Chalmers University, with the object of bringing industrial simulations one step forward in terms of accuracy and reliability. In this report the special needs and demands of industrial analysts regarding material modeling will be discussed. With this background some recent yield criteria will be presented and analyzed.*

1 INTRODUCTION

In the present paper results from a project going on at Volvo Cars and Chalmers University, aiming at improving the quality and reliability of sheet forming simulations by improving the material modeling and characterization. The first results of this project were presented in Mattiasson and Sigvant[1]. In that study the yield condition by Barlat and Lian[2] (Yld89) was used in combination with the Miyauchi shear test for determining the plastic hardening curve.

There are several aspects of material modeling, which have to be considered, such as yield condition, plastic hardening curve, hardening law, strain rate dependence, etc. In the present report only the first of these aspects will be considered – the yield condition.

In the area of mechanical simulation there is one, big, fundamental difference between the academic and the industrial view of the matter, and that is time. The primary object of the academic researcher is to produce results with as good agreement with the reality as possible, without consideration of time in any respect. For the industrial analyst, on the other hand, time is always a factor to consider. This concerns the simulation time itself, as well as the time for performing material tests and so on. In the area of sheet metal forming simulation this puts limitations on the complexity of the material models. Even if we limit the scope to phenomenological models, a complex model involving many parameters still have to be supported by several time-consuming, and expensive material tests. A complex material model usually also deteriorates the numerical efficiency. To sum up, in an industrial environment accuracy and efficiency always have to be balanced.

The standard test for sheet metals is the uniaxial tensile test, which normally is performed in three different directions. Such a set of tests yields six parameters, which can be used to determine the shape of the yield locus: the uniaxial yield stresses and the R-values (Lankford coefficients) in three directions. The uniaxial tensile tests have usually to be supplemented by some kind of biaxial test (e.g. shear or hydraulic bulge test) in order to determine the plastic hardening curve for large values of plastic strain. Such a test yields additional one or two material parameters. Thus, normally we have access to seven or eight material parameters to determine the shape of the yield locus. It should be pointed out that the well-known Hill'48 and Yld89 yield criteria only make use of four of these parameters.

2 RECENT YIELD CRITERIA FOR METALLIC SHEETS

2.1 Background

In the following we will just consider yield criteria in the plane stress sub space. The yield conditions are assumed to be written in the form

$$f = \bar{\sigma} - \sigma_Y = 0 \tag{1}$$

where $\bar{\sigma}$ is the effective stress and σ_Y is the yield stress.

In 1972 Hosford[3] presented a non-quadratic, isotropic yield function, which in plane stress has the following form

$$\bar{\sigma} = \left\{ \frac{1}{2}\left(|\sigma_1|^m + |\sigma_2|^m + |\sigma_1 - \sigma_2|^m \right) \right\}^{1/m} \tag{2}$$

The exponent m is here assumed to be a real number in the range $2 \le m < \infty$. In the limits the current yield condition is identical to the von Mises and the Tresca yield criteria, respectively. During the years several generalizations of Hosford's yield criteria to planar anisotropy have been published. They are all said to belong to the "Hosford family" of yield criteria. The most well-known of these is the one by Barlat and Lian[2] from 1989. Two of the most recent ones are reviewed in the following sections.

2.2 The yield condition by Banabic et al. (BBC2000)

Recently, Banabic et al.[4, 5, 6] have in a series of papers presented different versions of a yield criterion, which is an extension of the Yld89 criterion by including more anisotropy parameters. This yield criterion will in the following be called BBC2000, and can in its most general form be written

$$\bar{\sigma} = \{ \frac{1}{2} (a \, |\Gamma+\Psi|^{m} + a \, |\Gamma-\Psi|^{m} + (2-a) \, |2\Lambda|^{m}) \}^{1/m} \tag{3}$$

$$\begin{aligned} \Gamma &= \frac{1}{2}\left(\gamma_1 \sigma_x + \gamma_2 \sigma_y\right) \\ \Psi &= \sqrt{\left(\frac{\psi_1 \sigma_x - \psi_2 \sigma_y}{2}\right)^2 + \psi_3^2 \tau_{xy}^2} \\ \Lambda &= \sqrt{\left(\frac{\lambda_1 \sigma_x - \lambda_2 \sigma_y}{2}\right)^2 + \lambda_3^2 \tau_{xy}^2} \end{aligned} \tag{4}$$

This criterion involves 8 independent parameters. By putting some of the parameters equal to each other, or putting them equal to one, the number of independent parameters can be reduced. The parameters must be determined from a number of experimental tests, which is equal to, or higher than, the number of independent parameters.

2.3 A new yield condition by Barlat et al. (Yld2000)

Barlat et al.[7] have presented a yield criterion (Yld2000), in which the anisotropy is introduced by means of two linear transformations of the Cauchy stress tensor. This criterion can be expressed as

$$\bar{\sigma} = \left[\frac{1}{2}\left(|\tilde{\sigma}'_1|^{m} + |\tilde{\sigma}'_2|^{m} + |\tilde{\sigma}''_1 - \tilde{\sigma}''_2|^{m} \right) \right]^{1/m} \tag{5}$$

where the variables $\tilde{\sigma}'_1$ and $\tilde{\sigma}'_2$ are principal values of the fictitious stress tensor $\tilde{\boldsymbol{\sigma}}'$ with components

$$\begin{Bmatrix} \tilde{\sigma}'_x \\ \tilde{\sigma}'_y \\ \tilde{\tau}'_{xy} \end{Bmatrix} = \begin{bmatrix} L'_{11} & L'_{12} & 0 \\ L'_{21} & L'_{22} & 0 \\ 0 & 0 & L'_{33} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} \qquad \{\tilde{\sigma}'\} = [L']\{\sigma\} \tag{6}$$

and $\tilde{\sigma}''_1$ and $\tilde{\sigma}''_2$ are principal values of the fictitious stress tensor $\tilde{\boldsymbol{\sigma}}''$ with components

$$\begin{Bmatrix} \tilde{\sigma}''_x \\ \tilde{\sigma}''_y \\ \tilde{\tau}''_{xy} \end{Bmatrix} = \begin{bmatrix} L''_{11} & 0 & 0 \\ 0 & L''_{22} & 0 \\ 0 & 0 & L''_{33} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} \qquad \{\tilde{\sigma}''\} = [L'']\{\sigma\} \tag{7}$$

There are a maximum number of independent anisotropy parameters $L'_{11}, L'_{12}, ..., L''_{33}$ equal to eight in this model. It is obvious that Yld89 is a special case of this criterion. It is also obvious that BBC2000 and Yld2000 are very similar. They are in fact identical in case the full set of independent parameters (eight) is used. It should finally be mentioned that the present yield criterion can be viewed as a special case of a general method for deriving anisotropic yield criteria based on linear stress transformations proposed by Barlat et al.[8].

3 CONCLUDING REMARKS

Both the BBC2000 and the Yld2000 yield condition seems to be ideally suited for industrial applications, since they can make use of all the available seven or eight material parameters. Furthermore, like for all the yield criteria within the "Hosford family" the shapes of the yield loci, mainly determined by the exponent *m,* are quite realistic, a fact that has been proven by numerous experiments, and by comparisons with polycrystalline models.

The anisotropy parameters involved in these models have to be determined, either by solving a nonlinear system of equations with, for instance, the Newton-Raphson method, or by minimizing an error functional.

Both the above models have been implemented as "user materials" in the dynamic, explicit FE-code LS-DYNA. In order to check the computational efficiency of the new models, a typical deep drawing problem was solved with these models, and also with the Yld89 model being part of the ordinary LS-DYNA material library (material 36). The use of the implemented models increased the total computing time with approximately 4-8 %. This is an insignificant increase, and the new models can, thus, be considered to fulfill any demands concerning efficiency.

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