International Journal of Mechanical Sciences 53 (2011) 425–435

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

journal homepage: www.elsevier.com/locate/ijmecsci

A model of one-surface cyclic plasticity and its application to springback prediction

S.L. Zang [a,b,*], C. Guo [a], S. Thuillier [b], M.G. Lee [c]

[a] School of Mechanical Engineering, Xi'an Jiaotong University, No. 28, Xianning Road, Xi'an, Shaanxi, China
[b] LIMATB, Université de Bretagne-Sud, Rue de Saint Maudé, BP 92116, F-56321 Lorient, France
[c] Graduate Institute of Ferrous Technology, Pohang University of Science and Technology, San 31, Hyoja-dong, Nam-gu, Pohang, Geongbuk 790-784, Republic of Korea

ARTICLE INFO

Article history:
Received 5 July 2010
Received in revised form
23 March 2011
Accepted 24 March 2011
Available online 2 April 2011

Keywords:
Permanent softening
Hardening model
Sheet metal forming

ABSTRACT

This paper presents an elasto-plastic constitutive model based on one-surface plasticity, which can capture the Bauschinger effect, transient behavior, permanent softening, and yield anisotropy. The combined isotropic–kinematic hardening law was used to model the hardening behavior, and the non-quadratic anisotropic yield function, Yld2000-2d, was chosen to describe the anisotropy. This model is closely related to the anisotropic non-linear kinematic hardening model of Chun et al. [2002. Modeling the Bauschinger effect for sheet metals, part I: theory. International Journal of Plasticity 18, 571–95.]. Different with the model, the current model captures in particular permanent softening with a constant stress offset as well as the Bauschinger effect and transient behavior under strain path reversal. Inverse identification was carried out to fit the material parameters of hardening model by using uni-axial tension/compression data. Springback predicted by the resulting material model was compared with experiments and with material models that do not account for permanent softening. The results show that the resulting material model has a good capability to predict springback.

1. Introduction

In the last two decades, the increasing application of high strength steels and aluminum alloys in the automotive industry has posted a challenging issue for the sheet metal forming process. Springback is one of the most serious defects faced, making tool designing more difficult and expensive because of the try-errors. The finite element method is an efficient tool to overcome such difficulties. But its accuracy depends on many factors, such as, element type and size, contact algorithm, especially material model used to describe the hardening behavior under complex, large-strain deformation paths.

Since strain path reversal is quite common in the sheet metal forming process, for example, bending–unbending on die shoulder and reverse bending–unbending at punch, several experimental tests have been performed to reveal the hardening behavior of sheets under such a deformation path (e.g. Miyauchi [1]; Yoshida et al. [2]; Boger et al. [3]; Bouvier et al. [4], Cao et al. [5]). At the beginning of reversal loading, (1) the Bauschinger effect and (2) transient behavior are observed as an early re-yielding and subsequent rapid change of hardening rate [6,7]. It is then followed by one of the two typical trends, (i) the reverse loading curve rapidly converges to the original curve [8]; (ii) or it eventually starts parallel to the original curve, which is termed as (3) permanent softening described by an offset $\Delta\sigma$ [9], as schematically illustrated in Fig. 1.

To accurately model the hardening behavior, many models have been proposed and modified (e.g. Yoshida and Uemori [7], Amstrong and Frederick [10], Cailletaud and Saï [11], Chaboche and Rousselier [12], Dafalias and Popov [13], Hu et al. [14], Lee et al. [15], Prager [16], Saï et al. [17], Saï and Cailletaud [18], Saï [19], Teodosiu and Hu [20], Wolff and Taleb [21], Yoshida and Uemori [22], Ziegler [23]). These models can be classified into three major frameworks [19]: (i) the so-called unified models in which the deformation sources are not differentiated, their mean effects are considered through a single inelastic strain; (ii) crystallographic models in which physical ingredients are represented as texture, local stresses or strains in the grain [19]; (iii) the multi-mechanism models in which the differences of deformation sources are considered by assigning different inelastic strains to each mechanism, as well considering an interaction between them [17–19]. For the current paper, the aim is to develop a one-surface model within the framework of unified models. Hence, only the related unified models are reviewed in detail here. In view of the number of yield surface, the unified models can be classified into two main categories: one based on isotropic and/or kinematic hardening of single yield surface, and the other involving multi-surface [24].

* Corresponding author at: School of Mechanical Engineering, Xi'an Jiaotong University, No. 28, Xianning Road, Xi'an, Shaanxi, China.
Tel.: +86 29 82668607-806.
E-mail address: shunlai.zang@gmail.com (S.L. Zang).

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doi:10.1016/j.ijmecsci.2011.03.005